

SECTION II
MATERIALS

2025

ASME Boiler and
Pressure Vessel Code
An International Code

Part C

Specifications for Welding Rods,
Electrodes, and Filler Metals

Markings such as “ASME,” “ASME Standard,” or any other marking including “ASME,” ASME logos, or the ASME Single Certification Mark shall not be used on any item that is not constructed in accordance with all of the applicable requirements of the Code or Standard. Use of the ASME Single Certification Mark requires formal ASME certification; if no certification program is available, such ASME markings may not be used. (For Certification and Accreditation Programs, see <https://www.asme.org/certification-accreditation>.)

Items produced by parties not formally possessing an ASME Certificate may not be described, either explicitly or implicitly, as ASME certified or approved in any code forms or other document.

AN INTERNATIONAL CODE

2025 ASME Boiler & Pressure Vessel Code

2025 Edition

July 1, 2025

II MATERIALS

Part C

Specifications for Welding Rods, Electrodes, and Filler Metals

ASME Boiler and Pressure Vessel Committee
on Materials



The American Society of
Mechanical Engineers

Two Park Avenue • New York, NY • 10016 USA

Date of Issuance: July 1, 2025

This international code or standard was developed under procedures accredited as meeting the criteria for American National Standards and it is an American National Standard. The standards committee that approved the code or standard was balanced to ensure that individuals from competent and concerned interests had an opportunity to participate. The proposed code or standard was made available for public review and comment, which provided an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not “approve,” “certify,” “rate,” or “endorse” any item, construction, proprietary device, or activity. ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a standard against liability for infringement of any applicable letters patent, nor does ASME assume any such liability. Users of a code or standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representatives or persons affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations of this document issued in accordance with the established ASME procedures and policies, which precludes the issuance of interpretations by individuals.

The endnotes and preamble in this document (if any) are part of this American National Standard.



ASME Collective Membership Mark



ASME Single Certification Mark

The Specifications published and copyrighted by the American Welding Society are reproduced with the Society's permission.

All rights reserved. “ASME” and the above ASME symbols are registered trademarks of The American Society of Mechanical Engineers. No part of this document may be copied, modified, distributed, published, displayed, or otherwise reproduced in any form or by any means, electronic, digital, or mechanical, now known or hereafter invented, without the express written permission of ASME. No works derived from this document or any content therein may be created without the express written permission of ASME. Using this document or any content therein to train, create, or improve any artificial intelligence and/or machine learning platform, system, application, model, or algorithm is strictly prohibited.

Library of Congress Catalog Card Number: 56-3934

Adopted by the Council of The American Society of Mechanical Engineers, 1914; latest edition 2025.

The American Society of Mechanical Engineers
Two Park Avenue, New York, NY 10016-5990

Copyright © 2025 by
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
All rights reserved
Printed in U.S.A.

TABLE OF CONTENTS

List of Sections	v
Foreword	vi
Statement of Policy on the Use of the ASME Single Certification Mark and Code Authorization in Advertising	viii
Statement of Policy on the Use of ASME Marking to Identify Manufactured Items	viii
Personnel	ix
AWS Personnel	xxxii
Correspondence With the Committee	xxxiv
Preface	xxxvi
Guideline on the Approval of New Welding and Brazing Material Classifications Under the ASME Boiler and Pressure Vessel Code	xxxvii
Summary of Changes	xxxix
Cross-Referencing in the ASME BPVC	xl
SFA-5.01M/SFA-5.01 Welding and Brazing Consumables — Procurement of Filler Materials and Fluxes	1
SFA-5.02/SFA-5.02M Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes	25
SFA-5.1/SFA-5.1M Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding	43
SFA-5.2/SFA-5.2M Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding	97
SFA-5.3/SFA-5.3M Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding	113
SFA-5.4/SFA-5.4M Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding	129
SFA-5.5/SFA-5.5M Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding	169
SFA-5.6/SFA-5.6M Specification for Copper and Copper-Alloy Electrodes for Shielded Metal Arc Welding	233
SFA-5.7/SFA-5.7M Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes	253
SFA-5.8/SFA-5.8M Specification for Filler Metals for Brazing and Braze Welding	267
SFA-5.9/SFA-5.9M Specification for Bare Stainless Steel Welding Electrodes and Rods	309
SFA-5.10/SFA-5.10M Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods	343
SFA-5.11/SFA-5.11M Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding	385
SFA-5.12/SFA-5.12M Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting	425
SFA-5.13/SFA-5.13M Specification for Surfacing Electrodes for Shielded Metal Arc Welding	447
SFA-5.14/SFA-5.14M Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods	481
SFA-5.15 Specification for Welding Electrodes and Rods for Cast Iron	511
SFA-5.16/SFA-5.16M Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods	537
SFA-5.17/SFA-5.17M Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding	559
SFA-5.18/SFA-5.18M Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding	591
SFA-5.20/SFA-5.20M Specification for Carbon Steel Electrodes for Flux Cored Arc Welding	627
SFA-5.21/SFA-5.21M Specification for Bare Electrodes and Rods for Surfacing	667
SFA-5.22/SFA-5.22M Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods	699
SFA-5.23/SFA-5.23M Specification for Low-Alloy and High Manganese Steel Electrodes and Fluxes for Submerged Arc Welding	753
SFA-5.24/SFA-5.24M Specification for Zirconium and Zirconium-Alloy Welding Electrodes and Rods	801
SFA-5.25/SFA-5.25M Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding	815
SFA-5.26/SFA-5.26M Specification for Carbon and Low-Alloy Steel Electrodes for Electrogas Welding	839
SFA-5.28/SFA-5.28M Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding	863

SFA-5.29/SFA-5.29M	Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding	909
SFA-5.30/SFA-5.30M	Specification for Consumable Inserts	955
SFA-5.31M/SFA-5.31	Specification for Fluxes for Brazing and Braze Welding	981
SFA-5.32M/SFA-5.32	Welding Consumables — Gases and Gas Mixtures for Fusion Welding and Allied Processes	1001
SFA-5.34/SFA-5.34M	Specification for Nickel-Alloy Flux Cored and Metal Cored Welding Electrodes ..	1025
SFA-5.35/SFA-5.35M	Specification for Covered Electrodes for Underwater Wet Shielded Metal Arc Welding	1055
SFA-5.39/SFA-5.39M	Specification for Flux and Electrode Combinations for Submerged Arc and Electroslag Joining and Surfacing of Stainless Steel and Nickel Alloys	1071
Mandatory Appendix I	Standard Units for Use in Equations	1110

LIST OF SECTIONS

(25)

SECTIONS

- I Rules for Construction of Power Boilers
- II Materials
 - Part A — Ferrous Material Specifications
 - Part B — Nonferrous Material Specifications
 - Part C — Specifications for Welding Rods, Electrodes, and Filler Metals
 - Part D — Properties (Customary)
 - Part D — Properties (Metric)
- III Rules for Construction of Nuclear Facility Components
 - Subsection NCA — General Requirements for Division 1 and Division 2
 - Appendices
 - Division 1
 - Subsection NB — Class 1 Components
 - Subsection NCD — Class 2 and Class 3 Components
 - Subsection NE — Class MC Components
 - Subsection NF — Supports
 - Subsection NG — Core Support Structures
 - Division 2 — Code for Concrete Containments
 - Division 3 — Containment Systems for Transportation and Storage of Spent Nuclear Fuel and High-Level Radioactive Material
 - Division 4 — Fusion Energy Devices
 - Division 5 — High Temperature Reactors
- IV Rules for Construction of Heating Boilers
- V Nondestructive Examination
- VI Recommended Rules for the Care and Operation of Heating Boilers
- VII Recommended Guidelines for the Care of Power Boilers
- VIII Rules for Construction of Pressure Vessels
 - Division 1
 - Division 2 — Alternative Rules
 - Division 3 — Alternative Rules for Construction of High Pressure Vessels
- IX Welding, Brazing, and Fusing Qualifications
- X Fiber Reinforced Plastic Pressure Vessels
- XI Rules for Inservice Inspection of Nuclear Reactor Facility Components
 - Division 1 — Rules for Inservice Inspection of Nuclear Power Plant Components
 - Division 2 — Requirements for Reliability and Integrity Management (RIM) Programs for Nuclear Reactor Facilities
- XII Rules for Construction and Continued Service of Transport Tanks
- XIII Rules for Overpressure Protection

FOREWORD*

In 1911, The American Society of Mechanical Engineers established the Boiler and Pressure Vessel Committee to formulate standard rules for the construction of steam boilers and other pressure vessels. In 2009, the Boiler and Pressure Vessel Committee was superseded by the following committees:

- (a) Committee on Power Boilers (I)
- (b) Committee on Materials (II)
- (c) Committee on Construction of Nuclear Facility Components (III)
- (d) Committee on Heating Boilers (IV)
- (e) Committee on Nondestructive Examination (V)
- (f) Committee on Pressure Vessels (VIII)
- (g) Committee on Welding, Brazing, and Fusing (IX)
- (h) Committee on Fiber-Reinforced Plastic Pressure Vessels (X)
- (i) Committee on Nuclear Inservice Inspection (XI)
- (j) Committee on Transport Tanks (XII)
- (k) Committee on Overpressure Protection (XIII)
- (l) Technical Oversight Management Committee (TOMC)

Where reference is made to “the Committee” in this Foreword, each of these committees is included individually and collectively.

The Committee’s function is to establish rules of safety relating to pressure integrity. The rules govern the construction** of boilers, pressure vessels, transport tanks, and nuclear components, and the inservice inspection of nuclear components and transport tanks. For nuclear items other than pressure-retaining components, the Committee also establishes rules of safety related to structural integrity. The Committee also interprets these rules when questions arise regarding their intent. The technical consistency of the Sections of the Code and coordination of standards development activities of the Committees is supported and guided by the Technical Oversight Management Committee. The Code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks, or nuclear components, or the inservice inspection of nuclear components or transport tanks. Users of the Code should refer to the pertinent codes, standards, laws, regulations, or other relevant documents for safety issues other than those relating to pressure integrity and, for nuclear items other than pressure-retaining components, structural integrity. Except for Sections XI and XII, and with a few other exceptions, the rules do not, of practical necessity, reflect the likelihood and consequences of deterioration in service related to specific service fluids or external operating environments. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of components addressed by the Code. The objective of the rules is to afford reasonably certain protection of life and property, and to provide a margin for deterioration in service to give a reasonably long, safe period of usefulness. Advancements in design and materials and evidence of experience have been recognized.

The Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction activities and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects that are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy, and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code

* The information contained in this Foreword is not part of this American National Standard (ANS) and has not been processed in accordance with ANSI’s requirements for an ANS. Therefore, this Foreword may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the Code.

** *Construction*, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and overpressure protection.

neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and the application of these programs to their design.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design, or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code cases, and requests for interpretations. Only the Committee has the authority to provide official interpretations of the Code. Requests for revisions, new rules, Code cases, or interpretations shall be addressed to the staff secretary in writing and shall give full particulars in order to receive consideration and action (see the Correspondence With the Committee page). Proposed revisions to the Code resulting from inquiries will be presented to the Committee for appropriate action. The action of the Committee becomes effective only after confirmation by ballot of the Committee and approval by ASME. Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute (ANSI) and published at <http://go.asme.org/BPVCPublicReview> to invite comments from all interested persons. After public review and final approval by ASME, revisions are published at regular intervals in Editions of the Code.

The Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the Committee. ASME is to be notified should questions arise concerning improper use of the ASME Single Certification Mark.

When required by context in the Code, the singular shall be interpreted as the plural, and vice versa.

The words "shall," "should," and "may" are used in the Code as follows:

- *Shall* is used to denote a requirement.
- *Should* is used to denote a recommendation.
- *May* is used to denote permission, neither a requirement nor a recommendation.

STATEMENT OF POLICY ON THE USE OF THE ASME SINGLE CERTIFICATION MARK AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use the ASME Single Certification Mark for marking items or constructions that have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the ASME Single Certification Mark for the benefit of the users, the enforcement jurisdictions, and the holders of the ASME Single Certification Mark who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the ASME Single Certification Mark, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not “approve,” “certify,” “rate,” or “endorse” any item, construction, or activity and there shall be no statements or implications that might so indicate. An organization holding the ASME Single Certification Mark and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities “are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code,” or “meet the requirements of the ASME Boiler and Pressure Vessel Code.” An ASME corporate logo shall not be used by any organization other than ASME.

The ASME Single Certification Mark shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of the ASME Single Certification Mark who may also use the facsimile in advertising to show that clearly specified items will carry the ASME Single Certification Mark.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the ASME Single Certification Mark described in the governing Section of the Code.

Markings such as “ASME,” “ASME Standard,” or any other marking including “ASME” or the ASME Single Certification Mark shall not be used on any item that is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME that tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

PERSONNEL

ASME Boiler and Pressure Vessel Standards Committees, Subgroups, and Working Groups

January 1, 2025

(25)

TECHNICAL OVERSIGHT MANAGEMENT COMMITTEE (TOMC)

R. E. McLaughlin, *Chair*
N. A. Finney, *Vice Chair*
S. J. Rossi, *Staff Secretary*
R. W. Barnes
T. L. Bedeaux
C. T. Brown
R. P. Deubler
G. W. Galanes
J. A. Hall
T. E. Hansen
G. W. Hembree
R. B. Keating
B. Linnemann
W. M. Lundy
D. I. Morris

M. D. Rana
S. C. Roberts
F. J. Schaaf, Jr.
G. Scribner
W. J. Sperko
D. Srnic
R. W. Swayne
J. Vattappilly
M. Wadkinson
D. W. Lamond, *Ex-Officio Member*
B. K. Nutter, *Ex-Officio Member*
E. M. Ortman, *Ex-Officio Member*
M. J. Pischke, *Ex-Officio Member*
J. F. Henry, *Honorary Member*

Task Group on Remote Inspection and Examination (SI-TOMC)

S. C. Roberts, *Chair*
M. Frediani, *Staff Secretary*
P. J. Coco
N. A. Finney
S. A. Marks
R. Rockwood

C. Stevens
M. Tannenbaum
J. Cameron, *Alternate*
A. Byk, *Contributing Member*
S. J. Rossi, *Contributing Member*
C. A. Sanna, *Contributing Member*

Special Working Group on High Temperature Technology (TOMC)

D. Dewees, *Chair*
F. W. Brust
T. D. Burchell
P. R. Donavin

B. F. Hantz
R. I. Jetter
P. Smith

Subgroup on Research and Development (TOMC)

S. C. Roberts, *Chair*
S. J. Rossi, *Staff Secretary*
R. W. Barnes
N. A. Finney
G. W. Galanes

R. B. Keating
R. E. McLaughlin
E. M. Ortman
D. Andrei, *Contributing Member*

Honors and Awards Committee (TOMC)

E. M. Ortman,
G. W. Galanes
D. W. Lamond

B. K. Nutter
R. E. McLaughlin

Subgroup on Strategic Initiatives (TOMC)

N. A. Finney, *Chair*
S. J. Rossi, *Staff Secretary*
R. W. Barnes
G. W. Galanes
G. W. Hembree

R. B. Keating
R. E. McLaughlin
E. M. Ortman
S. C. Roberts
M. Wadkinson

ADMINISTRATIVE COMMITTEE

R. E. McLaughlin, *Chair*
N. A. Finney, *Vice Chair*
S. J. Rossi, *Staff Secretary*
G. W. Galanes
R. B. Keating
D. W. Lamond
B. Linnemann

B. K. Nutter
E. M. Ortman
M. J. Pischke
M. D. Rana
S. C. Roberts
R. R. Stevenson
M. Wadkinson

Task Group on Field Sites (TOMC)

R. V. Wielgoszinski, *Chair*
M. Vazquez, *Staff Secretary*
P. Becker
T. Bedeaux

J. Hoskinson
D. T. Peters
G. Scribner

MARINE CONFERENCE GROUP

J. Oh, *Staff Secretary*
J. G. Hungerbuhler, Jr.
G. Nair

H. N. Patel
N. Prokopuk
J. D. Reynolds

CONFERENCE COMMITTEE

R. D. Troutt — Texas, *Chair*
J. T. Amato — Ohio, *Secretary*
M. O. Amuzie — New Jersey
R. Becker — Colorado
H. Berny — Minnesota
T. D. Boggs — Missouri
R. A. Boillard — Indiana
D. P. Brockerville —
Newfoundland and Labrador,
Canada
R. J. Bunte — Iowa
A. Buquis — Arizona
J. H. Burpee — Maine
M. Carlson — Washington
T. Carter — Mississippi
N. Chiasson — Prince Edward
Island, Canada
T. G. Clark — Oregon
B. J. Crawford — Georgia
E. L. Creaser — New Brunswick,
Canada
J. J. Dacanay — Hawaii
M. Davidian — California
R. DeLury — Manitoba, Canada
A. Denham — Michigan
C. Derks — Wisconsin
C. Dinic — Ontario, Canada
D. A. Ehler — Nova Scotia, Canada
S. D. Frazier — Washington
A. Gibbs — Wisconsin
T. J. Granneman II — Oklahoma
M. L. Jordan — Kentucky
R. Kamboj — British Columbia,
Canada
E. Kawa — Massachusetts
A. Khssassi — Quebec, Canada
D. Kinney — North Carolina
K. S. Lane — Alaska
A. M. Lorimor — South Dakota
T. Maher — Illinois
M. Mailman — Northwest
Territories, Canada
W. McGivney — City of New York,
New York
S. F. Noonan — Maryland
B. S. Oliver — New Hampshire
J. L. Oliver — Nevada
P. B. Polick — Illinois
B. Ricks — Montana
W. J. Ross — Pennsylvania
M. H. Sansone — New York
T. S. Seime — North Dakota
C. S. Selinger — Saskatchewan,
Canada
J. E. Sharier — Ohio
R. Spiker — North Carolina
D. Srnic — Alberta, Canada
D. J. Stenrose — Michigan
R. J. Stimson II — Kansas
R. K. Sturm — Utah
D. K. Sullivan — Arkansas
J. Taveras — Rhode Island
R. Termini — Louisiana
S. Van Slavens — Delaware
D. M. Warburton — Florida
E. Wiggins — Alabama

INTERNATIONAL INTEREST REVIEW GROUP

V. Felix
Y.-G. Kim
S. H. Leong
W. Lin
O. F. Manafa
C. Minu
Y.-W. Park
A. R. Reynaga Nogales
P. Williamson

COMMITTEE ON POWER BOILERS (BPV I)

E. M. Ortman, *Chair*
D. E. Tompkins, *Vice Chair*
U. D'Urso, *Staff Secretary*
D. I. Anderson
R. Antoniuk
J. L. Arnold
K. K. Coleman
S. Fincher
G. W. Galanes
P. F. Gilston
T. E. Hansen
J. S. Hunter
M. Ishikawa
M. Lemmons
M. Lewis
C. T. McDaris
R. E. McLaughlin
L. Moedinger
Y. Oishi
M. Ortolani
A. Spangenberg
D. E. Tuttle
J. Vattappilly
M. Wadkinson
F. Zeller
H. Michael, *Contributing Member*
D. Berger, *Honorary Member*
P. D. Edwards, *Honorary Member*
J. G. Feldstein, *Honorary Member*
D. N. French, *Honorary Member*
J. Hainsworth, *Honorary Member*
J. F. Henry, *Honorary Member*
P. A. Molvie, *Honorary Member*
J. T. Pillow, *Honorary Member*
B. W. Roberts, *Honorary Member*
J. M. Tanzosh, *Honorary Member*
R. V. Wielgoszinski, *Honorary Member*
R. L. Williams, *Honorary Member*

Executive Committee (BPV I)

D. E. Tompkins, *Chair*
E. M. Ortman, *Vice Chair*
P. Becker
J. R. Braun
P. F. Gilston
A. Hantodkar
M. Lewis
C. T. McDaris
L. S. Nicol
A. Spangenberg
K. Thanupillai
M. Wadkinson

Subgroup on Design (BPV I)

C. T. McDaris, *Chair*
L. S. Tsai, *Secretary*
T. K. Acharya
D. I. Anderson
P. Becker
T. Huynh
L. Krupp
N. S. Ranck
J. Vattappilly
M. Wadkinson
C. Welles

Subgroup on Fabrication and Examination (BPV I)

P. F. Gilston, *Chair*
P. Becker, *Vice Chair*
J. L. Arnold
K. K. Coleman
S. Fincher
G. W. Galanes
T. E. Hansen
M. Lewis
S. J. Lombardo
C. T. McDaris
R. E. McLaughlin
Y. Oishi

Subgroup on General Requirements and Piping (BPV I)

D. E. Tompkins, *Chair*
M. Wadkinson, *Vice Chair*
M. Lemmons, *Secretary*
R. Antoniuk
T. E. Hansen
M. Ishikawa
S. J. Lombardo
R. E. McLaughlin
L. Moedinger
E. M. Ortman
D. E. Tuttle
J. Vattappilly

Subgroup on Locomotive Boilers (BPV I)

J. R. Braun, *Chair*
S. M. Butler, *Secretary*
G. W. Galanes
S. A. Lee
L. Moedinger
G. M. Ray
M. W. Westland

Subgroup on Materials (BPV I)

M. Lewis, *Chair*
L. S. Nicol, *Vice Chair*
S. H. Bowes
K. K. Coleman
G. W. Galanes
P. F. Gilston
K. Hayes
J. S. Hunter
E. Liebl
F. Masuyama
M. Ortolani
D. W. Rahoi
F. Zeller
B. W. Roberts, *Contributing Member*
J. M. Tanzosh, *Contributing Member*

Subgroup on Solar Boilers (BPV I)

R. E. Hearne, *Secretary*
S. Fincher
J. S. Hunter
P. Swarnkar

Task Group on Additive Manufacturing (BPV I)

K. K. Coleman, *Chair*
P. Becker, *Secretary*
J. L. Arnold
G. W. Galanes
P. F. Gilston
L. Moedinger
J. Vattappilly

Task Group on Modernization (BPV I)

S. J. Lombardo, <i>Chair</i>	G. W. Galanes
U. D'Urso, <i>Staff Secretary</i>	R. E. McLaughlin
D. I. Anderson	E. M. Ortman
J. L. Arnold	D. E. Tuttle

European International Working Group (BPV I)

A. Spangenberg, <i>Chair</i>	H. Michael
B. Daume	F. Miunske
J. Fleischfresser	M. Sykora
C. Jaekel	P. Chavdarov, <i>Contributing Member</i>
R. Kauer	J. Henrichsmeyer, <i>Contributing Member</i>
D. Koelbl	B. Müller, <i>Contributing Member</i>
S. Krebs	
T. Ludwig	
R. A. Meyers	

India International Working Group (BPV I)

K. Thanupillai, <i>Chair</i>	R. Madnani
A. Hantodkar, <i>Vice Chair</i>	S. Purkait
A. Ghosh, <i>Secretary</i>	A. Relekar
P. Brahma	M. Shiroya
H. Dalal	D. K. Shrivastava
T. Dhanraj	K. Singha
A. S. Ganeth	R. Sundararaj
S. Gopalakrishnan	S. Velu
A. Jain	S. Venkataramana

COMMITTEE ON MATERIALS (BPV II)

G. W. Galanes, <i>Chair</i>	F. Zeller
M. Ortolani, <i>Vice Chair</i>	J. Cameron, <i>Contributing Member</i>
C. E. Rodrigues, <i>Staff Secretary</i>	A. Chaudouet, <i>Contributing Member</i>
A. Appleton	K. K. Coleman, <i>Contributing Member</i>
P. Chavdarov	D. W. Gandy, <i>Contributing Member</i>
J. F. Grubb	K. L. Hayes, <i>Contributing Member</i>
J. A. Hall	W. Hoffelner, <i>Contributing Member</i>
D. O. Henry	K. E. Orie, <i>Contributing Member</i>
K. M. Hottle	D. T. Peters, <i>Contributing Member</i>
M. Ishikawa	B. W. Roberts, <i>Contributing Member</i>
M. Kowalczyk	J. M. Tanzosh, <i>Contributing Member</i>
D. L. Kurle	E. Uptis, <i>Contributing Member</i>
F. Masuyama	T. M. Cullen, <i>Honorary Member</i>
S. Neilsen	G. C. Hsu, <i>Honorary Member</i>
L. S. Nicol	
D. W. Rahoi	
W. Ren	
E. Shapiro	
R. C. Sutherland	

Executive Committee (BPV II)

G. W. Galanes, <i>Chair</i>	K. L. Hayes
C. E. Rodrigues, <i>Staff Secretary</i>	K. M. Hottle
E. Alexis	W. MacDonald
A. Appleton	M. Ortolani
J. Cameron	P. K. Rai
P. Chavdarov	J. Robertson
J. F. Grubb	E. Shapiro
S. Guzey	

Subgroup on External Pressure (BPV II)

E. Alexis, <i>Chair</i>	J. F. Grubb
S. Guzey, <i>Vice Chair</i>	S. Krishnamurthy
J. A. A. Morrow, <i>Secretary</i>	D. L. Kurle
L. F. Campbell	R. W. Mikitka
H. Chen	P. K. Rai
M. Ghorashi	M. Wadkinson
D. S. Griffin	

Subgroup on Ferrous Specifications (BPV II)

K. M. Hottle, <i>Chair</i>	Y.-J. Kim
A. Appleton, <i>Vice Chair</i>	W. C. Mack
C. Hyde, <i>Secretary</i>	J. Nickel
D. Amire-Brahimi	D. Powelleit
G. Cuccio	R. Rezaeifar
O. Elkadim	R. Schmidt
D. Fialkowski	E. Uptis
J. Grimm	L. Watzke
J. F. Grubb	C. Meloy, <i>Contributing Member</i>
D. S. Janikowski	

Subgroup on International Material Specifications (BPV II)

P. Chavdarov, <i>Chair</i>	D. O. Henry
M. Ishikawa, <i>Vice Chair</i>	W. M. Lundy
C. Zhou, <i>Secretary</i>	F. Zeller
A. Chaudouet	T. F. Miskell, <i>Contributing Member</i>
H. Chen	E. Uptis, <i>Contributing Member</i>
A. F. Garbolevsky	

Subgroup on Nonferrous Alloys (BPV II)

J. Robertson, <i>Chair</i>	R. Rezaeifar
W. MacDonald, <i>Vice Chair</i>	E. Shapiro
R. M. Beldyk	J. Shubilla
J. M. Downs	R. C. Sutherland
H. Dutta	R. Wright
J. F. Grubb	S. Yem
J. A. Hall	D. B. Denis, <i>Contributing Member</i>
D. Maitra	D. T. Peters, <i>Contributing Member</i>
D. W. Rahoi	

Subgroup on Physical Properties (BPV II)

P. K. Rai, <i>Chair</i>	P. K. Lam
S. Neilsen, <i>Vice Chair</i>	D. W. Rahoi
D. Chandiramani	E. Shapiro
H. Eshraghi	D. K. Verma
J. F. Grubb	S. Yem
B. F. Hantz	D. B. Denis, <i>Contributing Member</i>
R. D. Jones	

Subgroup on Strength, Ferrous Alloys (BPV II)

M. Ortolani, <i>Chair</i>	F. Masuyama
S. Rosinski, <i>Vice Chair</i>	M. Osterfoss
L. S. Nicol, <i>Secretary</i>	D. W. Rahoi
G. W. Galanes	M. Ueyama
J. A. Hall	F. Zeller
M. Ishikawa	F. Abe, <i>Contributing Member</i>
S. W. Knowles	

Subgroup on Strength of Weldments (BPV II & BPV IX)

K. L. Hayes, <i>Chair</i>	W. F. Newell, Jr.
G. W. Galanes, <i>Vice Chair</i>	J. A. Penso
S. H. Bowes, <i>Secretary</i>	D. W. Rahoi
K. K. Coleman, <i>Chair</i>	W. J. Sperko
M. Denault	J. P. Swezy, Jr.
D. W. Gandy	B. W. Roberts, <i>Contributing Member</i>
M. Ghahremani	

China International Working Group (BPV II)

Sanjiang Liu, <i>Chair</i>	C. Wang
H. Zhang, <i>Vice Chair</i>	Jinguang Wang
T. Xu, <i>Secretary</i>	Jiongxiang Wang
W. Cai	Q.-J. Wang
W. Fang	H.-C. Yang
F. Kong	J. Yang
H. Li	L. Yin
J. Li	X.-H. Zhang
Z. Rongcan	Y. Zhang
S. Tan	

Working Group on Creep Strength Enhanced Ferritic Steels (BPV II)

M. Ortolani, <i>Chair</i>	J. J. Sanchez-Hanton
G. W. Galanes, <i>Vice Chair</i>	J. A. Siefert
P. Becker, <i>Secretary</i>	W. J. Sperko
S. H. Bowes	F. Zeller
K. Kimura	F. Abe, <i>Contributing Member</i>
M. Lang	K. K. Coleman, <i>Contributing Member</i>
S. Luke	J. M. Tanzosh, <i>Contributing Member</i>
F. Masuyama	
T. Melfi	
W. F. Newell, Jr.	

Working Group on Data Analysis and the Materials Properties Database (BPV II)

W. MacDonald, <i>Chair</i>	D. Andrei, <i>Contributing Member</i>
C. E. Rodrigues, <i>Staff Secretary</i>	J. Cameron, <i>Contributing Member</i>
J. F. Grubb	G. W. Galanes, <i>Contributing Member</i>
F. Masuyama	W. C. Mack, <i>Contributing Member</i>
S. Neilsen	D. T. Peters, <i>Contributing Member</i>
M. Ortolani	W. Ren, <i>Contributing Member</i>
R. C. Sutherlin	E. Shapiro, <i>Contributing Member</i>
M. J. Swindeman	
F. Abe, <i>Contributing Member</i>	

Task Group on Modernization of Materials Data (BPV II)

C. E. Rodrigues, <i>Staff Secretary</i>	S. Neilsen
E. Alexis	L. S. Nicol
M. Brijlani	W. Ren
D. B. Denis	J. C. Sowinski
G. W. Galanes	M. Wadkinson
J. A. Hall	J. Cameron, <i>Contributing Member</i>
B. F. Hantz	J. F. Grubb, <i>Contributing Member</i>
A. Hassan	W. Hoffelner, <i>Contributing Member</i>
W. MacDonald	

COMMITTEE ON CONSTRUCTION OF NUCLEAR FACILITY COMPONENTS (BPV III)

R. B. Keating, <i>Chair</i>	K. Matsunaga
T. M. Adams, <i>Vice Chair</i>	B. McClone
D. E. Matthews, <i>Vice Chair</i>	S. McKillop
A. Maslowski, <i>Staff Secretary</i>	J. B. McLean
A. Appleton	J. C. Minichiello
S. Asada	M. N. Mitchell
R. W. Barnes	T. Nagata
W. H. Borter	J. B. Ossmann
M. E. Cohen	S. Pellet
R. P. Deubler	E. L. Pleins
P. R. Donavin	W. J. Sperko
A. C. Eberhardt	Y. J. Wang
J. V. Gardiner	W. Windes
W. J. Geringer	C. Basavaraju, <i>Alternate</i>
J. Grimm	T. P. Davis, <i>Contributing Member</i>
S. Hunter	T.-L. Sham, <i>Contributing Member</i>
R. I. Jetter	C. T. Smith, <i>Contributing Member</i>
J. I. Kim	R. M. Jessee, <i>Honorary Member</i>
G. H. Koo	E. B. Branch, <i>Honorary Member</i>
D. W. Lewis	M. N. Bressler, <i>Honorary Member</i>
M. A. Lockwood	G. D. Cooper, <i>Honorary Member</i>
D. W. Mann	D. F. Landers, <i>Honorary Member</i>
K. A. Manoly	C. Pieper, <i>Honorary Member</i>

Executive Committee (BPV III)

R. B. Keating, <i>Chair</i>	K. A. Manoly
A. Maslowski, <i>Secretary</i>	D. E. Matthews
T. M. Adams	B. McClone
T. P. Davis	S. McKillop
P. R. Donavin	J. B. McLean
D. W. Lewis	Yanli Wang
D. Mann	K. A. Kavanagh, <i>Alternate</i>

Latin America International Working Group (BPV III)

M. F. Liendo, <i>Chair</i>	A. J. Dall'Osto
J. Fernández, <i>Vice Chair</i>	J. I. Duo
O. Martinez, <i>Staff Secretary</i>	M. M. Gamizo
P. Yamamoto, <i>Secretary</i>	I. M. Guerreiro
E. H. Aldaz	I. A. Knorr
G. O. Anteri	D. E. Matthews
A. P. Antipasti	A. E. Pastor
D. O. Bordato	M. Rivero
G. Bourguigne	R. Taboada
M. Brusa	O. A. Verastegui
A. Claus	M. D. Vigliano
R. G. Cocco	M. Zunino

China International Working Group (BPV III)

Yong Wang, <i>Chair</i>	C. Peiyin
J. Gu, <i>Vice Chair</i>	Z. Sun
C. Jiang, <i>Vice Chair</i>	G. Tang
H. Yu, <i>Secretary</i>	L. Ting
L. Feng	J. Wen
L. Guo	F. Wu
D. Kang	C. Yang
Y. Li	P. Yang
H. Lin	W. Yang
Shenghua Liu	H. Yin
W. Liu	D. Yuangang
J. Ma	D. Zhao
K. Mao	Z. Zhong
D. E. Matthews	Q. Zhou
J. Ming	H. Zhu
W. Pei	

Korea International Working Group (BPV III)

G. H. Koo, <i>Chair</i>	B. Lee
O.-S. Kim, <i>Secretary</i>	D. Lee
H. Ahn	D. W. Lee
S. Cho	Sanghoon Lee
G.-S. Choi	Sungjae Lee
M. Choi	S.-G. Lee
M.-J. Choi	H. Lim
S. Choi	I.-K. Nam
J. Y. Hong	C.-K. Oh
N.-S. Huh	C.-Y. Oh
S. S. Hwang	E.-J. Oh
C. Jang	C. Park
I.-S. Jeong	H. Park
S. H. Kang	Y.-H. Park
J. Kim	Y. S. Pyun
J. I. Kim	J. H. Seo
J.-S. Kim	T. Shin
M.-W. Kim	S. Song
S.-S. Kim	T.-K. Song
Y.-B. Kim	W. J. Sperko
Y.-S. Kim	J. S. Yang
D. Kwon	O. Yoo

European International Working Group (BPV III)

J. Wendt, <i>Chair</i>	F. Juettemann
D. Koelbl, <i>Vice Chair</i>	M. H. Koeppen
R. Gersinska, <i>Secretary</i>	C. Kuschke
P. Ancion	H.-W. Lange
P. R. Donavin	T. Ludwig
R. Döring	M. Reichert
C. G. Frantescu	G. Roos
T. Hantzka	J. Rudolph
A. Huber	L. Sybertz
R. E. Hueggenberg	I. Tewes
E. Iacopetta	R. Tiete
A. Juengert	F. Wille

Seismic Design Steering Committee (BPV III)

T. M. Adams, <i>Chair</i>	R. M. Pace
K. Gresh, <i>Secretary</i>	M. Pérès
C. Basavaraju	K. Shibukuwa
D. Chowdhury	F. G. Abatt, <i>Contributing Member</i>
R. Döring	M. Arcaro, <i>Contributing Member</i>
G. H. Koo	P. R. Donavin, <i>Contributing Member</i>
A. Maekawa	
J. B. McLean	R. W. Haupt, <i>Contributing Member</i>

Task Group on Alternate Requirements (BPV III)

J. Wen, <i>Chair</i>	K. A. Manoly
R. R. Romano, <i>Secretary</i>	D. E. Matthews
T. Basso	S. McKillop
P. J. Coco	B. P. Nolan
P. R. Donavin	J. B. Ossmann
J. V. Gardiner	E. C. Renaud
F. Grant	M. A. Richter
J. Grimm	R. Summitt
R. S. Hill III	K. Voelsing
M. Kris	Yanli Wang
M. A. Lockwood	I. H. Tseng, <i>Alternate</i>

India International Working Group (BPV III)

S. B. Parkash, <i>Chair</i>	T. Mukherjee
V. Sehgal, <i>Vice Chair</i>	D. Narain
M. Brijlani, <i>Secretary</i>	A. D. Paranjpe
S. Aithal	J. R. Patel
A. D. Bagdare	E. L. Pleins
H. Dalal	S. Ponnappan
S. K. Goyal	T. J. P. Rao
D. Kulkarni	S. Singh
Raj Kumar	B. K. Sreedhar
Ritesh Kumar	N. Mistry, <i>Alternate</i>
S. Kumar	

United Kingdom International Working Group (BPV III)

P. M. James, <i>Chair</i>	S. A. Jones
J. Emslie, <i>Vice Chair</i>	B. McGlone
C. B. Carpenter, <i>Secretary</i>	B. Pellereau
T. Bann	E. I. S. Pendry
M. J. Chevalier	J. Randles
A. J. Cole-Baker	C. R. Schneider
M. Consonni	J. W. Stairmand
M. J. Crathorne	J. Sulley
P. Gill	J. Talamantes-Silva
G. Innes	A. J. Holt, <i>Contributing Member</i>

Special Working Group on New Plant Construction Issues (BPV III)

J. B. Ossmann, <i>Chair</i>	Z. McLucas
A. Maslowski, <i>Staff Secretary</i>	N. J. McTiernan
M. C. Buckley, <i>Secretary</i>	K. Pigg
M. Arcaro	E. L. Pleins
K. Burnett	J. Pollak
A. Cardillo	D. W. Sandusky
P. J. Coco	M. C. Scott
K. Harris	R. R. Stevenson
E. Henry	H. Xu
J. Honcharik	J. Yan
M. Kris	J. C. Minichiello, <i>Contributing Member</i>
R. E. McLaughlin	
A. McLendon	

Special Working Group on Editing and Review (BPV III)

D. E. Matthews, <i>Chair</i>	J. C. Minichiello
R. P. Deubler	J. F. Strunk
A. C. Eberhardt	Yanli Wang
S. Hunter	C. Wilson
B. McGlone	

Special Working Group on HDPE Stakeholders (BPV III)

S. Patterson, <i>Secretary</i>	J. E. O'Sullivan
M. Kuntz	

Special Working Group on Honors and Awards (BPV III)

R. W. Barnes, <i>Chair</i>	D. E. Matthews
A. Appleton	J. C. Minichiello
R. M. Jessee	

Special Working Group on International Meetings and IWG Liaisons (BPV III)

D. E. Matthews, <i>Chair</i>	P. R. Donavin
A. Maslowski, <i>Staff Secretary</i>	E. L. Pleins
R. W. Barnes	W. J. Sperko

Joint ACI-ASME Committee on Concrete Components for Nuclear Service (BPV III)

J. B. McLean, <i>Chair</i>	J. S. Saini
L. J. Colarusso, <i>Vice Chair</i>	J. F. Strunk
A. Dinizulu, <i>Staff Secretary</i>	G. Thomas
S. Bae	A. Varma
C. J. Bang	S. Wang
A. C. Eberhardt	A. Istar, <i>Alternate</i>
B. D. Hovis	A. Adediran, <i>Contributing Member</i>
T. C. Inman	J.-B. Domage, <i>Contributing Member</i>
C. Jones	P. S. Ghosal, <i>Contributing Member</i>
T. Kang	M. R. Senecal, <i>Contributing Member</i>
N.-H. Lee	Z. Shang, <i>Contributing Member</i>
S. Malushte	M. Sircar, <i>Contributing Member</i>
J. A. Munshi	C. T. Smith, <i>Contributing Member</i>
T. Muraki	

Special Working Group on Modernization (SG Div 2) (BPV III)

A. Varma, <i>Chair</i>	S. Wang
J. B. McLean, <i>Vice Chair</i>	I. Zivanovic
J. S. Saini, <i>Vice Chair</i>	R. Janowiak, <i>Contributing Member</i>
A. Adediran	F. Lin, <i>Contributing Member</i>
S. Malushte	J. A. Pires, <i>Contributing Member</i>

Task Group on Steel-Concrete Composite Containments (SG Div 2) (BPV III)

A. Varma, <i>Chair</i>	J. B. McLean
R. Janowiak	J. A. Pires
S. Malushte	J. S. Saini

Working Group on Design (SG Div 2) (BPV III)

N.-H. Lee, <i>Chair</i>	S. Wang
S. Bae	A. Istar, <i>Alternate</i>
L. J. Colarusso	P. S. Ghosal, <i>Contributing Member</i>
A. C. Eberhardt	S.-Y. Kim, <i>Contributing Member</i>
B. D. Hovis	J. Kwon, <i>Contributing Member</i>
T. C. Inman	S. E. Ohler-Schmitz, <i>Contributing Member</i>
C. Jones	B. B. Scott, <i>Contributing Member</i>
J. A. Munshi	Z. Shang, <i>Contributing Member</i>
T. Muraki	M. Shin, <i>Contributing Member</i>
J. S. Saini	M. Sircar, <i>Contributing Member</i>
G. Thomas	

Working Group on Materials, Fabrication, and Examination (SG Div 2) (BPV III)

C. Jones, <i>Chair</i>	Z. Shang
A. Eberhardt, <i>Vice Chair</i>	J. F. Strunk
C. J. Bang	I. Zivanovic
B. Birch	A. A. Aboelmagd, <i>Contributing Member</i>
J.-B. Domage	P. S. Ghosal, <i>Contributing Member</i>
T. Kang	
N.-H. Lee	

Subcommittee on Design (BPV III)

P. R. Donavin, <i>Chair</i>	M. N. Mitchell
S. McKillop, <i>Vice Chair</i>	B. Pellereau
R. P. Deubler, <i>Secretary</i>	Yanli Wang
T. P. Davis	W. F. Weitz
M. A. Gray	C. Basavaraju, <i>Alternate</i>
R. I. Jetter	G. L. Hollinger, <i>Contributing Member</i>
R. B. Keating	W. J. O'Donnell, Sr., <i>Contributing Member</i>
J. I. Kim	K. Wright, <i>Contributing Member</i>
K. A. Manoly	
D. E. Matthews	

Subgroup on Component Design (SC-D) (BPV III)

D. E. Matthews, <i>Chair</i>	J. C. Minichiello
P. Vock, <i>Vice Chair</i>	T. Mitsuhashi
D. Chowdhury, <i>Secretary</i>	D. Murphy
D. J. Ammerman	T. M. Musto
G. A. Antaki	T. Nagata
J. J. Arthur	S. Pellet
S. Asada	S. Willoughby-Braun
C. Basavaraju	C. Wilson
N. A. Costanzo	T. M. Adams, <i>Contributing Member</i>
R. P. Deubler	R. B. Keating, <i>Contributing Member</i>
P. Hirschberg	O.-S. Kim, <i>Contributing Member</i>
M. Kassir	R. J. Masterson, <i>Contributing Member</i>
D. Keck	H. S. Mehta, <i>Contributing Member</i>
T. R. Liszkai	G. Z. Tokarski, <i>Contributing Member</i>
K. A. Manoly	J. P. Tucker, <i>Contributing Member</i>
R. Martin	
K. R. May	

Task Group on Pressurized Heavy Water Reactor (SG-CD) (BPV III)

R. W. Barnes, <i>Chair</i>	E. L. Pleins
M. Brijlani	W. D. Reinhardt
D. E. Matthews	C. A. Sanna
B. McGlone	V. Sehgal
J. B. Ossmann	S. Singh
S. B. Parkash	

Task Group to Improve Section III/XI Interface (SG-CD) (BPV III)

P. Vock, <i>Chair</i>	C. A. Nove
E. Henry, <i>Secretary</i>	T. Nuoffer
G. A. Antaki	J. B. Ossmann
A. Cardillo	A. T. Roberts III
D. Chowdhury	J. Sciulli
J. Honcharik	A. Udyawar
J. Hurst	S. Willoughby-Braun
J. Lambin	

Working Group on Core Support Structures (SG-CD) (BPV III)

R. Martin, <i>Chair</i>	M. D. Snyder
R. Z. Ziegler, <i>Secretary</i>	R. O. Vollmer
G. W. Delpont	T. M. Wiger
L. C. Hartless	C. Wilson
D. Keck	Y. Wong
T. R. Liszkai	K. Hsu, <i>Alternate</i>
M. Nakajima	H. S. Mehta, <i>Contributing Member</i>

Working Group on Design of Division 3 Containment Systems (SG-CD) (BPV III)

D. J. Ammerman, <i>Chair</i>	D. Siromani
S. Klein, <i>Secretary</i>	C. R. Sydnor
J. Bignell	R. Sypulski
G. Bjorkman	R. Williamson
V. Broz	X. Zhai
D. D. Imholte	X. Zhang
D. W. Lewis	J. Smith, <i>Alternate</i>
A. Rigato	J. C. Minichiello, <i>Contributing Member</i>
P. Sakalaukus, Jr.	

Working Group on HDPE Design of Components (SG-CD) (BPV III)

M. Brandes	K. A. Manoly
J. R. Hebeisen	D. P. Munson
P. Krishnaswamy	R. Stakenborghs
M. Kuntz	B. Lin, <i>Alternate</i>

Working Group on Piping (SG-CD) (BPV III)

G. A. Antaki, <i>Chair</i>	W. F. Weitze
S. Weindorf, <i>Secretary</i>	K. Hsu, <i>Alternate</i>
C. Basavaraju	R. B. Keating, <i>Contributing Member</i>
J. Catalano	T. B. Littleton, <i>Contributing Member</i>
C. M. Faigy	Y. Liu, <i>Contributing Member</i>
R. G. Gilada	J. F. McCabe, <i>Contributing Member</i>
M. A. Gray	J. C. Minichiello, <i>Contributing Member</i>
R. J. Gurdal	A. N. Nguyen, <i>Contributing Member</i>
R. W. Haupt	M. S. Sills, <i>Contributing Member</i>
A. Hirano	N. C. Sutherland, <i>Contributing Member</i>
P. Hirschberg	G. Z. Tokarski, <i>Contributing Member</i>
M. Kassir	E. A. Wais, <i>Contributing Member</i>
D. Lieb	C.-I. Wu, <i>Contributing Member</i>
M. Moenssens	
I.-K. Nam	
K. E. Reid II	
B. Still	
D. Vlaicu	

Working Group on Pressure Relief (SG-CD) (BPV III)

K. R. May, <i>Chair</i>	B. J. Yonsky
J. F. Ball, <i>Vice Chair</i>	Y. Wong, <i>Alternate</i>
R. Krithivasan, <i>Secretary</i>	J. Yu, <i>Alternate</i>
J. W. Dickson	M. Brown, <i>Contributing Member</i>
N. Hansing	S. T. French, <i>Contributing Member</i>
S. Jones	S. Ruesenberg, <i>Contributing Member</i>
D. Miller	
T. Patel	

Working Group on Pumps (SG-CD) (BPV III)

D. Chowdhury, <i>Chair</i>	K. J. Noel
J. V. Gregg, Jr., <i>Secretary</i>	D. Skidmore
B. Busse	J. Sulley
R. Ibrahim	Y. Wong
T. Johnson	N. Chandran, <i>Alternate</i>

Working Group on Supports (SG-CD) (BPV III)

N. A. Costanzo, <i>Chair</i>	G. Z. Tokarski
U. S. Bandyopadhyay, <i>Secretary</i>	L. Vandersip
K. Avrithi	P. Wiseman
N. M. Bisceglia	J. Bozga, <i>Alternate</i>
R. P. Deubler	R. J. Masterson, <i>Contributing Member</i>
N. M. Graham	R. Roche-Rivera, <i>Contributing Member</i>
Y. Matsubara	J. R. Stinson, <i>Contributing Member</i>
S. Pellet	
G. Thomas	

Working Group on Valves (SG-CD) (BPV III)

P. Vock, <i>Chair</i>	C. A. Mizer
S. Jones, <i>Secretary</i>	H. O'Brien
M. C. Buckley	J. O'Callaghan
N. Hansing	M. Rain
G. A. Jolly	K. E. Reid II
J. Lambin	J. Sulley
T. Lippucci	Y. Wong, <i>Alternate</i>

Working Group on Vessels (SG-CD) (BPV III)

D. Murphy, <i>Chair</i>	M. C. Scott
S. Willoughby-Braun, <i>Secretary</i>	J. Shupert
J. J. Arthur	D. Vlaicu
C. Basavaraju	C. Wilson
M. Brijlani	R. Z. Ziegler
L. Constantinescu	M. R. Breach, <i>Alternate</i>
J. I. Kim	B. Basu, <i>Contributing Member</i>
D. E. Matthews	R. B. Keating, <i>Contributing Member</i>
T. Mitsuhashi	W. F. Weitze, <i>Contributing Member</i>
T. J. Schrieffer	

Subgroup on Design Methods (SC-D) (BPV III)

S. McKillop, <i>Chair</i>	W. D. Reinhardt
P. R. Donavin, <i>Vice Chair</i>	P. Smith
J. Wen, <i>Secretary</i>	R. O. Vollmer
K. Avrithi	W. F. Weitze
M. A. Gray	Y. Wong, <i>Alternate</i>
J. V. Gregg, Jr.	S. R. Gosselin, <i>Contributing Member</i>
K. Hsu	H. T. Harrison III, <i>Contributing Member</i>
E. Isom	W. J. O'Donnell, Sr., <i>Contributing Member</i>
R. Kalnas	K. Wright, <i>Contributing Member</i>
D. Keck	
J. I. Kim	
B. Pellereau	

Special Working Group on Computational Modeling for Explicit Dynamics (SG-DM) (BPV III)

G. Bjorkman, <i>Chair</i>	P. Sakalaukus, Jr.
D. J. Ammerman, <i>Vice Chair</i>	D. Siromani
V. Broz, <i>Secretary</i>	C.-F. Tso
J. Bignell	M. C. Yaksh
S. Kuehner	U. Zencker
D. Molitoris	X. Zhang
W. D. Reinhardt	M. R. Breach, <i>Contributing Member</i>
E. Rosvall	Y. Wong, <i>Contributing Member</i>

Working Group on Design Methodology (SG-DM) (BPV III)

B. Pellereau, <i>Chair</i>	W. F. Weitze
R. O. Vollmer, <i>Secretary</i>	J. Wen
K. Avrithi	T. M. Wiger
C. Basavaraju	J. Wu
F. Berkepile	K. Hsu, <i>Alternate</i>
M. Cho	G. Banyay, <i>Contributing Member</i>
D. Clarkson	D. S. Bartran, <i>Contributing Member</i>
C. M. Faigy	R. D. Blevins, <i>Contributing Member</i>
Y.-J. Gao	M. R. Breach, <i>Contributing Member</i>
M. Kassir	H. T. Harrison III, <i>Contributing Member</i>
J. I. Kim	P. Hirschberg, <i>Contributing Member</i>
T. R. Liszkai	S. McKillop, <i>Contributing Member</i>
D. Lytle	A. Walker, <i>Contributing Member</i>
K. Matsunaga	K. Wright, <i>Contributing Member</i>
S. Ranganath	
W. D. Reinhardt	
S. Wang	

Working Group on Environmental Fatigue Evaluation Methods (SG-DM) (BPV III)

M. A. Gray, <i>Chair</i>	B. Pellereau
W. F. Weitze, <i>Secretary</i>	T. Seppanen
S. Asada	D. Vlaicu
K. Avrithi	K. Wang
R. C. Cipolla	K. A. Manoly, <i>Alternate</i>
T. M. Damiani	S. Cuvilliez, <i>Contributing Member</i>
C. M. Faigy	T. D. Gilman, <i>Contributing Member</i>
A. Hirano	S. R. Gosselin, <i>Contributing Member</i>
P. Hirschberg	Y. He, <i>Contributing Member</i>
K. Hsu	H. S. Mehta, <i>Contributing Member</i>
A. Morley	K. Wright, <i>Contributing Member</i>
J.-S. Park	

Working Group on Fatigue Strength (SG-DM) (BPV III)

P. R. Donavin, <i>Chair</i>	Y. Zou
T. M. Damiani	C. E. Hinnant, <i>Contributing Member</i>
D. W. DeJohn	P. Hirschberg, <i>Contributing Member</i>
C. M. Faigy	S. H. Kleinsmith, <i>Contributing Member</i>
P. Gill	S. Majumdar, <i>Contributing Member</i>
R. J. Gurdal	H. S. Mehta, <i>Contributing Member</i>
K. Hsu	W. J. O'Donnell, Sr., <i>Contributing Member</i>
J. I. Kim	S. Ranganath, <i>Contributing Member</i>
A. Morley	K. Wright, <i>Contributing Member</i>
B. Pellereau	
M. S. Shelton	
I. Viscarra	
Yanli Wang	
W. F. Weitze	

Working Group on Probabilistic Methods in Design (SG-DM) (BPV III)

M. Golliet, <i>Chair</i>	K. A. Manoly
R. Kalnas, <i>Vice Chair</i>	A. Morley
G. Brouette	B. Pellereau
R. Fougousse	A. Weaver
J. Hakii	M. Yagodich
E. Hanson	I. H. Tseng, <i>Alternate</i>
D. O. Henry	K. Avrithi, <i>Contributing Member</i>
A. Hirano	R. S. Hill III, <i>Contributing Member</i>

Subgroup on Containment Systems for Spent Nuclear Fuel and High-Level Radioactive Material (BPV III)

D. W. Lewis, <i>Chair</i>	C. R. Sydnor
D. J. Ammerman, <i>Vice Chair</i>	R. Sypulski
S. Klein, <i>Secretary</i>	J. Wellwood
J. Bignell	X. J. Zhai
G. Bjorkman	X. Zhang
V. Broz	J. Smith, <i>Alternate</i>
D. D. Imholte	W. H. Borter, <i>Contributing Member</i>
A. Rigato	E. L. Pleins, <i>Contributing Member</i>
P. Sakalaukus, Jr.	N. M. Simpson, <i>Contributing Member</i>
D. Siromani	

Subgroup on Fusion Energy Devices (BPV III)

T. P. Davis, <i>Chair</i>	I. Kimihiro
A. Maslowski, <i>Staff Secretary</i>	P. Mokaria
M. Ellis, <i>Secretary</i>	F. J. Schaaf, Jr.
L. Babu	P. Smith
M. Bashir	Y. Song
J. P. Blanchard	D. White
B. R. Doshi	R. W. Barnes, <i>Contributing Member</i>
L. El-Guebaly	W. K. Sowder, Jr., <i>Contributing Member</i>
R. Holmes	
D. Johnson	

Special Working Group on Fusion Stakeholders (SG-FED) (BPV III)

R. Holmes, <i>Chair</i>	S. S. Desai
C. Barnes	F. Deschamps
R. W. Barnes	M. Hua
J. Brister	S. Krishnan
A. A. Campbell	W. K. Sowder, Jr.
V. Chugh	N. Young
T. P. Davis	

Working Group on General Requirements (SG-FED) (BPV III)

P. Smith, <i>Chair</i>	B. McGlone
L. Babu	P. Mokaria
T. P. Davis	W. K. Sowder, Jr.
M. Ellis	D. White, <i>Contributing Member</i>

Working Group on In-Vessel Components (SG-FED) (BPV III)

M. Bashir, <i>Chair</i>	S. T. Madabusi
T. P. Davis	

Working Group on Magnets (SG-FED) (BPV III)

D. S. Bartran	W. K. Sowder, Jr., <i>Contributing Member</i>

Working Group on Materials (SG-FED) (BPV III)

T. P. Davis

Working Group on Vacuum Vessels (SG-FED) (BPV III)

I. Kimihiro, <i>Chair</i>	D. Johnson
B. R. Doshi	

Subgroup on General Requirements (BPV III)

B. McGlone, <i>Chair</i>	L. Noyes
A. McLendon, <i>Secretary</i>	E. C. Renaud
V. Apostolescu	T. N. Rezk
A. Appleton	J. Rogers
S. Bell	B. S. Sandhu
G. Brouette	R. Spuhl
P. J. Coco	J. L. Williams
G. C. Deleanu	Y. Diaz-Castillo, <i>Alternate</i>
N. DeSantis	J. DeKleine, <i>Contributing Member</i>
O. Elkadim	S. F. Harrison, Jr., <i>Contributing Member</i>
J. V. Gardiner	H. Michael, <i>Contributing Member</i>
J. Grimm	D. J. Roszman, <i>Contributing Member</i>
J. Harris	C. T. Smith, <i>Contributing Member</i>
J. W. Highlands	G. E. Szabatura, <i>Contributing Member</i>
E. V. Imbro	
K. A. Kavanagh	
Y.-S. Kim	
D. T. Meisch	

Working Group on General Requirements for Graphite and Ceramic Composite Core Components and Assemblies (SG-GR) (BPV III)

W. J. Geringer, <i>Chair</i>	M. N. Mitchell
A. Appleton	J. Potgieter
J. R. Berry	E. C. Renaud
A. A. Campbell	S. Sekar
C. Cruz	R. Spuhl
Y. Diaz-Castillo	W. Windes
J. Lang	B. Lin, <i>Alternate</i>

Subgroup on High Temperature Reactors (BPV III)

Yanli Wang, <i>Chair</i>	X. Wei
N. Broom	W. Windes
F. W. Brust	R. Wright
M. E. Cohen	G. L. Zeng
W. J. Geringer	J. Bass, <i>Alternate</i>
B. F. Hantz	P. Carter, <i>Contributing Member</i>
M. Hiser	W. O'Donnell, Sr., <i>Contributing Member</i>
R. I. Jetter	T.-L. Sham
K. Kimura	L. Shi, <i>Contributing Member</i>
G. H. Koo	R. W. Swindeman, <i>Contributing Member</i>
W. Li	
M. C. Messner	

Special Working Group on High Temperature Reactor Stakeholders (SG-HTR) (BPV III)

M. E. Cohen, <i>Chair</i>	R. I. Jetter
M. C. Albert	G. H. Koo
M. Arcaro	N. J. McTiernan
R. W. Barnes	M. N. Mitchell
R. Bass	K. J. Noel
N. Broom	J. Roll
K. Burnett	B. Song
A. A. Campbell	Yanli Wang
V. Chugh	X. Wei
W. Corwin	G. L. Zeng
G. C. Deleanu	R. M. Iyengar, <i>Alternate</i>
R. A. Fleming	T. Asayama, <i>Contributing Member</i>
K. Harris	

Task Group on Alloy 709 Code Case (SG-HTR) (BPV III)

Yanli Wang, <i>Chair</i>	W. J. Sperko
H. Mahajan, <i>Secretary</i>	R. Wright
R. I. Jetter	T.-L. Sham, <i>Contributing Member</i>
M. C. Messner	

Working Group on Allowable Stress Criteria (SG-HTR) (BPV III)

R. Wright, <i>Chair</i>	M. C. Messner
M. McMurtrey, <i>Secretary</i>	T. Patterson
R. W. Barnes	Yanli Wang
R. Bass	X. Wei
K. Kimura	R. M. Iyengar, <i>Alternate</i>
W. Li	R. W. Swindeman, <i>Contributing Member</i>
D. Maitra	
R. J. McReynolds	

Task Group on Class A Rewrite (SG-HTR) (BPV III)

Yanli Wang, <i>Chair</i>	N. J. McTiernan
R. W. Barnes	M. C. Messner
M. E. Cohen	T. Nguyen
R. I. Jetter	D. Pease
H. Mahajan	X. Wei
S. McKillop	J. Young

Working Group on Analysis Methods (SG-HTR) (BPV III)

M. C. Messner, <i>Chair</i>	X. Song
H. Mahajan, <i>Secretary</i>	Yanli Wang
R. Adibi-Asl	X. Wei
R. W. Barnes	S. X. Xu
J. A. Blanco	J. Young
P. Carter	J. Bass, <i>Alternate</i>
R. I. Jetter	M. R. Breach, <i>Contributing Member</i>
G. H. Koo	Y.-J. Gao, <i>Contributing Member</i>
T. Nguyen	T. Hassan, <i>Contributing Member</i>
M. Petkov	S. Krishnamurthy, <i>Contributing Member</i>
K. Pigg	M. J. Swindeman, <i>Contributing Member</i>
H. Qian	
T. Riordan	

Task Group on Division 5 AM Components (SG-HTR) (BPV III)

R. Wright, <i>Chair</i>	T. Patterson
R. W. Barnes	E. C. Renaud
F. W. Brust	D. Rudland
Z. Feng	B. Sutton
S. Lawler	I. J. Van Rooyen
X. Lou	Yanli Wang
M. McMurtrey	X. Wei
M. C. Messner	R. Bass, <i>Alternate</i>

Working Group on Creep-Fatigue and Negligible Creep (SG-HTR) (BPV III)

W. Li, <i>Chair</i>	M. McMurtrey
J. Bass	M. C. Messner
C. M. Brusconi	H. Qian
P. Carter	R. Rajasekaran
M. E. Cohen	M. Shah
J. I. Duo	Yanli Wang
R. I. Jetter	X. Wei
G. H. Koo	J. Young
H. Mahajan	R. Bass, <i>Alternate</i>

Task Group on Graphite Design Analysis (SG-HTR) (BPV III)

A. Mack, <i>Chair</i>	P.-A. Juan
J. Bass	J. Potgieter
S. Baylis	J. Quick
G. Beirnaert	M. Saitta
O. Booler	A. Walker

Working Group on Nonmetallic Design and Materials (SG-HTR) (BPV III)

W. Windes, <i>Chair</i>	J. Parks
W. J. Geringer, <i>Vice Chair</i>	K. Pigg
J. Potgieter, <i>Secretary</i>	J. Podhiny
G. Beirnaert	J. Roll
A. A. Campbell	A. Tzelepi
C. Chen	A. Walker
A. N. Chereskin	Yanli Wang
V. Chugh	G. L. Zeng
C. Contescu	J. Bass, <i>Alternate</i>
N. Gallego	A. Appleton, <i>Contributing Member</i>
S. T. Gonczy	R. W. Barnes, <i>Contributing Member</i>
K. Harris	S.-H. Chi, <i>Contributing Member</i>
M. G. Jenkins	Y. Katoh, <i>Contributing Member</i>
P.-A. Juan	J. B. Ossmann, <i>Contributing Member</i>
J. Lang	
A. Mack	J. Quick, <i>Contributing Member</i>
M. P. Metcalfe	M. Saitta, <i>Contributing Member</i>
M. N. Mitchell	

Task Group on High Temperature Piping Design (SG-HTR) (BPV-III)

G. A. Antaki, <i>Chair</i>	H. Mahajan
S. Weindorf, <i>Secretary</i>	J. C. Minichiello
R. Adibi-Asl	D. Pease
T. D. Al-Shawaf	Yanli Wang
D. Bankston, Jr.	C. D. Weary
R. P. Deubler	T.-L. Sham, <i>Contributing Member</i>
R. I. Jetter	

Subgroup on Materials, Fabrication, and Examination (BPV III)

D. W. Mann, <i>Chair</i>	M. Kris
J. Grimm, <i>Vice Chair</i>	T. Melfi
J. B. Ossmann, <i>Vice Chair</i>	I.-K. Nam
S. Hunter, <i>Secretary</i>	J. E. O'Sullivan
W. H. Borter	M. C. Scott
M. Brijlani	W. J. Sperko
G. R. Cannell	J. F. Strunk
A. Cardillo	W. Windes
S. Cho	R. Wright
P. J. Coco	H. Xu
R. H. Davis	S. Yee
D. B. Denis	J. Wise, Jr., <i>Alternate</i>
B. D. Frew	S. Wolbert, Jr., <i>Alternate</i>
D. W. Gandy	R. W. Barnes, <i>Contributing Member</i>
S. E. Gingrich	S. Levitus, <i>Contributing Member</i>
M. Golliet	H. Michael, <i>Contributing Member</i>
L. S. Harbison	

Working Group on Advanced Manufacturing (SG-MFE) (BPV III)

D. W. Mann, <i>Chair</i>	E. C. Renaud
D. W. Gandy, <i>Secretary</i>	W. J. Sperko
D. Chowdhury	J. F. Strunk
P. J. Coco	J. Sulley
B. D. Frew	S. Tate
J. Grimm	J. Wise
J. Lambin	S. Wolbert
T. Lippucci	H. Xu
T. Melfi	R. H. Davis, <i>Alternate</i>
A. Mori	S. Malik, <i>Contributing Member</i>

Joint Working Group on HDPE (SG-MFE) (BPV III)

M. Brandes, <i>Chair</i>	K. Manoly
T. M. Musto, <i>Chair</i>	D. P. Munson
J. B. Ossmann, <i>Secretary</i>	J. O'Sullivan
G. Brouette	V. Rohatgi
M. C. Buckley	F. Schaaf, Jr.
S. Choi	S. Schuessler
M. Golliet	R. Stakenborg
J. Hebeisen	M. Troughton
J. Johnston, Jr.	P. Vibien
P. Krishnaswamy	J. Wright
M. Kuntz	T. Adams, <i>Contributing Member</i>
B. Lin	

COMMITTEE ON HEATING BOILERS (BPV IV)

M. Wadkinson, <i>Chair</i>	J. A. Hall
J. L. Kleiss, <i>Vice Chair</i>	M. Mengon
C. R. Ramcharran, <i>Staff Secretary</i>	Y. Teng
B. Ahee	D. Picart, <i>Delegate</i>
L. Badziagowski	Y. R. Cho, <i>Alternate</i>
T. L. Bedeaux	B. J. Iske, <i>Alternate</i>
B. Calderon	T. Wagner, <i>Alternate</i>
J. P. Chicoine	H. Michael, <i>Contributing Member</i>
C. Dinic	P. A. Molvie, <i>Contributing Member</i>
J. M. Downs	

Executive Committee (BPV IV)

M. Wadkinson, <i>Chair</i>	J. P. Chicoine
C. R. Ramcharran, <i>Staff Secretary</i>	J. A. Hall
T. L. Bedeaux	J. L. Kleiss

Subgroup on Cast Boilers (BPV IV)

J. P. Chicoine, <i>Chair</i>	J. L. Kleiss
J. M. Downs, <i>Vice Chair</i>	M. Mengon
C. R. Ramcharran, <i>Staff Secretary</i>	B. J. Iske, <i>Alternate</i>
T. L. Bedeaux	T. Wagner, <i>Alternate</i>
J. A. Hall	

Subgroup on Materials (BPV IV)

J. A. Hall, <i>Chair</i>	T. L. Bedeaux
J. M. Downs, <i>Vice Chair</i>	Y. Teng
C. R. Ramcharran, <i>Staff Secretary</i>	M. Wadkinson
L. Badziagowski	

Subgroup on Water Heaters (BPV IV)

J. L. Kleiss, <i>Chair</i>	C. Dinic
L. Badziagowski, <i>Vice Chair</i>	M. Mengon
C. R. Ramcharran, <i>Staff Secretary</i>	Y. Teng
B. Ahee	B. J. Iske, <i>Alternate</i>
M. Carlson	T. Wagner, <i>Alternate</i>
J. P. Chicoine	P. A. Molvie, <i>Contributing Member</i>

Subgroup on Welded Boilers (BPV IV)

T. L. Bedeaux, <i>Chair</i>	J. L. Kleiss
J. P. Chicoine, <i>Vice Chair</i>	M. Mengon
C. R. Ramcharran, <i>Staff Secretary</i>	M. Wadkinson
B. Ahee	M. Washington
E. Alexis	B. J. Iske, <i>Alternate</i>
L. Badziagowski	M. J. Melita, <i>Alternate</i>
B. Calderon	T. J. Wagner, <i>Alternate</i>
M. Carlson	P. A. Molvie, <i>Contributing Member</i>
C. Dinic	

COMMITTEE ON NONDESTRUCTIVE EXAMINATION (BPV V)

N. A. Finney, <i>Chair</i>	P. Lang
C. May, <i>Vice Chair</i>	T. R. Lerohl
C. R. Ramcharran, <i>Staff Secretary</i>	J. Schoneweis
D. Bajula	P. B. Shaw
P. L. Brown	C. Vorwald
M. A. Burns	M. Carlson, <i>Alternate</i>
N. Carter	J. E. Batey, <i>Contributing Member</i>
C. Emslander	T. Clausing, <i>Contributing Member</i>
A. F. Garbolevsky	J. F. Halley, <i>Contributing Member</i>
P. T. Hayes	R. W. Kruzic, <i>Contributing Member</i>
G. W. Hembree	L. E. Mullins, <i>Contributing Member</i>
F. B. Kovacs	H. C. Graber, <i>Honorary Member</i>
K. Krueger	T. G. McCarty, <i>Honorary Member</i>
B. D. Laite	

Executive Committee (BPV V)

C. May, <i>Chair</i>	F. B. Kovacs
N. A. Finney, <i>Vice Chair</i>	K. Krueger
C. R. Ramcharran, <i>Staff Secretary</i>	B. D. Laite
V. F. Godinez-Azcuaga	E. Peloquin
P. T. Hayes	C. Vorwald
G. W. Hembree	

**Subgroup on General Requirements/Personnel Qualifications and
Inquiries (BPV V)**

C. Vorwald, <i>Chair</i>	P. Lang
K. Krueger, <i>Vice Chair</i>	T. R. Lerohl
D. Bajula	C. May
N. Carter	J. Schoneweis
P. Chavdarov	T. Clausing, <i>Contributing Member</i>
C. Emslander	J. F. Halley, <i>Contributing Member</i>
N. A. Finney	D. I. Morris, <i>Contributing Member</i>
G. W. Hembree	J. P. Swezy, Jr., <i>Contributing Member</i>
F. B. Kovacs	

Subgroup on Volumetric Methods (BPV V)

C. May, <i>Chair</i>	K. Krueger
P. T. Hayes, <i>Vice Chair</i>	N. Pasemko
P. L. Brown	E. Peloquin
N. A. Finney	J. Schoneweis
A. F. Garbolevsky	C. Vorwald
V. F. Godinez-Azcuaga	J. F. Halley, <i>Contributing Member</i>
C. Hansen	R. W. Kruzic, <i>Contributing Member</i>
R. W. Hardy	L. E. Mullins, <i>Contributing Member</i>
G. W. Hembree	C. Wassink, <i>Contributing Member</i>
F. B. Kovacs	

Working Group on Radiography (SG-VM) (BPV V)

C. Vorwald, <i>Chair</i>	B. D. Laite
D. M. Woodward, <i>Vice Chair</i>	T. R. Lerohl
D. Bajula	C. May
P. L. Brown	R. J. Mills
C. Emslander	J. F. Molinaro
A. F. Garbolevsky	N. Pasemko
R. W. Hardy	J. Schoneweis
G. W. Hembree	T. L. Clifford, <i>Contributing Member</i>
P. Howie	R. W. Kruzic, <i>Contributing Member</i>
F. B. Kovacs	

Working Group on Ultrasonics (SG-VM) (BPV V)

K. Krueger, <i>Chair</i>	C. May
D. Bajula, <i>Vice Chair</i>	E. Peloquin
D. Adkins	J. Schoneweis
C. T. Brown	D. Van Allen
C. Emslander	C. Vorwald
N. A. Finney	J. F. Halley, <i>Contributing Member</i>
P. Furr	R. W. Kruzic, <i>Contributing Member</i>
C. Hansen	P. Mudge, <i>Contributing Member</i>
P. T. Hayes	L. E. Mullins, <i>Contributing Member</i>
G. W. Hembree	M. J. Quarry, <i>Contributing Member</i>
B. D. Laite	J. Vanvelsor, <i>Contributing Member</i>
T. R. Lerohl	

**Special Working Group for Advance UT Techniques
(WG-UT) (BPV V)**

K. Krueger, <i>Chair</i>	P. Hayes
J. Schoneweis, <i>Vice Chair</i>	B. D. Laite
D. Bajula	T. R. Lerohl
C. David	E. Peloquin
N. A. Finney	D. Tompkins
P. Furr	D. Van Allen
J. Garner	C. Wassink
C. Hansen	

Working Group on Acoustic Emissions (SG-VM) (BPV V)

V. F. Godinez-Azcuaga, <i>Chair</i>	S. R. Doctor
J. Catty, <i>Vice Chair</i>	N. F. Douglas, Jr.

Working Group on Full Matrix Capture (SG-VM) (BPV V)

E. Peloquin, <i>Chair</i>	M. Lozev
P. T. Hayes, <i>Vice Chair</i>	R. Nogueira
D. Bajula	D. Richard
J. Catty	M. Sens
N. A. Finney	D. Tompkins
J. L. Garner	J. F. Halley, <i>Contributing Member</i>
R. T. Grotenhuis	L. E. Mullins, <i>Contributing Member</i>
G. W. Hembree	C. Wassink, <i>Contributing Member</i>
K. Krueger	

**Subgroup on Inservice Examination Methods and Techniques
(BPV V)**

P. T. Hayes, <i>Chair</i>	V. F. Godinez-Azcuaga
E. Peloquin, <i>Vice Chair</i>	C. Hansen
D. Bajula	G. W. Hembree
R. Barker	K. Krueger
R. J. Bunte	C. May
M. A. Burns	N. Pasemko
M. Carlson	D. D. Raimander
T. Demmer	B. Ray
N. Douglas, Jr.	J. Schoneweis
N. A. Finney	C. Vorwald

Working Group on Assisted Analysis (SG-ISI) (BPV V)

T. Demmer, <i>Chair</i>	G. W. Hembree
C. Hansen, <i>Vice Chair</i>	G. I. Kraljic
J. Aldrin	G. M. Lozev
J. Chen	R. S. F. Orozco
M. Elen	E. Peloquin
N. A. Finney	T. Thulien
V. F. Godinez-Azcuaga	J. Williams
R. T. Grotenhuis	S. Zafar
K. Hayes	

Working Group on Methods and Techniques (SG-ISI) (BPV V)

C. May, <i>Chair</i>	P. T. Hayes
R. J. Bunte, <i>Vice Chair</i>	K. Krueger
D. Bajula	B. D. Laite
R. Barker	G. Morais
M. A. Burns	N. Pasemko
M. Carlson	J. Schoneweis
J. Catty	

**Working Group on Supplemental Requirements for Corrosion and
Other Damage Mechanisms (SG-ISI) (BPV V)**

J. Schoneweis, <i>Chair</i>	C. Hansen
N. Pasemko, <i>Vice Chair</i>	P. T. Hayes
D. Bajula	K. Krueger
R. Barker	E. Peloquin
N. A. Finney	I. Roux

Subgroup on Surface Examination Methods (BPV V)

B. D. Laite, <i>Chair</i>	C. May
D. Bajula	G. Morais
R. Behe	J. Schoneweis
R. M. Beldyk	P. B. Shaw
P. L. Brown	R. Tedder
N. Carter	C. Vorwald
C. Emslander	D. M. Woodward
N. Farenbaugh	T. Clausing, <i>Contributing Member</i>
N. A. Finney	J. F. Halley, <i>Contributing Member</i>
A. F. Garbolevsky	K. Hayes, <i>Contributing Member</i>
G. W. Hembree	R. W. Kruzic, <i>Contributing Member</i>
K. Krueger	L. E. Mullins, <i>Contributing Member</i>
T. R. Lerohl	C. Wassink, <i>Contributing Member</i>

Germany International Working Group (BPV V)

P. Chavdarov, <i>Chair</i>	C. Kringe
V. Pohl, <i>Vice Chair</i>	S. Mann
H.-P. Schmitz, <i>Secretary</i>	V. Reusch
D. Kaiser	P. Van IJS

India International Working Group (BPV V)

P. Kumar, <i>Chair</i>	J. V. Muthukumaraswamy
A. V. Bhagwat, <i>Vice Chair</i>	A. Relekar
V. Ligade, <i>Secretary</i>	V. J. Sonawane
S. Jobanputra	N. Suryawanshi
D. Joshi	D. B. Tanpure
G. R. Joshi	

Italy International Working Group (BPV V)

D. D. Raimander, <i>Chair</i>	E. Ferrari
O. Oldani, <i>Vice Chair</i>	M. A. Grimoldi
C. R. Ramcharan, <i>Staff Secretary</i>	G. Luoni
P. Campli, <i>Secretary</i>	U. Papponetti
M. Agostini	P. Pedersoli
T. Aldo	A. Veroni
F. Bresciani	M. Zambon
N. Caputo	G. Gobbi, <i>Contributing Member</i>
M. Colombo	A. Gusmaroli, <i>Contributing Member</i>
P. L. Dinelli	G. Pontiggia, <i>Contributing Member</i>
F. Ferrarese	

COMMITTEE ON PRESSURE VESSELS (BPV VIII)

S. C. Roberts, <i>Chair</i>	J. P. Swezy, Jr.
M. D. Lower, <i>Vice Chair</i>	S. Terada
J. Oh, <i>Staff Secretary</i>	E. Upitis
S. J. Rossi, <i>Staff Secretary</i>	A. Viet
S. R. Babka	K. Xu
L. Bower	K. Oyamada, <i>Delegate</i>
P. Chavdarov	M. E. Papponetti, <i>Delegate</i>
B. F. Hantz	G. Auriolles, Sr., <i>Contributing Member</i>
C. S. Hinson	R. J. Basile
J. Hoskinson	A. Chaudouet, <i>Contributing Member</i>
M. Kowalczyk	D. B. DeMichael, <i>Contributing Member</i>
D. L. Kurle	K. T. Lau, <i>Contributing Member</i>
R. Mahadeen	H. Michael, <i>Contributing Member</i>
S. A. Marks	R. W. Mikitka, <i>Contributing Member</i>
P. Matkovics	D. A. Swanson, <i>Contributing Member</i>
D. T. Peters	G. G. Karcher, <i>Honorary Member</i>
M. J. Pischke	U. R. Miller, <i>Honorary Member</i>
M. D. Rana	T. P. Pastor, <i>Honorary Member</i>
G. B. Rawls, Jr.	K. K. Tam, <i>Honorary Member</i>
F. L. Richter	
C. D. Rodery	
J. C. Sowinski	
D. Sronic	
P. L. Sturgill	
K. Subramanian	

Executive Committee (BPV VIII)

M. D. Lower, <i>Chair</i>	J. Hoskinson
S. J. Rossi, <i>Staff Secretary</i>	P. Matkovics
G. Auriolles, Sr.	S. C. Roberts
C. W. Cary	J. C. Sowinski
P. Chavdarov	K. Subramanian
T. Halligan	K. Xu

Subgroup on Design (BPV VIII)

J. C. Sowinski, <i>Chair</i>	S. Terada
C. S. Hinson, <i>Vice Chair</i>	K. Xu
S. R. Babka	K. Oyamada, <i>Delegate</i>
O. A. Barsky	M. E. Papponetti, <i>Delegate</i>
M. Faulkner	G. Auriolles, Sr., <i>Contributing Member</i>
D. Francis	R. J. Basile, <i>Contributing Member</i>
B. F. Hantz	D. Chandiramani, <i>Contributing Member</i>
C. E. Hinnant	M. H. Jawad, <i>Contributing Member</i>
S. Krishnamurthy	P. K. Lam, <i>Contributing Member</i>
D. L. Kurle	K. Mokhtarian, <i>Contributing Member</i>
K. Kescu	C. D. Rodery, <i>Contributing Member</i>
M. D. Lower	D. A. Swanson, <i>Contributing Member</i>
R. W. Mikitka	K. K. Tam, <i>Contributing Member</i>
B. Millet	E. Upitis, <i>Contributing Member</i>
M. D. Rana	
G. B. Rawls, Jr.	
S. C. Roberts	
T. G. Seipp	
D. Sronic	

Working Group on Design-by-Analysis (BPV VIII)

B. F. Hantz, <i>Chair</i>	S. Krishnamurthy
T. W. Norton, <i>Secretary</i>	C. Nadarajah
J. Bedoya	T. G. Seipp
A. Feller	M. Shah
S. Guzey	S. Terada
C. E. Hinnant	D. A. Arnett, <i>Contributing Member</i>
S. Kataoka	A. Mann, <i>Contributing Member</i>
S. Kilambi	K. Saboda, <i>Contributing Member</i>
K. D. Kirkpatrick	

Task Group on Electrochemical Cell Stacks (TG-ECS) (BPV VIII)

K. Xu, <i>Chair</i>	K. Choi, <i>Contributing Member</i>
K. Quackenbush, <i>Vice Chair</i>	L. T. Dalton, <i>Contributing Member</i>
N. Barkley	M. Duda, <i>Contributing Member</i>
E. Gadsby	R. Fournier, <i>Contributing Member</i>
S. Goyette	E. Gernot, <i>Contributing Member</i>
T. Halligan	S. Grimm, <i>Contributing Member</i>
R. Kauer	N. Hart, <i>Contributing Member</i>
P. Matkovics	R. Müller, <i>Contributing Member</i>
L. Moulthrop	P. K. Panigrahy, <i>Contributing Member</i>
J. Panicker	R. Robles, <i>Contributing Member</i>
E. Prause	M. Stelzel, <i>Contributing Member</i>
P. T. Shanks	M. Sweetland, <i>Contributing Member</i>
S. Ulemek	
E. Andrade, <i>Contributing Member</i>	
B. D. Carter, <i>Contributing Member</i>	

Working Group on Elevated Temperature Design (BPV I and VIII)

C. Nadarajah, <i>Chair</i>	C. T. McDaris
L. S. Tsai, <i>Secretary</i>	M. C. Messner
D. Anderson	M. N. Mitchell
D. Dewees	P. Prueter
B. F. Hantz	A. Ramos
R. I. Jetter	M. Rathinasabapathy
S. Kataoka	M. J. Swindeman
S. Krishnamurthy	A. Mann, <i>Contributing Member</i>
S. R. Kummari	N. McMurray, <i>Contributing Member</i>
T. Le	B. J. Mollitor, <i>Contributing Member</i>
B.-L. Lyow	

Task Group on Fired Heater Pressure Vessels (BPV VIII)

J. Hoskinson, <i>Chair</i>	P. T. Shanks
D. Nelson	E. Smith
R. Robles	D. Srnic
J. Rust	

Subgroup on Fabrication and Examination (BPV VIII)

T. Halligan, <i>Chair</i>	B. F. Shelley
D. I. Morris, <i>Vice Chair</i>	P. L. Sturgill
D. Smith, <i>Secretary</i>	J. P. Swezy, Jr.
J. Lu	E. Uptis
S. A. Marks	C. Violand
O. Mulet	K. Oyamada, <i>Delegate</i>
M. J. Pischke	W. J. Bees, <i>Contributing Member</i>
M. J. Rice	L. F. Campbell, <i>Contributing Member</i>
J. Roberts	N. Carter, <i>Contributing Member</i>
C. D. Rodery	

Subgroup on Heat Transfer Equipment (BPV VIII)

P. Matkovics, <i>Chair</i>	E. Smith
L. Bower, <i>Vice Chair</i>	A. M. Voytko
T. Bunyarattaphantu, <i>Secretary</i>	R. P. Wiberg
S. R. Babka	G. Auriolles, Sr., <i>Contributing Member</i>
J. H. Barbee	K. M. Chikhaliya, <i>Contributing Member</i>
O. A. Barsky	J. Pasek, <i>Contributing Member</i>
A. Chaudouet	D. Srnic, <i>Contributing Member</i>
D. L. Kurle	Z. Tong, <i>Contributing Member</i>
R. Mahadeen	
S. Mayeux	
S. Neilsen	

Subgroup on General Requirements (BPV VIII)

J. Hoskinson, <i>Chair</i>	J. Rust
M. Faulkner, <i>Vice Chair</i>	P. T. Shanks
N. Barkley	J. C. Sowinski
T. P. Beirne	P. Speranza
R. Darby	D. Srnic
Z. Jakovljevic	D. B. Stewart
M. D. Lower	D. B. DeMichael, <i>Contributing Member</i>
T. Newman	T. P. Pastor, <i>Contributing Member</i>
I. A. Powell	R. Robles, <i>Contributing Member</i>
J. Qu	D. A. Swanson, <i>Contributing Member</i>
G. B. Rawls, Jr.	Y. Yang, <i>Contributing Member</i>
F. L. Richter	
S. C. Roberts	

Working Group on Plate Heat Exchangers (BPV VIII)

D. I. Morris, <i>Chair</i>	P. Matkovics
S. R. Babka	M. J. Pischke
V. Gudge	P. T. Shanks
T. Halligan	E. Smith
Z. Jakovljevic	D. Srnic

Subgroup on High Pressure Vessels (BPV VIII)

K. Subramanian, <i>Chair</i>	F. W. Tatar
M. Sarzynski, <i>Vice Chair</i>	S. Terada
A. Dinizulu, <i>Staff Secretary</i>	Y. Xu
L. P. Antalffy	A. M. Clayton, <i>Contributing Member</i>
N. Barkley	R. Cordes, <i>Contributing Member</i>
J. Barlow	R. D. Dixon, <i>Contributing Member</i>
R. C. Biel	J. Hademenos, <i>Contributing Member</i>
P. N. Chaku	R. M. Hoshman, <i>Contributing Member</i>
L. Fridlund	F. Kirkemo, <i>Contributing Member</i>
D. Fuenmayor	G. M. Mital, <i>Contributing Member</i>
J. Gibson	M. Parr, <i>Contributing Member</i>
R. T. Hallman	M. D. Rana, <i>Contributing Member</i>
K. Karpanan	C. Tipple, <i>Contributing Member</i>
A. K. Khare	K.-J. Young, <i>Contributing Member</i>
G. T. Nelson	D. J. Burns, <i>Honorary Member</i>
D. T. Peters	G. J. Mraz, <i>Honorary Member</i>
E. D. Roll	
J. R. Sims	
E. Smith	

Argentina International Working Group (BPV VIII)

A. Dominguez, <i>Chair</i>	M. A. Mendez
R. Robles, <i>Vice Chair</i>	J. J. Monaco
G. Glissent, <i>Secretary</i>	C. Parente
A. Antipasti	M. A. A. Pipponzi
D. A. Bardelli	L. C. Rigoli
R. A. Barey	A. Rivas
O. S. Bretones	D. Rizzo
A. Burgueno	M. A. Sena
G. Casanas	G. Telleria
D. A. Del Teglia	C. Alderetes, <i>Contributing Member</i>
M. Favareto	D. H. Da Rold, <i>Contributing Member</i>
J. A. Labastidas	J. C. Rubeo, <i>Contributing Member</i>
F. P. Larrosa	

China International Working Group (BPV VIII)

X. Chen, <i>Chair</i>	C. Miao
B. Shou, <i>Vice Chair</i>	L. Sun
Z. Fan, <i>Secretary</i>	C. Wu
Y. Chen	J. Xiaobin
J. Cui	F. Xu
R. Duan	G. Xu
J.-G. Gong	F. Yang
B. Han	Y. Yang
J. Hu	Y. Yuan
Q. Hu	Yanfeng Zhang
H. Hui	Yijun Zhang
K. Li	S. Zhao
D. Luo	J. Zheng
Y. Luo	G. Zhu

Subgroup on Materials (BPV VIII)

P. Chavdarov, <i>Chair</i>	D. Pugh
M. Kowalczyk, <i>Vice Chair</i>	D. W. Rahoi
S. Kilambi, <i>Secretary</i>	E. Uptis
J. Cameron	K. Xu
H. Dutta	M. Katcher, <i>Contributing Member</i>
J. F. Grubb	R. C. Sutherlin, <i>Contributing Member</i>
D. Maitra	
R. K. Patadia	

Subgroup on Toughness (BPV VIII)

K. Xu, <i>Chair</i>	J. P. Swezy, Jr.
T. Halligan, <i>Vice Chair</i>	S. Terada
T. Finn	E. Uptis
C. S. Hinson	J. Vattappilly
S. Kilambi	K. Oyamada, <i>Delegate</i>
D. L. Kurlle	L. Dong, <i>Contributing Member</i>
T. Newman	S. Krishnamurthy, <i>Contributing Member</i>
J. Qu	D. A. Swanson, <i>Contributing Member</i>
M. D. Rana	
F. L. Richter	
K. Subramanian	

Germany International Working Group (BPV VIII)

R. Kauer, <i>Chair</i>	S. Krebs
M. Sykora, <i>Vice Chair</i>	T. Ludwig
A. Aloui	R. A. Meyers
P. Chavdarov	H. Michael
M. Delzeit	R. Müller
A. Emrich	S. Reich
C. Jaekel	A. Spangenberg
S. Jetzlsperger	C. Stobbe
D. Koelbl	

India International Working Group (BPV VIII)

D. Chandiramani, <i>Chair</i>	T. Mukherjee
D. Kulkarni, <i>Vice Chair</i>	P. C. Pathak
A. D. Dalal, <i>Secretary</i>	D. Prabhu
P. Arulkumar	A. Sadasivam
P. Gandhi	M. P. Shah
U. Ganesan	Y. Z. Shaikh
S. K. Goyal	R. Tiru
V. Jayabalan	V. T. Valavan
V. K. Joshi	M. Sharma, <i>Contributing Member</i>
A. Kakumanu	

Subgroup on Graphite Pressure Equipment (BPV VIII)

C. W. Cary, <i>Chair</i>	H. Lee, Jr.
A. Viet, <i>Vice Chair</i>	S. Mehrez
G. C. Becherer	T. Rudy
F. L. Brown	A. A. Stupica
J. D. Clements	J. Wince

Italy International Working Group (BPV VIII)

M. Millefanti, <i>Chair</i>	A. F. Magri
P. Campli, <i>Secretary</i>	L. Moracchioli
P. Aliprandi	P. Pacor
A. Avogadri	S. Sarti
A. Camanni	A. Teli
M. Camposaragna	N. Wagner
N. Caputo	V. Calo, <i>Contributing Member</i>
M. Colombo	G. Gobbi, <i>Contributing Member</i>
P. Conti	A. Gusmaroli, <i>Contributing Member</i>
D. Cortassa	G. Pontiggia, <i>Contributing Member</i>
A. Fabiano	D. D. Raimander, <i>Contributing Member</i>
F. Finco	
M. Guglielmetti	

COMMITTEE ON WELDING, BRAZING, AND FUSING (BPV IX)

M. J. Pischke, <i>Chair</i>	E. G. Reichelt
P. L. Sturgill, <i>Vice Chair</i>	M. J. Rice
R. Rahaman, <i>Staff Secretary</i>	W. J. Sperko
D. Barborak	J. P. Swezy, Jr.
M. Bernasek	A. D. Wilson
M. A. Boring	L. Costa, <i>Delegate</i>
D. A. Bowers	D. Pojatar, <i>Delegate</i>
N. Carter	D. D. Raimander, <i>Delegate</i>
J. G. Feldstein	A. Roza, <i>Delegate</i>
P. Gilston	M. Consonni, <i>Contributing Member</i>
S. E. Gingrich	R. M. Jessee, <i>Contributing Member</i>
K. L. Hayes	P. L. Van Fosson, <i>Contributing Member</i>
J. S. Lee	R. K. Brown, Jr., <i>Honorary Member</i>
W. M. Lundy	M. L. Carpenter, <i>Honorary Member</i>
D. W. Mann	B. R. Newmark, <i>Honorary Member</i>
S. A. Marks	S. D. Reynolds, Jr., <i>Honorary Member</i>
T. Melfi	
W. F. Newell, Jr.	

Special Working Group on Bolted Flanged Joints (BPV VIII)

W. Brown, <i>Chair</i>	R. W. Mikitka
M. Osterfoss, <i>Vice Chair</i>	D. Nash
D. Bankston, Jr.	M. Ruffin
C. W. Cary	M. Siddiqui
A. Chaudouet	E. Jamalyaria, <i>Contributing Member</i>
H. Chen	G. Van Zyl, <i>Contributing Member</i>
D. Francis	J. Veiga, <i>Contributing Member</i>
H. Lejeune	R. Wacker, <i>Contributing Member</i>
A. Mann	
W. McDaniel	

Subgroup on Brazing (BPV IX)

S. A. Marks, <i>Chair</i>	M. J. Pischke
E. W. Beckman	P. L. Sturgill
A. F. Garbolevsky	J. P. Swezy, Jr.
N. Mohr	

Subgroup on General Requirements (BPV IX)

N. Carter, <i>Chair</i>	K. Meszaros
P. Gilston, <i>Vice Chair</i>	H. B. Porter
S. A. Marks, <i>Secretary</i>	D. Smith
J. P. Bell	P. L. Sturgill
D. A. Bowers	J. P. Swezy, Jr.
T. Bunyarattaphantu	E. W. Woelfel
M. Cox	L. Costa, <i>Delegate</i>
M. Heinrichs	E. W. Beckman, <i>Contributing Member</i>
R. M. Jessee	A. Davis, <i>Contributing Member</i>
P. Matkovics	B. R. Newmark, <i>Honorary Member</i>
W. May	

Subgroup on Interpretations (BPV VIII)

P. Matkovics, <i>Chair</i>	D. T. Peters
J. Oh, <i>Staff Secretary</i>	J. Qu
S. R. Babka	F. L. Richter
L. Bower	S. C. Roberts
T. Bunyarattaphantu	C. D. Rodery
J. Cameron	T. G. Seipp
C. W. Cary	E. Smith
P. Chavdarov	J. C. Sowinski
M. Faulkner	K. Subramanian
T. Halligan	J. P. Swezy, Jr.
B. F. Hantz	A. Viet
J. Hoskinson	K. Xu
M. Kowalczyk	G. Auriolos, Sr., <i>Contributing Member</i>
D. L. Kurlie	R. J. Basile, <i>Contributing Member</i>
K. Kuscu	D. A. Swanson, <i>Contributing Member</i>
M. D. Lower	
S. A. Marks	
D. I. Morris	

Subgroup on Materials (BPV IX)

M. Bernasek, <i>Chair</i>	D. D. Raimander
T. Anderson	A. Roza
L. Constantinescu	C. E. Sainz
E. Cutlip	P. L. Sturgill
S. E. Gingrich	C. Zafir
L. S. Harbison	L. Costa, <i>Delegate</i>
M. James	V. G. V. Giunto, <i>Delegate</i>
R. M. Jessee	D. J. Kotecki, <i>Contributing Member</i>
T. Melfi	B. Krueger, <i>Contributing Member</i>
S. D. Nelson	W. J. Sperko, <i>Contributing Member</i>
M. J. Pischke	M. J. Stanko, <i>Contributing Member</i>

Subgroup on Plastic Fusing (BPV IX)

K. L. Hayes, <i>Chair</i>	M. J. Rice
M. Brandes	S. Schuessler
R. M. Jessee	M. Troughton
J. Johnston, Jr.	C. Violand
J. E. O'Sullivan	E. W. Woelfel
E. G. Reichelt	J. Wright

Subgroup on Welding Qualifications (BPV IX)

T. Melfi, <i>Chair</i>	M. J. Rice
A. D. Wilson, <i>Vice Chair</i>	M. B. Sims
K. L. Hayes, <i>Secretary</i>	A. Spangenberg
M. Bernasek	W. J. Sperko
M. A. Boring	P. L. Sturgill
D. A. Bowers	J. P. Swezy, Jr.
R. Campbell	C. Violand
R. B. Corbit	L. Costa, <i>Delegate</i>
L. S. Harbison	D. D. Raimander, <i>Delegate</i>
M. Heinrichs	D. Chandiramani, <i>Contributing Member</i>
J. S. Lee	M. Consonni, <i>Contributing Member</i>
W. M. Lundy	M. Dehghan, <i>Contributing Member</i>
D. W. Mann	T. C. Wiesner, <i>Contributing Member</i>
K. Meszaros	
W. F. Newell, Jr.	
E. G. Reichelt	

COMMITTEE ON FIBER-REINFORCED PLASTIC PRESSURE VESSELS (BPV X)

J. L. Bustillos, <i>Chair</i>	D. H. McCauley
D. Eisberg, <i>Vice Chair</i>	N. L. Newhouse
C. R. Ramcharan, <i>Staff Secretary</i>	G. Ramirez
A. L. Beckwith	J. R. Richter
B. R. Colley	B. F. Shelley
T. W. Cowley	G. A. Van Beek
I. L. Dinovo	S. L. Wagner
J. Eihusen	D. O. Yancey, Jr.
K. L. Gilmore	P. H. Ziehl
M. R. Gorman	D. H. Hodgkinson, <i>Contributing Member</i>
B. Hebb	D. L. Keeler, <i>Contributing Member</i>
L. E. Hunt	
B. Linnemann	

COMMITTEE ON NUCLEAR INSERVICE INSPECTION (BPV XI)

D. W. Lamond, <i>Chair</i>	G. C. Park
S. D. Kulat, <i>Vice Chair</i>	D. A. Scarth
A. T. Roberts III, <i>Vice Chair</i>	F. J. Schaaf, Jr.
D. Miro-Quesada, <i>Staff Secretary</i>	R. W. Swayne
M. L. Benson	S. Takaya
C. T. Brown	A. Udyawar
S. B. Brown	D. Vetter
T. L. Chan	J. G. Weicks
R. C. Cipolla	M. Weis
R. Clow	B. K. Welch
D. R. Cordes	Y.-K. Chung, <i>Delegate</i>
H. Do	C. Ye, <i>Delegate</i>
E. V. Farrell, Jr.	M. Homiack, <i>Alternate</i>
M. J. Ferlisi	C. Latiolais, <i>Alternate</i>
J. Hakii	R. O. McGill, <i>Alternate</i>
M. L. Hall	T. J. Griesbach, <i>Contributing Member</i>
P. J. Hennessey	J. T. Lindberg, <i>Contributing Member</i>
D. O. Henry	T. V. Vo, <i>Contributing Member</i>
R. Hinkle	C. D. Cowfer, <i>Honorary Member</i>
K. Hojo	E. B. Gerlach, <i>Honorary Member</i>
A. E. Keyser	R. E. Gimple, <i>Honorary Member</i>
H. Malikowski	F. E. Gregor, <i>Honorary Member</i>
S. L. McCracken	R. D. Kerr, <i>Honorary Member</i>
L. A. Melder	P. C. Riccardella, <i>Honorary Member</i>
S. A. Norman	R. A. West, <i>Honorary Member</i>
T. Nuoffer	C. J. Wirtz, <i>Honorary Member</i>
J. Nygaard	R. A. Yonekawa, <i>Honorary Member</i>
J. E. O'Sullivan	
N. A. Palm	

Argentina International Working Group (BPV IX)

A. Burgueno, <i>Chair</i>	J. Caprarulo
A. R. G. Frinchaboy, <i>Vice Chair</i>	M. Favareto
R. Rahaman, <i>Staff Secretary</i>	J. A. Gandola
M. D. Kuhn, <i>Secretary</i>	M. A. Mendez
P. J. Cabot	A. E. Pastor

Germany International Working Group (BPV IX)

P. Chavadarov, <i>Chair</i>	P. Müller
R. Rahaman, <i>Staff Secretary</i>	S. Wegener
P. Khwaja, <i>Secretary</i>	J. Daldrup, <i>Contributing Member</i>
B. Daume	E. Floer, <i>Contributing Member</i>
D. Haase	A. Scherpenisse, <i>Contributing Member</i>
S. Krebs	K.-G. Toelle, <i>Contributing Member</i>
T. Ludwig	

Italy International Working Group (BPV IX)

D. D. Raimander, <i>Chair</i>	P. Pacor
F. Ferrarese, <i>Vice Chair</i>	G. Signoretta
R. Rahaman, <i>Staff Secretary</i>	V. Calo, <i>Contributing Member</i>
P. Campli, <i>Secretary</i>	G. Gobbi, <i>Contributing Member</i>
M. Bernasek	A. Gusmaroli, <i>Contributing Member</i>
A. Camanni	G. Pontiggia, <i>Contributing Member</i>
M. Mandina	P. Siboni, <i>Contributing Member</i>
A. S. Monastra	
L. Moracchioli	

Spain International Working Group (BPV IX)

F. J. Q. Pandelo, <i>Chair</i>	B. B. Miguel
F. Manas, <i>Vice Chair</i>	A. D. G. Munoz
R. Rahaman, <i>Staff Secretary</i>	A. B. Pascual
F. R. Hermda, <i>Secretary</i>	G. Gobbi, <i>Contributing Member</i>
C. A. Celimendiz	R. G. Garcia, <i>Contributing Member</i>
M. A. F. Garcia	

Executive Committee (BPV XI)

S. D. Kulat, <i>Chair</i>	N. A. Palm
D. W. Lamond, <i>Vice Chair</i>	G. C. Park
D. Miro-Quesada, <i>Staff Secretary</i>	A. T. Roberts III
M. L. Benson	R. W. Swayne
M. J. Ferlisi	D. Vetter
D. O. Henry	M. Homiack, <i>Alternate</i>
S. L. McCracken	

Latin American International Working Group (BPV XI)

O. Martinez, <i>Staff Secretary</i>	F. J. Schaaf, Jr.
A. Claus	F. M. Schroeter
I. M. Guerreiro	P. Yamamoto
L. R. Miño	

China International Working Group (BPV XI)

T. Yuchun, <i>Chair</i>	W. N. Pei
J. F. Cai, <i>Vice Chair</i>	L. Shiwei
C. Ye, <i>Vice Chair</i>	S. Shuo
M. W. Zhou, <i>Secretary</i>	Y. Sixin
M. Chao	Y. X. Sun
H. D. Chen	Z. Wan
Y. Cheng	Q. Wang
C. Gao	Q. W. Wang
Y. Guanghua	Z. S. Wang
Y. B. Guo	L. Xing
Y. Hongqi	F. Xu
D. R. Horn	S. X. Xu
Y. Hou	Q. Yin
Y. S. Li	Y. Zhe
Shangyuan Liu	Z. M. Zhong
Y. Nie	

Working Group on Spent Nuclear Fuel Storage and Transportation Containment Systems (BPV XI)

K. Hunter, <i>Chair</i>	K. Mauskar
M. Orihuela, <i>Secretary</i>	R. M. Meyer
D. J. Ammerman	R. M. Pace
J. Broussard	M. A. Richter
C. R. Bryan	B. Sarno
T. Carraher	R. Sindelar
D. Dunn	M. Staley
N. Fales	J. Tatman
R. C. Folley	J. Wellwood
A. Gonzalez	K. A. Whitney
G. Grant	X. J. Zhai
B. Gutherman	P.-S. Lam, <i>Alternate</i>
M. W. Joseph	G. White, <i>Alternate</i>
M. Keene	H. Smith, <i>Contributing Member</i>
M. Liu	

European International Working Group (BPV XI)

R. Döring, <i>Chair</i>	H.-W. Lange
M. Hagenbruch, <i>Vice Chair</i>	N. Legl
R. Piel, <i>Secretary</i>	T. Ludwig
P. Ancion	M. Reichert
A. Casse	L. Sybertz
C. G. Frantescu	I. Tewes
T. Hantzka	R. Tiete
E. Iacopetta	Yixing Wang
A. Juengert	J. Wendt
S. D. Kulat	

Task Group on Mitigation and Repair of Spent Nuclear Fuel Canisters (WG-SNFS & TCS) (BPV XI)

J. Tatman, <i>Chair</i>	M. Kris
D. J. Ammerman	M. Liu
J. Broussard	K. Mauskar
C. R. Bryan	S. L. McCracken
G. R. Cannell	M. Orihuela
K. Dietrich	M. Richter
D. Dunn	K. E. Ross
N. Fales	B. Sarno
R. C. Folley	R. Sindelar
D. Jacobs	J. Wellwood
N. Klymyshyn	A. Williams

India International Working Group (BPV XI)

S. B. Parkash, <i>Chair</i>	K. K. Rai
D. Narain, <i>Vice Chair</i>	D. Rawal
Z. M. Mansuri	R. Sahai
M. R. Nadgouda	R. K. Sharma
N. Palm	

Subgroup on Evaluation Standards (BPV XI)

N. A. Palm, <i>Chair</i>	R. O. McGill
S. X. Xu, <i>Secretary</i>	R. M. Pace
M. L. Benson	S. Ranganath
R. C. Cipolla	C. J. Sallaberry
C. M. Faigy	D. A. Scarth
M. M. Farooq	D. J. Shim
T. J. Griesbach	A. Udyawar
K. Hojo	T. V. Vo
M. Kirk	G. M. Wilkowski
D. R. Lee	K. Hasegawa, <i>Contributing Member</i>
Y. S. Li	H. S. Mehta, <i>Contributing Member</i>

Special Working Group on Editing and Review (BPV XI)

R. W. Swayne, <i>Chair</i>	M. Orihuela
R. C. Cipolla	D. A. Scarth
D. O. Henry	A. Udyawar

Task Group on Inspectability (BPV XI)

E. Henry, <i>Chair</i>	J. Honcharik
B. Langston, <i>Secretary</i>	C. Latiolais
D. Brown	J. T. Lindberg
A. Bushmire	L. Loomis
A. Cardillo	S. Matsumoto
K. Caver	D. E. Matthews
D. R. Cordes	P. J. O'Regan
D. O. Henry	J. B. Ossmann

Task Group on Evaluation of Beyond Design Basis Events (SG-ES) (BPV XI)

R. M. Pace, <i>Chair</i>	S. A. Kleinsmith
S. X. Xu, <i>Secretary</i>	M. Moenssens
G. A. Antaki	T. V. Vo
P. R. Donavin	K. Voelsing
R. G. Gilada	G. M. Wilkowski
T. J. Griesbach	F. G. Abatt, <i>Contributing Member</i>
M. Hayashi	H. S. Mehta, <i>Contributing Member</i>
K. Hojo	

**Working Group on Flaw Evaluation
(SG-ES) (BPV XI)**

R. C. Cipolla, <i>Chair</i>	C. Liu
S. X. Xu, <i>Secretary</i>	M. Liu
M. L. Benson	G. A. Miessi
H. D. Chung	S. Noronha
N. G. Cofie	R. K. Qashu
M. A. Erickson	D. A. Scarth
C. M. Faidy	W. L. Server
M. M. Farooq	D. J. Shim
B. R. Ganta	S. Smith
R. G. Gilada	M. Uddin
C. Guzman-Leong	A. Udyawar
K. Hojo	T. V. Vo
F. Iwamatsu	M. Walter
S. Kalyanam	K. Wang
Y. Kim	B. Wasiluk
V. Lacroix	G. M. Wilkowski
D. R. Lee	H. S. Mehta, <i>Contributing Member</i>
Y. S. Li	

**Working Group on Flaw Evaluation Reference Curves
(SG-ES) (BPV XI)**

A. Udyawar, <i>Chair</i>	A. Morley
D. A. Scarth, <i>Secretary</i>	B. Pellereau
M. L. Benson	S. Ranganath
F. W. Brust	D. J. Shim
R. C. Cipolla	S. Smith
M. M. Farooq	M. Uddin
A. E. Freed	T. V. Vo
K. Hasegawa	G. White
K. Hojo	S. X. Xu
F. Iwamatsu	H. S. Mehta, <i>Contributing Member</i>
V. Lacroix	

**Working Group on High Temperature Flaw Evaluation
(SG-ES) (BPV XI)**

C. J. Sallaberry, <i>Chair</i>	M. Petkov
F. W. Brust	H. Qian
P. Carter	D. A. Scarth
K. Gresh	D. J. Shim
S. Kalyanam	A. Udyawar
B. Lin	X. Wei
B.-L. Lyow	S. X. Xu
M. C. Messner	J. Bass, <i>Alternate</i>

Working Group on Operating Plant Criteria (SG-ES) (BPV XI)

M. Kirk, <i>Chair</i>	R. M. Pace
D. Rudland, <i>Secretary</i>	N. A. Palm
D. B. Denis	S. Ranganath
M. A. Erickson	W. L. Server
A. E. Freed	C. A. Tomes
T. J. Griesbach	A. Udyawar
B. Hall	T. V. Vo
M. Hayashi	H. Q. Xu
R. Janowiak	M. Yamamoto
S. A. Kleinsmith	E. Haywood, <i>Alternate</i>
H. Kobayashi	H. S. Mehta, <i>Contributing Member</i>
A. D. Odell	

Task Group on Appendix L (WG-OPC) (SG-ES) (BPV XI)

N. Glunt, <i>Chair</i>	A. D. Odell
R. M. Pace, <i>Secretary</i>	C.-S. Oh
C. Coleman	H. Park
J. I. Duo	S. Ranganath
A. E. Freed	A. Scott
M. A. Gray	D. J. Shim
T. J. Griesbach	S. Smith
H. Nam	A. Udyawar
A. Nana	T. V. Vo

Working Group on Pipe Flaw Evaluation (SG-ES) (BPV XI)

D. A. Scarth, <i>Chair</i>	Y. S. Li
S. Kalyanam, <i>Secretary</i>	R. O. McGill
K. Azuma	G. A. Miessi
F. W. Brust	S. M. Parker
H. D. Chung	S. H. Pellet
R. C. Cipolla	D. Rudland
N. G. Cofie	C. J. Sallaberry
C. M. Faidy	W. L. Server
M. M. Farooq	D. J. Shim
B. R. Ganta	S. Smith
R. G. Gilada	M. F. Uddin
S. R. Gosselin	A. Udyawar
C. E. Guzman-Leong	T. V. Vo
K. Hasegawa	K. Wang
K. Hojo	B. Wasiluk
D. N. Hopkins	G. M. Wilkowski
E. J. Houston	S. X. Xu
F. Iwamatsu	Y. Zou
R. Janowiak	K. Gresh, <i>Alternate</i>
Y. Kim	H. S. Mehta, <i>Contributing Member</i>
V. Lacroix	

Task Group on Code Case N-513 (WG-PFE) (SG-ES) (BPV XI)

R. O. McGill, <i>Chair</i>	R. Janowiak
S. M. Parker, <i>Secretary</i>	M. Kassir
G. A. Antaki	S. H. Pellet
R. C. Cipolla	D. Rudland
M. M. Farooq	D. A. Scarth
K. Gresh	S. X. Xu
E. J. Houston	

**Task Group on Evaluation Procedures for Degraded Buried Pipe
(WG-PFE) (SG-ES) (BPV XI)**

R. O. McGill, <i>Chair</i>	M. Kassir
S. X. Xu, <i>Secretary</i>	M. Moenssens
F. G. Abatt	R. M. Pace
G. A. Antaki	S. H. Pellet
R. C. Cipolla	D. Rudland
R. G. Gilada	D. A. Scarth
R. Janowiak	

**Task Group on Flaw Evaluation for HDPE Pipe
(WG-PFE) (SG-ES) (BPV XI)**

S. Kalyanam, <i>Chair</i>	D. J. Shim
P. Krishnaswamy	M. Troughton
C. Liu	R. Wolfe
M. Moenssens	J. Wright
D. P. Munson	S. X. Xu
D. A. Scarth	

Subgroup on Nondestructive Examination (BPV XI)

D. O. Henry, <i>Chair</i>	J. Harrison
T. Cinson, <i>Secretary</i>	D. A. Kull
C. T. Brown	C. Latiolais
A. Bushmire	J. T. Lindberg
T. L. Chan	F. J. Schaaf, Jr.
D. R. Cordes	D. R. Slivon
S. E. Cumblidge	R. V. Swain
K. J. Hacker	C. A. Nove, <i>Alternate</i>

Task Group on Nonmetallic Component Degradation and Failure Monitoring (SG-RIM) (BPV XI)

M. P. Metcalfe, <i>Chair</i>	N. Craft
A. Tzelepi, <i>Secretary</i>	W. J. Geringer
M. T. Audrain	K. Harris
S. Baylis	P.-A. Juan
G. Beirnaert	J. Lang
A. A. Campbell	C. Marks
C. Chen	J. Potgieter

Working Group on Personnel Qualification and Surface Visual and Eddy Current Examination (SG-NDE) (BPV XI)

C. T. Brown, <i>Chair</i>	D. O. Henry
M. Orihuela, <i>Secretary</i>	B. Langston
D. Brown	C. Shinsky
T. Cinson	R. Tedder
S. E. Cumblidge	T. Thulien
N. Farenbaugh	J. T. Timm
J. Harrison	

ASME/JSME Joint Working Group on RIM Processes and System-Based Code (SG-RIM) (BPV XI)

S. Takaya, <i>Chair</i>	R. Meyer
C. Wax, <i>Vice Chair</i>	T. Muraki
M. T. Audrain	S. Okajima
K. Dozaki	A. T. Roberts III
J. T. Fong	C. J. Sallaberry
J. Hakii	F. J. Schaaf, Jr.
K. Harris	R. Vayda
M. Hayashi	D. Watanabe
S. Kalyanam	H. Yada
D. R. Lee	K. Yamada
H. Machida	T. Asayama, <i>Contributing Member</i>
M. Mallet	T. Lupold, <i>Contributing Member</i>
R. J. McReynolds	

Working Group on Procedure Qualification and Volumetric Examination (SG-NDE) (BPV XI)

J. Harrison, <i>Chair</i>	C. Latiolais
D. A. Kull, <i>Secretary</i>	C. A. Nove
A. Bushmire	D. R. Slivon
D. R. Cordes	R. V. Swain
K. J. Hacker	D. Van Allen
R. E. Jacob	J. Williams
W. A. Jensen	B. Lin, <i>Alternate</i>

Subgroup on Repair/Replacement Activities (BPV XI)

S. L. McCracken, <i>Chair</i>	L. A. Melder
E. V. Farrell, Jr., <i>Secretary</i>	G. T. Olson
M. Brandes	J. E. O'Sullivan
S. B. Brown	G. C. Park
R. Clow	A. Patel
S. J. Findlan	R. A. Patel
M. L. Hall	R. R. Stevenson
R. Hinkle	R. W. Swayne
J. Honcharik	J. G. Weicks
A. B. Meichler	

Subgroup on Reliability and Integrity Management Program (BPV XI)

A. T. Roberts III, <i>Chair</i>	M. P. Metcalfe
D. Vetter, <i>Secretary</i>	R. Meyer
T. Anselmi	M. Orihuela
M. T. Audrain	C. J. Sallaberry
N. Broom	F. J. Schaaf, Jr.
F. W. Brust	H. M. Stephens, Jr.
S. R. Doctor	R. W. Swayne
J. D. Fletcher	S. Takaya
J. T. Fong	C. Wax
K. Harris	B. K. Welch
P. J. Hennessey	R. W. Youngblood
S. Kalyanam	B. Lin, <i>Alternate</i>
D. R. Lee	V. Chugh, <i>Contributing Member</i>
C. Mallet	R. Grantom, <i>Contributing Member</i>
R. J. McReynolds	T. Lupold, <i>Contributing Member</i>

Working Group on Design and Programs (SG-RRR) (BPV XI)

S. B. Brown, <i>Chair</i>	A. B. Meichler
R. A. Patel, <i>Secretary</i>	G. C. Park
O. Bhatti	M. A. Pyne
R. Clow	A. Rezaei
R. R. Croft	R. R. Stevenson
E. V. Farrell, Jr.	K. Sullivan
K. Harris	R. W. Swayne
H. Malikowski	

Task Group on Repair and Replacement Optimization (WG-D&P) (SG-RRR) (BPV XI)

S. L. McCracken, <i>Chair</i>	M. L. Hall
S. J. Findlan, <i>Secretary</i>	D. Jacobs
T. Basso	H. Malikowski
R. Clow	G. C. Park
K. Dietrich	A. Patel
E. V. Farrell, Jr.	R. R. Stevenson
M. J. Ferlisi	J. G. Weicks
R. C. Folley	

Working Group on MANDE (SG-RIM) (BPV XI)

H. M. Stephens, Jr., <i>Chair</i>	J. T. Fong
M. Orihuela, <i>Vice Chair</i>	D. O. Henry
M. Turnbow, <i>Secretary</i>	R. J. McReynolds
T. Anselmi	R. Meyer
M. T. Audrain	K. Yamada
S. R. Doctor	T. Lupold, <i>Contributing Member</i>
N. A. Finney	

**Working Group on Nonmetals Repair/Replacement Activities
(SG-RRR) (BPV XI)**

J. E. O'Sullivan, <i>Chair</i>	A. Rezaei
S. Schuessler, <i>Secretary</i>	S. Rios
M. Brandes	F. J. Schaaf, Jr.
S. W. Choi	R. Stakenborghs
M. Golliet	P. Vibien
J. Johnston, Jr.	M. P. Marohl, <i>Contributing Member</i>
T. M. Musto	A. Pridmore, <i>Contributing Member</i>

**Task Group on Repair by Carbon Fiber Composites
(WG-NMRR) (SG-RRR) (BPV XI)**

S. W. Choi, <i>Chair</i>	R. P. Ojdovic
W. Bushika	J. E. O'Sullivan
D. Cimock	N. Otten
M. J. Constable	A. Pridmore
M. Elen	S. Rios
M. Golliet	J. Sealey
P. Krishnaswamy	R. Stakenborghs
M. Kuntz	D. J. Swaim
H. Lu	M. Tatkowski
L. Nadeau	M. F. Uddin
C. A. Nove	J. Wen

**Working Group on Welding and Special Repair Processes
(SG-RRR) (BPV XI)**

J. G. Weicks, <i>Chair</i>	D. Jacobs
G. T. Olson, <i>Secretary</i>	M. Kris
D. Barborak	S. E. Marlette
K. Dietrich	S. L. McCracken
S. J. Findlan	L. A. Melder
R. C. Folley	J. E. O'Sullivan
M. L. Hall	A. Patel
J. Honcharik	

**Task Group on Temper Bead Welding
(WG-W&SRP) (SG-RRR) (BPV XI)**

S. J. Findlan, <i>Chair</i>	H. Kobayashi
J. Tatman, <i>Secretary</i>	S. L. McCracken
D. Barborak	N. Mohr
D. Barton	G. T. Olson
R. C. Folley	J. E. O'Sullivan
J. Graham	A. Patel
M. L. Hall	J. G. Weicks
D. Jacobs	

Task Group on Weld Overlay (WG-W&SRP) (SG-RRR) (BPV XI)

S. L. McCracken, <i>Chair</i>	S. E. Marlette
S. Hunter, <i>Secretary</i>	S. K. Min
D. Barborak	G. T. Olson
D. Barton	A. Patel
S. J. Findlan	D. W. Sandusky
J. Graham	J. Tatman
M. L. Hall	J. G. Weicks
D. Jacobs	

Subgroup on Water-Cooled Systems (BPV XI)

M. J. Ferlisi, <i>Chair</i>	D. W. Lamond
J. Nygaard, <i>Secretary</i>	T. Nomura
S. T. Chesworth	S. A. Norman
J. Collins	M. A. Pyne
H. Q. Do	H. M. Stephens, Jr.
K. W. Hall	M. Weis
P. J. Hennessey	B. K. Welch
A. Keller	I. A. Anchondo-Lopez, <i>Alternate</i>
A. E. Keyser	Y.-K. Chung, <i>Contributing Member</i>
S. D. Kulat	

Task Group on High Strength Nickel Alloys Issues (SG-WCS) (BPV XI)

H. Malinkowski, <i>Chair</i>	H. Kobayashi
C. Waskey, <i>Secretary</i>	S. E. Marlette
T. Cinson	J. Robinson
J. Collins	D. Van Allen
O. Cruz	G. White
K. Dietrich	K. A. Whitney

Working Group on Containment (SG-WCS) (BPV XI)

M. J. Ferlisi, <i>Chair</i>	M. Sircar
S. Walden, <i>Secretary</i>	P. C. Smith
H. T. Hill	R. S. Spencer
S. Johnson	A. Staller
A. E. Keyser	J. Swan
P. Leininger	C. Tillotson
J. A. Munshi	G. Z. Wang
S. Richter	M. Weis

**Working Group on Inspection of Systems and Components
(SG-WCS) (BPV XI)**

H. Q. Do, <i>Chair</i>	A. Keller
M. Weis, <i>Secretary</i>	E. E. Keyser
R. W. Blyde	S. D. Kulat
J. Collins	E. Lantz
M. J. Ferlisi	J. C. Nygaard
M. L. Garcia Heras	S. Orita
K. W. Hall	R. S. Spencer
E. Henry	M. Walter
J. Howard	A. W. Wilkens

Working Group on Pressure Testing (SG-WCS) (BPV XI)

S. A. Norman, <i>Chair</i>	S. Levitus
M. Moenssens, <i>Secretary</i>	R. A. Nettles
T. Anselmi	J. Swan
A. Knighton	K. Whitney
D. W. Lamond	

Working Group on Risk-Informed Activities (SG-WCS) (BPV XI)

M. A. Pyne, <i>Chair</i>	J. T. Jewell
S. T. Chesworth, <i>Secretary</i>	S. D. Kulat
G. Brouette	D. W. Lamond
R. Fougereousse	E. Lantz
J. Hakii	P. J. O'Regan
K. W. Hall	N. A. Palm
M. J. Homiack	S. E. Woolf

Working Group on General Requirements (BPV XI)

D. Vetter, <i>Chair</i>	A. Mills
S. E. Woolf, <i>Secretary</i>	G. Ramaraj
T. L. Chan	T. N. Rezk
P. J. Hennessey	A. T. Roberts III
R. Hinkle	B. K. Welch
K. A. Kavanagh	B. Harris, <i>Alternate</i>

Subgroup on Nonmandatory Appendices (BPV XII)

T. A. Rogers, <i>Chair</i>	T. J. Rishel
S. Staniszewski, <i>Secretary</i>	R. C. Sallash
P. Chilukuri	D. G. Shelton
N. J. Paulick	Y. Doron, <i>Contributing Member</i>
M. Pitts	

COMMITTEE ON TRANSPORT TANKS (BPV XII)

N. J. Paulick, <i>Chair</i>	J. Roberts
M. D. Rana, <i>Vice Chair</i>	T. A. Rogers
J. Oh, <i>Staff Secretary</i>	R. C. Sallash
A. N. Antoniou	M. Shah
K. W. A. Cheng	S. Staniszewski
P. Chilukuri	A. P. Varghese
O. Mulet	R. Meyers, <i>Contributing Member</i>
M. Pitts	

COMMITTEE ON OVERPRESSURE PROTECTION (BPV XIII)

B. K. Nutter, <i>Chair</i>	J. F. Ball, <i>Contributing Member</i>
A. Donaldson, <i>Vice Chair</i>	R. W. Barnes, <i>Contributing Member</i>
C. E. Rodrigues, <i>Staff Secretary</i>	R. D. Danzy, <i>Contributing Member</i>
R. Antoniuk	J. Grace, <i>Contributing Member</i>
T. P. Beirne	S. F. Harrison, Jr., <i>Contributing Member</i>
Joey Burgess	A. Hassan, <i>Contributing Member</i>
D. B. DeMichael	P. K. Lam, <i>Contributing Member</i>
J. W. Dickson	M. Mengon, <i>Contributing Member</i>
B. Engman	J. Mize, <i>Contributing Member</i>
K. R. May	M. Mullavey, <i>Contributing Member</i>
D. Miller	J. Phillips, <i>Contributing Member</i>
T. Patel	S. Ruesenberg, <i>Contributing Member</i>
B. F. Pittel	
T. R. Tarbay	K. Shores, <i>Contributing Member</i>
D. E. Tompkins	D. E. Tezzo, <i>Contributing Member</i>
J. A. West	A. Wilson, <i>Contributing Member</i>
M. Edwards, <i>Alternate</i>	

Executive Committee (BPV XII)

M. D. Rana, <i>Chair</i>	M. Pitts
N. J. Paulick, <i>Vice Chair</i>	T. A. Rogers
J. Oh, <i>Staff Secretary</i>	S. Staniszewski
P. Chilukuri	

Executive Committee (BPV XIII)

A. Donaldson, <i>Chair</i>	K. R. May
B. K. Nutter, <i>Vice Chair</i>	T. Patel
C. E. Rodrigues, <i>Staff Secretary</i>	B. F. Pittel
T. Beirne	

Subgroup on Design and Materials (BPV XII)

P. Chilukuri, <i>Chair</i>	A. P. Varghese
K. W. A. Cheng	K. Xu
S. L. McWilliams	D. K. Chandiramani, <i>Contributing Member</i>
N. J. Paulick	Y. Doron, <i>Contributing Member</i>
M. D. Rana	M. Pitts, <i>Contributing Member</i>
T. J. Rishel	D. G. Shelton, <i>Contributing Member</i>
T. A. Rogers	B. E. Spencer, <i>Contributing Member</i>
R. C. Sallash	J. Zheng, <i>Contributing Member</i>
M. Shah	
S. Staniszewski	

Subgroup on Design and Materials (BPV XIII)

T. Patel, <i>Chair</i>	D. Miller
V. Kalyanasundaram, <i>Vice Chair</i>	T. R. Tarbay
A. Williams, <i>Secretary</i>	J. A. West
T. K. Acharya	D. J. Azukas, <i>Contributing Member</i>
W. E. Chapin	R. D. Danzy, <i>Contributing Member</i>
B. Joergensen	M. Mullavey, <i>Contributing Member</i>
R. Krithivasan	G. Ramirez, <i>Contributing Member</i>
J. Latshaw	S. Zalar, <i>Contributing Member</i>

Subgroup on Fabrication, Inspection, and Continued Service (BPV XII)

M. Pitts, <i>Chair</i>	J. Roberts
P. Chilukuri, <i>Secretary</i>	R. C. Sallash
K. W. A. Cheng	S. Staniszewski
Y. Doron	K. Mansker, <i>Contributing Member</i>
M. Koprivnak	G. McRae, <i>Contributing Member</i>
O. Mulet	T. A. Rogers, <i>Contributing Member</i>
T. J. Rishel	

Subgroup on General Requirements (BPV XIII)

B. F. Pittel, <i>Chair</i>	D. E. Tezzo
J. Grace, <i>Secretary</i>	D. E. Tompkins
R. Antoniuk	J. F. White
J. F. Ball	M. Edwards, <i>Alternate</i>
Joey Burgess	P. Chavdarov, <i>Contributing Member</i>
John Burgess	J. L. Freiler, <i>Contributing Member</i>
D. B. DeMichael	G. D. Goodson, <i>Contributing Member</i>
A. Donaldson	B. Joergensen, <i>Contributing Member</i>
S. T. French	P. K. Lam, <i>Contributing Member</i>
J. Horne	E. Pearson, <i>Contributing Member</i>
R. Klimas, Jr.	J. Phillips, <i>Contributing Member</i>
Z. E. Kumana	S. Ruesenberg, <i>Contributing Member</i>
D. Mainiero-Cessna	S. Zalar, <i>Contributing Member</i>
K. R. May	
J. Mize	
L. Moedinger	
M. Mullavey	
A. Peck	

Subgroup on General Requirements (BPV XII)

S. Staniszewski, <i>Chair</i>	T. J. Rishel
A. N. Antoniou	R. C. Sallash
P. Chilukuri	Y. Doron, <i>Contributing Member</i>
J. L. Freiler	S. L. McWilliams, <i>Contributing Member</i>
O. Mulet	
B. F. Pittel	T. A. Rogers, <i>Contributing Member</i>
M. Pitts	D. G. Shelton, <i>Contributing Member</i>

Subgroup on Nuclear (BPV XIII)

K. R. May, <i>Chair</i>	S. Jones
J. F. Ball, <i>Vice Chair</i>	D. Miller
R. Krithivasan, <i>Secretary</i>	T. Patel
M. Brown	B. J. Yonsky
J. W. Dickson	J. Yu, <i>Alternate</i>
N. Hansing	S. T. French, <i>Contributing Member</i>

Subgroup on Testing (BPV XIII)

T. P. Beirne, <i>Chair</i>	R. Lack, <i>Alternate</i>
J. W. Dickson, <i>Vice Chair</i>	M. Brown, <i>Contributing Member</i>
C. Hofmeister, <i>Secretary</i>	J. Mize, <i>Contributing Member</i>
V. Chicola III	M. Mullavey, <i>Contributing Member</i>
B. Engman	S. Ruesenberg, <i>Contributing Member</i>
R. J. Garnett	C. Sharpe, <i>Contributing Member</i>
R. Houk	K. Shores, <i>Contributing Member</i>
N. Jump	A. Strecker, <i>Contributing Member</i>
B. K. Nutter	A. Wilson, <i>Contributing Member</i>
J. R. Thomas, Jr.	
C. Bauer, <i>Alternate</i>	

COMMITTEE ON NUCLEAR CERTIFICATION (CNC)

R. R. Stevenson, <i>Chair</i>	T. N. Rezk
M. A. Lockwood, <i>Vice Chair</i>	E. A. Whittle
H. Ruan, <i>Secretary</i>	T. Aldo, <i>Alternate</i>
S. Andrews	M. Blankinship, <i>Alternate</i>
A. Appleton	G. Brouette, <i>Alternate</i>
G. Claffey	Y. Diaz-Castillo, <i>Alternate</i>
N. DeSantis	P. D. Edwards, <i>Alternate</i>
C. Dinic	R. Hinkle, <i>Alternate</i>
G. Gobbi	K. M. Hottle, <i>Alternate</i>
J. Grimm	J. Kiefer, <i>Alternate</i>
J. W. Highlands	S. J. Montano, <i>Alternate</i>
K. A. Kavanagh	R. Spuhl, <i>Alternate</i>
J. C. Krane	M. Wilson, <i>Alternate</i>
B. McGlone	S. Yang, <i>Alternate</i>
I. Olson	M. Burke, <i>Contributing Member</i>
E. L. Pleins	S. F. Harrison, Jr., <i>Contributing Member</i>
L. Ponce	
T. E. Quaka	

COMMITTEE ON BOILER AND PRESSURE VESSEL CONFORMITY ASSESSMENT (CBPVCA)

L. E. McDonald, <i>Chair</i>	P. Williams
E. Whittle, <i>Vice Chair</i>	T. P. Beirne, <i>Alternate</i>
G. Moino, <i>Staff Secretary</i>	N. Caputo, <i>Alternate</i>
P. Chavdarov	J. M. Downs, <i>Alternate</i>
J. P. Chicoine	Y.-S. Kim, <i>Alternate</i>
A. Donaldson	B. L. Krasiun, <i>Alternate</i>
T. E. Hansen	K. Roewe, <i>Alternate</i>
W. Hibdon	B. C. Turczynski, <i>Alternate</i>
M. Prefumo	R. Underwood, <i>Alternate</i>
R. Rockwood	J. Yu, <i>Alternate</i>
G. Scribner	D. Cheetham, <i>Contributing Member</i>
D. E. Tuttle	A. J. Spencer, <i>Honorary Member</i>
R. V. Wielgoszinski	

AWS PERSONNEL Officers of AWS Committees

(Cooperating in the Development of the Specifications Herein)

January 27, 2025

A5 COMMITTEE ON FILLER METALS AND ALLIED MATERIALS

R. V. Decker, Jr., <i>Chair</i>	F. B. Lake
M. F. Sinfield, <i>Vice Chair</i>	J. S. Lee
B. A. Pletcher, <i>2nd Vice Chair</i>	C. McEvoy
K. R. Bulger, <i>Secretary</i>	T. Melfi
A. Anderson	W. C. Mosier
A. Boulianne	T. C. Myers
J. C. Bundy	K. Roossinck
J. L. Caron	K. Sampath
G. L. Chouinard	J. D. Schaefer
T. J. Eckardt	J. Schaeffer
D. A. Fink	D. Singh
R. J. Fox	R. C. Sutherland
M. James	H. D. Wehr
S. J. Knostman	J. Zhang
L. G. Kvidahl	

A5A SUBCOMMITTEE ON CARBON AND LOW ALLOY STEEL ELECTRODES AND RODS FOR SHIELDED METAL ARC AND OXYFUEL GAS WELDING

M. James, <i>Chair</i>	J. Lipko
K. R. Bulger, <i>Secretary</i>	T. C. Myers
R. V. Decker, Jr.	K. Sampath
S. J. Knostman	J. Zalokar

A5B SUBCOMMITTEE ON CARBON AND LOW ALLOY STEEL ELECTRODES AND FLUXES FOR SUBMERGED ARC WELDING

T. Melfi, <i>Chair</i>	R. J. Fox
K. R. Bulger, <i>Secretary</i>	B. D. Gaal
H. Beck	J. Procaro
A. Boulianne	

A5C SUBCOMMITTEE ON ALUMINUM ALLOY FILLER METALS

A. Anderson, <i>Chair</i>	W. J. Sperko
P. Berube, <i>Vice Chair</i>	G. J. White
K. R. Bulger, <i>Secretary</i>	C. Williams
E. Ash	V. Yasnogorodski
S. E. Pollard	J. Zhang
P. Pugsley	

A5D SUBCOMMITTEE ON STAINLESS STEEL FILLER METALS

F. B. Lake, <i>Chair</i>	M. James
K. R. Bulger, <i>Secretary</i>	S. J. Knostman
M. Barrett	H. D. Wehr
R. V. Decker, Jr.	A. Zaddach
M. Denault	J. M. Zawodny
T. J. Eckardt	

A5E SUBCOMMITTEE ON NICKEL AND NICKEL ALLOY FILLER METALS

M. E. Barrett, <i>Chair</i>	F. B. Lake
B. Gaal, <i>Vice Chair</i>	J. S. Lee
K. R. Bulger, <i>Secretary</i>	J. R. Logan
J. L. Caron	T. Melfi
G. S. Clark	J. J. Perdomo
M. Denault	B. A. Pletcher
R. D. Golluhue	V. B. Rajan
D. D. Kiilunen	H. D. Wehr

A5F SUBCOMMITTEE ON COPPER AND COPPER ALLOY FILLER METALS

K. Roossinck, <i>Chair</i>	J. D. Schaefer
K. R. Bulger, <i>Secretary</i>	J. Turriff
D. D. Dehner	H. D. Wehr
P. W. Fischer	

A5G SUBCOMMITTEE ON HARDFACING FILLER METALS

G. L. Chouinard, <i>Chair</i>	K. Meszaros
K. R. Bulger, <i>Secretary</i>	R. A. Miller
T. A. Barnhart	J. G. Postle
F. B. Lake	V. B. Rajan
P. F. Mendez	J.-M. Tetevuide

A5H SUBCOMMITTEE ON FILLER METALS AND FLUXES FOR BRAZING

C. F. Darling, <i>Chair</i>	S. McAllister
K. R. Bulger, <i>Secretary</i>	W. Miglietti
J. Arbogast	S. Nelson
J. Bush	T. Oyama
D. Chalasani	M. Paponetti
W. M. Coughlan	D. Pruchenski
D. Dehner	S. S. Rajan
G. DeVries	B. Schneidman
P. Ditzel	A. E. Shapiro
S. Feldbauer	L. A. Shapiro
R. Gourley	M. Strojczek
M. T. Graham	E. Theisen
T. Grostad	C. M. Volpe
J. Gutierrez	M. Weinstein
T. P. Hirthe	M. Wilson
K. Landgraf	Z. Yu
S. Lindsey	H. Zhao
J. Longabucco	

A5I SUBCOMMITTEE ON TUNGSTEN ELECTRODES

K. R. Bulger, <i>Chair</i>	A. Endemann
G. Cleveland	S. Fyffe

A5K SUBCOMMITTEE ON TITANIUM AND ZIRCONIUM FILLER METALS

R. C. Sutherlin, <i>Chair</i>	B. Krueger
S. Borrero, <i>Secretary</i>	K. T. Tran
W. Craig	G. E. Trepus

A5P SUBCOMMITTEE ON CARBON AND LOW ALLOY STEEL ELECTRODES FOR ELECTROSLAG AND ELECTROGAS WELDING

B. A. Pletcher, <i>Chair</i>	D. A. Fink
J. S. Lee, <i>Vice Chair</i>	K. K. Ishizaki
K. R. Bulger, <i>Secretary</i>	R. B. Turpin
D. R. Bajek	

A5M SUBCOMMITTEE ON CARBON AND LOW ALLOY STEEL ELECTRODES FOR FLUX CORED ARC WELDING

J. Schaeffer, <i>Chair</i>	D. W. Haynie
B. A. Pletcher, <i>Vice Chair</i>	B. L. Kahut
K. R. Bulger, <i>Secretary</i>	T. C. Myers
A. Boulianne	M. F. Sinfield
M. R. Brinkman	T. VanLoon
J. C. Bundy	

A5S SUBCOMMITTEE ON GASES FOR GAS SHIELDED ARC WELDING

J. M. Zawodny, <i>Vice Chair</i>	N. Moyer
K. R. Bulger, <i>Secretary</i>	F. Rupp
R. Mercer	J. Wallace

A5T SUBCOMMITTEE ON FILLER METAL PROCUREMENT GUIDELINES

S. J. Knostman, <i>Chair</i>	D. A. Fink
H. D. Wehr, <i>Vice Chair</i>	J. S. Lee
K. R. Bulger, <i>Secretary</i>	T. Melfi
T. A. Davenport	K. Sampath
R. V. Decker, Jr.	

A5N SUBCOMMITTEE ON CONSUMABLE INSERTS

S. Williams, <i>Chair</i>	R. V. Decker, Jr.
W. J. Sperko, <i>Vice Chair</i>	W. F. Newell
K. R. Bulger, <i>Secretary</i>	H. D. Wehr

A5O SUBCOMMITTEE ON SOLID CARBON AND LOW ALLOY STEEL ELECTRODES AND RODS FOR GAS SHIELDED ARC WELDING

J. C. Bundy, <i>Chair</i>	J. Lipko
M. F. Sinfield, <i>Vice Chair</i>	T. C. Myers
K. R. Bulger, <i>Secretary</i>	V. B. Rajan
A. Boulianne	K. Sampath
R. V. Decker, Jr.	J. Schaeffer
R. J. Fox	

A5W SUBCOMMITTEE ON MOISTURE AND HYDROGEN

J. D. Farren, <i>Chair</i>	J. S. Lee
B. L. Kahut, <i>Vice Chair</i>	J. Lipko
K. R. Bulger, <i>Secretary</i>	C. Miller
A. Boulianne	M. F. Sinfield
D. A. Fink	K. T. Wiest
R. J. Fox	

CORRESPONDENCE WITH THE COMMITTEE

General

ASME codes and standards are developed and maintained by committees with the intent to represent the consensus of concerned interests. Users of ASME codes and standards may correspond with the committees to propose revisions or cases, report errata, or request interpretations. Correspondence for this Section of the ASME Boiler and Pressure Vessel Code (BPVC) should be sent to the staff secretary noted on the Section's committee web page, accessible at <https://go.asme.org/CSCcommittees>.

NOTE: See ASME BPVC Section II, Part D for guidelines on requesting approval of new materials. See Section II, Part C for guidelines on requesting approval of new welding and brazing materials ("consumables").

Revisions and Errata

The committee processes revisions to this Code on a continuous basis to incorporate changes that appear necessary or desirable as demonstrated by the experience gained from the application of the Code. Approved revisions will be published in the next edition of the Code.

In addition, the committee may post errata and Special Notices at <http://go.asme.org/BPVCerrata>. Errata and Special Notices become effective on the date posted. Users can register on the committee web page to receive email notifications of posted errata and Special Notices.

This Code is always open for comment, and the committee welcomes proposals for revisions. Such proposals should be as specific as possible, citing the paragraph number, the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent background information and supporting documentation.

Cases

- (a) The most common applications for cases are
 - (1) to permit early implementation of a revision based on an urgent need
 - (2) to provide alternative requirements
 - (3) to allow users to gain experience with alternative or potential additional requirements prior to incorporation directly into the Code
 - (4) to permit use of a new material or process
- (b) Users are cautioned that not all jurisdictions or owners automatically accept cases. Cases are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design, or as limiting in any way the freedom of manufacturers, constructors, or owners to choose any method of design or any form of construction that conforms to the Code.
- (c) The committee will consider proposed cases concerning the following topics only:
 - (1) equipment to be marked with the ASME Single Certification Mark, or
 - (2) equipment to be constructed as a repair/replacement activity under the requirements of Section XI
- (d) A proposed case shall be written as a question and reply in the same format as existing cases. The proposal shall also include the following information:
 - (1) a statement of need and background information
 - (2) the urgency of the case (e.g., the case concerns a project that is underway or imminent)
 - (3) the Code Section and the paragraph, figure, or table number to which the proposed case applies
 - (4) the editions of the Code to which the proposed case applies
- (e) A case is effective for use when the public review process has been completed and it is approved by the cognizant supervisory board. Cases that have been approved will appear in the next edition or supplement of the Code Cases books, "Boilers and Pressure Vessels" or "Nuclear Components." Each Code Cases book is updated with seven Supplements. Supplements will be sent or made available automatically to the purchasers of the Code Cases books until the next edition of the Code. Annulments of Code Cases become effective six months after the first announcement of the annulment in a Code Case Supplement or Edition of the appropriate Code Case book. The status of any case is available at <http://go.asme.org/BPVCCDatabase>. An index of the complete list of Boiler and Pressure Vessel Code Cases and Nuclear Code Cases is available at <http://go.asme.org/BPVCC>.

Interpretations

(a) Interpretations clarify existing Code requirements and are written as a question and reply. Interpretations do not introduce new requirements. If a revision to resolve conflicting or incorrect wording is required to support the interpretation, the committee will issue an intent interpretation in parallel with a revision to the Code.

(b) Upon request, the committee will render an interpretation of any requirement of the Code. An interpretation can be rendered only in response to a request submitted through the online Inquiry Submittal Form at <http://go.asme.org/InterpretationRequest>. Upon submitting the form, the inquirer will receive an automatic email confirming receipt.

(c) ASME does not act as a consultant for specific engineering problems or for the general application or understanding of the Code requirements. If, based on the information submitted, it is the opinion of the committee that the inquirer should seek assistance, the request will be returned with the recommendation that such assistance be obtained. Inquirers may track the status of their requests at <http://go.asme.org/Interpretations>.

(d) ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME committee or subcommittee. ASME does not “approve,” “certify,” “rate,” or “endorse” any item, construction, proprietary device, or activity.

(e) Interpretations are published in the ASME Interpretations Database at <http://go.asme.org/Interpretations> as they are issued.

Committee Meetings

The ASME BPVC committees regularly hold meetings that are open to the public. Persons wishing to attend any meeting should contact the secretary of the applicable committee. Information on future committee meetings can be found at <http://go.asme.org/BCW>.

PREFACE

On January 3, 1919, ASME participated with several other organizations in a meeting to discuss the continuation of wartime research in welding. Out of that meeting, the American Welding Society was established and since that time there has been a constant and interwoven record of development by the American Welding Society and The American Society of Mechanical Engineers of the techniques of welding. Through all of these great years of growth, many of the leaders in the field of engineering had the common interest of pressure equipment design and manufacture and the development of welding as a powerful tool in that manufacture. The evolution of this cooperative effort is contained in Professor A. M. Greene's "History of the ASME Boiler Code," which was published as a series of articles in *Mechanical Engineering* from July 1952 through August 1953 and is now available from ASME in a special bound edition. The following quotation from this history based on the minutes of the Committee notes the cooperative nature of the work done in the area of welding.

"During 1919, a number of cases involving welding were referred by the Boiler Code Committee to the Subcommittee on Welding.

"As the National Welding Council was to be discontinued, a new organization was to be formed to be known as the American Welding Society with which the American Bureau of Welding was to be affiliated. This was to be a body representing the entire industry and would eliminate commercial aspects, undertake research and standardization, and act as a judicial body providing a medium for advancing the science and art of welding."

In 1935 the AWS-ASTM Joint Committee on Filler Metal was organized to provide standard specifications for welding rods, electrodes, filler metals, and fluxes for this developing U.S. industry.

In 1969 these two sponsors agreed to dissolve this joint activity and to permit the American Welding Society to assume sole responsibility for the family of welding rods, electrodes, filler metal, and flux specifications then in being.

In 1992, the ASME Board of Pressure Technology Codes and Standards endorsed the use of materials produced to other than AWS specifications. It is the intent of ASME to follow its procedures and practices currently in use to implement the adoption of material specifications of AWS and other recognized national or international organizations.

Section II, Part C contains material specifications, most of which are identical to corresponding specifications published by AWS and other recognized national or international organizations. All adopted specifications are either reproduced in the Code, where permission to do so has been obtained from the originating organization, or so referenced, and information about how to obtain them from the originating organization is provided. The ASME Committee reviews all material specifications submitted to it and if it is felt that there is any need to adapt them for Code purposes, revisions are made to them. However, there is constant liaison between ASME and AWS and other recognized national or international organizations, and there will be continuing effort to see that the specifications as produced by AWS and other recognized national or international organizations and those printed in the ASME Code are identical.

To assure that there will be a clear understanding on the part of the users of Section II, ASME publishes both the identical specifications and those amended for Code usage every 2 years.

The ASME Boiler and Pressure Vessel Code has been adopted into law by 50 states and many municipalities in the United States and by all of the Canadian provinces.

GUIDELINE ON THE APPROVAL OF NEW WELDING AND BRAZING MATERIAL CLASSIFICATIONS UNDER THE ASME BOILER AND PRESSURE VESSEL CODE

Code Policy. It is the policy of the ASME Boiler and Pressure Vessel Committee to adopt for inclusion in Section II, Part C, only such specifications as have been adopted by the American Welding Society (AWS), and by other recognized national or international organizations.

It is expected that requests for Code approval will normally be for welding and brazing materials (hereafter termed “consumables”) for which there is a recognized national or international specification. For consumables made to a recognized national or international specification other than those of the AWS, the inquirer shall give notice to the standards developing organization that a request has been made to ASME for adoption of their specification under the ASME Code, and shall request that the organization to grant ASME permission to reprint the standard. For other consumables, a request shall be made to the AWS, or a recognized national or international organization, to develop a specification that can be presented to the Code Committee.

It is the policy of the ASME Boiler and Pressure Vessel Committee to consider requests to adopt new consumables for use by boiler, pressure vessel, or nuclear power plant component Manufacturers or end users. Further, such requests should be for consumables for which there is a reasonable expectation of use in a boiler, pressure vessel, or nuclear power plant component constructed to the rules of one of the Sections of this Code.

Application. The inquirer shall identify to the Committee all product forms, size ranges, and specifications for which incorporation is desired, and state whether or not the consumable is covered by patents, whether or not it is licensed, and if licensed, any limitations on its manufacture.

Weldability/Brazability. The inquirer shall furnish complete data on procedure qualification tests made in accordance with the requirements of Section IX. Such tests shall be made over the full range of base metal thickness in which the consumable is to be used. Pertinent information on deposited metal, such as effects from postweld heat treatment, susceptibility to air hardening, effects of joining processes, expected notch toughness values, and the amount of experience in use of the consumable shall be given.

Physical Changes. For new consumables, it is important to know the structural stability characteristics and the degree of retention of properties with exposure at temperature. The influence of welding or brazing and thermal treatment operations on the mechanical properties, ductility, and microstructure of the deposited metal are important, particularly where degradation in properties may occur. Where particular temperature ranges of exposure or heat treatment, cooling rates, combinations of mechanical working and thermal treatments, fabrication practices, exposure to particular environments, etc., cause significant changes in the mechanical properties, microstructure, resistance to brittle fracture, etc., it is of prime importance to call attention to those conditions that should be avoided in service or in manufacture of parts or vessels using the consumable.

Requests for Additional Data. The Committee may request additional data, including data on properties or deposited metal behavior not explicitly treated in the construction Code in which adoption is desired.

Code Case. The Code Committee will consider the issuance of an ASME Code Case, to be effective for a period of three years, permitting the treatment of a new welding or brazing material under an existing ASME Section IX grouping for qualification purposes, provided that the following conditions are met:

- (a) The inquirer provides evidence that a request for coverage of the consumable in a specification has been made to the AWS or a recognized national or international organization;
- (b) the consumable is commercially available and can be purchased within the proposed specification requirements;
- (c) the inquirer shows that there will be a reasonable demand for the consumable by industry and that there exists an urgency for approval by means of a Code Case;
- (d) the request for approval of the consumable shall clearly describe it in specification form, including applicable items as scope, process, manufacture, conditions for delivery, heat treatment, chemical and tensile requirements, testing specifications and requirements, workmanship, finish, marking, inspection, and rejection;
- (e) all other requirements identified previously under Code Policy and Application apply; and
- (f) the inquirer shall furnish the Code Committee with all the data specified in this Guideline.

Requirements for Requests for ASME Acceptance of Welding and Brazing Material Specifications to Recognized National or International Standards Other Than the AWS. The Committee will consider only requests in accordance with the Boiler and Pressure Vessel Committee Operating and Administrative Procedures, OP-8.6 (English language: U.S. or SI/metric units). The Committee will consider accepting specifications of recognized national or international organizations in accordance with OP-8.6 such as, but not limited to, AWS, CSA, CEN, DIN, and JIS. Consumable specifications of other than national or international organizations, such as those of consumable producers and suppliers, will not be considered for acceptance.

Requirements for Recognized National or International Specifications. Acceptable consumable specifications will be identified by date or edition. Approved edition(s) will be stated in the subtitle of the ASME specification. Minimum requirements that must be contained in a consumable specification for which acceptance is being requested include such items as name of national or international organization, scope, reference documents, process, manufacture, conditions for delivery, heat treatment, chemical and tensile requirements, testing specifications and requirements, workmanship, finish, marking, inspection, and rejection.

Publication of Recognized National or International Specifications. Specifications for which ASME has not been given permission to publish by the originating organization will be referenced on a cover sheet in appropriate Appendices in Section II, Part C, along with information xxix on where to obtain a copy of those documents. Documents that are referenced in non-AWS consumable specifications will not be published by ASME. However, information on where to obtain a copy of those documents will be maintained in Section II, Part C. Additions and exceptions to the consumable specification will be noted in the subtitle of the specification.

New Welding and Brazing Materials Checklist. To assist inquirers desiring Code coverage for new consumables, or extending coverage of existing consumables, the Committee has developed the following checklist of items that ought to be addressed by each inquiry. The Committee reserves the right to request additional data and application information when considering new consumables.

- (a) Has a qualified inquirer request been provided?
- (b) Has a request for either revision to existing Code requirements or for a Code Case been defined?
- (c) Has a letter to the AWS been submitted requesting coverage of the new consumable in a specification, and has a copy been submitted to the Committee? Alternatively, is this consumable already covered by a specification issued by a recognized national or international organization, and has an English language version been provided?
- (d) Has the Construction Code and Division coverage been identified?
- (e) Have mechanical property data been submitted (ultimate tensile strength, yield strength, reduction of area, and elongation) for each intended joining process?
- (f) Have toughness considerations required by the Construction Code been defined and has appropriate data been submitted?
- (g) Have joining requirements been defined and has procedure qualification test data been submitted?
- (h) Has influence of fabrication practices on deposited metal properties been defined?

SUMMARY OF CHANGES

Changes listed below are identified on the pages by a margin note, **(25)**, placed next to the affected area.

<i>Page</i>	<i>Location</i>	<i>Change</i>
v	List of Sections	Title of Section XI, Division 1 revised
vi	Foreword	Third, fourth, seventh, tenth, and eleventh paragraphs editorially revised
ix	Personnel	Updated
xxxii	AWS Personnel	Updated
1	SFA-5.01M/SFA-5.01	Revised in its entirety
25	SFA-5.02/SFA-5.02M	Revised in its entirety
43	SFA-5.1/SFA-5.1M	Revised in its entirety
113	SFA-5.3/SFA-5.3M	Revised in its entirety
343	SFA-5.10/SFA-5.10M	Revised in its entirety
425	SFA-5.12/SFA-5.12M	Revised in its entirety
447	SFA-5.13/SFA-5.13M	Revised in its entirety
481	SFA-5.14/SFA-5.14M	Revised in its entirety
511	SFA-5.15	Revised in its entirety
591	SFA-5.18/SFA-5.18M	Revised in its entirety
667	SFA-5.21/SFA-5.21M	Revised in its entirety
699	SFA-5.22/SFA-5.22M	Revised in its entirety
815	SFA-5.25/SFA-5.25M	Revised in its entirety
863	SF-5.28/SFA-5.28M	Title of para. 15 reinstated (inadvertently omitted in 2023 Edition)

CROSS-REFERENCING IN THE ASME BPVC

Paragraphs within the ASME BPVC may include subparagraph breakdowns, i.e., nested lists. The following is a guide to the designation and cross-referencing of subparagraph breakdowns:

(a) Hierarchy of Subparagraph Breakdowns

- (1) First-level breakdowns are designated as (a), (b), (c), etc.
- (2) Second-level breakdowns are designated as (1), (2), (3), etc.
- (3) Third-level breakdowns are designated as (-a), (-b), (-c), etc.
- (4) Fourth-level breakdowns are designated as (-1), (-2), (-3), etc.
- (5) Fifth-level breakdowns are designated as (+a), (+b), (+c), etc.
- (6) Sixth-level breakdowns are designated as (+1), (+2), etc.

(b) Cross-References to Subparagraph Breakdowns. Cross-references within an alphanumerically designated paragraph (e.g., PG-1, UIG-56.1, NCD-3223) do not include the alphanumeric designator of that paragraph. The cross-references to subparagraph breakdowns follow the hierarchy of the designators under which the breakdown appears. The following examples show the format:

- (1) If X.1(c)(1)(-a) is referenced in X.1(c)(1), it will be referenced as (-a).
- (2) If X.1(c)(1)(-a) is referenced in X.1(c)(2), it will be referenced as (1)(-a).
- (3) If X.1(c)(1)(-a) is referenced in X.1(e)(1), it will be referenced as (c)(1)(-a).
- (4) If X.1(c)(1)(-a) is referenced in X.2(c)(2), it will be referenced as X.1(c)(1)(-a).

WELDING AND BRAZING CONSUMABLES — PROCUREMENT OF FILLER MATERIALS AND FLUXES



SFA-5.01M/SFA-5.01



(25)

(Identical with AWS Specification A5.01M/A5.01:2019 (R2024) (ISO 14344:2010 MOD). In case of dispute, the original AWS text applies.)

Welding and Brazing Consumables— Procurement of Filler Materials and Fluxes

1. Scope

This standard identifies various information necessary for communication between a purchaser and a supplier of welding or brazing consumables. This standard, together with an AWS, ISO, or other recognized welding or brazing consumable standard, provides a method for preparing those specific details needed for welding and brazing consumable procurement which consist of the following:

- (1) the welding or brazing consumable classification (selected from the pertinent AWS, ISO, or other applicable welding or brazing consumable standard),
- (2) the lot class (selected from Clause 4 of this standard),
- (3) the testing schedule (selected from Clause 5 of this standard).

Selection of the specific welding or brazing consumable classification, lot class, and testing schedule will depend upon the requirements of the application for which the consumable is being procured.

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to weld metal properties. The specification with the designation A5.01M uses SI Units. The specification A5.01 uses U.S. Customary Units. The latter are shown within brackets [] or in appropriate columns in tables and figures. The standard dimensions based on either system may be used for the sizing of electrodes, packaging, or both under A5.01M or A5.01 specifications.

2. Normative References

The following normative documents contain provisions which, through references in this text, constitute provisions of this standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest editions of the normative documents referred to apply. Members of ISO and IEC maintain registers of currently valid International Standards.

The following AWS standards are referenced in the mandatory section of this document.

AWS A3.0 M/A3.0, *Standard Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*

The following ISO standards are referenced in the mandatory section of this document.

ISO 544, *Welding consumables — Technical delivery conditions for welding filler materials — Type of product, dimensions, tolerances and markings*

ISO 10474, *Steel and steel products — Inspection documents*

The following EN standard is referenced in the mandatory section of this document.

EN 10204, *Metallic Products — Types of Inspection Documents*

3. Terms and Definitions

In production, the components of welding or brazing consumables shall be divided into discrete quantities so that satisfactory tests with a sample from that quantity will establish that the entire quantity meets specification requirements. These quantities, known by such terms as heats, lots, blends, batches, and mixes, vary in size according to the manufacturer. For identification purposes, each manufacturer assigns a unique designation to each quantity. This designation usually consists of a series of numbers or letters, or combinations thereof, which will enable the manufacturer to determine the date and time (or shift) of manufacture, the raw materials used, and the details of the procedures used in producing the welding or brazing consumable. This designation stays with the welding or brazing consumable and can be used to identify the material later, in those cases in which identification is necessary.

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*, provides the basis for terms and definitions used herein. However, the following terms and definitions are included below to accommodate usage specific to this document.

3.1 Dry Batch. The quantity of dry ingredients mixed at one time in one mixing vessel.

NOTE: Liquid(s), such as binders, when added to a dry batch, produce a wet mix. A dry batch may be divided into homogeneous smaller quantities, in which case addition of the liquid(s) produces a corresponding number of smaller wet mixes.

3.2 Dry Blend. Two or more dry batches from which quantities of each are combined proportionately, then mixed in a mixing vessel to produce a larger quantity in which the ingredients are as uniformly dispersed as they would have been had the entire quantity been mixed together at one time in one large mixer.

NOTE: A dry blend, as in the case of a dry batch, may be used singly or divided into smaller quantities, in which case addition of liquid(s) produces a corresponding number of smaller wet mixes.

3.3 Wet Mix. The combination of liquid(s) and a dry batch, dry blend, or a portion thereof, mixed at one time in one mixing vessel.

3.4 Heat. For fully metallic consumables, or the fully metallic rod, tube, or strip used to fabricate tubular cored or covered electrodes and rods the following apply. The specific definition is dependent on the method of melting and refining of the metal:

3.4.1 The material obtained from one furnace melt, where slag-metal or gas-metal reactions occur in producing the specified alloy (e.g., open hearth, electric arc, basic oxygen, argon-oxygen processes). Mill splicing of coils from different heats is not permitted, and coils containing transition heats may not be classified in this manner.

3.4.2 An uninterrupted series of melts from one controlled batch of metals and alloying ingredients in one melting furnace under the same melting conditions, each melt conforming to the chemical composition range approved by the purchaser of the material (i.e., the producer of the welding or brazing consumable) where significant chemical reactions do not occur in producing the specified alloy (e.g., induction melting in a controlled atmosphere or in a vacuum).

3.4.3 An uninterrupted series of remelts in one furnace under the same remelting conditions using one or more consumable electrodes produced from a single heat, each remelt conforming to the chemical composition range approved by the purchaser of the material (i.e., the producer of the welding or brazing consumable) in processes involving continuous melting and casting (e.g., consumable electrode remelt).

3.5 Controlled Chemical Composition

3.5.1 Covering or core ingredients consisting of one or more wet mixes, dry batches, or dry blends that are subjected to sufficient tests to assure that all within the lot are equivalent. These tests shall include chemical analysis, the results of which shall fall within the manufacturer's acceptance limits. The identification of the test procedure and the results of the tests shall be recorded.

3.5.2 Fully metallic consumables, or the fully metallic rod, tube, or strip used to fabricate tubular cored or covered electrodes that consist of mill coils of one or more heats from which samples have been taken for chemical analysis and validated as described in this clause. Mill coils from mills that do not permit spliced-coil practice need to be sampled only on one end. Coils from mills that permit spliced-coil practice with a maximum of one splice per coil need to be sampled on both ends. Coils with more than one splice are not permitted under this definition. The results of the analysis of each sample shall be recorded and be within the manufacturer's composition limits for that material.

3.6 Lot. A unique identifying designation for a specific type and quantity of welding or brazing consumable, usually beginning with the word “lot” and followed by a series of numbers and/or letters. The lot class, as identified in Clause 4, details the requirements for grouping consumables into a single lot.

3.7 Production Schedule. A manufacturing campaign of a single lot number produced by either a single manufacturing operation or a series of manufacturing operations, any of which is uninterrupted by the production of any other product or any other lot number of the same product.

3.8 Certificate of Compliance. A statement that the product meets the requirements of the AWS, ISO, or other applicable welding or brazing consumable specification/classification.

A summary of results may be included and may be in the form of averages, ranges, or single representative values and is not necessarily from a single set of tests run at the same time, or even unique for a specific size.

3.9 Certificate of Conformance. A test report documenting that the product meets the requirements of the AWS, ISO, or other applicable welding or brazing consumable specification/classification.

The reported results shall be in the form of a single set of tests run at the same time, using representative material/product, and may be for a specific size (diameter) or for all sizes (diameters) required to be tested for classification. Actual test values for all tests required for the AWS, ISO, or other applicable welding or brazing consumable classification shall be reported and include a date showing when these actual tests were completed. The report shall not consist of averages, ranges, or single random or “representative” values. It is not usually specific to the actual material supplied.

The date when the test(s) were actually completed must be shown, but there is no requirement as to how recently they must have been completed (e.g., within 12 months of the date of the purchase order, etc.).

3.10 Certified Material Test Report (CMTR). A CMTR is a test report where there is specific reference to the tests being conducted on the actual material supplied. The CMTR may contain results of some or all of the tests required for classification, or other tests as agreed upon by the purchaser and supplier. Several examples of what these may include follow.

(1) Chemical analysis only (per each heat or lot, for the size supplied)—Schedule 3 or H per AWS A5.01M/A5.01.

(2) Tests listed in Table 2 of AWS A5.01M/A5.01 (per each heat or lot, for the size supplied)—Schedule 4 or I per AWS A5.01M/A5.01.

(3) All tests required for classification per the applicable AWS or ISO specification (per each heat or lot, for the size supplied)—Schedule 5 or J per AWS A5.01M/A5.01.

(4) Any additional tests required by the purchaser (per each heat or lot, for the size supplied)—Schedule 6 or K per AWS A5.01M/A5.01.

3.11 Material Test Report (MTR). An MTR is a report documenting the results of tests performed by the manufacturer to fulfill the requirements of the material specification. Results of tests performed to meet supplementary or special requirements specified by the purchaser may also be included on the MTR. An MTR shall identify the applicable material specification and shall include unique identification linking it to the actual material supplied. A Certificate of Conformance, Certificate of Compliance, or “Typical” Test report are not considered acceptable replacements for, or equivalent to, an MTR. A CMTR is a certified copy of an MTR.

3.12 Typical Test Report (“Typical”). A Typical Test Report is a nonstandard term which does not have a consistent definition. See Certificate of Compliance or Certificate of Conformance.

4. Lot Class

A Lot Class is a two-character designation consisting of a letter representing the form of the consumable *at its final size* and a number designating how the grouping of a quantity of consumables into a single lot is allowed. The lot class shall be selected by the purchaser from those listed below.

4.1 Fully Metallic Solid Consumables

4.1.1 Lot Class S1. The quantity of fully metallic solid welding or brazing consumables not exceeding the manufacturer's standard lot, as defined in the manufacturer's quality assurance program.

4.1.2 Lot Class S2. The quantity not exceeding 45 000 kg [100 000 lb] of one fully metallic solid welding or brazing consumable classification, size, form, and temper produced in 24 hours of consecutively scheduled production (i.e., consecutive normal work shifts) from one heat as defined in 3.4 or from controlled chemical composition material as defined in 3.5.2. *For production schedules consisting of a series of manufacturing operations, only those that significantly affect the chemical composition or operability as defined in the manufacturer's quality system are limited to the 24-hour restriction. In these cases, each of those individual manufacturing operations rather than the manufacturing campaign is subject to an independent 24-hour restriction.*

4.1.3 Lot Class S3. The quantity of one fully metallic solid welding or brazing consumable classification and one size produced in one production schedule as defined in 3.7 from one heat as defined in 3.4.

4.1.4 Lot Class S4. The quantity not exceeding 45 000 kg [100 000 lb] of one fully metallic solid welding or brazing consumable classification, size, form, and temper produced under one production schedule as defined in 3.7 from one heat as defined in 3.4 or from controlled chemical composition material as defined in 3.5.2.

4.2 Tubular Cored Electrodes and Rods

4.2.1 Lot Class T1. The quantity of tubular welding consumables not exceeding the manufacturer's standard lot, as defined in the manufacturer's quality assurance program.

4.2.2 Lot Class T2. The quantity not exceeding 45 000 kg [100 000 lb] of one tubular welding consumable classification and size produced in 24 hours of consecutively scheduled production (i.e., consecutive normal work shifts) from rod, tube, or strip from one heat as defined in 3.4 or by controlled chemical composition as defined in 3.5.2, and core ingredients from one dry batch as defined in 3.1, one dry blend as defined in 3.2, or controlled chemical composition as defined in 3.5.1. *For production schedules consisting of a series of manufacturing operations, only those that significantly affect the chemical composition or operability as defined in the manufacturer's quality system are limited to the 24-hour restriction. In these cases, each of those individual manufacturing operations rather than the manufacturing campaign is subject to an independent 24-hour restriction.*

4.2.3 Lot Class T3. The quantity of one tubular welding consumable classification and size produced from rod, tube, or strip from one heat as defined in 3.4 and core ingredients from one dry batch as defined in 3.1 or one dry blend as defined in 3.2.

4.2.4 Lot Class T4. The quantity not exceeding 45 000 kg [100 000 lb] of one tubular welding consumable classification and size produced under one production schedule as defined in 3.7 from rod, tube, or strip from one heat as defined in 3.4 or by controlled chemical composition as defined in 3.5.2, and core ingredients from one dry batch as defined in 3.1, one dry blend as defined in 3.2, or controlled chemical composition as defined in 3.5.1.

4.3 Covered Electrodes

4.3.1 Lot Class C1. The quantity of covered electrodes not exceeding the manufacturer's standard lot, as defined in the manufacturer's quality assurance program.

4.3.2 Lot Class C2. The quantity not exceeding 45 000 kg [100 000 lb] of one covered electrode welding consumable classification and size produced in 24 hours of consecutively scheduled production (i.e., consecutive normal work shifts). *For production schedules consisting of a series of manufacturing operations, only those that significantly affect the chemical composition or operability as defined in the manufacturer's quality system are limited to the 24-hour restriction. In these cases, each of those individual manufacturing operations rather than the manufacturing campaign is subject to an independent 24-hour restriction.*

4.3.3 Lot Class C3. The quantity not exceeding 45 000 kg [100 000 lb] of one covered electrode welding consumable classification and size produced under one production schedule as defined in 3.7 from core wire from one heat as defined in 3.4 or controlled chemical composition as defined in 3.5.2, and covering ingredients from one wet mix as defined in 3.3 or controlled chemical composition as defined in 3.5.1.

4.3.4 Lot Class C4. The quantity of one covered electrode welding consumable classification and size produced from core wire from one heat as defined in 3.4 and covering ingredients from one wet mix as defined in 3.3.

4.3.5 Lot Class C5. The quantity of one covered electrode welding consumable classification and size produced from core wire from one heat as defined in 3.4 and covering ingredients from one dry batch as defined in 3.1 or one dry blend as defined in 3.2.

4.4 Fluxes for Submerged Arc and Electroslag Welding

4.4.1 Lot Class F1. The quantity of flux not exceeding the manufacturer's standard lot, as defined in the manufacturer's quality assurance program.

4.4.2 Lot Class F2. The quantity of flux produced from the same combination of raw materials under one production schedule as defined in 3.7.

5. Level of Testing

Table 1 provides a summary of the levels of testing described below.

5.1 Schedule 1 or F. The level of testing shall be the manufacturer's standard. A statement, "the product supplied will meet the requirements of the applicable AWS, ISO, or other applicable welding consumable standard when tested in accordance with that standard" and a summary of the typical properties of the material, when tested in that manner, shall be supplied upon written request.

5.2 Schedule 2 or G. Test results shall be supplied from any product manufactured within twelve months preceding the date of the purchase order. This shall include results of all tests required for that classification in the AWS, ISO, or other applicable welding or brazing consumable standard.

5.3 Schedule 3 or H. Chemical analysis of the specific lot of consumables shall be supplied. The analysis shall include those elements required for that classification in the AWS, ISO, or other applicable welding or brazing consumable standard.

5.4 Schedule 4 or I. Results of the tests called for in Table 2 for the specific lot of consumables shall be supplied. These tests represent a consensus of those frequently requested for consumables certification; however, they do not necessarily include all tests required for Schedule 5 or J. The tests shall be performed as prescribed for that classification in the AWS standard.

Table 1
Testing Schedules^a

Schedule ^b	Requirements	Reference Clause	Minimum Inspection Document Type ^c
1 or F	The manufacturer's standard testing schedule	5.1	2.2
2 or G	Classification tests from product manufactured within 12 months preceding the date of the purchase order	5.2	2.2
3 or H	Chemical analysis of the specific lot	5.3	3.1
4 or I	Tests called for by Table 2, for the specific lot	5.4	3.1
5 or J	All tests prescribed for classification in the AWS, ISO, or other applicable welding or brazing consumable standard, for the specific lot	5.5	3.1
6 or K	All tests specified by the purchaser for the specific lot	5.6	3.1

^a Testing shall be conducted in accordance with the applicable filler metal classification standard, unless otherwise agreed upon by purchaser and seller.

^b Either the numeric or alphabetic designation may be used interchangeably.

^c Inspection document types per ISO 10474 or EN 10204. See these standards for detailed requirements.

Table 2
Schedule 4 or I—Required Tests^{a, b, c}

Product Type	Carbon Steel		Low-Alloy Steel		Stainless Steel	Nickel and Ni-Alloy	Surfacing		Cast Iron	Aluminum and Al-Alloy	Copper and Cu-Alloy	Magnesium and Mg-Alloy	Titanium and Ti-Alloy	Zirconium and Zr-Alloy	Brazing and Braze Welding Filler Metals
Covered Solid and Metal Cored (Composite) Electrodes for SMAW	(A5.1) 1, 2, 3, 4, 5 ^d		(A5.5) 1, 2, 3, 4, 5 ^d		(A5.4) 1	(A5.11) 1, 2, 4, 6	(A5.13) 1	(A5.21) 1	(A5.15) 1	(A5.3) 1	(A5.6) 1, 4	—	—	—	—
Bare Solid and Metal Cored (Composite) Rods and Electrodes for GTAW, PAW, GMAW, EGW	(A5.18, A5.36) 1, 2, 4	(A5.26) 1, 2, 3, 4	(A5.26) 1, 2, 3, 4	(A5.28, A5.36) 1, 2, 4	(A5.9) 1	(A5.14) 1	(A5.13) 1	(A5.21) 1	(A5.15) 1	(A5.10) 1, 4 ^e , 9 ^e	(A5.7) 1	(A5.19) 1	(A5.16) 1	(A5.24) 1	—
Bare Solid and Metal Cored (Composite) Electrodes for SAW	(A5.17) 1		(A5.23) 1		(A5.9) 1	(A5.14) 1	—	—		—	—	—	—	—	—
Flux Cored Electrodes for FCAW and EGW	(A5.20, A5.36) 1, 2, 3, 4	(A5.26) 1, 2, 3, 4	(A5.26) 1, 2, 3, 4	(A5.29, A5.36) 1, 2, 3, 4	(A5.22) 1	(A5.34) 1	—	—	(A5.15) 1	—	—	—	—	—	—
Solid or Metal Cored Electrode—Flux Combinations for SAW and ESW	(A5.17) 1, 2, 3, 4	(A5.25) 1, 2, 3, 4	(A5.23) 1, 2, 3, 4	(A5.25) 1, 2, 3, 4	—	—	—	—	(A5.15) 1	—	—	—	—	—	—
Solid and Composite Rods for OFW	(A5.2) 1		(A5.2) 1		—	—	(A5.13) 1	(A5.21) 1	(A5.15) 1	(A5.10) 1, 9	(A5.7) 1	(A5.19) 1	—	—	—

(Continued)

Table 2 (Continued)
Schedule 4 or I—Required Tests^{a, b, c}

Product Type	Carbon Steel	Low-Alloy Steel	Stainless Steel	Nickel and Ni-Alloy	Surfacing	Cast Iron	Aluminum and Al-Alloy	Copper and Cu-Alloy	Magnesium and Mg-Alloy	Titanium and Ti-Alloy	Zirconium and Zr-Alloy	Brazing and Braze Welding Filler Metals
Consumable Inserts	(A5.30) 1	(A5.30) 1	(A5.30) 1	(A5.30) 1	—	—	—	—	—	—	—	—
Bare Brazing and Braze Welding Filler Metals	—	—	—	—	—	—	—	—	—	—	—	(A5.8) 1
Vacuum Grade Brazing Fillers	—	—	—	—	—	—	—	—	—	—	—	(A5.8) 1
Brazing Metal Powders	—	—	—	—	—	—	—	—	—	—	—	(A5.8) 1, 8

^a Designations in parentheses refer to the AWS filler metal specification.

^b Tests called for in this table shall be performed only when they are required by the applicable AWS specification for the particular classification involved. Tests shall be performed in the manner prescribed by the applicable specification. Testing to one current and polarity shall be adequate.

^c Test Designations are as follows:

- 1—Chemical analysis
- 2—Tensile
- 3—Impact
- 4—Soundness (x-ray)
- 5—Moisture test
- 6—Bend (face, side, or both)
- 7—Spattering characteristics
- 8—Sieve analysis
- 9—Bead-on-plate weld test

^d Low-hydrogen electrodes only

^e Test 4—for electrodes, Test 9—for rods

5.5 Schedule 5 or J. Results of all the tests required for classification in the AWS, ISO, or other applicable welding or brazing consumable standard for the specific lot of consumables shall be supplied.

5.6 Schedule 6 or K. In addition to, or in place of, any of the tests called for in the AWS, ISO, or other applicable welding or brazing consumable standard, the purchaser may require other tests (such as testing after a specified heat treatment). In all such cases, the purchaser shall identify on the purchase order the specific tests that are to be conducted, the procedures to be followed, the requirements that shall be met and the results to be reported for the specific lot of consumables.

ASMENORMDOC.COM : Click to view the full PDF of ASME BPVC.II.C (ASME BPVC Section II part C) 2025

Annex A (Normative)

Quality Assurance

This annex is part of this standard and includes mandatory elements for use with this standard.

A1. Manufacturer's or Supplier's Quality Assurance System

A1.1 The certification of the product is accomplished through a quality assurance program, by which the manufacturer or supplier verifies that the product meets the requirements of this specification. Such a program includes planning, documentation, surveillance, inspection, testing, and certification of the test results. It also includes control of the inspection and measuring equipment, as well as control of any nonconforming material. It involves auditing of the activities and provides for developing and implementing any corrective action that may become necessary.

A1.2 It is the responsibility of the purchaser to review the quality assurance program of the manufacturer or supplier for conformance to the purchaser's specific requirements.

A1.3 Suppliers who receive electrodes in bulk and package them for distribution, or who repackage under their own label shall as a minimum maintain an adequate control system to ensure that the package contents are traceable to the original manufacturer's records. Additional quality assurance requirements shall be as agreed between the purchaser and the supplier.

A1.4 See AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*, for packaging information. ISO 544, *Welding consumables — Technical delivery conditions for welding filler materials — Type of product, dimensions, tolerances and markings*, could also be a suitable standard.

A2. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Material, specimens, or samples for retest may be taken from the original test assembly or sample, or from a new test assembly or sample. For chemical analysis, retest need be only for those specific elements that failed to meet the test requirement. If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that, during preparation or after completion of any test, it is clearly determined that prescribed or proper procedures were not followed in preparing the weld test assembly or test specimen(s) or test sample(s), or in conducting the test, the test shall be considered invalid, without regard to whether the test was actually completed, or whether test results met, or failed to meet, the requirement. That test shall be repeated, following proper prescribed procedures. In this case, the requirement for doubling the number of test specimens does not apply.

A3. Supplementary Requirements—Department of Defense

When specified for products used in construction for the United States Department of Defense, one or more of the following clauses may be used in contracts.

A3.1 Alloy Identity. Alloy identity procedures provide type separation through quality checks at all phases of production in the manufacture of filler metals. The test method may include chemical analysis, metal sorting devices, other approved methods, or a combination of methods. When required, alloy identity procedures shall be specified in Procurement Detail

Forms using Item III, "Other Requirements." See Tables B1 through B7 (in Annex B) for Procurement Detail Forms and examples of their use.

A3.1.1 Electrode, Rod, and Core Wire Alloy Identity. Each end of rod, wire, or strip to be spliced during processing shall be tested for alloy identity prior to rewinding, spooling, or straightening and cutting into rods or electrode core wire lengths.

A3.1.2 Single Coil. For continuous process operations where a single rod coil is drawn to finish size, straightened, and cut to length without removal from the machine, both ends of each rod coil shall be alloy identity tested immediately prior to the start of the continuous processing operation.

A3.1.3 Multiple Coils. When multiple coils are to be spliced during continuous processing operations, each end of each coil to be spliced shall be alloy identity tested at the process station just prior to splicing. In addition, the leading end of the first coil and the tail end of the last coil for each continuous process run shall be alloy identity tested.

Annex B (Informative)

Guide to Welding and Brazing Consumables— Procurement of Filler Materials and Fluxes

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

This guide is appended to the specification as a source of information; it is not mandatory and does not form a part of the specification. Its purpose is to provide descriptive information and examples that will aid in the use of AWS A5.01M/A5.01:2019 (ISO 14344:2010 MOD), *Welding and Brazing Consumables—Procurement of Filler Materials and Fluxes*.

B2. General Information

The general requirements, testing requirements and procedures, method of manufacture, identification, and packaging for filler metals are specified in the filler metal specification and are not intended to be duplicated or modified in this specification, except as the purchaser specifies. The complete list of AWS filler metal specifications including AWS A5.02/A5.02M:2007, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*, is given for reference in the back of this document.

Those specifications, used in conjunction with these Procurement Guidelines, provide a basis for specifying in a procurement document the filler metal requirements in a precise, reproducible, uniform manner.

The Procurement Detail Forms in Tables B.1 through B.5 are suggested forms intended to serve as a check list for detailing filler metal requirements for procurement. They could also serve as a basis for efficient communication between departments within an organization (e.g., communication between welding or production departments and purchasing concerning the specific requirements for filler metal to be procured).

B3. Acceptance

The acceptance of welding or brazing consumables classified under AWS filler metal specifications is in accordance with the tests and requirements of the applicable filler metal specification. Any testing a purchaser requires of the supplier, for filler metal shipped in accordance with a filler metal specification, needs to be clearly stated in the purchase order according to the provisions of this specification. In the absence of any such statement in the purchase order, the supplier may ship the filler metal with whatever testing the supplier normally conducts on filler metal of that classification. Thus, the default for testing schedule is Schedule 1 or F, and the default for Lot Class is S1, T1, C1, or F1, as applicable. Testing in accordance with any other Schedule or classification to any other Lot Class must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

B4. Certification

The act of placing the AWS specification and classification designations, and optional supplemental designators, if applicable, on the packaging enclosing the product, or the classification on the product itself, constitutes the supplier's or manufacturer's certification that the product meets all of the requirements of the specification. The only testing require-

ment implicit in this certification is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that that material met the requirements of the specification. Representative material, in this case, is material from any production run of that classification using the same formulation. Certification is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the certification required by the specification is the classification test of representative material cited above, and the Manufacturer's Quality Assurance Program in AWS A5.01 M/A5.01 (ISO 14344 MOD).

B5. Examples

Examples of the manner in which the Procurement Detail Forms might be used are given in Tables B.6 and B.7.

In Table B.6, the four examples demonstrate the manner in which different packaging, lot classification, supplemental designators, and testing requirements would be specified in a purchase order for 1000 lb of 3/16 in diameter E7018 electrodes. The differences are summarized below.

Example 1. The test and certification requirements specified are those the manufacturer of the electrodes uses as "standard practice" in the conduct of the manufacturer's business (see Table 1 in the body of this specification).

Example 2. Requirements include 10 lb unit packages, a -1 (read as "dash one") supplemental designator, and, for the lot supplied, a certificate showing the results of the chemical analysis, the tensile, impact, and soundness tests, and the moisture content of the covering (for low-hydrogen electrodes, as the filler metal specification requires). (See Tables 1 and 2.) The lot classification, in this case, is the manufacturer's standard lot (see 4.3.1).

Example 3. Requirements include 10 lb unit packages, an H4 supplemental designator, and, for the lot supplied, a certificate showing the results of all tests AWS A5.1 requires for the classification of E7018 electrodes. The definition of the lot classification, in this case, is given in 4.3.3.

Example 4. The requirements here are the same as in Example 3, except that the electrode length is 18 in and the supplemental designator is H4R. The lot classification is as defined in 4.3.2 and the level of testing is that which the purchaser has specified in Item III, Other Requirements. Those tests, in this case, would be the tests required for classification of the electrode, except that the mechanical property tests (strength and toughness) would be conducted on weld metal obtained from the test assembly after the assembly had been given a postweld heat treatment at $650\text{ }^{\circ}\text{C} \pm 15\text{ }^{\circ}\text{C}$ [$1200\text{ }^{\circ}\text{F} \pm 25\text{ }^{\circ}\text{F}$] for 12 hours with the heating and cooling rates specified in Item III, Other Requirements.

Examples 5 and 6. Table B.7 demonstrates the use of the Procurement Detail Form for listing the requirements for obtaining straight lengths (rods) and spooled (electrode) aluminum filler metal to filler metal specification AWS A5.10/A5.10M, *Welding Consumables—Wire Electrodes, Wires and Rods for Welding of Aluminum and Aluminum Alloys—Classification*. Example 5 is for rods and Example 6 is for spooled electrodes. In both cases, the tests to be conducted are those called for in Table 2, as indicated by Schedule 4 or I (see Table 1 for description). The tests for aluminum rods are different from those for aluminum electrodes, but no other requirements are specified in this case.

Table B.1
Suggested Procurement Detail Form for Covered Electrodes

I. General

A. Quantity	_____
B. AWS Specification	_____
C. AWS Classification	_____
D. Supplemental Designators, if required	_____
E. Diameter	_____
F. Length	_____
G. Unit Package Type and Weight	
1. Carton	_____
2. Can	_____
3. Other	_____

II. Certification and Testing

A. Lot Classification (4.3)	_____
B. Level of Testing (5.1 through 5.6)	_____

III. Other Requirements

Table B.2
Suggested Procurement Detail Form
for Bare Solid Electrodes and Rods

I. General

A. Quantity	_____
B. AWS Specification	_____
C. AWS Classification	_____
D. Supplemental Designators, if required	_____
E. Diameter	_____
F. Length (for rods)	_____
G. Unit Package Type and Weight	
1. Spool	_____
2. Coil with Support	_____
3. Coil without Support	_____
4. Rim (reel)	_____
5. Drum	_____
6. Straight Lengths	_____
7. Other	_____

II. Certification and Testing

A. Lot Classification (4.1)	_____
B. Level of Testing (5.1 through 5.6)	_____

III. Other Requirements

Table B.3
Suggested Procurement Detail Form for
Flux Cored and Metal Cored Electrodes and Rods

I. General

A. Quantity	_____
B. AWS Specification	_____
C. AWS Classification	_____
D. Supplemental Designators, if required	_____
E. Diameter	_____
F. Unit Package Type and Weight	_____
1. Spool	_____
2. Coil with Support	_____
3. Coil without Support	_____
4. Rim (reel)	_____
5. Drum	_____
6. Other	_____

II. Certification and Testing

A. Lot Classification (4.2)	_____
B. Level of Testing (5.1 through 5.6)	_____

III. Other Requirements

Table B.4
Suggested Procurement Detail form for Submerged Arc
Electrodes and Flux and Brazing and Braze Welding Filler Metal

	Electrode or Rod	Flux
I. General		
A. Quantity	_____	_____
B. AWS Specification	_____	_____
C. AWS Classification	_____	_____
D. Supplemental Designators, if required	_____	_____
E. Diameter	_____	_____
F. Unit Package Type and Weight		
1. Spool	_____	_____
2. Coil with Support	_____	_____
3. Coil without Support	_____	_____
4. Rim (reel)	_____	_____
5. Drum	_____	_____
6. Bag, Box, or Drum (for flux)	_____	_____
7. Other	_____	_____
II. Certification and Testing		
A. Lot Classification (4.1 and 4.4)	_____	_____
B. Level of Testing (5.1 through 5.6)	_____	_____
III. Other Requirements	_____	_____

Table B.5
Suggested Procurement Detail Form for Consumable Inserts

I. General	
A. Quantity ^a	_____
B. AWS Specification	_____
C. AWS Classification	_____
D. Shape (Class)	_____
E. Style	_____
F. Size	_____
II. Certification and Testing	
A. Lot Classification (4.1)	_____
B. Level of Testing (5.1 through 5.6)	_____
III. Other Requirements	_____

^a Number of pieces or meters [feet], according to the style.

Table B.6
Example of Use of the Procurement Detail Form for Covered Electrodes

	Example 1	Example 2	Example 3	Example 4
I. General				
A. Quality	1000 lbs	1000 lbs	1000 lbs	1000 lbs
B. AWS Specification	A5.1	A5.1	A5.1	A5.1
C. AWS Classification	E7018	E7018	E7018	E7018
D. Supplemental Designators		-1	H4	H4R
E. Diameter	3/16 in	3/16 in	3/16 in	3/16 in
F. Length	14 in	14 in	14 in	18 in
G. Unit Package Type and Weight				
1. Carton	50 lb			
2. Can		10 lb	10 lb	10 lb
3. Other				
II. Certification and Testing				
A. Lot Classification	C1	C1	C3	C2
B. Level of Testing	Schedule 1 or F	Schedule 4 or I	Schedule 5 or J	Schedule 6 or K
III. Other Requirements (Example No. 4 Only)	The lots of electrodes that are shipped must meet all classification test requirements of the specification. The strength and toughness of the weld metal must meet specification requirements after a postweld heat treatment at 1200 °F ± 25 °F for 12 hours. The heating and cooling rates above 600 °F shall not exceed 200 °F/hour.			

Table B.7

Example of Use of the Procurement Detail Form for Bare Solid Aluminum Electrodes and Rods

	Example 5	Example 6
I. General		
A. Quality	400 lbs	1000 lbs
B. AWS Specification	A5.10	A5.10
C. AWS Classification	R4043	ER4043
D. Diameter	3/32 in	3/64 in
E. Length	36 in	—
F. Unit Package Type and Weight		
1. Spool	—	4 in, 1 lb
2. Coil with Support	—	—
3. Coil without Support	—	—
4. Rim (reel)	—	—
5. Drum	—	—
6. Straight	5 lbs	—
II. Certification and Testing		
A. Lot Classification	Class S2	Class S2
B. Level of Testing	Schedule 4 or I	Schedule 4 or I
III. Other Requirements	None	None

Annex C (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

C1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

C2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

C3. General Procedure for all Requests

C3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

C3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

C3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1/D1.1M:2012) that contains the provision(s) the inquirer is addressing.

C3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

C3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

C3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

C4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

C5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

C6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

Annex D (Informative)

List of Deviations from ISO 14344:2010

This annex is not part of this standard but is included for informational purposes only.

Global change: Revised organization and wording of document for simplicity and clarity. “Identification” section was removed and added to “Terms and Definitions” or “Lot Classification” sections as necessary. Various forms of fully metallic welding consumables were consolidated with no substantive changes in lot classifications and testing schedules. Removed 24 hour restriction from Lot Class C3 for consistency with other lot classifications. Defined the term “Production Schedule.” Changed wording in several places from “for each lot shipped” to “for each lot supplied.” *Added inspection document types and clarification of 24-hour limits.*

Added subclause 1.2.

Added Normative Annex A—*Quality Assurance*.

Added Informative Annex B—*Guide to Welding Consumables—Procurement of Filler Materials and Fluxes*.

Added Informative Annex C—*Requesting an Official Interpretation on an AWS Standard*.

Added Informative Annex D—*List of Deviations from ISO 14344:2010*.

AWS Filler Metal Specifications by Material and Welding Process

	OFW	SMAW	GTAW GMAW PAW	FCAW	SAW	ESW	EGW	Brazing
Carbon Steel	A5.2	A5.1, A5.35	A5.18	A5.20	A5.17	A5.25	A5.26	A5.8, A5.31
Low-Alloy Steel	A5.2	A5.5	A5.28	A5.29	A5.23	A5.25	A5.26	A5.8, A5.31
Stainless Steel		A5.4, A5.35	A5.9, A5.22	A5.22	A5.9, A5.22, A5.39	A5.9, A5.22, A5.39	A5.9	A5.8, A5.31
Cast Iron	A5.15	A5.15	A5.15	A5.15				A5.8, A5.31
Nickel Alloys		A5.11, A5.35	A5.14, A5.34	A5.34	A5.14, A5.34, A5.39	A5.14, A5.34, A5.39		A5.8, A5.31
Aluminum Alloys		A5.3	A5.10					A5.8, A5.31
Copper Alloys		A5.6	A5.7					A5.8, A5.31
Titanium Alloys			A5.16					A5.8, A5.31
Zirconium Alloys			A5.24					A5.8, A5.31
Magnesium Alloys			A5.19					A5.8, A5.31
Tungsten Electrodes			A5.12					
Brazing Alloys and Fluxes								A5.8, A5.31
Surfacing Alloys	A5.21	A5.13	A5.21	A5.21	A5.21			
Consumable Inserts			A5.30					
Shielding Gases			A5.32	A5.32			A5.32	

AWS Filler Metal Specifications and Related Documents

Designation	Title
A4.2M (ISO 8249 MOD)	<i>Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal</i>
A4.3	<i>Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding</i>
A4.4M	<i>Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings</i>
A4.5M/A4.5 (ISO 15792-3 MOD)	<i>Standard Methods for Classification Testing of Positional Capacity and Root Penetration of Welding Consumables in a Fillet Weld</i>
A5.01M/A5.01 (ISO 14344 MOD)	<i>Welding and Brazing Consumables—Procurement of Filler Materials and Fluxes</i>
A5.02/A5.02M	<i>Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes</i>
A5.1/A5.1M	<i>Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding</i>
A5.2/A5.2M	<i>Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding</i>
A5.3/A5.3M	<i>Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.4/A5.4M	<i>Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding</i>
A5.5/A5.5M	<i>Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding</i>
A5.6/A5.6M	<i>Specification for Copper and Copper-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.7/A5.7M	<i>Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes</i>
A5.8M/A5.8	<i>Specification for Filler Metals for Brazing and Braze Welding</i>
A5.9/A5.9M (ISO 14343 MOD)	<i>Specification for Bare Stainless Steel Welding Electrodes and Rods</i>
A5.10/A5.10M (ISO 18273 MOD)	<i>Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods</i>
A5.11/A5.11M	<i>Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding</i>
A5.12M/A5.12 (ISO 6848 MOD)	<i>Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting</i>
A5.13/A5.13M	<i>Specification for Surfacing Electrodes for Shielded Metal Arc Welding</i>
A5.14/A5.14M	<i>Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods</i>
A5.15	<i>Specification for Welding Electrodes and Rods for Cast Iron</i>
A5.16/A5.16M (ISO 24034 MOD)	<i>Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods</i>
A5.17/A5.17M	<i>Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.18/A5.18M	<i>Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.19	<i>Specification for Magnesium-Alloy Welding Electrodes and Rods</i>
A5.20/A5.20M	<i>Specification for Carbon Steel Electrodes for Flux Cored Arc Welding</i>
A5.21/A5.21M	<i>Specification for Bare Electrodes and Rods for Surfacing</i>
A5.22/A5.22M	<i>Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods</i>
A5.23/A5.23M	<i>Specification for Low-Alloy and High Manganese Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.24/A5.24M	<i>Specification for Zirconium and Zirconium-Alloy Welding Electrodes and Rods</i>
A5.25/A5.25M	<i>Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding</i>
A5.26/A5.26M	<i>Specification for Carbon and Low-Alloy Steel Electrodes for Electrogas Welding</i>
A5.28/A5.28M	<i>Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.29/A5.29M	<i>Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding</i>
A5.30/A5.30M	<i>Specification for Consumable Inserts</i>
A5.31M/A5.31	<i>Specification for Fluxes for Brazing and Braze Welding</i>
A5.32M/A5.32 (ISO 14175 MOD)	<i>Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes</i>
A5.34/A5.34M	<i>Specification for Nickel-Alloy Flux Cored and Metal Cored Welding Electrodes</i>
A5.35/A5.35M-AMDI	<i>Specification for Covered Electrodes for Underwater Wet Shielded Metal Arc Welding</i>
A5.39/A5.39M	<i>Specification for Flux and Electrode Classifications for Submerged Arc and Electroslag Joining and Surfacing of Stainless Steel and Nickel Alloys</i>

INTENTIONALLY LEFT BLANK

SPECIFICATION FOR FILLER METAL STANDARD SIZES, PACKAGING, AND PHYSICAL ATTRIBUTES



SFA-5.02/SFA-5.02M



(25)

(Identical with AWS Specification A5.02/A5.02M:2025. In case of dispute, the original AWS text applies.)

Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes

1. Scope

1.1 This specification prescribes requirements for standard sizes and packages of welding filler metals and their physical attributes, such as product appearance and identification. *This specification does not apply to filler materials for brazing or braze welding or tungsten and oxide-dispersed tungsten electrodes.*

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way. The specification with the designation A5.02 uses U.S. Customary Units. The specification A5.02M uses SI Units. The latter are shown within brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing of filler metal or packaging.

1.3 Safety. Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein.

Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, Safety in Welding, Cutting, and Allied Processes
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. Unless otherwise defined in this document, welding terms are as defined in AWS A3.0M/A3.0. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to or revisions of any of these publications do not apply.

American Welding Society:

AWS A3.0/A3.0M, Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying

American National Standards Institute (ANSI) document:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

ASTM International (ASTM) document:

ASTM E29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

International Organization for Standardization (ISO) document:

ISO 544 *Welding consumables — Technical Delivery Conditions for Welding Filler Materials — Type of Product, Dimensions, Tolerances and Markings.*

ISO 80000-1:2022, Quantities and units — Part 1: General.

3. Rounding Procedure

For the purpose of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest unit in the last right-hand place of figures used in expressing the limiting values for that quantity. The rounded results shall fulfill the requirements.

4. Covered Electrodes

4.1 Standard Sizes and Lengths. Standard sizes (diameter of the core wire) and lengths of electrodes are shown in Table 1.

4.1.1 The diameter of the core wire shall not vary more than ± 0.002 in if measured in U.S. Customary units or more than ± 0.05 mm if measured in SI units from the diameter specified.

4.1.2 The length shall not vary more than $\pm 1/4$ in if measured in U.S. Customary units or more than ± 10 mm if measured in SI units from that specified.

4.2 Core Wire and Covering. The core wire and covering shall be free of defects that would interfere with the uniform deposition of the electrode. The core and covering shall be concentric to the extent that the maximum core-plus-one-covering dimension shall not exceed the minimum core-plus-one-covering dimension by more than:

- (1) 7% of the mean dimension in sizes of 3/32 in [2.5 mm] and smaller
- (2) 5% of the mean dimension in sizes larger than 3/32 in [2.5 mm] and smaller than 3/16 in [5 mm]
- (3) 4% of the mean dimension in sizes 3/16 in [5 mm] and larger.

Concentricity may be measured by any suitable means.

4.3 Exposed Core

4.3.1 The grip end of each electrode shall be bare (free of covering) for a distance of not less than 1/2 in [12 mm] nor more than 1-1/4 in [30 mm] for electrodes 5/32 in [4.0 mm] and smaller, and not less than 3/4 in [20 mm] nor more than 1-1/2 in [40 mm] for electrodes 3/16 in [5 mm] and larger, to provide for electrical contact with the electrode holder.

4.3.2 The arc end of each electrode shall be sufficiently conductive, and the covering sufficiently tapered, to permit easy striking of the arc. The length of the conductive portion (measured from the end of the core wire to the location where the full cross section of the covering is obtained) shall not exceed 1/8 in [3 mm] or the diameter of the core wire, whichever is less. Electrodes with chipped coverings near the arc end, baring the core wire no more than the lesser of 1/4 in [6 mm] or twice the diameter of the core wire, meet the requirements of this specification provided no chip uncovers more than 50% of the circumference of the core.

4.4 Electrode Identification. All electrodes shall be identified as follows:

4.4.1 At least one imprint of the electrode designation (classification plus any optional designators) shall be applied to the electrode covering starting within 2-1/2 in [65 mm] of the grip end of the electrode. The prefix letter E in the classification may be omitted from the imprint.

4.4.2 The numbers and letters of the imprint shall be of bold block type of a size large enough to be legible.

4.4.3 The ink used for imprinting shall provide sufficient contrast with the electrode covering so that, in normal use, the numbers and letters are legible both before and after welding.

4.4.4 When an electrode is classified as meeting the requirements of A5.X and A5.XM, both electrode designations shall be applied.

4.4.5 If allowed by the specific A5 specification *or by agreement between the supplier and the purchaser*, in lieu of imprinting, electrodes may be identified by:

- (1) Attaching securely to the bare grip end of each electrode a tag bearing the classification number, or
- (2) Embossing the classification number on the bare grip end of each electrode. In this case a slight flattening of the grip end will be permitted in the area of the embossing.

4.5 Packaging

4.5.1 Electrodes shall be suitably packaged to protect them from damage during shipment and storage under normal conditions.

4.5.2 Standard package *types and* weights shall be as agreed upon between purchaser and supplier.

4.5.3 Hermetically Sealed Containers. When specified for protection against atmospheric moisture during shipment and storage, electrodes shall be packaged in one of the following manners.

4.5.3.1 Rigid Metal Package. The container may be of either steel or aluminum. Each steel container shall have its sides lock-seamed and soldered or seam welded and the top and bottom mechanically seamed containing a suitable organic sealant. Aluminum containers shall be tubes formed in two sections, one flared slightly for a friction fit and the closure seam shall be sealed with a suitable pressure sensitive tape. Metal containers after loading at ambient pressure and sealing shall be capable of passing a leak test.

4.5.3.2 Vacuum Foil Package. High density plastic pouches laminated with a suitable metal foil vapor barrier shall be heat sealed after filling and evacuating. The pouches shall be overpacked with an outer container to protect them from damage that *may* cause loss of vacuum. Packages which *allow* the contents to be loose within the pouch do not meet the requirements of this specification.

4.5.3.3 Other Package Construction. As agreed upon between purchaser and supplier, alternate packaging for protection of electrode coverings from absorption of moisture in excess of that specified by the classification shall be demonstrated by suitable tests, such as those described *below*.

4.5.4 Leak Testing for Hermetically Sealed Containers. Unit containers shall be immersed in water that is at a temperature of at least 50 °F [18 °C] above that of the packaged material (room temperature). The container shall be immersed so that the surface under observation is 1 in [25 mm] below the water surface and the greatest basic dimension of the container is parallel to the surface of the water. A leaker is indicated by a steady stream of bubbles emanating from the container. A container with a stream that lasts for 30 s or more does not meet the requirements of this specification.

4.6 Marking of Packages

4.6.1 The following product information (as a minimum) shall be legibly marked on the outside of each unit package:

- (1) AWS specification and classification designations along with applicable optional designators (year of issue may be excluded)
- (2) Supplier's name and trade designation
- (3) Size and net weight
- (4) Lot, control, or heat number

4.6.2 The appropriate precautionary information or its equivalent, as given in ANSI Z49.1, (as a minimum) shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages enclosed within a larger package. Typical examples of “warning labels” and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

4.6.3 *Product packaging may have applicable national or local labeling requirements, such as those specified under the U.S. OSHA Hazard Communication Standard, 29 CFR 1910.1200 2012 [GHS].*

5. Bare Solid and Tubular Electrodes and Rods

5.1 Standard Sizes and Shapes

5.1.1 Standard sizes of filler metal (except strip electrodes) and straight lengths of rods and their tolerances are shown in Table 2 and Table 2M. Table 2 provides requirements for products labeled with U.S. Customary Units (inches). Table 2M provides requirements labeled with SI Units (millimeters). For products labeled with both U.S. Customary and SI Units, compliance with both tables is required.

5.1.2 Standard sizes for strip electrodes in coils are shown in Table 3 (strip electrodes are predominantly sold only in SI Unit dimensions).

5.2 Finish and Uniformity

5.2.1 All filler metal shall have a smooth finish that is free from slivers, depressions, scratches, scale, seams, laps (exclusive of a longitudinal joint in flux cored or metal cored filler metal), and foreign matter that would adversely affect the welding characteristics or the properties of the weld metal.

5.2.2 Each continuous length of filler metal shall be from a single heat or lot of material, and welds, when present, shall have been made so as not to interfere with the uniform, uninterrupted feeding of the filler metal on automatic and semiautomatic equipment.

5.2.3 The core ingredients in flux cored and metal cored filler metal shall be distributed with sufficient uniformity throughout the length of the electrode so as not to adversely affect the performance of the electrode or the properties of the weld metal or deposited weld overlay.

5.2.4 A suitable protective coating may be applied to any filler metal. *Protective coatings may be specifically restricted or limited by the filler metal specification or a specific classification within a filler metal specification.*

5.3 Packaging

5.3.1 Filler metals shall be suitably packaged to protect them from damage during shipment and storage under normal conditions.

5.3.2 Standard package forms are straight lengths, coils with support, coils without support, spools, and drums. Standard package dimensions for each form are given in Table 4. Dimensions for standard spools are given in Figures 1A through 1D. Package forms and sizes other than these shall be as agreed upon between purchaser and supplier.

5.3.3 The liners in coils with support shall be designed and constructed to prevent distortion of the coil during normal handling and use, and shall be clean and dry enough to maintain the cleanliness of the filler metal.

5.3.4 Spools shall be designed and constructed to prevent distortion of the spool and the filler metal during normal handling and use, and shall be clean and dry enough to maintain the cleanliness of the filler metal.

5.3.5 As agreed upon between purchaser and supplier, alternate packaging for protection of filler metals from environmental or other conditions may be specified. This packaging may include, but not be limited to, hermetically sealed packaging as specified in 4.5.3.

5.4 Winding Requirements

5.4.1 Filler metal on spools and in coils (including drums) shall be wound so that kinks, waves, or sharp bends are not encountered and the filler metal is free to unwind without restriction. The outside end of the filler metal (the end with which welding is to begin) shall be identified so it can be located readily and shall be fastened to avoid unwinding.

5.4.2 The cast and helix of filler metal in coils, spools, and drums shall be such that the filler metal will feed in an uninterrupted manner in automatic and semiautomatic equipment.

5.5 Filler Metal Identification

5.5.1 Each bare straight length filler rod shall be durably marked with identification traceable to the unique product type of the manufacturer or supplier. Suitable methods of identification *may* include stamping, coining, embossing, imprinting, flag-tagging or color coding. If color-coding is used, the choice of color shall be as agreed upon between the purchaser and supplier, and the color shall be identified on the packaging. When the AWS classification designation is used, the *E*, *R*, or ER may be omitted; for example, “308L” for classification “ER308L.” Additional identification shall be as agreed upon between purchaser and supplier.

5.5.2 The product information and the precautionary information required in 5.6 for marking each package shall also appear on each coil, spool, and drum.

5.5.3 Coils without support shall have a tag containing this information securely attached to the filler metal at the inside end of the coil.

5.5.4 Coils with support shall have the information securely affixed in a prominent location on the support.

5.5.5 Spools shall have the information securely affixed in a prominent location on the outside of at least one flange of the spool.

5.5.6 Drums shall have the information securely affixed in a prominent location on the side of the drum.

5.6 Marking of Packages

5.6.1 The following product information (as a minimum) shall be legibly marked so as to be visible from the outside of each unit package:

- (1) AWS specification and classification designations along with applicable optional designators (year of issue may be excluded)
- (2) Supplier’s name and trade designation
- (3) Size and net weight or other suitable measure of quantity
- (4) Lot, control, or heat number

5.6.2 The appropriate precautionary information *or its equivalent*, as given in ANSI Z49.1 (as a minimum), shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages enclosed within a larger package. Typical examples of “warning labels” and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

5.6.3 *Product packaging may have applicable national or local labeling requirements, such as those specified under the U.S. OSHA Hazard Communication Standard, 29 CFR 1910.1200 2012 [GHS].*

Table 1
Standard Sizes and Lengths of Covered Electrodes

Standard Size		Standard Length ^{a, b}	
in	mm	in	mm
1/16 ^c	1.6 ^c	9	230
5/64 ^c	2.0 ^c	9 or 12	230 or 300
3/32 ^c	2.4 ^{c, d}	9, 12, or 14	230, 300, or 350
—	2.5 ^c	—	300 or 350
1/8	3.2	12, 14, or 18	300, 350, or 450
5/32	4.0	14 or 18	350 or 450
3/16	4.8 ^d	14 or 18	350 or 450
—	5.0	14 or 18	350 or 450
7/32 ^c	5.6 ^{c, d}	14 or 18	350 or 450
—	6.0	14 or 18	350 or 450
1/4 ^c	6.4 ^c	14 or 18	350 or 450
5/16 ^c	8.0 ^c	18	450

^a Lengths other than these shall be as agreed upon between purchaser and supplier.

^b In all cases, end-gripped electrodes are standard.

^c These diameters are not standard sizes for all classifications.

^d These metric sizes are not shown in ISO 544.

Table 2
Standard Sizes and Tolerances of Solid and Tubular Bare Wires^a

Nominal Diameter (in)	Solid Wire for GMAW or GTAW ^b	Solid Wire for SAW or EGW or ESW	Cast Electrodes or Rods ^c	Tubular Cored Wire for All Processes and All Wire for Hardfacing	Tungsten Carbide (WC) Rods ^c	Copper and Copper-Alloy Electrodes and Rods
0.020	0.019–0.021	—	—	—	—	0.018–0.022
0.025	0.024–0.026	—	—	—	—	—
0.030	0.029–0.031	—	—	0.028–0.032	—	0.028–0.032
0.035	0.034–0.036	—	—	0.033–0.037	—	0.033–0.037
0.045	0.044–0.046	—	—	0.043–0.047	—	0.043–0.047
3/64	0.045–0.049	—	—	0.045–0.049	—	—
0.052	0.050–0.054	—	—	0.050–0.054	—	—
1/16	0.060–0.064	0.060–0.064	—	0.060–0.064	—	0.060–0.064
0.068	0.066–0.070	0.066–0.070	—	0.065–0.071	—	—
0.072	0.070–0.074	0.070–0.074	—	0.069–0.075	—	—
5/64	0.076–0.080	0.076–0.080	—	0.075–0.081	—	0.076–0.080
3/32	0.092–0.096	0.092–0.096	0.074–0.114	0.091–0.097	—	0.092–0.096
7/64	0.106–0.112	0.106–0.112	—	0.106–0.112	—	—
1/8	0.122–0.128	0.122–0.128	0.105–0.145	0.122–0.128	0.062–0.188	0.123–0.127
5/32	—	0.152–0.160	0.136–0.176	0.152–0.160	0.093–0.219	0.154–0.158
3/16	—	0.184–0.192	0.168–0.208	0.184–0.192	0.125–0.251	0.186–0.190
7/32	—	0.215–0.223	—	0.215–0.223	—	—
1/4	—	0.246–0.254	0.220–0.280	0.246–0.254	0.187–0.313	0.248–0.252
5/16	—	0.308–0.316	0.282–0.342	0.308–0.316	0.249–0.375	—
3/8	—	—	—	—	0.312–0.438	—

^a Dashes indicate a non-standard size. Dimensions, tolerances, and package forms other than those shown shall be as agreed upon between purchaser and supplier.

^b Bare straight lengths shall be 18.0 in (±0.5 in) or 36.0 in (±0.5 in).

^c Lengths shall be as agreed upon between the manufacturer and the purchaser.

Table 2M
Standard Sizes and Tolerances of Solid and Tubular Bare Wires^a

Nominal Diameter (mm)	Solid Wire for GMAW or GTAW ^b	Solid Wire for SAW or EGW or ESW	Cast Electrodes or Rods ^{c,d}	Tubular Cored Wire for All Processes and All Wire for Hardfacing	Tungsten Carbide (WC) Rods ^{c,d}	Copper and Copper-Alloy Electrodes and Rods
0.5	0.47–0.51	—	—	—	—	0.47–0.51
0.6	0.57–0.61	—	—	—	—	0.57–0.61
0.8	0.76–0.81	—	—	0.75–0.82	—	0.76–0.81
0.9	0.86–0.91	—	—	0.85–0.92	—	0.86–0.91
1.0	0.96–1.01	0.96–1.04	—	0.95–1.02	—	0.96–1.01
1.2	1.16–1.21	1.16–1.24	—	1.15–1.22	—	1.16–1.21
1.4	1.36–1.41	1.36–1.44	—	1.35–1.42	—	1.36–1.41
1.6	1.56–1.61	1.56–1.64	—	1.54–1.62	—	1.56–1.61
1.8	1.76–1.81	1.76–1.84	—	1.74–1.82	—	1.76–1.81
2.0	1.96–2.01	1.96–2.04	—	1.94–2.02	—	1.96–2.01
2.4	2.36–2.41	2.36–2.44	1.89–2.91	2.34–2.42	—	2.36–2.41
2.5	2.46–2.51	2.46–2.54	—	2.44–2.52	—	2.46–2.51
2.8	2.73–2.81	2.76–2.84	—	2.74–2.82	—	2.73–2.81
3.0	2.93–3.01	2.94–3.06	—	2.93–3.02	—	2.93–3.01
3.2	3.13–3.21	3.14–3.26	2.69–3.71	3.13–3.22	1.6–4.8	3.13–3.21
4.0	3.93–4.01	3.94–4.06	3.49–4.51	3.93–4.02	2.4–5.6	3.93–4.01
4.8	—	4.74–4.86	4.29–5.31	4.73–4.82	—	—
5.0	—	4.94–5.06	—	4.92–5.02	3.4–6.6	—
5.6	—	5.54–5.66	—	5.52–5.62	—	—
6.0	—	5.94–6.06	—	5.92–6.02	—	—
6.4	—	6.34–6.46	5.64–7.16	6.32–6.42	4.8–8.0	—
8.0	—	7.94–8.06	7.24–8.76	7.92–8.02	6.4–9.6	—
9.5	—	—	—	—	7.9–11.1	—

^a Dashes indicate a non-standard size. Dimensions, tolerances, and package forms other than those shown shall be as agreed upon between purchaser and supplier.

^b Bare straight lengths shall be 450 mm (± 12 mm), 500 mm (± 12 mm), 900 mm (± 12 mm), or 1000 mm (± 12 mm).

^c Lengths shall be as agreed upon between the manufacturer and the purchaser.

^d These products are not covered in ISO 544.

Table 3
Standard Sizes of Strip Electrodes

Width, mm	Thickness, mm
30	0.5
60	0.5
90	0.5
120	0.5

Notes:

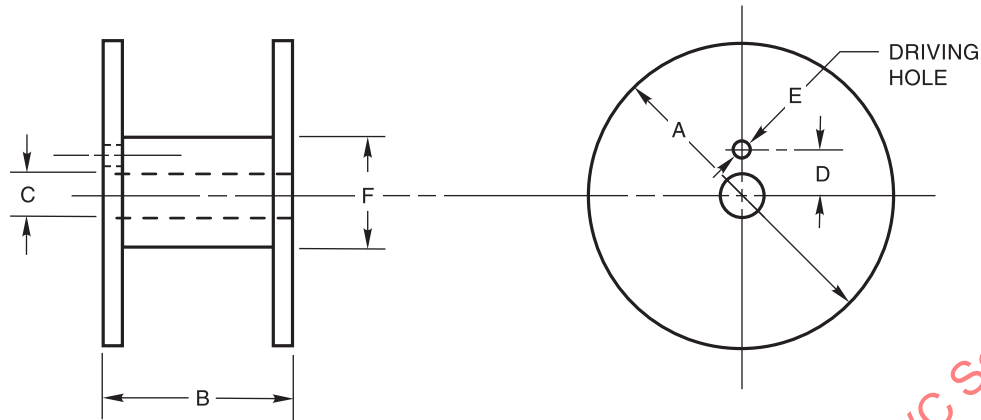
1. Other sizes shall be as agreed upon between purchaser and supplier.
2. Strip electrodes shall not vary more than ± 0.2 mm in width and more than ± 0.05 mm in thickness.
3. The edge of the strip electrodes (camber) shall not deviate from a straight line by more than 12 mm in any 2.5 m length.

Table 4
Standard Packages^{a, b}

Type of Package	Width		Inside Diameter		Outside Diameter, Max.	
	in	mm ^b	in	mm ^b	in	mm ^b
Coils with Support	2-1/2 max.	—	12 $\pm$ 1/8	—	17	—
	—	64, +0, -15	—	300, +15, -0	—	435
	3 max.	75 max.	6-3/4 $\pm$ 1/8	170 $\pm$ 3	12	—
	4-5/8 max.	—	12 $\pm$ 1/8	—	18	—
	—	100, +10, -5	—	300, +15, -5	—	450
	5 max.	—	24	—	32	—
	—	120, +10, -5	—	600, +20, -0	—	800
Coils without support	As agreed upon between purchaser and supplier					
Spools	See Figures 1A, 1B, and 1C				4	100
					8	200
					12	300
					13.5	340
					14	350
					22	560
					24	610
					30	760
Drums	Not applicable				15.5	400
					20	500
					23	600

^a Dimensions, tolerances, and package forms other than those shown shall be as agreed upon between purchaser and supplier.

^b Shaded values in the metric columns are as specified in ISO 544 for coils both with and without supports.

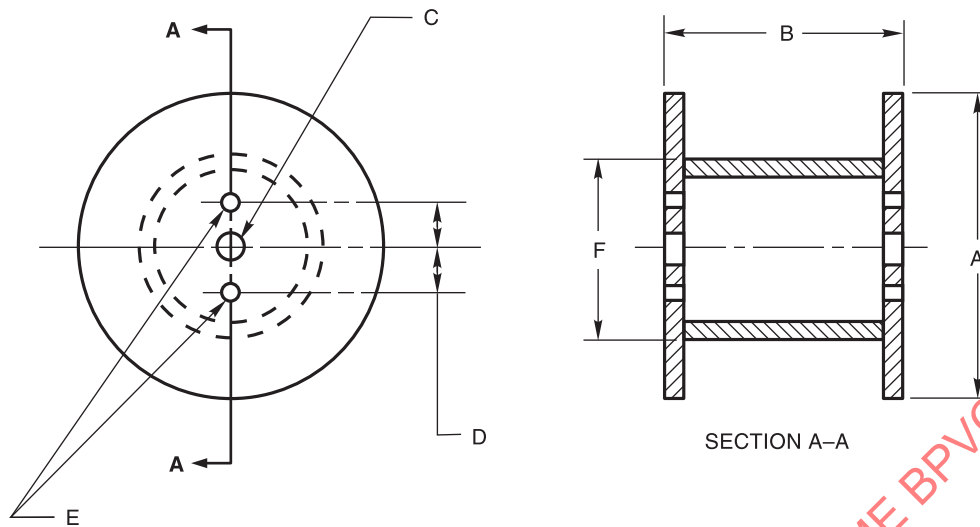


DIMENSIONS									
		4 in [100 mm] Spools		8 in [200 mm] Spools		12 in [300 mm] Spools		14 in [350 mm] Spools	
		in	mm	in	mm	in	mm	in	mm
A	Diameter, max. (Note 4)	4.0	102	8.0	203	12	305	14	355
B	Width	1.75	45	2.16	55	4.0	103	4.0	103
	Tolerance	± 0.03	$+0, -2$	± 0.03	$+0, -3$	± 0.06	$+0, -3$	± 0.06	$+0, -3$
C	Diameter	0.63	16.5	2.03	50.5	2.03	50.5	2.03	50.5
	Tolerance	$+0.01, -0$	$+1, -0$	$+0.06, -0$	$+2.5, -0$	$+0.06, -0$	$+2.5, -0$	$+0.06, -0$	$+2.5, -0$
D	Distance Between Axes	—	—	1.75	44.5	1.75	44.5	1.75	44.5
	Tolerance	—	—	± 0.02	± 0.5	± 0.02	± 0.5	± 0.02	± 0.5
E	Diameter (Note 3)	—	—	0.44	10	0.44	10	0.44	10
	Tolerance	—	—	$+0, -0.06$	$+1, -0$	$+0, -0.06$	$+1, -0$	$+0, -0.06$	$+1, -0$

Notes:

1. Outside diameter of barrel, dimension F, shall be such as to permit proper feeding of the electrode.
2. Inside diameter of the barrel shall be such that swelling of the barrel or misalignment of the barrel and flanges will not result in the inside of the diameter of the barrel being less than the inside diameter of the flanges.
3. Holes are provided on each flange, but they need not be aligned. No driving holes required for 4 in [100 mm] spools.
4. Metric dimensions and tolerances conform to ISO 544, except that "A" specifies $\pm$ tolerances on the nominal diameter, rather than a plus tolerance only, which is shown here as a maximum.

Figure 1A—Dimensions of 4 in, 8 in, 12 in, and 14 in [100 mm, 200 mm, 300 mm, and 350 mm] Spools

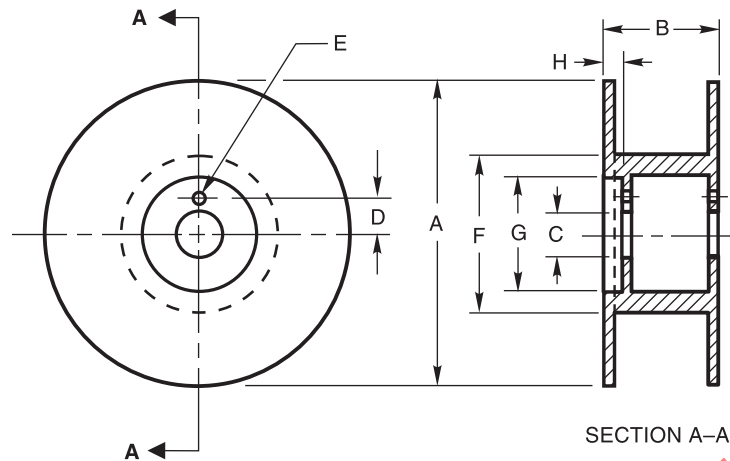


DIMENSIONS							
		22 in [560 mm] Spools		24 in [610 mm] Spools		30 in [760 mm] Spools	
		in	mm	in	mm	in	mm
A	Diameter, max. (Note 4)	22	560	24	610	30	760
B	Width, max.	12	305	13.5	345	13.5	345
C	Diameter Tolerance	1.31 +0.13, -0	35.0 ±1.5	1.31 +0.13, -0	35.0 ±1.5	1.31 +0.13, -0	35.0 ±1.5
D	Distance, Center-to-Center Tolerance	2.5 ±0.1	63.5 ±1.5	2.5 ±0.1	63.5 ±1.5	2.5 ±0.1	63.5 ±1.5
E	Diameter (Note 3) Tolerance	0.69 +0, -0.06	16.7 ±0.7	0.69 +0, -0.06	16.7 ±0.7	0.69 +0, -0.06	16.7 ±0.7

Notes:

1. Outside diameter of barrel, dimension F, shall be such as to permit proper feeding of the electrode.
2. Inside diameter of barrel shall be such that swelling of the barrel or misalignment of the barrel and flanges will not result in the inside diameter of the barrel being less than the inside diameter of the flanges.
3. Two holes are provided on each flange and shall be aligned on both flanges with the center hole.
4. Metric dimensions and tolerances conform to ISO 544, except that "A" specifies ± tolerances on the nominal diameter, rather than a plus tolerance only, which is shown here as a maximum.

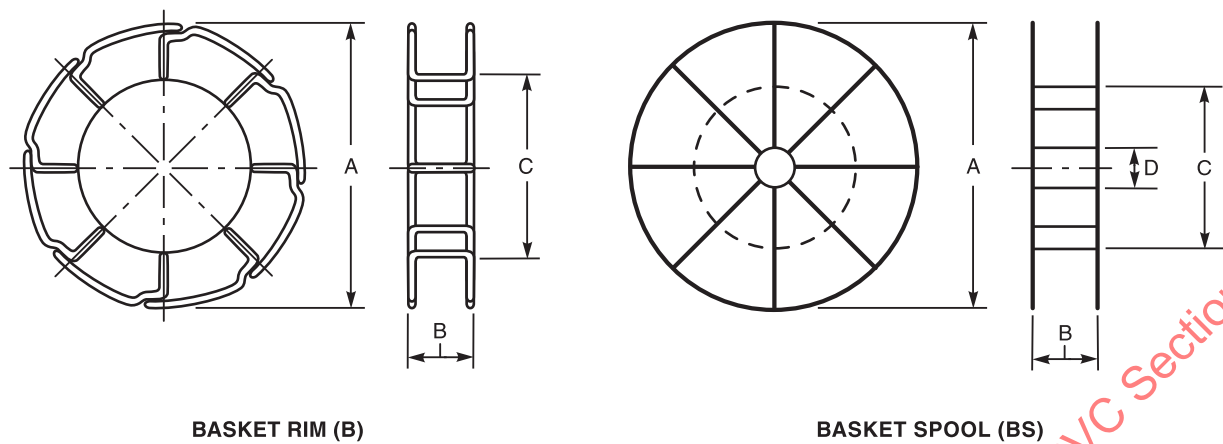
**Figure 1B—Dimensions of 22 in, 24 in, and 30 in
[560 mm, 610 mm, and 760 mm] Spools (Reels)**



DIMENSIONS			
		in	mm
A	Diameter Tolerance	13.50 +0, -0.06	342 ±2
B	Width Tolerance	5.13 ±0.06	130 ±2
C	Diameter Tolerance	2.03 +0.06, -0	50.5 +2.5, -0
D	Distance Between Axes Tolerance	1.75 ±0.02	44.5 ±0.5
E	Diameter Tolerance	0.44 +0, -0.06	10 +1, -0
F	Diameter Tolerance	7.0 ±0.03	177.5 ±1.0
G	Diameter Tolerance	5.0 ±0.03	127 ±0.8
H	Recess Tolerance	1.13 +0.12, -0	31 ±2

Note: Holes are provided on each flange, but they need not be aligned.

**Figure 1C—Dimensions of 13-1/2 in [340 mm] Spools
(for Al and Mg Alloys Only)**



DIMENSIONS							
		Basket Rim		Basket Rim		Basket Spool	
		in	mm	in	mm	in	mm
A	Diameter Tolerance	11.7 ±0.1	300 +0, -5	17.7 max.	450 max.	12.0 +0, -0.4	300 ±5
B	Width Tolerance	4.0 ±0.06	103 +0, -3	4 +0.06, -0.18	100 ±3	4.0 ±0.06	103 +0, -3
C	Diameter Tolerance	7.0 +0.2, -0	180 ±2	12.0 +0, -0.4	300 ±5	7.44 ±0.02	189 ±0.5
D	Bore Diameter	—	—	—	—	2.03 +0.06, -0	50.5 +2.5, -0

Figure 1D—Dimensions of Basket Rims and Basket Spools

Annex A (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

A1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

A2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

A3. General Procedure for all Requests

A3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

A3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

A3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

A3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

A3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

A3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

A4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

A5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

A6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

AWS Filler Metal Specifications by Material and Welding Process

	OFW	SMAW	GTAW GMAW PAW	FCAW	SAW	ESW	EGW	Brazing
Carbon Steel	A5.2	A5.1, A5.35	A5.18	A5.20	A5.17	A5.25	A5.26	A5.8, A5.31
Low-Alloy Steel	A5.2	A5.5	A5.28	A5.29	A5.23	A5.25	A5.26	A5.8, A5.31
Stainless Steel		A5.4, A5.35	A5.9, A5.22	A5.22	A5.9, A5.22, A5.39	A5.9, A5.22, A5.39	A5.9	A5.8, A5.31
Cast Iron	A5.15	A5.15	A5.15	A5.15				A5.8, A5.31
Nickel Alloys		A5.11, A5.35	A5.14, A5.34	A5.34	A5.14, A5.34, A5.39	A5.14, A5.34, A5.39		A5.8, A5.31
Aluminum Alloys		A5.3	A5.10					A5.8, A5.31
Copper Alloys		A5.6	A5.7					A5.8, A5.31
Titanium Alloys			A5.16					A5.8, A5.31
Zirconium Alloys			A5.24					A5.8, A5.31
Magnesium Alloys			A5.19					A5.8, A5.31
Tungsten Electrodes			A5.12					
Brazing Alloys and Fluxes								A5.8, A5.31
Surfacing Alloys	A5.21	A5.13	A5.21	A5.21	A5.21			
Consumable Inserts			A5.30					
Shielding Gases			A5.32	A5.32			A5.32	

AWS Filler Metal Specifications and Related Documents

Designation	Title
A4.2M (ISO 8249 MOD)	Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal
A4.3-ADD1	Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding
A4.4M	Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings
A4.5M/A4.5 (ISO 15792-3 MOD)	Standard Methods for Classification Testing of Positional Capacity and Root Penetration of Welding Consumables in a Fillet Weld
A5.01M/A5.01 (ISO 14344 MOD)	Welding Consumables—Procurement of Filler Materials and Fluxes
A5.02/A5.02M	Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes
A5.1/A5.1M	Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding
A5.2/A5.2M	Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding
A5.3/A5.3M	Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding
A5.4/A5.4M	Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding
A5.5/A5.5M	Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding
A5.6/A5.6M	Specification for Copper and Copper-Alloy Electrodes for Shielded Metal Arc Welding
A5.7/A5.7M	Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes
A5.8M/A5.8	Specification for Filler Metals for Brazing and Braze Welding
A5.9/A5.9M (ISO 14343 MOD)	Specification for Bare Stainless Steel Welding Electrodes and Rods
A5.10/A5.10M (ISO 18273 MOD)	Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods
A5.11/A5.11M	Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding
A5.12M/A5.12 (ISO 6848 MOD)	Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting
A5.13/A5.13M	Specification for Surfacing Electrodes for Shielded Metal Arc Welding
A5.14/A5.14M	Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods
A5.15	Specification for Welding Electrodes and Rods for Cast Iron
A5.16/A5.16M (ISO 24034 MOD)	Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods
A5.17/A5.17M	Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding
A5.18/A5.18M	Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding
A5.19	Specification for Magnesium-Alloy Welding Electrodes and Rods
A5.20/A5.20M	Specification for Carbon Steel Electrodes for Flux Cored Arc Welding
A5.21/A5.21M	Specification for Bare Electrodes and Rods for Surfacing
A5.22/A5.22M	Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods
A5.23/A5.23M	Specification for Low-Alloy and High Manganese Steel Electrodes and Fluxes for Submerged Arc Welding
A5.24/A5.24M	Specification for Zirconium and Zirconium-Alloy Welding Electrodes and Rods
A5.25/A5.25M	Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding
A5.26/A5.26M	Specification for Carbon and Low-Alloy Steel Electrodes for Electrogas Welding
A5.28/A5.28M	Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding
A5.29/A5.29M	Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding
A5.30/A5.30M	Specification for Consumable Inserts
A5.31M/A5.31	Specification for Fluxes for Brazing and Braze Welding
A5.32M/A5.32 (ISO 14175 MOD)	Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes
A5.34/A5.34M	Specification for Nickel-Alloy Flux Cored and Metal Cored Welding Electrodes
A5.35/A5.35M-AMD1	Specification for Covered Electrodes for Underwater Wet Shielded Metal Arc Welding
A5.39/A5.39M	Specification for Flux and Electrode Combinations for Submerged Arc and Electroslag Joining and Surfacing of Stainless Steel and Nickel Alloys

SPECIFICATION FOR CARBON STEEL ELECTRODES FOR SHIELDED METAL ARC WELDING



SFA-5.1/SFA-5.1M



(25)

(Identical with AWS Specification A5.1/A5.1M:2025. In case of dispute, the original AWS text applies.)

Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding

1. Scope

1.1 This specification prescribes requirements for the classification of carbon steel electrodes for shielded metal arc welding of carbon steels.

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to material properties. The specification designated A5.1 uses U.S. Customary Units. The specification designated A5.1M uses SI Units. The latter units are shown within brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing of filler metal or packaging or both under either the A5.1 or the A5.1M specification.

1.3 Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in Annex A, Clauses A5 and A10.

Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies.

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to or revisions of any of these publications do not apply.

American Welding Society (AWS) documents:

AWS A3.0M/A3.0, Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying

AWS A4.3 ADD1, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*

AWS A4.4M, *Standard Procedure for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coatings*

AWS A4.5M/A4.5, *Standard Methods for Classification Testing of Positional Capacity and Root Penetration of Welding Consumables in a Fillet Weld*

AWS A5.01M/A5.01, *Welding and Brazing Consumables—Procurement of Filler Metals and Fluxes*

AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*

AWS B4.0, *Standard Methods for Mechanical Testing of Welds*

American National Standards Institute (ANSI) document:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

ASTM International (ASTM) documents:

ASTM A29/A29M, *Standard Specification for General Requirements for Steel Bars, Carbon and Alloy, Hot-Wrought*

ASTM A36/A36M, *Standard Specification for Carbon Structural Steel*

ASTM A131/A131M, *Standard Specification for Structural Steel for Ships*

ASTM A283/A283M, *Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates*

ASTM A285/A285M, *Standard Specification for Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength*

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

ASTM E350, *Standard Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron*

ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*

ASTM E2033, *Standard Practice for Radiographic Examination Using Computed Radiography (Photostimulable Luminescence Method)*

ASTM E2698, *Standard Practice for Radiographic Examination Using Digital Detector Arrays*

International Organization for Standardization (ISO) document:

ISO 80000-1, *Quantities and units — Part 1: General*.

3. Classification

3.1 The welding electrodes covered by the A5.1 and A5.1M specifications utilize a classification system (shown in Figure 1) based upon U.S. Customary Units and the International System of Units (SI), respectively, and are classified according to:

- (1) Type of current (Table 1)
- (2) Type of covering (Table 1)
- (3) Welding position (Table 1)
- (4) Mechanical properties of the weld metal in the as-welded condition (Tables 4 and 5)

3.2 Electrodes classified under one classification shall not be classified under any other classification in this specification, except as herein noted. *Electrodes classified as E60-G [E43-G] or E70-G [E49-G] may also be classified as any other classification provided that the electrode meets all of the requirements of both classifications.* E7018M [E4918M] electrodes may also be classified as E7018 [E4918] provided that the electrode meets all of the requirements of both classifications.

3.3 Electrodes may be classified under A5.1 using U.S. Customary Units or under A5.1M using the International System of Units (SI), or they may be classified under both systems. Electrodes classified under either classification system must meet all requirements for classification under that system. The classification system is shown in Figure 1.

4. Acceptance

Acceptance of the welding electrodes shall be in accordance with the provisions of AWS A5.01M/A5.01. See A3 (in Annex A) for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

5. Certification

By affixing the AWS specification and classification designations to the packaging, or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification. See A4 (in Annex A) for further information concerning certification and the testing called for to meet this requirement.

6. Rounding Procedure

For the purpose of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average.

An observed or calculated value shall be rounded to the nearest 1 000 psi (1 ksi) for tensile and yield strength for A5.1, to the nearest 10 MPa for tensile and yield strength for A5.1M, and to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities.

7. Summary of Tests

The tests required for each classification are specified in Table 2. The purpose of these tests is to determine the chemical composition, mechanical properties, soundness of the weld metal, the usability of the electrode, and the moisture content of the low-hydrogen electrode covering. The base metal for the weld test assemblies, the welding and testing procedures to be employed, and the results required are given in Clauses 9 through 16. The supplemental tests for absorbed moisture (see Clause 17) and for diffusible hydrogen (see Clause 18) are not required for classification of electrodes (see Note h of Table 2).

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Specimens for retest may be taken from the original test assembly or sample or from a new test assembly or sample. For chemical analysis, retest need be only for those specific elements that failed to meet the test requirement. If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that, during preparation or after completion of any test, it is clearly determined that specified or proper procedures were not followed in preparing the weld test assembly or in conducting the test, the test shall be considered invalid, without regard to whether the test was actually completed, or whether test results met, or failed to meet, the requirement. That test shall be repeated, following proper prescribed procedures. In this case, the requirement for doubling the number of test specimens does not apply.

9. Weld Test Assemblies

9.1 One or more of the following weld test assemblies are required for classification testing. They are:

- (1) The weld pad in Figure 2 for chemical analysis of the weld metal.
- (2) The groove weld in Figure 3 for mechanical properties and soundness of the weld metal for all classifications except E6022 [E4322] and E7018M [E4918M].
- (3) The fillet weld in Figure 4 for the usability of the electrode.
- (4) The groove weld in Figure 6 for transverse tensile and longitudinal bend tests for welds made with the E6022 [E4322] single pass electrode.
- (5) The groove weld in Figure 5 *to be used in place of (2) above*, for mechanical properties and soundness of the weld metal for E7018M [E4918M] electrodes.

The sample for chemical analysis may be taken from the reduced section of the fractured tension test specimen or from a corresponding location (or any location above it) along the weld centerline of the weld metal in the groove weld in Figure 3 or Figure 5, thereby avoiding the need to make the weld pad. In case of dispute, the weld pad shall be the referee method.

9.2 Preparation of each weld test assembly shall be as specified in 9.3 through 9.5. The base metal for each assembly shall be as required in Table 7 and shall meet the requirements of the ASTM specification shown there or a chemically equivalent specification. Electrodes other than low-hydrogen electrodes shall be tested without conditioning. Low-hydrogen electrodes, if they have not been adequately protected against moisture pickup in storage, shall be held at a temperature within the range 500 °F to 800 °F [260 °C to 430 °C] for a minimum of one hour prior to testing. Testing of assemblies shall be as prescribed in Clauses 10 through 15.

9.3 Weld Pad. A weld pad shall be prepared as specified in Figure 2, except when one of the alternatives in 9.1 (taking the sample from the broken tension test specimen or from a corresponding location or any location above it along the weld centerline in the weld metal of the groove weld in Figure 3 or Figure 5) is selected. Base metal of any convenient size, of the type specified in Table 7 shall be used as the base for the weld pad. The surface of the base metal on which the filler metal is to be deposited shall be clean. The pad shall be welded in the flat position with multiple layers, to obtain undiluted weld metal.

The preheat temperature shall not be less than 60 °F [15 °C] and the interpass temperature shall not exceed 300 °F [150 °C]. The slag shall be removed after each pass. The pad may be quenched in water between passes, *but must be dry before the start of the next pass*. The dimensions of the completed pad shall be as shown in Figure 2. Testing of this assembly shall be as specified in Clause 10, Chemical Analysis.

9.4 Groove Weld

9.4.1 Mechanical Properties and Soundness. A test assembly shall be prepared and welded as specified in Figure 3 or Figure 5, using base metal of the appropriate type specified in Table 7. *Welding shall use each type of current and position as specified in Table 2.*

Prior to welding, the assembly may be preset to yield a welded joint sufficiently flat to facilitate removal of the test specimens. As an alternative, restraint or a combination of restraint and presetting may be used to keep the welded joint within 5 degrees of plane. A completed welded test assembly that is more than 5 degrees out of plane shall be discarded. Straightening of the test assembly is prohibited.

Preheat and interpass temperatures shall be as specified in Figure 3 or 5. Testing of this assembly shall be as specified in Clauses 11, 12, and 14. The assembly shall be tested in the as-welded condition.

9.4.2 Transverse Tension and Longitudinal Bend Tests. A test assembly shall be prepared and welded as specified in Figure 6 using base metal of the appropriate type specified in Table 7. Testing of this assembly shall be as specified in 12.5 and Clause 13. The assembly shall be tested in the as-welded condition.

9.5 Fillet Weld. *One or more* test assemblies shall be prepared and welded as specified in Table 8 and shown in Figure 4 using base metal of the appropriate type as specified in Table 7. The welding positions shall be as specified in Table 8 and Figure 7, according to the size and classification of the electrode. Testing of the assembly shall be as specified in AWS A4.5M/A4.5.

10. Chemical Analysis

10.1 The sample for analysis shall be taken from weld metal produced with the electrode. The sample shall be taken from a weld pad or the reduced section of the fractured tension test specimen (Figure 3 or 5) or from a corresponding location *or any location along the weld centerline above it of the groove weld* in Figure 3 or 5. Areas where arc starts or craters exist shall be avoided.

The top surface of the pad described in 9.3 and shown in Figure 2 shall be removed and discarded and a sample for analysis shall be obtained from the underlying metal of this same top layer by any means *that will not affect the chemical composition*. The sample shall be free of slag and shall be taken from metal that is at least 1/4 in [6 mm] from the original base metal surface *as specified in Figure 2*.

The sample from the reduced section of the fractured tension test specimen or from a corresponding location (or any location along the weld centerline above it) in the groove weld in Figure 3 or 5 shall be prepared for analysis by any suitable means *that will not affect the chemical composition*.

10.2 The sample shall be analyzed by accepted analytical methods. The referee method shall be ASTM E350.

10.3 The results of the analysis shall meet the requirements of Table 6 for the classification of electrode under test.

11. Radiographic Test

11.1 When required in Table 2, the groove weld described in 9.4.1 and shown in Figure 3 or 5 shall be radiographed to evaluate the soundness of the weld metal. In preparation for radiography, the backing shall be removed and both surfaces of the weld shall be machined or ground smooth and flush with the original surfaces of the base metal or with a reasonably uniform reinforcement not exceeding 3/32 in [2.5 mm].

It is permitted on both sides of the test assembly, to remove base metal to a depth of 1/16 in [1.5 mm] below the original base metal surface, in order to facilitate backing and/or buildup removal. The thickness of the weld metal shall not be reduced by more than 1/16 in [1.5 mm] so that the thickness of the prepared radiographic test specimen equals at least the thickness of the base metal minus 1/16 in [1.5 mm]. Both surfaces of the test assembly in the area of the weld shall be smooth enough to avoid difficulty in interpreting the radiograph.

11.2 The weld shall be radiographed in accordance with one of the following. The quality level of inspection shall be 2-2T.

(1) *Film Radiology: ASTM E1032.*

(2) *Computed Radiology (CR): ASTM E2033 and the requirements of ASTM E1032, except where CR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2033, refers to phosphor imaging plate.*

(3) *Digital Radiology (DR): ASTM E2698 and the requirements of ASTM E1032, except where DR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2698, refers to digital detector array (DDA).*

11.3 The soundness of the weld metal meets the requirements of this specification if the radiograph shows:

(1) no cracks, no incomplete fusion, and no incomplete penetration, and

(2) no slag inclusions longer than 1/4 in [6 mm] or 1/3 of the thickness of the weld, whichever is greater, or no groups of slag inclusions in line that have an aggregate length greater than the thickness of the weld in a length 12 times the thickness of the weld except when the distance between the successive inclusions exceeds six times the length of the longest inclusion in the group, and

(3) no rounded indications in excess of those permitted by the radiographic standards in Figure 8A (Grade 1), Figure 8B (Grade 2), or Figure 8C (Grade 3), according to the grade specified in Table 3.

In evaluating the radiograph, one inch [25 mm] of the weld on each end of the test assembly shall be disregarded.

11.4 A rounded indication is an indication on the radiograph whose length is no more than three times its width. Rounded indications may be circular or irregular in shape, and may have tails. The size of a rounded indication is the largest dimension of the indication, including any tail that may be present.

The indication may be of porosity or slag. Indications whose largest dimension does not exceed 1/64 in [0.4 mm] shall be disregarded. Test assemblies with indications larger than the large indications permitted in the radiographic standards do not meet the requirements of this specification.

12. Tension Test

12.1 For all electrodes except E6022 [E4322], one all-weld-metal tension test specimen as specified in the Tension Test clause of AWS B4.0 shall be machined from the groove weld described in Clause 9 and shown in Figure 3 or 5. For specimens machined from 3/4 in [20 mm] or thicker weld assemblies, the all-weld-metal tension test specimen shall have a nominal diameter of 0.500 in [12.5 mm]. *For specimens machined from 1/2 in [12.5 mm] thick weld assemblies, the all-weld-metal tension test specimen shall have a nominal diameter of 0.250 in [6.5 mm]. The nominal gauge length-to-diameter ratio shall be 4:1 in each case.*

12.2 After machining, but before testing, the specimen for all electrodes except the low hydrogen classifications may be aged at a temperature not to exceed 220 °F [105 °C] for up to 48 hours, then allowed to cool to room temperature. Refer to Annex A, A6.3 for a discussion on the purpose of aging. *In case of dispute, aging the tensile specimen shall be the referee method. No aging shall be performed prior to radiographic examination. The purchaser may, by mutual agreement with the supplier, have the thermal aging of specimens prohibited for all mechanical testing done to Schedule I or J of AWS A5.01M/A5.01.*

12.3 The tension test specimens shall be tested in the manner described in the Tension Test clause of AWS B4.0.

12.4 The results of the tension test shall meet the requirements specified in Table 4.

12.5 For E6022 [E4322], one transverse rectangular tension test specimen as specified in the Tension Test clause of AWS B4.0, shall be machined from the test assembly described in 9.4.2 and shown in Figure 6. The transverse rectangular tensile specimen shall be a full-thickness specimen machined transverse to the weld with a nominal reduced section width of 1.50 in [38 mm].

13. Bend Test

13.1 One longitudinal face bend specimen, as required in Table 2, shall be machined from the groove weld test assembly described in 9.4.2 and shown in Figure 6. The nominal length of the specimen shall be 6 in [150 mm], the nominal width of the specimen shall be 1.50 in [38 mm], and the nominal thickness shall be 0.25 in [6mm]. Other dimensions shall be as specified in the Bend Test clause of AWS B4.0.

13.2 After machining, but before testing, the specimen may be aged at a temperature not to exceed 220 °F [105 °C] for up to 48 hours, then allowed to cool to room temperature. Refer to Annex A, A6.3 for a discussion on the purpose of aging.

13.3 The specimen shall be tested in the manner described in the Bend Test clause of AWS B4.0, by bending it uniformly through 180° over a 3/4 in [19 mm] radius in any suitable jig, as specified in AWS B4.0. Positioning of the face bend specimen shall be such that the weld face of the last side welded shall be in tension.

13.4 Each specimen, after bending, shall conform to the 3/4 in [19 mm] radius, with an appropriate allowance for spring-back, and the weld metal shall not contain openings in excess of 1/8 in [3 mm] on the convex surface.

14. Impact Test

14.1 Five full-size Charpy V-notch impact test specimens shall be machined from the test assembly shown in Figure 3 or 5, for those classifications for which impact testing is required in Table 2. The Charpy V-notch specimens shall have the notched and struck surfaces parallel with each other within 0.002 in [0.05 mm]. The other two surfaces of the specimen

shall be square with the notched or struck surfaces within 10 minutes of a degree. The notch shall be smoothly machined and shall be square with the longitudinal edge of the specimen within one degree.

The geometry of the notch shall be measured on at least one specimen in a set of five specimens. Measurement shall be done at a minimum 10X magnification. The correct location of the notch shall be verified by etching before or after machining.

14.2 The five specimens shall be tested in accordance with the Fracture Toughness Test clause of AWS B4.0. The test temperature shall be at or below the temperature specified in Table 5, for the classification under test. The actual temperature used shall be listed on the certification documentation when issued.

14.3 In evaluating the results for all except E7018M [E4918M], the lowest and the highest values obtained shall be disregarded. Two of the remaining three values shall equal or exceed the specified 20 ft-lbf [27 J] energy level. One of the three may be lower, but not lower than the single value indicated in Table 5, and the average of the three shall be not less than the required average energy level.

14.4 In evaluating the results for E7018M [E4918M], all five impact values shall be included. At least four of the five shall equal, or exceed, the specified 50 ft-lbf [67 J] energy level. One of the five may be lower than that, but not lower than 40 ft-lbf [54 J]. The average of the five results shall be not less than the required 50 ft-lbf [67 J] energy level.

15. Fillet Weld Test

15.1 The fillet weld test assembly, when required in Table 2, shall be made in accordance with the requirements of 9.5, and Figure 4 and AWS A4.5M/A4.5. There shall be no indication of cracks and the weld shall be reasonably free of undercut, overlap, trapped slag, and surface porosity. After the visual examination, the fillet weld size, leg lengths and convexity shall be measured using the methods of AWS A4.5M/A4.5. Fillet weld measurements shall meet the requirements of Table 8, and Table 9 for convexity and permissible difference in the length of the legs.

15.2 A minimum of 10 in [250 mm] of the test assembly shall be broken longitudinally through the fillet weld by a force exerted as shown in AWS A4.5M/A4.5. Cutting of the test assembly into two or more lengths before fracture is permitted, but a sufficient number of segments shall be fractured such that a minimum of 10 in [250 mm] is examined. When necessary, to facilitate fracture through the fillet, one or more of the procedures listed in AWS A4.5M/A4.5 may be used.

Tests in which the weld metal pulls out of the base metal during bending are invalid. Specimens in which this occurs shall be replaced, specimen for specimen, and the test completed. In this case, the doubling of the specimens required for retest in Clause 8 does not apply.

15.3 The fractured surfaces shall be examined. They shall be free of cracks and shall be reasonably free of porosity and trapped slag. Incomplete fusion at the root of the weld shall not exceed 20% of the total length of the weld. Slag beyond the root of the joint shall not be considered incomplete fusion. There shall be no continuous length of incomplete fusion greater than one inch [25 mm] as measured along the weld axis, except for electrodes of E6012 [E4312], E6013 [E4313], and E7014 [E4914] classifications. Fillet welds made with electrodes of these classifications may exhibit incomplete fusion at the root through the entire weld length. They may also exhibit incomplete fusion at the weld face, which shall at no point exceed 25% of the smaller leg of the fillet weld.

16. Moisture Test

16.1 The moisture content of the covering of the electrode, when required in Table 2, shall be determined by any suitable method. In case of dispute, the method described in AWS A4.4M shall be the referee method.

16.2 The electrodes shall be tested without conditioning, unless the manufacturer recommends otherwise. Conditioning can be considered to be any special preparation or procedure, such as baking the electrode. If the electrodes are conditioned, that fact, along with the method used for conditioning and the time and temperature involved in the conditioning, shall be noted on the Certificate of Conformance. The moisture content shall not exceed the limit specified in Table 10, for the classification under test.

17. Absorbed Moisture Test

17.1 In order for a low-hydrogen electrode to be designated as low-moisture-absorbing, with the optional supplemental “R” suffix designator, or classified as E7018M [E4918M], sufficient electrodes shall be exposed to an environment of 80 °F [27 °C] and 80 percent relative humidity (RH) for a period of not less than nine hours by any suitable method. In case of dispute, the exposure method described in 17.2 through 17.6 shall be the referee method.

The moisture content of the electrode covering on the low-moisture-absorbing, low-hydrogen electrodes (for example, E7015R [E4915R], E7016R [E4916R], E7016-1R [E4916-1R], E7018R [E4918R], E7018-1R [E4918-1R], E7018M [E4918M], E7028R [E4928R], E7048R [E4948R]) shall be determined by any suitable method. In case of dispute, the method described in AWS Specification A4.4M shall be the referee method. The moisture content of the exposed covering shall not exceed the maximum specified moisture content for the designated electrode and classification in Table 10.

17.2 An electrode sample of each size of E7018M [E4918M] or the smallest and the largest sizes of “R” designated electrode shall be exposed. If the electrodes are conditioned prior to exposure, that fact, along with the method used for conditioning, and the time and temperature involved in conditioning, shall be noted on the certificate of conformance. Conditioning of electrodes after exposure is not permitted.

17.3 The electrode sample shall be exposed in a suitably calibrated and controlled environmental chamber for a minimum of nine hours at 80 °F to 85 °F, [27 °C to 30 °C] and 80% to 85% relative humidity.

17.4 The environmental chamber shall meet the following design requirements:

- (1) The apparatus shall be an insulated humidifier which produces the temperature of adiabatic saturation through regenerative evaporation or vaporization of water.
- (2) The apparatus shall have an average air speed of 100 fpm to 325 fpm [0.5 m/s to 1.7 m/s] within the envelope of air surrounding the covered electrode.
- (3) The apparatus shall have a drip-free area where the covered electrode up to 18 in [450 mm] in length can be positioned with length as perpendicular as practical to the general air flow.
- (4) The apparatus shall have a calibrated means of continuously measuring and recording the dry bulb temperature and either the wet bulb temperature or the differential between the dry bulb and wet bulb temperature over the period of time required.
- (5) The apparatus shall have an air speed of at least 900 fpm [4.5 m/s] over the wet bulb sensor unless the wet bulb sensor can be shown to be insensitive to air speed or has a known correction factor that will provide for an adjusted wet bulb reading equal to the temperature of adiabatic saturation.
- (6) The apparatus shall have the wet bulb sensor located on the suction side of the fan so that there is an absence of heat radiation on the sensor.

17.5 The exposure procedure shall be as follows:

- (1) The electrode sample, in previously unopened packages or from a reconditioned lot shall be brought to a temperature, -0°F , $+10^{\circ}\text{F}$ [-0°C , $+6^{\circ}\text{C}$] above the dew point of the chamber at the time of loading.
- (2) The electrode sample shall be loaded into the chamber without delay after the packages are opened. *Or, in the case of a reconditioned lot, the sample shall be loaded without delay once conditioning is complete and the sample reaches the temperature prescribed in 17.5 (1).*
- (3) The electrodes shall be placed in the chamber in a vertical or horizontal position on 1 in [25 mm] centers, with the length of the electrode as perpendicular as practical to the general air flow.
- (4) Time, temperature, and humidity shall be continuously recorded for the period that the electrodes are in the chamber.
- (5) Counting of the exposure time shall start when the required temperature and humidity in the chamber are established.
- (6) At the end of the exposure time, the electrodes shall be removed from the chamber and a sample of the electrode covering taken for moisture determination, as specified in Clause 16, Moisture Test.

17.6 The manufacturer shall control other test variables *which are not defined, but which must be controlled* to ensure a greater consistency of results.

18. Diffusible Hydrogen Test

18.1 The smallest and largest sizes of an electrode to be identified by an optional supplemental diffusible hydrogen designator and all sizes of E7018M [E4918M], shall be tested according to one of the methods given in AWS A4.3. Based upon the average value of test results that satisfy the requirements of Table 11, the appropriate diffusible hydrogen designator may be added at the end of the classification.

18.2 Testing shall be done without conditioning of the electrode, unless the manufacturer recommends otherwise. *Conditioning can be considered to be any special preparation or procedure, such as baking the electrode.* If the electrodes are conditioned, that fact, along with the method used for conditioning, and the time and temperature involved in the conditioning shall be noted on the *Certificate of Conformance*.

18.3 For purposes of certifying compliance with diffusible hydrogen requirements, the reference atmospheric condition shall be an absolute humidity of ten (10) grains of moisture/lb [1.43 g/kg] of dry air at the time of welding. See A8.1.4 in Annex A. The actual atmospheric conditions shall be reported along with the average value for the tests, according to AWS A4.3.

18.4 When the absolute humidity equals or exceeds the reference condition at the time of preparation of the test assemblies, the test shall be acceptable as demonstrating compliance with the requirements of this specification provided the actual test results satisfy the diffusible hydrogen requirements for the applicable designator. If the actual test results for an electrode meet the requirements for the lower or lowest hydrogen designator, as specified in Table 11, the electrode also meets the requirements for all higher hydrogen designators in Table 11 without need to retest.

19. Method of Manufacture

The electrodes classified according to this specification may be manufactured by any method that will produce electrodes that meet the requirements of this specification.

20. Standard Sizes and Lengths

Standard sizes (diameter of the core wire) and lengths of electrodes *and their respective tolerances are as specified in AWS A5.02/A5.02M.*

21. Core Wire and Covering

Requirements for the core wire and covering, including concentricity requirements, are as specified in AWS A5.02/A5.02M.

22. Exposed Core

22.1 *Requirements for the grip end of each electrode are as specified in AWS A5.02/A5.02M.*

22.2 *Requirements for the arc end of each electrode are as specified in AWS A5.02/A5.02M.*

23. Electrode Identification

23.1 *All electrodes shall be identified (imprinted) as specified in AWS A5.02/A5.02M.*

23.2 *In lieu of imprinting, electrodes may be identified by the alternate methods specified in AWS A5.02/A5.02M.*

23.3 *In the case of electrodes that have two classifications, in accordance with 3.2 or 3.3, whether the method of identification in 23.1 or 23.2 is chosen, it is at the manufacturer's discretion to identify electrodes with either of the classifications or both of the classifications. Purchaser can specify a preference for identification using AWS A5.01M/A5.01.*

24. Packaging

Electrodes shall be packaged *as specified in AWS A5.02/A5.02M*. E7018M [E4918M] electrodes shall be packaged in hermetically sealed containers. These containers shall be capable of passing the test specified in AWS A5.02/A5.02M *for hermetically sealed containers*.

25. Marking of Packages

25.1 The product information *specified in AWS A5.02/A5.02M (as a minimum)* shall be legibly marked on the outside of each unit package.

25.2 The appropriate precautionary information as given in ANSI Z49.1 (as a minimum) or its equivalent shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages enclosed within a larger package. Typical examples of "warning labels" and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

Table 1
Electrode Classification

AWS Classification		Type of Covering	Type of Current ^a	Welding Position Capability ^b
A5.1	[A5.1M]			
E6010	[E4310]	High cellulose sodium	DCEP	F, V ^c , OH ^c , H
E6011	[E4311]	High cellulose potassium	AC, DCEP	F, V ^c , OH ^c , H
E6012	[E4312]	High titania sodium	AC, DCEN	F, V ^c , OH ^c , H
E6013	[E4313]	High titania potassium	AC, DCEP, DCEN	F, V ^c , OH ^c , H
E6018 ^e	[E4318 ^e]	Low-hydrogen potassium, iron powder	AC, DCEP	F, V ^d , OH ^d , H
E6019	[E4319]	Iron oxide titania potassium	AC, DCEP, DCEN	F, V ^c , OH ^c , H
E6020	[E4320]	High iron oxide	AC, DCEN	H-fillet
			AC, DCEP, DCEN	F
E6022 ^f	[E4322 ^f]	High iron oxide	AC, DCEN	F, H-fillet
E6027	[E4327]	High iron oxide, iron powder	AC, DCEN	H-fillet
			AC, DCEP, DCEN	F
E7014	[E4914]	Iron powder, titania	AC, DCEP, DCEN	F, V ^d , OH ^d , H
E7015	[E4915]	Low-hydrogen sodium	DCEP	F, V ^d , OH ^d , H
E7016 ^e	[E4916 ^e]	Low-hydrogen potassium	AC, DCEP	F, V ^d , OH ^d , H
E7018 ^e	[E4918 ^e]	Low-hydrogen potassium, iron powder	AC, DCEP	F, V ^d , OH ^d , H
E7018M	[E4918M]	Low-hydrogen iron powder	DCEP	F, V ^d , OH ^d , H
E7024 ^e	[E4924 ^e]	Iron powder, titania	AC, DCEP, DCEN	H-fillet, F
E7027	[E4927]	High iron oxide, iron powder	AC, DCEN	H-fillet
			AC, DCEP, DCEN	F
E7028 ^e	[E4928 ^e]	Low-hydrogen, potassium, iron powder	AC, DCEP	H-fillet, F
E7048	[E4948]	Low-hydrogen, potassium, iron powder	AC, DCEP	F, OH, H, V-down ^d
E60-G	[E43-G]	As agreed between purchaser and supplier		
E70-G	[E49-G]	As agreed between purchaser and supplier		

^a The term “DCEP” refers to direct current electrode positive (dc, reverse polarity). The term “DCEN” refers to direct current electrode negative (dc, straight polarity). The term “AC” indicates alternating current.

^b The abbreviations “F, H, H-fillet, V, V-down, and OH” indicate the welding positions as follows: F = Flat, H = Horizontal, H-fillet = Horizontal fillet, V = vertical, progression upwards, V-down = Vertical, progression downwards, OH = Overhead.

^c For electrodes 3/16 in [5.0 mm] and under.

^d For electrodes 5/32 in [4.0 mm] and under.

^e Electrodes with supplemental elongation, notch toughness, absorbed moisture, and diffusible hydrogen requirements may be further identified as shown in Tables 4, 5, 10, and 11.

^f Electrodes of the E6022 [E4322] classification are intended for single-pass welds only.

Table 2
Required Tests^a

AWS Classification A5.1 [A5.1M]	Current and Polarity ^{b,c}	Electrode Size in [mm]	All-Weld Metal Tests				Fillet Weld Test	Electrode Covering Moisture Test I
			Chemical Analysis ^d	Radio-graphic Test ^d	Tension Test ^d	Impact Test ^d		
E6010 [E4310]	DCEP	3/32, 1/8 [2.4, 2.5, 3.2]	NR	NR	NR	NR	NR	NR
		5/32, 3/16 [4.0, 4.8, 5.0]	R	R	R	R	V & OH	NR
		7/32 [5.6]	NR	NR	NR	NR	NR	NR
		1/4 [6.0, 6.4]	R	R	R	R	H-fillet	NR
		5/16 [8.0]	NR	R	R	NR	NR	NR
E6011 [E4311]	AC and DCEP	3/32, 1/8 [2.4, 2.5, 3.2]	NR	NR	NR	NR	NR	NR
		5/32, 3/16 [4.0, 4.8, 5.0]	R	R	R	R	V & OH	NR
		7/32 [5.6]	NR	NR	NR	NR	NR	NR
		1/4 [6.0, 6.4]	R	R	R	R	H-fillet	NR
		5/16 [8.0]	NR	R	R	NR	NR	NR
E6012 [E4312]	AC and DCEN	1/16 to 1/8 [1.6 to 3.2] inc.	NR	NR	NR	NR	NR	NR
		5/32, 3/16 [4.0, 4.8, 5.0]	R	NR	R	NR	V & OH	NR
		7/32 [5.6]	NR	NR	NR	NR	NR	NR
		1/4, 5/16 [6.0, 6.4, 8.0]	R	NR	R	NR	H-fillet	NR
E6013 [E4313]	AC, DCEP, and DCEN	1/16 to 1/8 [1.6 to 3.2] inc.	NR	NR	NR	NR	NR	NR
		5/32, 3/16 [4.0, 4.8, 5.0]	R	R	R	NR	V & OH	NR
		7/32 [5.6]	NR	NR	NR	NR	NR	NR
		1/4, 5/16 [6.0, 6.4, 8.0]	R	R	R	NR	H-fillet	NR
E6018 [E4318]	AC and DCEP	3/32, 1/8 [2.4, 2.5, 3.2]	NR	NR	NR	NR	NR	NR
		5/32 [4.0]	R	R	R	R	V & OH	R
		3/16 [4.8, 5.0]	NR	R	R	R	H-fillet	NR
		7/32 [5.6]	NR	NR	NR	NR	NR	NR
		1/4 [6.0, 6.4]	R	R	R	R	H-fillet	R
		5/16 [8.0]	NR	R	R	NR	NR	NR
E6019 [E4319]	AC, DCEP, and DCEN	5/64 to 1/8 [2.0 to 3.2] inc.	NR	NR	NR	NR	NR	NR
		5/32, 3/16 [4.0, 4.8, 5.0]	R ^g	R ^g	R ^g	R ^g	V & OH	NR
		7/32 [5.6]	NR	NR	NR	NR	NR	NR
		1/4, 5/16 [6.0, 6.4, 8.0]	R ^g	R ^g	R ^g	R ^g	H-fillet	NR
E6020 [E4320]	AC, DCEP, and DCEN	1/8 [3.2]	NR	NR	NR	NR	NR	NR
		5/32, 3/16 [4.0, 4.8, 5.0]	R	R	R	NR	H-fillet	NR
		7/32 [5.6]	NR	NR	NR	NR	NR	NR
		1/4 [6.0, 6.4]	R	R	R	NR	H-fillet	NR
		5/16 [8.0]	NR	R	R	NR	NR	NR

(Continued)

Table 2 (Continued)
Required Tests^a

AWS Classification A5.1 [A5.1M]	Current and Polarity ^{b,c}	Electrode Size in [mm]	All-Weld Metal Tests				Fillet Weld Test	Electrode Covering Moisture Test I
			Chemical Analysis ^d	Radio-graphic Test ^d	Tension Test ^d	Impact Test ^d		
E6022 [E4322]	AC and DCEN	1/8 [3.2]	NR	NR	R ^f	NR	NR	NR
		5/32 to 7/32 [4.0 to 5.6] inc.	NR	NR	R ^f	NR	NR	NR
E6027 [E4327]	AC, DCEP, and DCEN	1/8 [3.2]	NR	NR	NR	NR	NR	NR
		5/32, 3/16 [4.0, 4.8, 5.0]	R ^g	R ^g	R ^g	R ^g	H-fillet	NR
		7/32 [5.6]	NR	NR	NR	NR	NR	NR
		1/4 [6.0, 6.4]	R ^g	R ^g	R ^g	R ^g	H-fillet	NR
		5/16 [8.0]	NR	R ^g	R ^g	NR	NR	NR
E7014 [E4914]	AC, DCEP, and DCEN	3/32, 1/8 [2.4, 2.5, 3.2]	NR	NR	NR	NR	NR	NR
		5/32 [4.0]	R	R	R	NR	V & OH	NR
		3/16 [4.8, 5.0]	NR	R	R	NR	H-fillet	NR
		7/32 [5.6]	NR	NR	NR	NR	NR	NR
		1/4 [6.0, 6.4]	R	R	R	NR	H-fillet	NR
		5/16 [8.0]	NR	R	R	NR	H-fillet	NR
E7015 [E4915]	DCEP	3/32, 1/8 [2.4, 2.5, 3.2]	NR	NR	NR	NR	NR	NR
		5/32 [4.0]	R	R	R	R	V & OH	R
		3/16 [4.8, 5.0]	NR	R	R	R	H-fillet	NR
		7/32 [5.6]	NR	NR	NR	NR	NR	NR
		1/4 [6.0, 6.4]	R	R	R	R	H-fillet	R
		5/16 [8.0]	NR	R	R	NR	NR	NR
E7016 [E4916]	AC and DCEP	3/32, 1/8 [2.4, 2.5, 3.2]	NR	NR	NR	NR	NR	NR
		5/32 [4.0]	R	R	R	R	V & OH	R
		3/16 [4.8, 5.0]	NR	R	R	R	H-fillet	NR
		7/32 [5.6]	NR	NR	NR	NR	NR	NR
		1/4 [6.0, 6.4]	R	R	R	R	H-fillet	R
		5/16 [8.0]	NR	R	R	NR	NR	NR
E7018 [E4918]	AC and DCEP	3/32, 1/8 [2.4, 2.5, 3.2]	NR	NR	NR	NR	NR	NR
		5/32 [4.0]	R	R	R	R	V & OH	R
		3/16 [4.8, 5.0]	NR	R	R	R	H-fillet	NR
		7/32 [5.6]	NR	NR	NR	NR	NR	NR
		1/4 [6.0, 6.4]	R	R	R	R	H-fillet	R
		5/16 [8.0]	NR	R	R	NR	NR	NR
E7018M [E4918M]	AC and DCEP	3/32 to 5/32 [2.4 to 4.0] inc.	R	R (Vertical)	R (Vertical)	R (Vertical)	NR	R ^h
		3/16 to 5/16 [4.8 to 8.0] inc.	R	R	R	R	NR	R ^h

(Continued)

Table 2 (Continued)
Required Tests^a

AWS Classification A5.1 [A5.1M]	Current and Polarity ^{b, c}	Electrode Size in [mm]	All-Weld Metal Tests				Fillet Weld Test	Electrode Covering Moisture Test I
			Chemical Analysis ^d	Radio- graphic Test ^d	Tension Test ^d	Impact Test ^d		
E7024 [E4924]	AC, DCEP, and DCEN	3/32, 1/8 [2.4, 2.5, 3.2]	NR	NR	NR	NR	NR	NR
		5/32 [4.0]	R	R	R	R ^{g, i}	H-fillet	NR
		3/16 [4.8, 5.0]	NR	R	R	R ^{g, i}	H-fillet	NR
		7/32 [5.6]	NR	NR	NR	NR	NR	NR
		1/4 [6.0, 6.4]	R	R	R	R ^{g, i}	H-fillet	NR
		5/16 [8.0]	NR	R	R	NR	NR	NR
E7027 [E4927]	For H-fillet, AC and DCEN For flat position, AC, DCEP, and DCEN	1/8 [3.2]	NR	NR	NR	NR	NR	NR
		5/32 [4.0]	R	R	R ^g	R	H-fillet	NR
		3/16 [4.8, 5.0]	NR	R	R ^g	R ^g	H-fillet	NR
		7/32 [5.6]	NR	NR	NR	NR	NR	NR
		1/4 [6.0, 6.4]	R	R	R ^g	R ^g	H-fillet	NR
		5/16 [8.0]	NR	R	R ^g	NR	NR	NR
E7028 [E4928]	AC and DCEP	1/8 [3.2]	NR	NR	NR	NR	NR	NR
		5/32 [4.0]	R	R	R ^g	R	H-fillet	R
		3/16 [4.8, 5.0]	NR	R	R ^g	R	H-fillet	NR
		7/32 [5.6]	NR	NR	NR	NR	NR	NR
		1/4 [6.0, 6.4]	R	R	R ^g	R	H-fillet	R
		5/16 [8.0]	NR	R	R ^g	NR	NR	NR
E7048 [E4948]	AC and DCEP	1/8 [3.2]	NR	NR	NR	NR	NR	NR
		5/32 [4.0]	R	R	R	R	V-down & OH	R
		3/16 [4.8, 5.0]	NR	R	R	R	V-down & H-fillet	NR
E60-G [E43-G]	As agreed upon between Purchaser and Supplier		R	NR	R	NR	NR	NR
E70-G [E49-G]	As agreed upon between Purchaser and Supplier		R	NR	R	NR	NR	NR

^a “R” indicates that the test is required. “NR” indicates that the test is not required.

^b The term “DCEP” refers to direct current electrode positive (dc, reverse polarity). The term “DCEN” refers to direct current electrode negative (dc, straight polarity). The term “AC” refers to alternating current.

^c When DCEP and DCEN are shown, only DCEN need be tested.

^d See Clause 10, 11, 12, or 14, as applicable.

^e The moisture test given in Clause 16 is the required test for moisture content of the covering. Optional, supplemental tests for absorbed moisture and diffusible hydrogen are included in Clauses 17 and 18.

^f An all-weld-metal tension test is not required for E6022 [E4322] electrodes. Instead, a transverse tension test (see 12.5) and a longitudinal guided bend test (see Clause 13) are required for classification of 5/32 in, 3/16 in, and 7/32 in [4.0 mm, 5.0 mm, and 6.0 mm] E6022 [E4322] electrodes.

^g Electrodes longer than 18 in [450 mm] will require a double length test assembly in accordance with Note 1 of Figure 3 to ensure uniformity of the entire electrode.

^h The Absorbed Moisture Test (Clause 17) and Diffusible Hydrogen Test (Clause 18) are required for all sizes of E7018M [E4918M].

ⁱ Electrodes identified as E7024-1 [E4924-1] shall be impact tested (see Table 5).

Table 3
Radiographic Soundness Requirements

AWS Classification A5.1 [A5.1M]	Radiographic Standard^{a, b}
E6018 [E4318], E6019 [E4319], E6020 [E4320], E7015 [E4915], E7016 [E4916], E7018 [E4918], E7018M [E4918M], and E7048 [E4948]	Grade 1
E6010 [E4310], E6011 [E4311], E6013 [E4313], E6027 [E4327], E7014 [E4914], E7027 [E4927], and E7028 [E4928]	Grade 2
E7024 [E4924]	Grade 3
E6012 [E4312] and E6022 [E4322]	Not Specified
E60-G [E43-G] and E70-G [E49-G]	Not Specified

^a See Figure 8.

^b The radiographic soundness obtainable under industrial conditions employed for various electrode classifications is discussed in A6.10.1 in Annex A.

Table 4
Tension Test Requirements^{a, b}

AWS Classification A5.1 [A5.1M]	Tensile Strength (minimum) ksi [MPa]	Yield Strength^c (minimum) ksi [MPa]	Percent Elongation^d (minimum)
E6010 [E4310]	60 [430]	48 [330]	22
E6011 [E4311]	60 [430]	48 [330]	22
E6012 [E4312]	60 [430]	48 [330]	22
E6013 [E4313]	60 [430]	48 [330]	22
E6018 [E4318]	60 [430]	48 [330]	22
E6019 [E4319]	60 [430]	48 [330]	22
E6020 [E4320]	60 [430]	48 [330]	22
E6022 [E4322] ^e	60 [430]	Not Specified	Not Specified
E6027 [E4327]	60 [430]	48 [330]	22
E60-G [E43-G]	60 [430]	48 [330]	17
E7014 [E4914]	70 [490]	58 [400]	17
E7015 [E4915]	70 [490]	58 [400]	22
E7016 [E4916]	70 [490]	58 [400]	22
E7018 [E4918]	70 [490]	58 [400]	22
E7018M [E4918M]	(g)	53–72 [370–500] ^h	24
E7024 [E4924]	70 [490]	58 [400]	17 ^f
E7027 [E4927]	70 [490]	58 [400]	22
E7028 [E4928]	70 [490]	58 [400]	22
E7048 [E4948]	70 [490]	58 [400]	22
E70-G [E49-G]	70 [490]	58 [400]	17

^a See Table 2 for sizes to be tested.

^b Requirements are to be in the as-welded condition with aging as specified in 12.2.

^c Yield strength at 0.2% offset.

^d Elongation percentage in 4x diameter length.

^e A transverse tensile test, as specified in 12.5 and a longitudinal guided bend test, as specified in Clause 13 are required.

^f Weld metal from electrodes identified as E7024-1 [E4924-1] shall have elongation of 22% minimum.

^g Tensile strength of this weld metal is a nominal 70 ksi [490 MPa]

^h For 3/32 in [2.4 mm] electrodes, the maximum yield strength shall be 77 ksi [530 MPa].

Table 5
Charpy V-Notch Impact Requirements

AWS Classification A5.1 [A5.1M]	Classifications with Optional, Supplemental “-1” Impact Designator	Acceptance Criteria ^{a, b}	
		Average (minimum)	Single Value (minimum)
E6010 [E4310]	—	20 ft·lbf at –20 °F [27 J at –30 °C]	15 ft·lbf at –20 °F [20 J at –30 °C]
E6011 [E4311]	—		
E6018 [E4318]	—		
E6027 [E4327]	—		
E7015 [E4915]	—		
E7016 [E4916]	—		
E7018 [E4918]	—		
E7027 [E4927]	—		
E7048 [E4948]	—		
	E7016-1 [E4916-1]	20 ft·lbf at –50 °F [27 J at –45 °C]	15 ft·lbf at –50 °F [20 J at –45 °C]
	E7018-1 [E4918-1]		
E7018M [E4918M] ^b	—	50 ft·lbf at –20 °F ^b [67 J at –30 °C]	40 ft·lbf at –20 °F ^b [54 J at –30 °C]
E6019 [E4319]	—	20 ft·lbf at 0 °F [27 J at –20 °C]	15 ft·lbf at 0 °F [20 J at –20 °C]
E7028 [E4928]	—		
	E7024-1 [E4924-1]	Not Specified	Not Specified
E6012 [E4312]	—		
E6013 [E4313]	—		
E6020 [E4320]	—		
E6022 [E4322]	—		
E7014 [E4914]	—		
E7024 [E4924]	—		
E60-G [E43-G]		Not Specified	Not Specified
E70-G [E49-G]			

^a Both the highest and lowest test values obtained shall be disregarded in computing the average. Two of the remaining three values shall equal or exceed 20 ft·lbf [27 J].

^b For the E7018M classification all five values obtained shall be used in computing the average. Four of the five values shall equal or exceed 50 ft·lbf [67 J].

Table 6
Chemical Composition Requirements for Weld Metal

AWS Classification A5.1 [A5.1M]	UNS ^c Number	Weight Percent ^{a, b}										
		C	Mn	Si	P	S	Ni	Cr	Mo	V	Combined Limit for Mn + Ni + Cr + Mo + V	Other Specified Elements
E6010 [E4310]	W06010	0.20	1.20	1.00	N.S.	N.S.	0.30	0.20	0.30	0.08	N.S.	—
E6011 [E4311]	W06011											—
E6012 [E4312]	W06012											—
E6013 [E4313]	W06013											—
E6019 [E4319]	W06019											—
E6020 [E4320]	W06020											—
E6027 [E4327]	W06027											—
E6018 [E4318]	W06018	0.03	0.60	0.40	0.025	0.015	0.30	0.20	0.30	0.08	N.S.	—
E60-G [E43-G]		N.S.										
E7015 [E4915]	W07015	0.15	1.25	0.90	0.035	0.035	0.30	0.20	0.30	0.08	1.50	—
E7016 [E4916]	W07016	0.15	1.60	0.75	0.035	0.035	0.30	0.20	0.30	0.08	1.75	—
E7018 [E4918]	W07018	0.15	1.60	0.75	0.035	0.035	0.30	0.20	0.30	0.08	1.75	—
E7014 [E4914]	W07014	0.15	1.25	0.90	0.035	0.035	0.30	0.20	0.30	0.08	1.50	—
E7024 [E4924]	W07024	0.15	1.25	0.90	0.035	0.035	0.30	0.20	0.30	0.08	1.50	—
E7027 [E4927]	W07027	0.15	1.60	0.75	0.035	0.035	0.30	0.20	0.30	0.08	1.75	—
E7028 [E4928]	W07028	0.15	1.60	0.90	0.035	0.035	0.30	0.20	0.30	0.08	1.75	—
E7048 [E4948]	W07048	0.15	1.60	0.90	0.035	0.035	0.30	0.20	0.30	0.08	1.75	—
E7018M [E4918M]	W07018	0.12	0.40 to 1.60	0.80	0.030	0.020	0.25	0.15	0.35	0.05	N.S.	—
E70-G [E49-G]		N.S.										

^a The filler metal shall be analyzed for the specific elements for which values are shown in this table. In addition to that, analysis is required to be reported for boron (B) if intentionally added, or if it is known to be present at levels greater than 0.0010%. Additionally, if the presence of unspecified elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total (excluding iron) does not exceed 0.50%.

^b Single values are maximums. N.S. means not specified.

^c SAE/ASTM Unified Numbering System for Metals and Alloys.

Table 7
Base Metal for Weld Test Assemblies

AWS Classification	Type	ASTM Specification ^a	UNS Number ^b
All	Carbon Steel	A131 Grade B	K02102
		A285 Grade A	K01700
		A285 Grade B	K02200
All except E7018M [E4918M]	Carbon Steel	A285 Grade C	K02801
		A283 Grade D	K02702
		A36	K02600
		A29 Grade 1015	G10150
		A29 Grade 1020	G10200

^aEquivalent steel may be used.

^bSAE/ASTM Unified Numbering System for Metals and Alloys.

Table 8
Requirements for Preparation of Fillet Weld Test Assemblies

AWS Classification ^a		Electrode				Plate Size ^b				Position of Welding	Size of Fillet Weld	
		Size		Length		Thickness (T)		Length (L) min. ^c			in	mm
A5.1	A5.1M	in	mm	in	mm	in	mm	in	mm			
E6010 E6011	E4310 E4311	3/32	2.4, 2.5	12	300	1/8	3	10	250	V & OH	5/32 max.	4 max.
		1/8	3.2	14	350	3/16	5	12	300	V & OH	3/16 max.	5 max.
		5/32	4.0	14	350	3/8	10	12	300	V & OH	1/4 max.	6 max.
		3/16	4.8, 5.0	14	350	3/8	10	12	300	V & OH	5/16 max.	8 max.
		7/32	5.6	14 or 18	350 or 450	1/2	12	12 or 16 ^c	300 or 400 ^c	H	1/4 min.	6 min.
		1/4 5/16	6.0, 6.4 8.0	18	450	1/2	12	16	400	H	1/4 min.	6 min.
E6012, E6013, E6019	E4312, E4313, E4319	1/16–5/64	1.6–2.0	12	300	1/8	3	6	150	V & OH	1/8 max.	3 max.
		3/32	2.4, 2.5	12	300	1/8	3	10	250	V & OH	1/8 max.	3 max.
		1/8	3.2	14	350	3/16	5	12	300	V & OH	3/16 max.	5 max.
		5/32	4.0	14	350	3/8	10	12	300	V & OH	1/4 max.	6 max.
		3/16	4.8, 5.0	14	350	1/2	12	12	300	V & OH	3/8 max.	10 max.
		7/32	5.6	14 or 18	350 or 450	1/2	12	12 or 16 ^c	300 or 400 ^c	H	1/4 min.	6 min.
		1/4	6.0, 6.4	14 or 18	350 or 450	1/2	12	16	400	H	5/16 min.	8 min.
		5/16	8.0	14 or 18	350 or 450	1/2	12	16	400	H	5/16 min.	8 min.
E7014	E4914	3/32	2.4, 2.5	12	300	1/8	3	12	300	V & OH	5/32 max.	4 max.
		1/8	3.2	14	350	3/16	5	12	300	V & OH	3/16 max.	5 max.
		5/32	4.0	14	350	3/8	10	12	300	V & OH	5/16 max.	8 max.
		3/16	4.8, 5.0	14	350	3/8	10	12	300	H	1/4 min.	6 min.
		7/32	5.6	14 or 18	350 or 450	3/8	10	12 or 16 ^c	300 or 400 ^c	H	1/4 min.	6 min.
		1/4	6.0, 6.4	14 or 18	350 or 450	1/2	12	16	400	H	5/16 min.	8 min.
		5/16	8.0	14 or 18	350 or 450	1/2	12	16	400	H	5/16 min.	8 min.

(Continued)

Table 8 (Continued)
Requirements for Preparation of Fillet Weld Test Assemblies

AWS Classification ^a		Electrode				Plate Size ^b				Position of Welding	Size of Fillet Weld	
		Size		Length		Thickness (T)		Length (L) min. ^c				
A5.1	A5.1M	in	mm	in	mm	in	mm	in	mm		in	mm
E7015 E7016	E4915 E4916	3/32	2.4, 2.5	12	300	1/8	3	10	250	V & OH	5/32 max.	4 max.
		1/8	3.2	14	350	1/4	6	12	300	V & OH	3/16 max.	5 max.
		5/32	4.0	14	350	3/8	10	12	300	V & OH	5/16 max.	8 max.
		3/16	4.8, 5.0	14	350	3/8	10	12	300	H	3/16 min.	5 min.
		7/32	5.6	14 or 18	350 or 450	1/2	12	12 or 16 ^c	300 or 400 ^c	H	1/4 min.	6 min.
		1/4	6.0, 6.4	14 or 18	350 or 450	1/2	12	16	400	H	5/16 min.	8 min.
		5/16	8.0	14 or 18	350 or 450	1/2	12	16	400	H	5/16 min.	8 min.
E6018 E7018	E4318 E4918	3/32	2.4, 2.5	12	300	1/8	3	10 or 12 ^d	250 or 300 ^d	V & OH	3/16 max.	5 max.
		1/8	3.2	14	350	1/4	6	12	300	V & OH	1/4 max.	6 max.
		5/32	4.0	14	350	3/8	10	12	300	V & OH	5/16 max.	8 max.
		3/16	4.8, 5.0	14	350	3/8	10	12	300	H	1/4 min.	6 min.
		7/32	5.6	14 or 18	350 or 450	1/2	12	12 or 16 ^c	300 or 400 ^c	H	1/4 min.	6 min.
		1/4	6.0, 6.4	14 or 18	350 or 450	1/2	12	16	400	H	5/16 min.	8 min.
		5/16	8.0	14 or 18	350 or 450	1/2	12	16	400	H	5/16 min.	8 min.
E6020	E4320	1/8	3.2	14	350	1/4	6	12	300	H	1/8 min.	3 min.
		5/32	4.0	14	350	3/8	10	12	300	H	5/32 min.	4 min.
		3/16	4.8, 5.0	14 or 18	350 or 450	3/8	10	12 or 16 ^c	300 or 400 ^c	H	3/16 min.	5 min.
		7/32	5.6	18 or 28	450 or 700	1/2	12	16	400	H	1/4 min.	6 min.
		1/4	6.0, 6.4	18 or 28	450 or 700	1/2	12	16	400	H	5/16 min.	8 min.
		5/16	8.0	18 or 28	450 or 700	1/2	12	16	400	H	5/16 min.	8 min.

(Continued)

Table 8 (Continued)
Requirements for Preparation of Fillet Weld Test Assemblies

AWS Classification ^a		Electrode				Plate Size ^b				Position of Welding	Size of Fillet Weld	
		Size		Length		Thickness (T)		Length (L) min. ^c			in	mm
A5.1	A5.1M	in	mm	in	mm	in	mm	in	mm			
E6027 E7024 E7027 E7028	E4327 E4924 E4927 E4928	3/32 ^e	2.4, 2.5 ^e	14	350	1/4	6	10	250	H	5/32 min.	4 min.
		1/8	3.2	14	350	1/4	6	12	300	H	5/32 min.	4 min.
		5/32	4.0	14	350	3/8	10	12	300	H	3/16 min.	6 min.
		3/16	4.8, 5.0	14 or 18	350 or 450	3/8	10	12 or 16 ^c	300 or 400 ^c	H	1/4 min.	6 min.
		7/32	5.6	18 or 28	450 or 700	1/2	12	16 or 26 ^f	400 or 650 ^f	H	1/4 min.	6 min.
		1/4	6.0, 6.4	18 or 28	450 or 700	1/2	12	16 or 26 ^f	400 or 650 ^f	H	5/16 min.	8 min.
		5/16	8.0	18 or 28	450 or 700	1/2	12	16 or 26 ^f	400 or 650 ^f	H	5/16 min.	8 min.
E7048	E4948	1/8	3.2	14	350	1/4	6	12	300	V-down & OH	1/4 max.	6 max
		5/32	4.0	14 or 18	350 or 450	3/8	10	12	300	V-down & OH	5/16 max.	8 max
		3/16	4.8, 5.0	14 or 18	350 or 450	3/8	10	12 or 16	300 or 400	H & V-down	1/4 min.	6 min.

^a See Figure 4. Any classification test can be conducted with either USC or SI thickness plate.

^b When the end of the bead with the first electrode will be less than 4 in [100 mm] from the end of the test assembly, a starting tab or a longer test assembly shall be used.

^c For 14 in [350 mm] electrodes, the minimum length of the test assembly shall be 12 in [300 mm]; for 18 in [450 mm] electrodes, the minimum length of the test assembly shall be 16 in [400 mm].

^d For 12 in [300 mm] electrodes, the minimum length of the test assembly shall be 10 in [250 mm]; for 14 in [350 mm] electrodes, the minimum length of the test assembly shall be 12 in [300 mm].

^e E7024 [E4924] only.

^f For 18 in [450 mm] electrodes, the minimum length of the test assembly shall be 16 in [400 mm]; for 28 in [700 mm] electrodes, the minimum length of the test assembly shall be 26 in [650 mm].

Table 9
Dimensional Requirements for Fillet Weld Usability Test Specimens

Measured Fillet Weld Size		Maximum Convexity		Maximum Difference Between Fillet Weld Legs	
in	mm	in	mm	in	mm
1/8 or less	3 or less	1/16	2	1/32	1
5/32	4	1/16	2	1/16	2
3/16	—	1/16	—	1/16	—
—	5	—	2	—	2
7/32	5	1/16	2	3/32	2
1/4	6	1/16	2	3/32	2
9/32	7	1/16	2	1/8	3
5/16	8	3/32	2	1/8	3
11/32	9	3/32	2	5/32	4
3/8 or more	10 or more	3/32	2	5/32	4

Table 10
Moisture Content Limits for Electrode Coverings

AWS Classification A5.1 [A5.1M]	Electrode Designation ^a A5.1 [A5.1M]	Limit of Moisture Content (maximum % by weight)	
		As-Received or Conditioned ^b	As-Exposed ^c
E6018 [E4318]	E6018 [E4318]	0.6	Not Specified
E7015 [E4915]	E7015 [E4915]		
E7016 [E4916]	E7016 [E4916]		
E7016 [E4916]	E7016-1 [E4916-1]		
E7018 [E4918]	E7018 [E4918]		
E7018 [E4918]	E7018-1 [E4918-1]		
E7028 [E4928]	E7028 [E4928]		
E7048 [E4948]	E7048 [E4948]		
E6018 [E4318]	E6018R [E4318R]	0.3	0.4
E7015 [E4915]	E7015R [E4915R]		
E7016 [E4916]	E7016R [E4916R]		
E7016 [E4916]	E7016-1R [E4916-1R]		
E7018 [E4918]	E7018R [E4918R]		
E7018 [E4918]	E7018-1R [E4918-1R]		
E7028 [E4928]	E7028R [E4928R]		
E7048 [E4948]	E7048R [E4948R]		
E7018M [E4918M]	E7018M [E4918M]	0.1	0.4

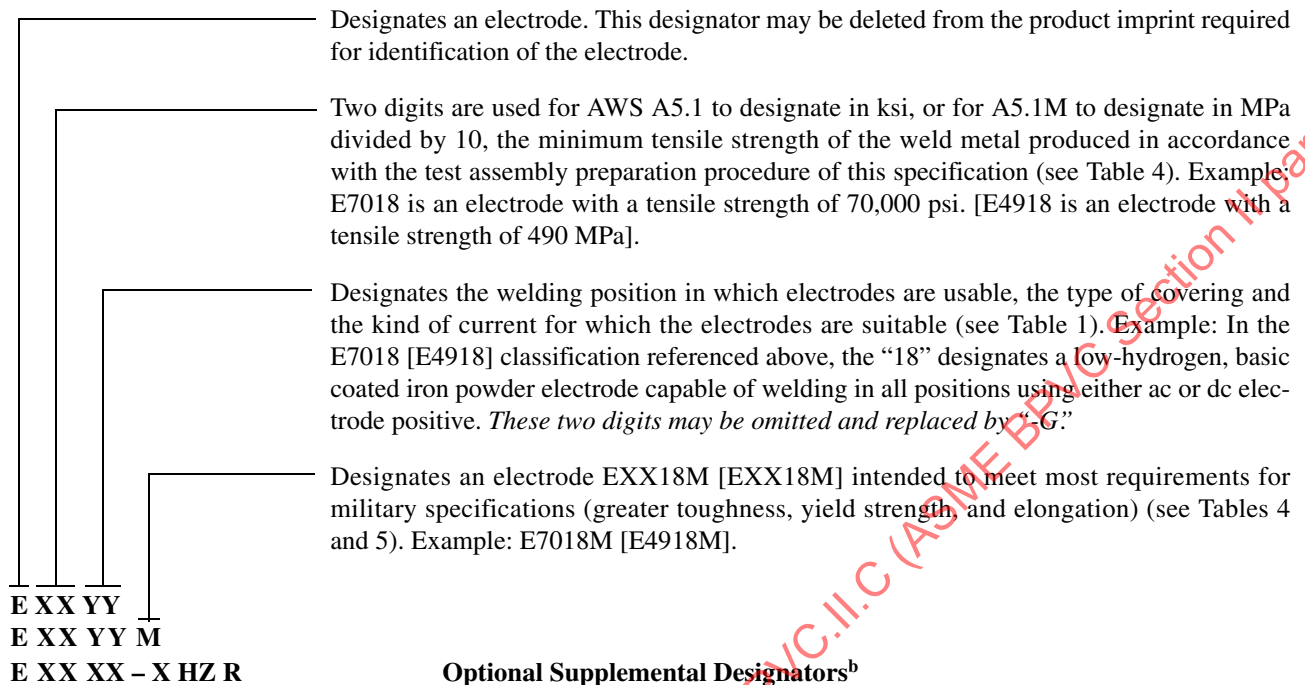
^a AWS classification with optional, supplemental designators applied.

^b As-received or conditioned electrode coverings shall be tested as specified in Clause 16, Moisture Test.

^c As-exposed electrode coverings shall have been exposed to a moist environment as specified in Clause 17, Absorbed Moisture Test, before being tested as specified in Clause 16.

Table 11
Diffusible Hydrogen Limits for Weld Metal

AWS Classification A5.1 [A5.1M]	Diffusible Hydrogen Designator	Diffusible Hydrogen Content Average mL/100g Deposited Metal (maximum)
E7018M [E4918M]	None	4
E6018 [E4318]	H16, H8, or H4	16 (for H16) 8 (for H8) 4 (for H4)
E7015 [E4915]		
E7016 [E4916]		
E7018 [E4918]		
E7028 [E4928]		
E7048 [E4948]		

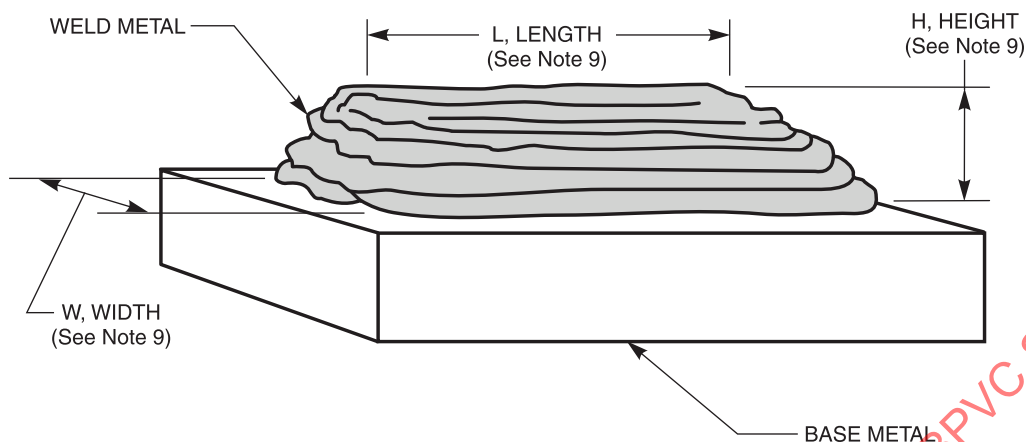
Mandatory Classification Designators^a

- Designates that the electrode meets the requirements of the absorbed moisture test (an optional supplemental test for all low hydrogen electrodes (see Table 10). Example: E7018R [E4918R].
- Designates that the electrode meets the requirements of the diffusible hydrogen test (an optional supplemental test of the weld metal from low-hydrogen electrodes) for electrodes in the as received or conditioned state, with an average diffusible hydrogen content not exceeding “Z” mL/100 g of deposited metal, where “Z” is 4, 8, or 16 (see Table 11). Example: E7018H8 [E4918H8]. In this case, the electrode will give a maximum of 8 mL of hydrogen per 100 g of deposited metal when tested in accordance with this specification.
- Designates that the electrode (E7016, E7018, or E7024) [E4916, E4918, or E4924] meets the requirements for improved toughness and ductility in the case of E7024 [E4924]—Optional supplemental test requirements are shown in Table 4 (note f) and Table 5.

^a The combination of these designators constitutes the electrode classification.

^b These designators are optional and do not constitute a part of the electrode classification.

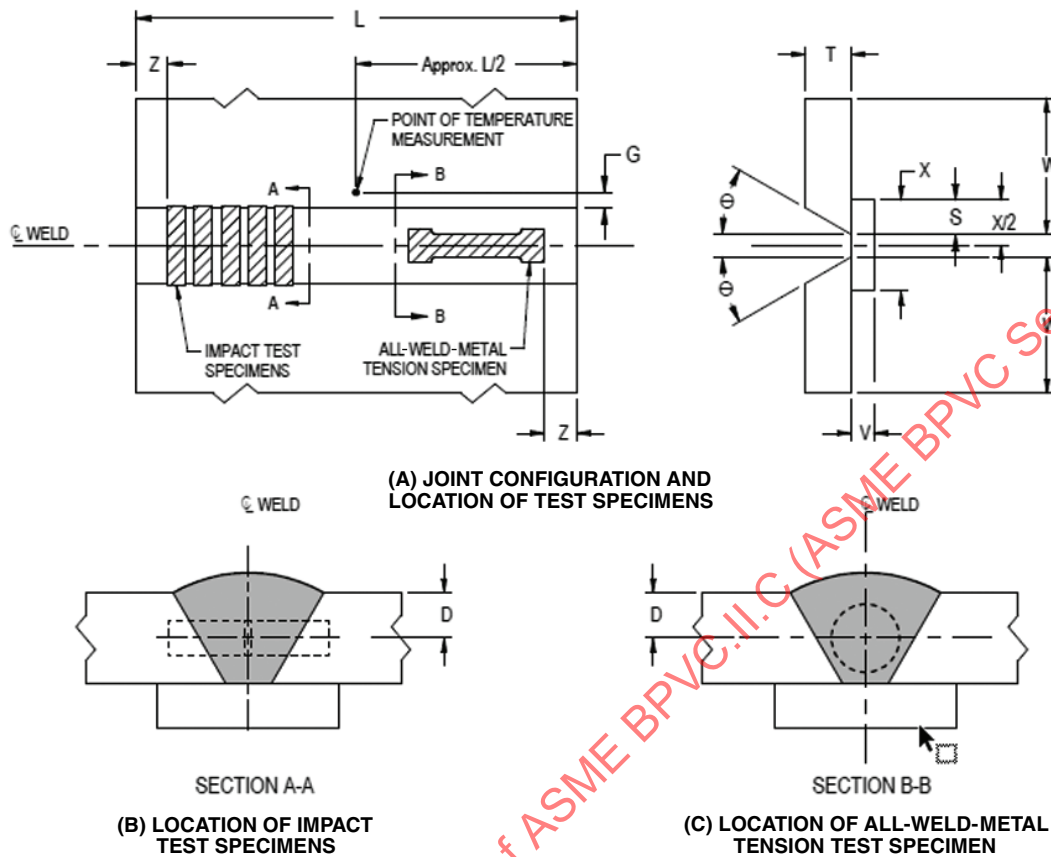
Figure 1—Order of Electrode Mandatory and Optional Supplemental Designators



Notes:

1. Base metal of any convenient size, of the type specified in Table 7, shall be used as the base for the weld pad.
2. The surface of the base metal on which the filler metal is to be deposited shall be clean.
3. The pad shall be welded in the flat position with successive layers to obtain undiluted weld metal.
4. One pad shall be welded for each type of current shown in Table 2 except for those classifications identified by note c in Table 2.
5. The number and size of the beads will vary according to the size of the electrode and the width of the weave, as well as the amperage employed. The width of each weld pass in each weld layer shall be no more than 2-1/2 times the diameter of the core wire.
6. The preheat temperature shall not be less than 60 °F [15 °C] and the interpass temperature shall not exceed 300 °F [150 °C].
7. The slag shall be removed after each pass.
8. The test assembly may be quenched in water between passes to control interpass temperature, but must be dry before welding resumes.
9. The minimum completed pad size shall be at least four layers in height (H) with length (L) and width (W) sufficient to perform analysis. The sample for analysis shall be taken from weld metal that is at least 1/4 in [6 mm] above the original base metal surface.

Figure 2—Pad for Chemical Analysis of Undiluted Weld Metal



Dimension	Description	A5.1						
		Electrode Size, in						
		3/32	1/8	5/32	3/16	7/32	3/4	5/16
G	Point of Temperature Measurement, Offset from Groove Edge, in	1/4 to 1/2						
L	Length, min., in (See Note 1)	10						
S	Backing Overlap, min., in	1/4						
V	Backing Thickness, min., in	1/4						
W	Width, min., in	5						
X	Backing Width, min., in	R + 1/2						
Z	Discard, min., in	1						
T	Nominal Plate Thickness, in	1/2 ± 1/32	1/2 ± 1/32	3/4 ± 1/32	3/4 ± 1/32	3/4 ± 1/32	1 ± 1/32	1-1/4 ± 1/32
D	Specimen Center, in	1/4 ± 1/32	1/4 ± 1/32	3/8 ± 1/32	3/8 ± 1/32	3/8 ± 1/32	1/2 ± 1/32	5/8 ± 1/32
R	Root Opening, in	3/8 -0, +1/16	1/2 -0, +1/16	5/8 -0, +1/16	3/4, -0, +1/16	7/8, -0, +1/16	1, -0, +1/16	1-1/8, -0, +1/16
Θ	Bevel Angle, degrees	10, +2.5, -0						
Passes per Layer		2	2	2	2	2	2	2
Total Layers		Not Specified	5 to 7	7 to 9	6 to 8	6 to 8	9 to 11	10 to 12

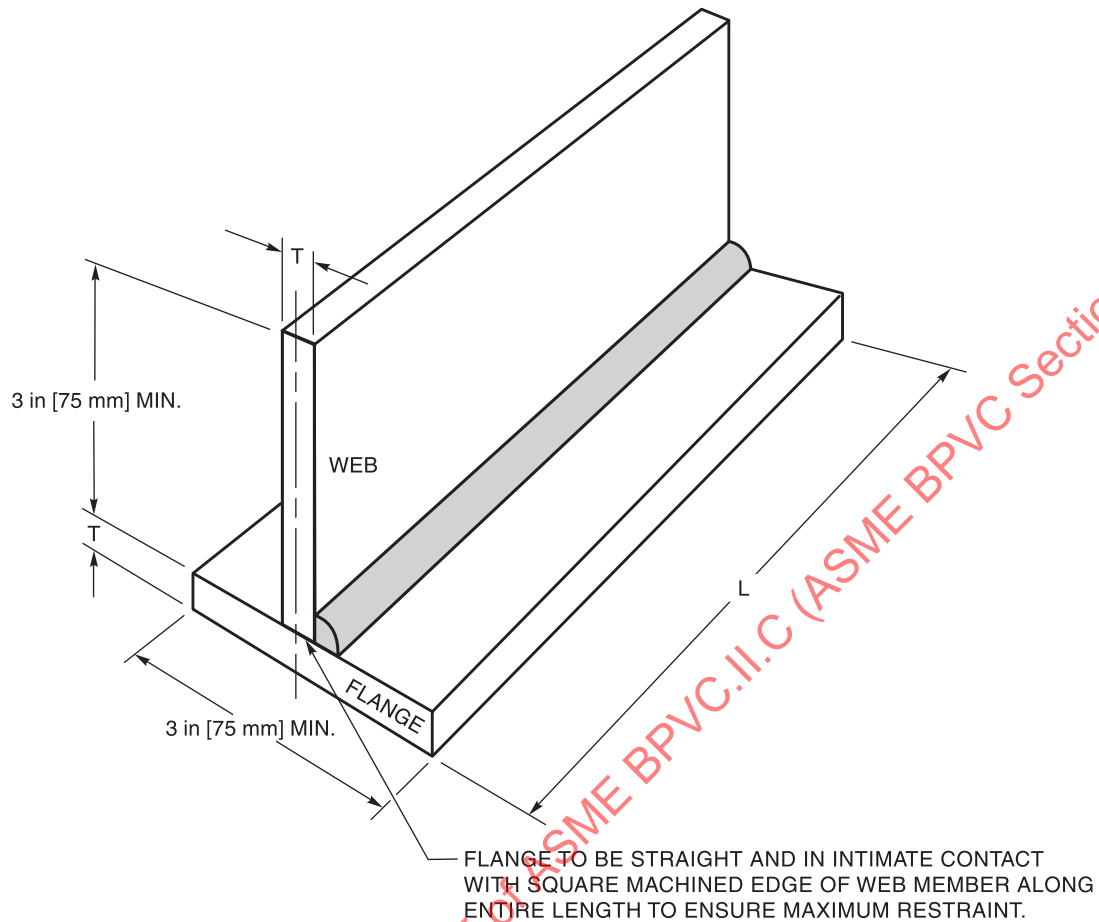
Figure 3—Groove Weld Test Assembly for Mechanical Properties and Soundness of Weld Metal Produced by Using All Electrode Classifications Except E6022 [E4322] and E7018M [E4918M] Electrodes

Dimension	Description	A5.1M					
		Electrode Size, mm					
		2.5	3.2	4	4.5, 5.0	6	8
G	Point of Temperature Measurement, Offset from Groove Edge, mm	6 to 13					
L	Length, min., mm (See Note 1)	250					
S	Backing Overlap, min., mm	6					
V	Backing Thickness, min., mm	6					
W	Width, min., mm	125					
X	Backing Width, min., mm	R + 12					
Z	Discard, min, mm	25					
T	Nominal Plate Thickness, mm	12 ± 1	12 ± 1	20 ± 1	20 ± 1	25 ± 1	30 ± 1
D	Specimen Center, mm	6 ± 1	6 ± 1	10 ± 1	10 ± 1	12 ± 1	16 ± 1
R	Root Opening, mm	10 –0, +1	13 –0, +1	16 –0, +1	19 –0, +1	25 –0, +1	28 –0, +1
Ø	Bevel Angle, degrees	10, +2.5, –0					
Passes per Layer		2	2	2	2	2	2
Total Layers		Not Specified	5 to 7	7 to 9	6 to 8	9 to 11	10 to 12

Notes:

1. For electrodes longer than 18 in [450 mm], a 20 in [500 mm] long test assembly shall be welded.
2. The surfaces to be welded shall be clean.
3. Base metal shall be as specified in Table 7.
4. Prior to welding, the assembly may be preset to yield a welded joint sufficiently flat to facilitate removal of the test specimens. As an alternative, restraint or a combination of restraint and presetting may be used to keep the welded joint within 5 degrees of plane. A completed welded test assembly that is more than 5 degrees out of plane shall be discarded. Straightening of the test assembly is prohibited.
5. Welding shall be in the flat position, using each type of current specified in Table 2 except for classifications identified by Note c in Table 2.
6. The preheat temperature shall be 225 °F [105 °C] minimum. The interpass temperature shall not be less than 225 °F [105 °C] nor more than 350 °F [175 °C].
7. For electrode size larger than 1/8 in [3.2 mm] the joint root may be seal welded with 3/32 or 1/8 in [2.5 or 3.2 mm] electrodes using stringer beads.
8. In addition to the stops and starts at the ends, each pass shall contain a stop and start in between the ends.
9. The completed weld shall be at least flush with the surface of the test plate.

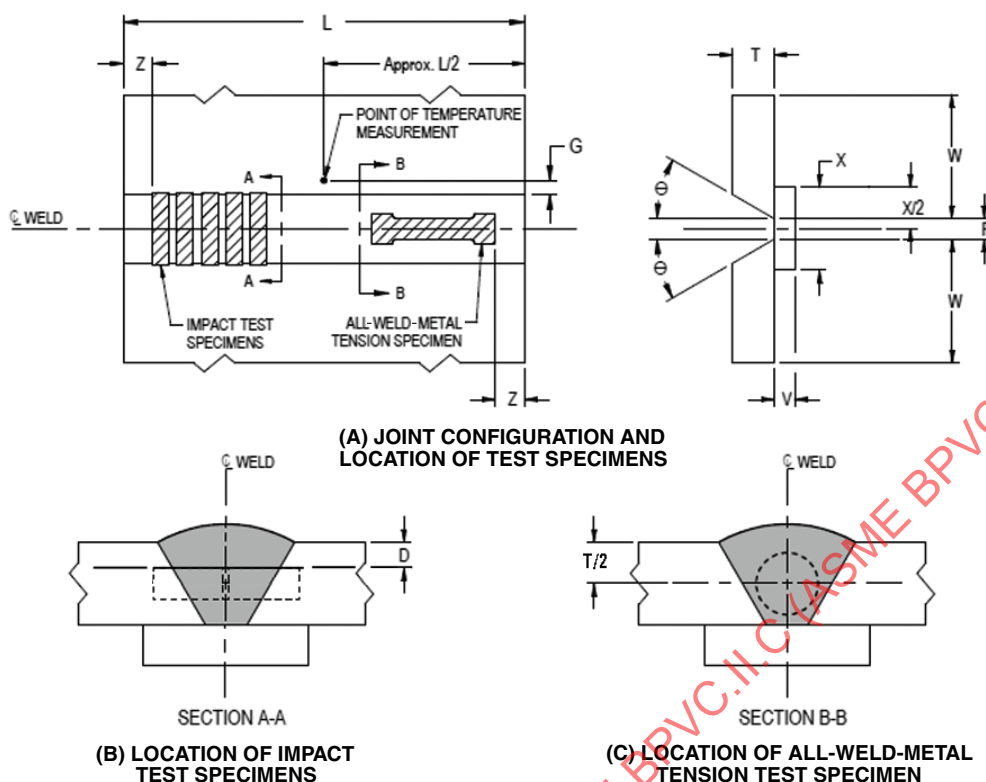
Figure 3 (Continued)—Groove Weld Test Assembly for Mechanical Properties and Soundness of Weld Metal Produced by Using All Electrode Classifications Except E6022 [E4322] and E7018M [E4918M] Electrodes



Notes:

1. See Table 8 for values of T and L.
2. Base metal shall be as specified in Table 7.
3. The surfaces to be welded shall be clean.
4. One assembly shall be welded for each position specified in Table 8 and shown in Figure 7 using each type of current and polarity specified in Table 2.
5. The preheat shall be 60 °F [15 °C] minimum.
6. A single pass fillet weld shall be made on one side of the joint. The first electrode shall be consumed to a stub length of no greater than 2 in [50 mm].
7. Progression in the vertical position shall be upwards, except the E7048 [E4948] classification where progression shall be downward.
8. Weld cleaning shall be limited to slag chipping, brushing and needle scaling. Grinding or filing of the final weld surface is prohibited.
9. The tests shall be conducted without postweld heat treatment.

Figure 4—Fillet Weld Test Assembly for Usability of the Electrode

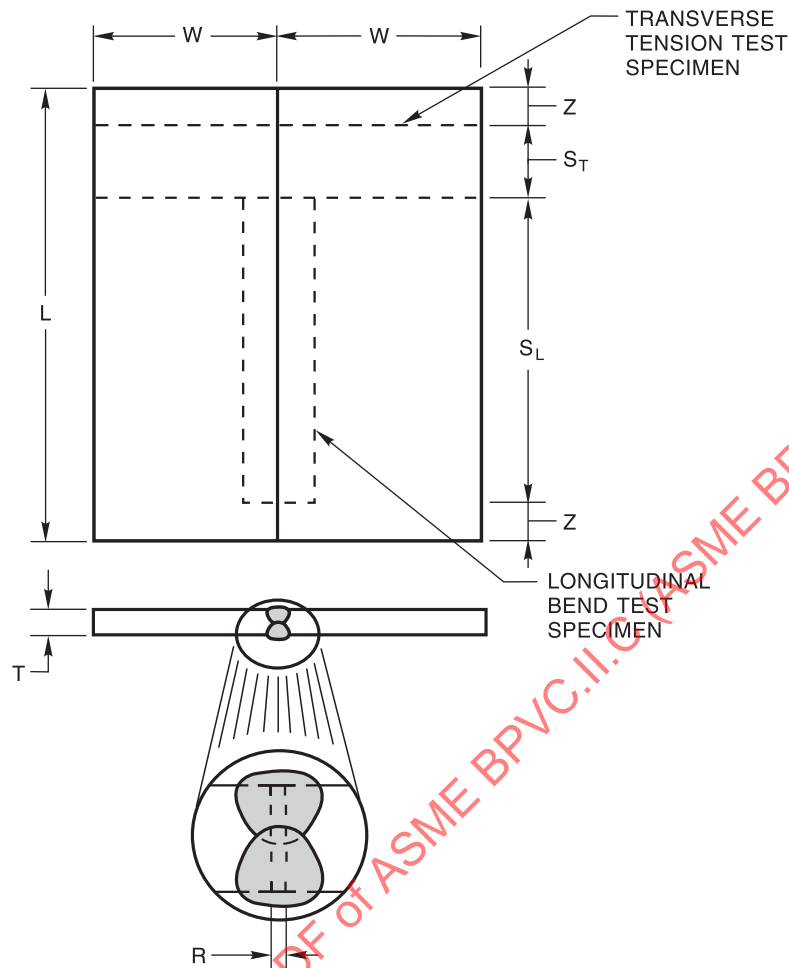


Dimension	Description	A5.1 E7018M						A5.1M E4918M				
		Electrode Size, in						Electrode Size, mm				
		3/32	1/8	5/32	3/16	7/32	1/4	2.5	3.2	4	5	6
D	Nominal CVN Location	1/8						3.2				
G	Point of Temperature Measurement, Offset from Groove Edge	1/4 to 1/2						6 to 13				
L	Length, min.	10						250				
V	Backing Thickness, min.	1/4						6				
W	Width, min.	5						125				
X	Backing Width, min.	3/4						20				
Z	Discard, min.	1						25				
T	Plate Thickness, min.	3/4						20				
R	Root Opening, min.	1/4						6				
Θ	Bevel Angle, degrees	30 -0°, +5°										
Total Layers		See Note 6										

Notes:

- Dimensions in inches are applicable to A5.1. Dimensions in mm are applicable to A5.1M.
- Base metal shall be as specified in Table 7. The surfaces to be welded shall be clean.
- Prior to welding, the assembly may be preset to yield a welded joint sufficiently flat to facilitate removal of the test specimens. As an alternative, restraint or a combination of restraint and presetting may be used to keep the welded joint within 5° of plane. A welded test assembly that is more than 5° out of plane shall be discarded. Straightening of the test assembly is prohibited.
- The assembly shall be welded in the vertical position with progression upward for electrodes 5/32 in [4.0 mm] and less in size, and in the flat position for electrodes 3/16 in [5.0 mm] and greater in size, using the type of current specified in Table 2 for the electrode and welding technique recommended by the electrode manufacturer.
- The preheat temperature and the interpass temperature shall be 200 °F to 250 °F [90 °C to 120 °C].
- The welding heat input shall be 30 kJ/in to 40 kJ/in [1.2 kJ/mm to 1.6 kJ/mm] for the 3/32 in [2.5 mm] size electrodes and 50 kJ/in to 60 kJ/in [2.0 kJ/mm to 2.4 kJ/mm] for the 1/8 in [3.2 mm] size and larger electrodes.
- In addition to the stops and starts at the ends, each pass shall contain a stop and start in between the ends.
- The completed weld shall be at least flush with the surface of the test plate. Maximum weld reinforcement shall be 3/16 in [5.0 mm]. Peening of weld beads is not permitted.

Figure 5—Groove Weld Test Assembly for Mechanical Properties and Soundness of Weld Metal Produced by Using E7018M [E4918M] Electrodes



Minimum Length (L) in [mm]	Minimum Width (W) in [mm]	Maximum Root Opening (R) in [mm]	Transverse Specimen (S_T) in [mm]	Longitudinal Specimen (S_L) in [mm]	Thickness (T) in [mm]	Minimum Discard (Z) in [mm]
10 [250]	4 [100]	1/16 [1.6]	2 [50]	6 [150]	1/4 [6]	1 [25]

Notes:

1. Dimensions in inches are applicable to A5.1. Dimensions in mm are applicable to A5.1M.
2. Base metal shall be as specified in Table 7. The surfaces to be welded shall be clean.
3. Prior to welding, the assembly may be preset to yield a welded joint sufficiently flat to facilitate removal of the test specimens. As an alternative, restraint or a combination of restraint and presetting may be used to keep the welded joint within 5° of plane. A welded test assembly that is more than 5° out of plane shall be discarded. Straightening of the test assembly is prohibited.
4. The assembly shall be welded in the flat position, using the type of current specified in Table 2.
5. The preheat temperature shall be 60 °F [15 °C] min. The interpass temperature shall not exceed 350 °F [180 °C].
6. In addition to the stops and starts at the ends, each pass shall contain a stop and start in between the ends.
7. Back gouging may be done to ensure sound weld metal through the entire thickness of test assembly.
8. The completed weld shall be at least flush with the surface of the test plate.

Figure 6—Test Assembly for Transverse Tension and Longitudinal Guided Bend Tests for Welds Made with E6022 [E4322] Electrodes

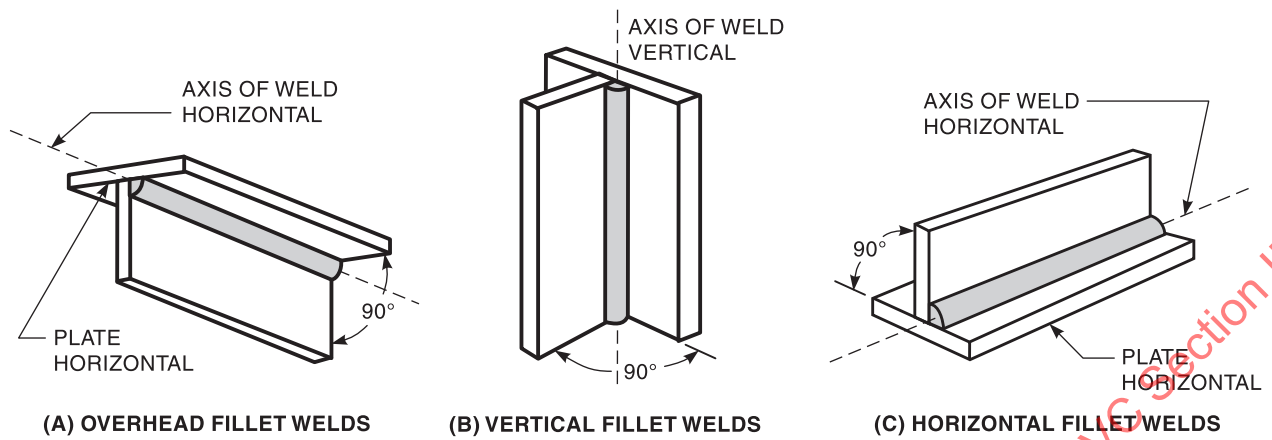
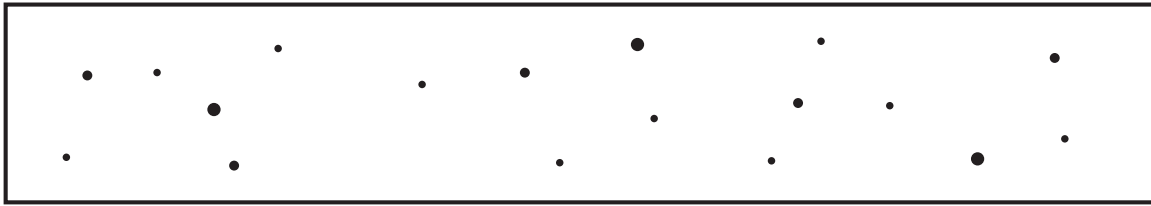


Figure 7—Welding Positions for Fillet Weld Test Assemblies

**(A) ASSORTED ROUNDED INDICATIONS**

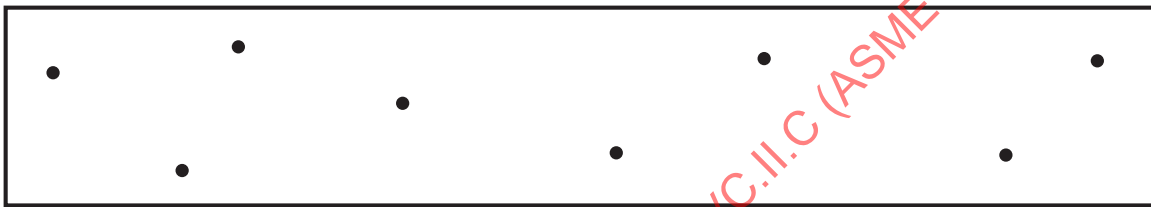
SIZE: 1/64 in [0.4 mm] to 1/16 in [1.6 mm] in diameter or in length.

Maximum number of indications in any 6 in [150mm] of weld is 18, with the following restrictions:

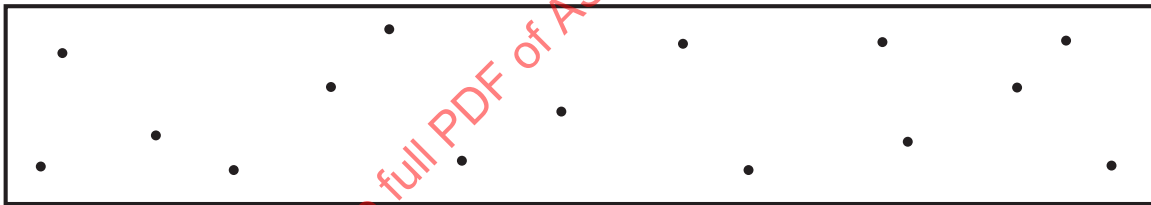
Maximum number of large (3/64 in [1.2 mm] to 1/16 in [1.6 mm] in diameter or length) indications is 3, and

Maximum number of medium (1/32 in [0.8 mm] to 3/64 in [1.2 mm] in diameter or in length) indications is 5, and

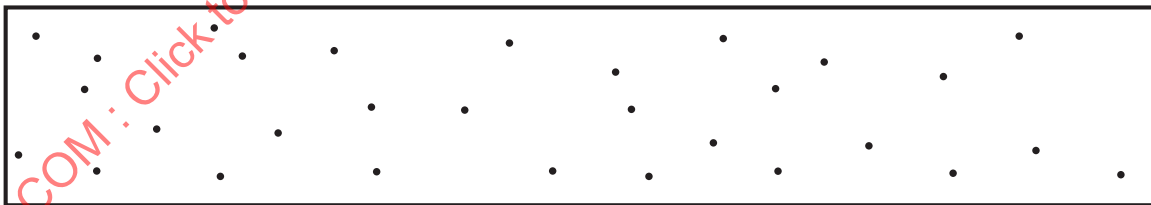
Maximum number of small (1/64 in [0.4 mm] to 1/32 in [0.8 mm] in diameter or in length) indications is 10.

**(B) LARGE ROUNDED INDICATIONS**

SIZE: 3/64 in [1.2 mm] to 1/16 in [1.6 mm] in diameter or in length. Maximum number of indications in any 6 in [150 mm] of weld is 8.

**(C) MEDIUM ROUNDED INDICATIONS**

SIZE: 1/32 in [0.8 mm] to 3/64 in [1.2 mm] in diameter or in length. Maximum number of indications in any 6 in [150 mm] of weld is 15.

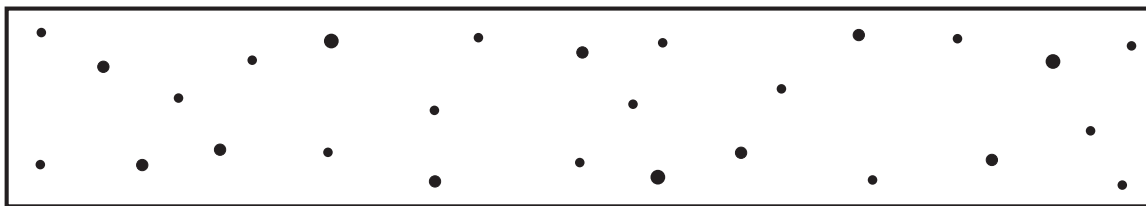
**(D) SMALL ROUNDED INDICATIONS**

SIZE: 1/64 in [0.4 mm] to 1/32 in [0.8 mm] in diameter or in length. Maximum number of indications in any 6 in [150 mm] of weld is 30.

Notes:

1. In using these standards, the chart which is most representative of the size of the rounded indications present in the test specimen radiograph, shall be used for determining conformance to these radiographic standards.
2. Since these are test welds specially made in the laboratory for classification purposes, the radiographic requirements for these test welds are more rigid than those which may be required for general fabrication.
3. Indications whose largest dimension does not exceed 1/64 in [0.4 mm] shall be disregarded.

Figure 8A—Radiographic Acceptance Standards for Rounded Indications (Grade 1)

**(E) ASSORTED ROUNDED INDICATIONS**

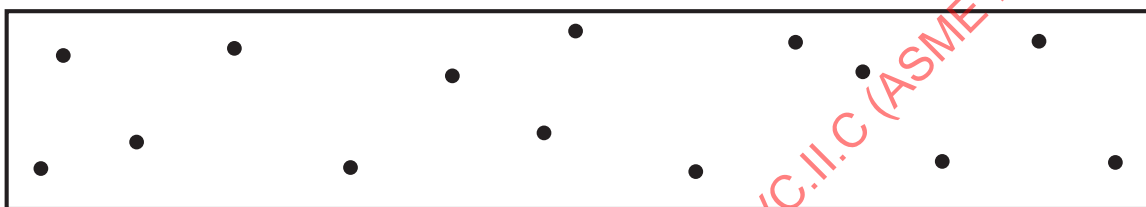
SIZE: 1/64 in [0.4 mm] to 5/64 in [2.0 mm] in diameter or in length.

Maximum number of indications in any 6 in [150 mm] of weld is 27, with the following restrictions:

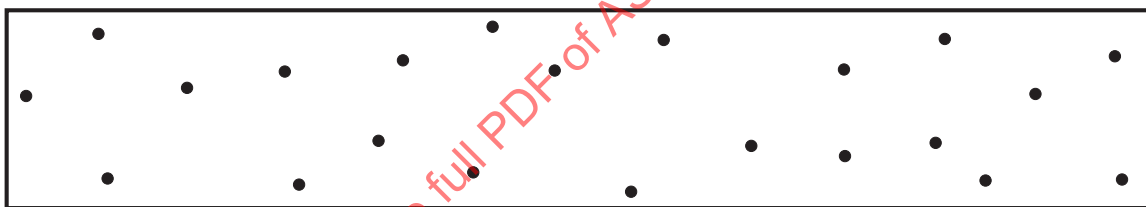
Maximum number of large (1/16 in [1.6 mm] to 5/64 in [2.0 mm] in diameter or in length) indications is 3, and

Maximum number of medium (3/64 in [1.2 mm] to 1/16 in [1.6 mm] in diameter or in length) indications is 8, and

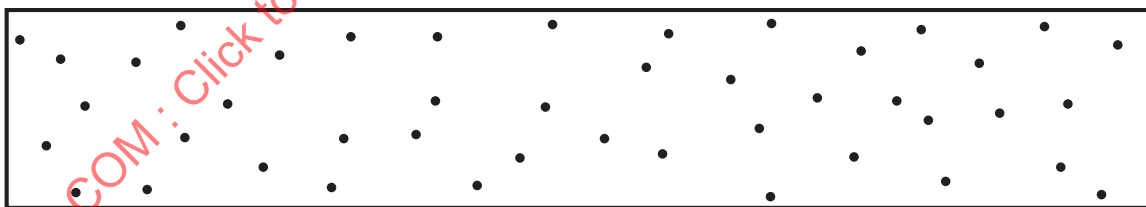
Maximum number of small (1/64 in [0.4 mm] to 3/64 in [1.2 mm] in diameter or in length) indications is 16.

**(F) LARGE ROUNDED INDICATIONS**

SIZE: 1/16 in [1.6 mm] to 5/64 in [2.0 mm] in diameter or in length. Maximum number of indications in any 6 in [150 mm] of weld is 14.

**(G) MEDIUM ROUNDED INDICATIONS**

SIZE: 3/64 in [1.2 mm] to 1/16 in [1.6 mm] in diameter or in length. Maximum number of indications in any 6 in [150 mm] of weld is 22.

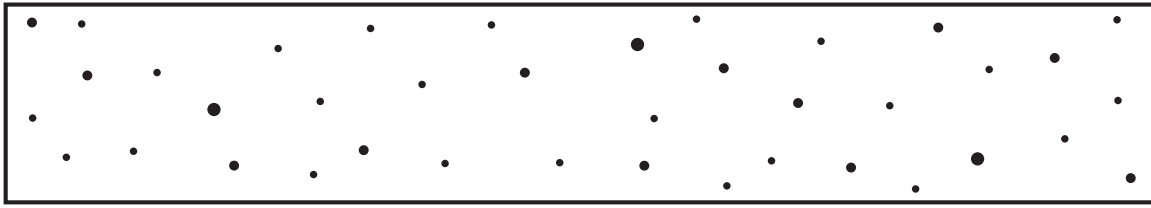
**(H) SMALL ROUNDED INDICATIONS**

SIZE: 1/64 in [0.4 mm] to 3/64 in [1.2 mm] in diameter or in length. Maximum number of indications in any 6 in [150 mm] of weld is 44.

Notes:

1. In using these standards, the chart which is most representative of the size of the rounded indications present in the test specimen radiograph, shall be used for determining conformance to these radiographic standards.
2. Since these are test welds specially made in the laboratory for classification purposes, the radiographic requirements for these test welds are more rigid than those which may be required for general fabrication.
3. Indications whose largest dimension does not exceed 1/64 in [0.4 mm] shall be disregarded.

Figure 8B—Radiographic Acceptance Standards for Rounded Indications (Grade 2)

**(I) ASSORTED ROUNDED INDICATIONS**

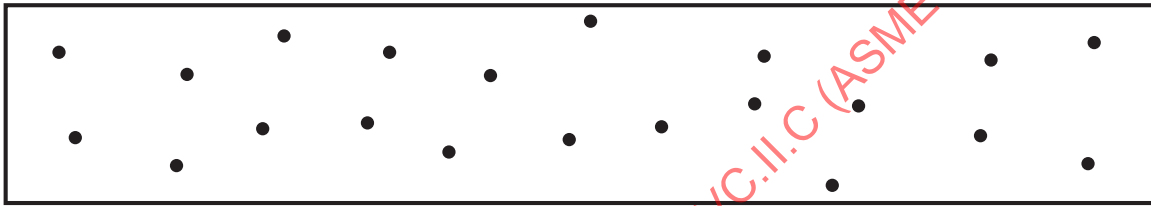
SIZE: 1/64 in [0.4 mm] to 5/64 in [2.0 mm] in diameter or in length.

Maximum number of indications in any 6 in [150mm] of weld is 39, with the following restrictions:

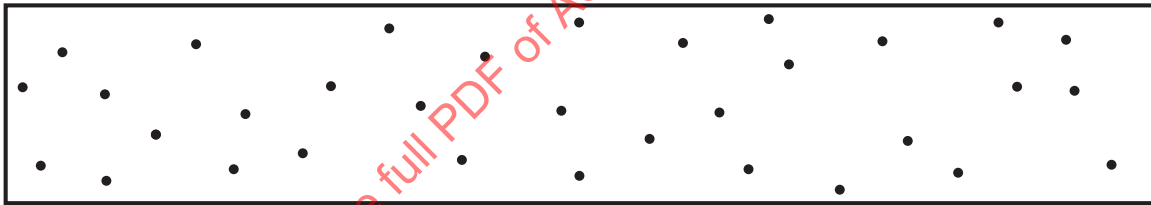
Maximum number of large 1/16 in [1.6 mm] to 5/64 in [2.0 mm] is 3, and

Maximum number of medium 3/64 in [1.2 mm] to 1/16 in [1.6 mm] is 12, and

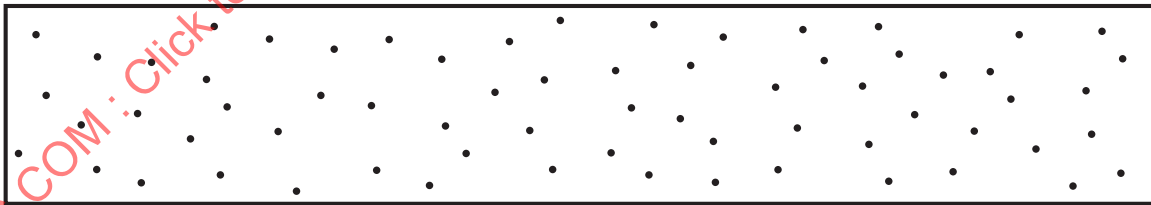
Maximum number of small 1/64 in [0.4 mm] to 3/64 in [1.2 mm] is 24.

**(J) LARGE ROUNDED INDICATIONS**

SIZE: 1/16 in [1.6 mm] to 5/64 in [2.0 mm] in diameter or in length. Maximum number of indications in any 6 in [150 mm] of weld is 21.

**(K) MEDIUM ROUNDED INDICATIONS**

SIZE: 3/64 in [1.2 mm] to 1/16 in [1.6 mm] in diameter or in length. Maximum number of indications in any 6 in [150 mm] of weld is 33.

**(L) SMALL ROUNDED INDICATIONS**

SIZE: 1/64 in [0.4 mm] to 3/64 in [1.2 mm] in diameter or in length. Maximum number of indications in any 6 in [150 mm] of weld is 66.

Figure 8C—Radiographic Acceptance Standards for Rounded Indications (Grade 3)

Annex A (Informative)

Guide to AWS Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding

This annex is not part of this standard, but is included for informational purposes only.

A1. Introduction

The purpose of this guide is to correlate the electrode classifications with their intended applications, so the specification can be used effectively. Appropriate base metal specifications are referred to whenever that can be done and when it would be helpful. Such references are intended only as examples rather than complete listings of the base metals for which each filler metal is suitable.

A2. Classification System

A2.1 The system for identifying the electrode classification in this specification follows the standard pattern used in other AWS filler metal specifications. The prefix letter “E” at the beginning of each classification stands for electrode. The first two digits, 60 [43], for example, designate tensile strength of at least 60 ksi [430 MPa] of the weld metal, welded in accordance with the test assembly preparation clause of this specification. The third digit designates position usability that will allow satisfactory welds to be produced with the electrode. In this document, the classification in U.S. Customary Units is followed by the SI Unit classification in brackets.

Thus, the “1,” as in E6010 [E4310], means that the electrode is usable in all positions (flat, horizontal, vertical, and overhead). The “2,” as in E6020 [E4320] designates that the electrode is suitable for use in the flat position and for making fillet welds in the horizontal position. The “4,” as in E7048 [E4948], designates that the electrode is suitable for use in vertical welding with downward progression and for other positions (see Table 1). The last two digits taken together designate the type of current with which the electrode can be used and the type of covering on the electrode, as listed in Table 1.

A2.2 Optional designators are also used in this specification in order to identify electrodes that have met the mandatory classification requirements and certain supplementary requirements as agreed to between the supplier and the purchaser. A “-1” designator following classification identifies an electrode which meets optional supplemental impact requirements at a lower temperature than required for the classification (see Table 5). An example of this is the E7024-1 [E4924-1] electrode which meets the classification requirements of E7024 [E4924] and also meets the optional supplemental requirements for toughness and improved elongation of the weld metal (see Note f to Table 4).

Certain low-hydrogen electrodes also may have optional designators. An optional supplemental designator “HZ” following the four digit classification designators or following the “-1” optional supplemental designator, if used, indicates an average diffusible hydrogen content of not more than “Z” mL/100g of deposited metal when tested in the “as-received” or conditioned state in accordance with AWS A4.3. Electrodes that are designated as meeting the lower or lowest hydrogen limits, as specified in Table 11, are also understood to be able to meet any higher hydrogen limits even though these are not necessarily designated along with the electrode classification. Therefore, as an example, an electrode designated as “H4” also meets “H8” and “H16” requirements without being designated as such. See Clause 18, Diffusible Hydrogen Test, and Table 11.

A letter “R” is a designator used with the low-hydrogen electrode classifications. It is used to identify electrodes that have been exposed to a humid environment for a given length of time and tested for moisture absorption in addition to the standard moisture test required for classification of low-hydrogen electrodes (see Clause 17 and Table 10).

A2.3 “G” Classification

A2.3.1 This specification includes filler metals classified as EXX-G. The last “G” indicates that the filler metal is of a *general* classification. It is *general* because the filler metal may not meet all requirements for any other classification. The purpose is to allow a useful filler metal to receive a classification before the specification is revised.

One filler metal of a “G” classification is not interchangeable with another filler metal of the same classification.

This specification contains provisions for the E60-G and E70-G [E43-G and E49-G] classifications.

A2.3.2 The point of difference between a particular filler metal of a “G” classification and all other filler metals of a similar classification with or without the “G” may be further clarified from the use of the words “not required” and “not specified” in the specification. The use of these words is as follows:

“Not Required” is used in those areas of the specification that specify the tests that must be conducted in order to classify a welding material. It indicates that that test is not required because the results for the particular test are not a requirement for that particular classification. When a test is “not required”, it is not necessary to conduct the corresponding test in order to classify a filler metal to that classification. When a purchaser wants the information provided by that test in order to consider a particular product of that classification for a certain application, the purchaser will have to arrange for that information with the supplier of the product. The purchaser will have to establish with that supplier just what the testing procedure and the acceptance requirements are to be for that test. The purchaser may want to incorporate that information (via AWS A5.01M/A5.01) in the purchase order.

“Not Specified” is used in those areas of the specification that refer to the results of some particular test. It indicates that the requirements for that test are not specified for that particular classification. If the required results from a specific test are listed as “not specified” but the test in question is shown as “required” then the test results must be reported.

A2.3.3 Request for Filler Metal Classification. When a filler metal cannot be classified other than as a “G” classification, a manufacturer may request that a new classification be established. The manufacturer shall do this using the following procedure:

(1) A request to establish a new filler metal classification must be submitted in writing. The request needs to provide sufficient detail to permit the Committee on Filler Metals and Allied Materials and the relevant Subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

- (a) Declaration that the new classification will be offered for sale commercially;
- (b) All classification requirements as given for existing classifications, such as, chemical composition ranges, mechanical property requirements, and usability test requirements;
- (c) Any conditions for conducting the tests used to demonstrate that the filler metal meets the classification requirements (It would be sufficient, for example, to state that welding conditions are the same as for other classifications);
- (d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the Annex);
- (e) Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.

A request for a new classification without the above information listed in (a) through (e) will be considered incomplete. The Secretary will return the request to the requester for further information.

(2) In order to comply with the AWS Policy on Patented Items, Trademarks, and Restraint of Trade, if the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester

shall disclose this. In these cases, the patent holder must allow the use of this technology, such as by license. The Secretary will provide examples of acceptable wording to the patent holder, as required.

(3) The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters for processing.

A2.3.4 *After the new classification is established, the –G classification may be retained for a period of time to allow for users to transition existing documents to the new classification.*

A2.4 International Classification System. An international system for designating welding filler metals has been developed by ISO. A complete series of ISO standards for filler metals and allied materials, including the vast majority of AWS classifications, but not all, has now been published. Some of these ISO standards have a single way of classification, like AWS standards. A number of the ISO standards dealing with steels are cohabitation standards. A cohabitation standard specifies two parallel systems, roughly corresponding to the European system (the “A” side) and the AWS system (the “B” side). In each case, the “B” side is usually similar to the AWS designation.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01M/A5.01 as the specification states. Any testing a purchaser requires of the supplier, for material shipped in accordance with this specification, needs to be clearly stated in the purchase order, according to the provisions of AWS A5.01M/A5.01. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing the supplier normally conducts on material of that classification, as specified in Schedule F, Table 1, of AWS A5.01M/A5.01. Testing in accordance with any other Schedule in that Table must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations, and optional designators, if applicable, on the packaging enclosing the product, or the classification on the product itself, constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification. The only testing requirement implicit in this *certification* is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that the material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation. *Certification* is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been made. The basis for the *certification* required by the specification is the classification test of *representative material* cited above, and the Manufacturer's Quality Assurance Program as defined in AWS A5.01M/A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes in the atmosphere to which welders and welding operators are exposed during welding. They are:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling);
- (2) Number of welders and welding operators working in that space;
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes used;
- (4) The proximity of welders and welding operators to the fumes, as these fumes issue from the welding zone, and to the gases and dust in the space in which they are working; and
- (5) The ventilation provided to the space in which the welding is done.

A5.2 American National Standard ANSI Z49.1, published by the American Welding Society, discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the clause on Ventilation in that document. See also AWS F3.2, *Ventilation Guide for Weld Fume* for more detailed descriptions of ventilation options.

A6. Welding Considerations

A6.1 Weld metal properties may vary widely, according to size of the electrode and amperage used, size of the weld beads, base metal thickness, joint geometry, preheat and interpass temperatures, surface condition, base metal composition, dilution, etc. Because of the profound effect of these variables, a test procedure was chosen for this specification that would represent good welding practice and minimize variation of the most potent of these variables.

A6.2 It should be recognized, however, that production practices may be different. The differences encountered may alter the properties of the weld metal. For instance, interpass temperatures may range from subfreezing to several hundred degrees. No single temperature or reasonable range of temperatures can be chosen for classification tests which will be representative of all of the conditions encountered in production work.

Properties of production welds may vary accordingly, depending on the particular welding conditions. Weld metal properties may not duplicate, or even closely approach, the values listed and prescribed for test welds. For example, ductility in single-pass welds in thick base metal made outdoors in cold weather without adequate preheating may drop to little more than half that required herein and normally obtained. This does not indicate that either the electrodes or the welds are below standard. It indicates only that the particular production conditions are more severe than the test conditions prescribed by this specification.

A6.3 Hydrogen is another factor to be considered in welding. Weld metals, other than those from low-hydrogen electrodes (E6018 [E4318], E7015 [E4915], E7016 [E4916], E7018 [E4918], E7018M [E4918M], E7028 [E4928], and E7048 [E4948]) contain significant quantities of hydrogen for some period of time after they have been made. Most of this hydrogen gradually escapes. After two to four weeks at room temperature or 24 hours to 48 hours at 200 °F to 220 °F [90 °C to 105 °C], most of it has escaped. As a result of this change in hydrogen content, ductility of the weld metal increases towards its inherent value, while yield, tensile and impact *properties* remain relatively unchanged.

This specification permits aging of the weld plate or test specimens of cellulosic electrodes at up to 220 °F [105 °C] for up to 48 hours before subjecting them to tension testing. This is done to minimize discrepancies in testing. Aging treatments are sometimes used for low-hydrogen electrodes, especially when testing high-strength deposits. Note that aging may involve holding test specimens at room temperature for several days or holding at a higher temperature for a shorter period of time. Consequently, users are cautioned to employ adequate preheat and interpass temperatures to avoid the deleterious effects of hydrogen in production welds.

A6.4 When weldments are given a postweld heat treatment, the temperature and time at temperature are very important. The tensile and yield strengths are generally decreased as postweld heat treatment temperatures and time at temperature are increased.

A6.5 Welds made with electrodes of the same classification and the same welding procedure will have significantly different tensile and yield strengths in the as-welded and postweld heat-treated conditions. Comparison of the values for as-welded and postweld heat-treated (1150 °F [620 °C] for one hour) weld metal will show the following:

A6.5.1 The tensile strength of the postweld heat-treated weld metal will be approximately 5 ksi [35 MPa] lower than that of the weld metal in the as-welded condition.

A6.5.2 The yield strength of the postweld heat-treated weld metal will be approximately 10 ksi [70 MPa] lower than that of the weld metal in the as-welded condition.

A6.6 Conversely, postweld heat-treated welds made with the same electrodes and using the same welding procedure except for variation in interpass temperature and postweld heat treatment time, can have almost identical tensile and yield strengths. As an example, almost identical tensile and yield strengths may be obtained in two welds, one using an interpass temperature of 300 °F [150 °C] and postweld heat-treated for 1 hour at 1150 °F [620 °C], and the other using an interpass temperature of 212 °F [100 °C] and postweld heat-treated for 10 hours at 1150 °F [620 °C].

A6.7 Electrodes which meet all the requirements of any given classification may be expected to have similar characteristics. Certain minor differences continue to exist from one brand to another due to differences in preferences that exist regarding specific operating characteristics. Furthermore, the only differences between the present E60XX and E70XX [E43XX and E49XX] classifications are the differences in chemical composition and mechanical properties of the weld metal, as shown in Tables 4, 5, and 6. In many applications, electrodes of either E60XX or E70XX [E43XX or E49XX] classifications may be used.

A6.8 Since the electrodes within a given classification have similar operating characteristics and mechanical properties, the user can limit the study of available electrodes to those within a single classification after determining which classification best suits the particular requirements.

A6.9 This specification does not establish values for all characteristics of the electrodes falling within a given classification, but it does establish values to measure those of major importance. In some instances, a particular characteristic is common to a number of classifications and testing for it is not necessary. In other instances, the characteristics are so intangible that no adequate tests are available. This specification does not necessarily provide all the information needed to determine which classification will best fulfill a particular need. The information included in Annex Clause A7 regarding typical applications for each classification supplements information given elsewhere in the specification and is intended to provide assistance in making electrode selections. However, it must be noted that it is the fabricator's responsibility to ensure that the electrode selected will satisfy all of the performance requirements for the intended applications under the specific fabrication conditions in use.

A6.10 Some important tests for measuring major electrode characteristics are as follows:

A6.10.1 Radiographic Test. Nearly all of the carbon steel electrodes covered by this specification are capable of producing welds that meet most radiographic soundness requirements. However, if incorrectly applied, unsound welds may be produced by any of the electrodes. For electrodes of some classifications, the radiographic requirements in Figure 8 are not necessarily indicative of the average radiographic soundness to be expected in production use. Electrodes of the E6010 [E4310], E6011 [E4311], E6019 [E4319], and E6020 [E4320] classifications can be expected to produce acceptable radiographic results.

Under certain conditions, notably in welding long, continuous joints in relatively thick base metal, low-hydrogen electrodes of the E7015 [E4915], E7016 [E4916], E7018 [E4918], and E7018M [E4918M] classifications will often produce even better results. On the other hand, in joints open to the atmosphere on the root side, at the ends of joints, in joints with many stops and starts, and in welds on small diameter pipe or in small, thin, irregularly shaped joints, the low-hydrogen electrodes tend to produce welds of poor radiographic soundness. For the shielded metal arc process, E6013 [E4313] electrodes usually produce the best radiographic soundness in welding small, thin parts.

E6027 [E4327], E7024 [E4924], and E7028 [E4928] electrodes produce welds which may be either quite good or rather inferior in radiographic soundness. The tendency seems to be in the latter direction. Of all types, the E6022 [E4322] and E6012 [E4312] electrodes generally produce welds with the least favorable radiographic soundness.

A6.10.2 Fillet Weld Test This test is included as a means of demonstrating the usability of an electrode. The test is concerned with the appearance of the weld (i.e., weld face contour and smoothness, undercut, overlap, size, and resistance to cracking). It also provides an excellent and inexpensive method of determining the adequacy of fusion at the weld root (one of the important considerations for an electrode). Test results may be influenced by the level of welder skill.

A6.10.3 Toughness. Charpy V-notch impact requirements are included in the specification. All classifications of electrodes in the specification can produce weld metal of sufficient toughness for many applications. The inclusion of impact requirements for certain electrode classifications allows the specification to be used as a guide in selecting electrodes where low-temperature toughness is required. There can be considerable variation in the weld-metal toughness unless particular attention is given to the welding procedure and the preparation and testing of the specimens. The impact energy values are for Charpy V-notch specimens and should not be confused with values obtained with other toughness tests.

A6.11 Electrode Covering Moisture Content and Conditioning

A6.11.1 Hydrogen can have adverse effects on welds in some steels under certain conditions. One source of this hydrogen is moisture in the electrode coverings. For this reason, the proper storage, treatment, and handling of electrodes are necessary.

A6.11.2 Electrodes are manufactured to be within acceptable moisture limits, consistent with the type of covering and strength of the weld metal. They are then normally packaged in a container, which has been designed to provide the degree of moisture protection considered necessary for the type of covering involved.

A6.11.3 If there is a possibility that the noncellulosic covered electrodes may have absorbed excessive moisture, they may be reconditioned by rebaking. Some electrodes require rebaking at a temperature as high as 800 °F [425 °C] for approximately 1 to 2 hours. The manner in which the electrodes have been produced and the relative humidity and temperature conditions under which the electrodes are stored determine the proper length of time and temperature used for conditioning. Some typical storage and drying conditions are included in Table A1.

A6.11.4 Cellulosic coverings for E6010 [E4310] and E6011 [E4311] electrodes need moisture levels of approximately 3% to 7% for proper operation. Therefore, storage or conditioning above ambient temperature may dry these electrodes too much and adversely affect their operation (see Table A1).

A6.12 Core Wire. The core wire for all the electrodes in this specification is usually a mild steel having a typical composition which may differ significantly from that of the weld metal produced by the covered electrode.

A6.13 Coverings

A6.13.1 Electrodes of some classifications have substantial quantities of iron and other metal powders added to their coverings. (Use of the term “iron powder” herein is intended to include metal powders added to the coating for alloying of the weld metal.) The iron powder fuses with the core wire as the electrode melts, and is deposited as part of the weld metal, just as is the core wire and other metals in the covering. Relatively high currents can be used since a considerable portion of the electrical energy passing through the electrode is used to melt the thicker covering containing iron powder. The result is that more weld metal may be obtained from a single electrode with iron powder in its covering than from a single electrode of the same size without iron powder.

A6.13.2 Due to the thick covering and deep cup produced at the arcing end of the electrode, iron powder electrodes can be used very effectively with a “drag” technique. This technique consists of keeping the electrode covering in contact with the workpiece at all times, which makes for easy handling. However, a technique using a short arc length is preferable if the 3/32 in [2.5 mm] or 1/8 in [3.2 mm] electrodes are to be used in other than flat or horizontal fillet welding positions or for making groove welds.

A6.13.3 The E70XX [E49XX] electrodes were included in this specification to recognize the higher strength levels obtained with many of the iron powder and low hydrogen electrodes, as well as to recognize the industry demand for electrodes with 70 ksi [490 MPa] minimum tensile strength. Unlike the E70XX-X [E49XX-X] classifications in AWS A5.5/A5.5M, these electrodes do not contain deliberate alloy additions, nor are they required to meet minimal tensile properties after postweld heat treatment.

A6.13.4 E70XX [E49XX] low-hydrogen electrodes have mineral coverings which are high in limestone and other ingredients that are low in moisture and hence produce weld deposits “low in hydrogen content.” Low-hydrogen electrodes were developed for welding low-alloy high-strength steels, some of which were high in carbon content. Electrodes with other than low-hydrogen coverings may produce “hydrogen-induced cracking” in those steels. These underbead cracks occur in the base metal, usually just below the weld bead. Weld metal cracks may also occur.

Low-hydrogen electrodes should be used when welding high-sulfur or enameling steels. Other electrodes are likely to cause porosity and/or cracks in high-sulfur steels. With enameling steels, the hydrogen that escapes after welding with other than low-hydrogen electrodes produces holes in the enamel.

Some extra-low hydrogen (H4) electrode coatings may be prone to reduced operability and producing unacceptable porosity. The unacceptable condition is usually associated with varying or excessive arc length and is highly dependent on operator skill level.

A6.14 Welding Parameters. Appropriate parameters vary by product, polarity, welding position, etc. The electrode manufacturer should be consulted for recommended parameters.

A7. Description and Intended Use of Electrodes

A7.1 E6010 [E4310] Classification

A7.1.1 E6010 [E4310] electrodes are characterized by a deeply penetrating, forceful, spray type arc and readily removable, thin, friable slag which may not seem to completely cover the weld bead. Fillet welds usually have a relatively flat weld face and have a rather coarse, unevenly spaced ripple. The coverings are high in cellulose, usually exceeding 30% by weight. The other materials generally used in the covering include titanium dioxide, metallic deoxidizers such as ferromanganese, various types of magnesium or aluminum silicates, and liquid sodium silicate as a binder. Because of their covering composition, these electrodes are generally described as the high-cellulose sodium type.

A7.1.2 These electrodes are recommended for all welding positions, particularly on multiple pass applications in the vertical and overhead welding positions and where welds of good soundness are required. They frequently are selected for joining pipe and generally are capable of welding in the vertical position with either uphill or downhill progression.

A7.1.3 The majority of applications for these electrodes is in joining carbon steel. However, they have been used to advantage on galvanized steel and on some low-alloy steels. Typical applications include shipbuilding, buildings, bridges, storage tanks, piping, and pressure vessel fittings. Since the applications are so widespread, a discussion of each is impractical. Sizes larger than 3/16 in [5.0 mm] generally have limited use in other than flat or horizontal-fillet welding positions.

A7.1.4 These electrodes have been designed for use with dcep (electrode positive). The maximum amperage that can generally be used with the larger sizes of these electrodes is limited in comparison to that for other classifications due to the high spatter loss that occurs with high amperage.

A7.2 E6011 [E4311] Classification

A7.2.1 E6011 [E4311] electrodes are designed to be used with ac current and to duplicate the usability characteristics and mechanical properties of the E6010 [E4310] classification. Although also usable with dcep (electrode positive), a decrease in joint penetration will be noted when compared to the E6010 [E4310] electrodes. Arc action, slag, and fillet weld appearance are similar to those of the E6010 [E4310] electrodes.

A7.2.2 The coverings are also high in cellulose and are described as the high-cellulose potassium type. In addition to the other ingredients normally found in E6010 [E4310] coverings, small quantities of calcium and potassium compounds usually are present.

A7.2.3 Sizes larger than 3/16 in [5.0 mm] generally have limited use in other than flat or horizontal-fillet welding positions.

A7.3 E6012 [E4312] Classification

A7.3.1 E6012 [E4312] electrodes are characterized by low penetrating arc and dense slag, which completely covers the bead. This may result in incomplete root penetration in fillet welded joints. The coverings are high in titania, usually exceeding 35% by weight, and usually are referred to as the "titania" or "rutile" type. The coverings generally also contain small amounts of cellulose and ferromanganese, and various siliceous materials such as feldspar and clay with sodium silicate as a binder. Also, small amounts of certain calcium compounds may be used to produce satisfactory arc characteristics on dcen (electrode negative).

A7.3.2 Fillet welds tend to have a convex weld face with smooth even ripples in the horizontal welding position, and widely spaced rougher ripples in the vertical welding position which become smoother and more uniform as the size of the weld is increased. Ordinarily, a larger size fillet must be made in the vertical and overhead welding positions using E6012 [E4312] electrodes compared to welds with E6010 [E4310] and E6011 [E4311] electrodes of the same diameter.

A7.3.3 The E6012 [E4312] electrodes are all-position electrodes and usually are suitable for welding in the vertical welding position with either the upward or downward progression. However, more often the larger sizes are used in the flat and horizontal welding positions rather than in the vertical and overhead welding positions. The larger sizes are often used for single pass, high-speed, high current fillet welds in the horizontal welding position. Their ease of handling, good fillet weld face, and ability to bridge wide root openings under conditions of poor fit, and to withstand high amperages make them very well suited to this type of work. The electrode size used for vertical and overhead position welding is frequently one size smaller than would be used with an E6010 [E4310] or E6011 [E4311] electrode.

A7.3.4 Weld metal from these electrodes is generally lower in ductility and may be higher in yield strength (1 ksi to 2 ksi [7 MPa to 14 MPa]) than weld metal from the same size of either the E6010 [E4310] or E6011 [E4311] electrodes.

A7.4 E6013 [E4313] Classification

A7.4.1 E6013 [E4313] electrodes, although very similar to the E6012 [E4312] electrodes, have distinct differences. Their flux covering makes slag removal easier and gives a smoother arc transfer than E6012 [E4312] electrodes. This is particularly the case for the small diameters 1/16 in, 5/64 in, and 3/32 in [1.6 mm, 2.0 mm, and 2.5 mm]. This permits satisfactory operation with lower open-circuit ac voltage. E6013 [E4313] electrodes were designed specifically for light sheet metal work. However, the larger diameters are used on many of the same applications as E6012 [E4312] electrodes and provide low penetrating arc. The smaller diameters provide a less penetrating arc than is obtained with E6012 [E4312] electrodes. This may result in incomplete penetration in fillet welded joints.

A7.4.2 Coverings of E6013 [E4313] electrodes contain rutile, cellulose, ferromanganese, potassium silicate as a binder, and other siliceous materials. The potassium compounds permit the electrodes to operate with ac at low amperages and low open-circuit voltages.

A7.4.3 E6013 [E4313] electrodes are similar to the E6012 [E4312] electrodes in usability characteristics and bead appearance. The arc action tends to be quieter and the bead surface smoother with a finer ripple. The usability characteristics of E6013 [E4313] electrodes vary slightly from brand to brand. Some are recommended for sheet metal applications where their ability to weld satisfactorily in the vertical welding position with downward progression is an advantage.

Others, with a more fluid slag, are used for horizontal fillet welds and other general purpose welding. These electrodes produce a flat fillet weld face rather than the convex weld face characteristic of E6012 [E4312] electrodes. They are also suitable for making groove welds because of their concave weld face and easily removable slag. In addition, the weld metal is definitely free of slag and oxide inclusions than E6012 [E4312] weld metal and exhibits better soundness. Welds with the smaller diameter E6013 [E4313] electrodes often meet the Grade 1 radiographic requirements of this specification.

A7.4.4 E6013 [E4313] electrodes usually cannot withstand the high amperages that can be used with E6012 [E4312] electrodes in the flat and horizontal welding positions. Amperages in the vertical and overhead positions, however, are similar to those used with E6012 [E4312] electrodes.

A7.5 E7014 [E4914] Classification

A7.5.1 E7014 [E4914] electrode coverings are similar to those of E6012 [E4312] and E6013 [E4313] electrodes, but with the addition of iron powder for obtaining higher deposition efficiency. The covering thickness and the amount of iron powder in E7014 [E4914] are less than in E7024 [E4924] electrodes (see A7.10).

A7.5.2 The iron powder also permits the use of higher amperages than are used for E6012 [E4312] and E6013 [E4313] electrodes. The amount and character of the slag permit E7014 [E4914] electrodes to be used in all positions.

A7.5.3 The E7014 [E4914] electrodes are suitable for welding carbon and low alloy steels. Typical weld beads are smooth with fine ripples. Joint penetration is approximately the same as that obtained with E6012 [E4312] electrodes (see A7.3.1), which is advantageous when welding over a wide root opening due to poor fit. The face of fillet welds tends to be flat to slightly convex. The slag is easy to remove. In many cases, it removes itself.

A7.6 Low-Hydrogen Electrodes

A7.6.1 Electrodes of the low-hydrogen classifications E6018 [E4318], E7015 [E4915], E7016 [E4916], E7018 [E4918], E7018M [E4918M], E7028 [E4928], and E7048 [E4948]) are made with inorganic coverings that contain minimal moisture. The covering moisture test such as specified in AWS A4.4M, converts hydrogen-bearing compounds in any form in the covering into water vapor that is collected and measured. The test thus assesses the potential hydrogen available from an electrode covering. All low-hydrogen electrodes, in the as-manufactured condition or after conditioning, are expected to meet a maximum covering moisture limit of 0.6% or less, as required in Table 10.

A7.6.2 The relative potential of an electrode to contribute to diffusible hydrogen in the weld metal can be assessed more directly, but less conveniently, by the diffusible hydrogen test, as specified in Clause 18. The results of this test, using electrodes in the as-manufactured condition or after conditioning, permit the addition of an optional supplemental diffusible hydrogen designator to the classification designation according to Table 11.

A7.6.3 In order to maintain low-hydrogen electrodes with minimal moisture in their coverings, these electrodes should be stored and handled with considerable care. Electrodes which have been exposed to humidity may absorb considerable moisture and their low-hydrogen character may be lost. Then conditioning can restore their low-hydrogen-character (see Table A.1).

A7.6.4 Low-hydrogen electrode coverings can be designed to resist moisture absorption for a considerable time in a humid environment. The absorbed moisture test (see Clause 17) assesses this characteristic by determining the covering moisture after nine hours exposure to 80 °F [27 °C], 80% relative humidity air. If, after this exposure, the covering moisture does not exceed 0.4%, then the optional supplemental designator, “R,” may be added to the electrode classification designation, as specified in Table 10.

A7.6.5 E7015 [E4915] Classification (Low Hydrogen)

A7.6.5.1 E7015 [E4915] electrodes are low-hydrogen electrodes to be used with dcep (electrode positive). The slag is chemically basic.

A7.6.5.2 E7015 [E4915] electrodes are commonly used for making small welds on thick base metal, since the welds are less susceptible to cracking. They are also used for welding high-sulfur and enameling steels. Welds made with E7015 [E4915] electrodes on high-sulfur steels may produce a very tight slag and a very rough or irregular bead appearance in comparison to welds with the same electrodes in steels of normal sulfur content.

A7.6.5.3 The arc of E7015 [E4915] electrodes is moderately penetrating. The slag is heavy, friable, and easy to remove. The weld face is convex, although a fillet weld face may be flat.

A7.6.5.4 E7015 [E4915] electrodes up to and including the 5/32 in [4.0 mm] size are used in all welding positions. Larger electrodes are used for groove welds in the flat welding position and fillet welds in the horizontal and flat welding positions.

A7.6.5.5 Amperages for E7015 [E4915] electrodes are higher than those used with E6010 [E4310] electrodes of the same diameter. The shortest possible arc length should be maintained for best results with E7015 [E4915] electrodes. This reduces the risk of porosity. The necessity for preheating is reduced; therefore, better welding conditions are provided.

A7.6.6 E7016 [E4916] Classification

A7.6.6.1 E7016 [E4916] electrodes have all the characteristics of E7015 [E4915] electrodes, plus the ability to operate on ac. The core wire and coverings are very similar to those of E7015 [E4915], except for the use of a potassium silicate binder or other potassium salts in the coverings to facilitate their use with ac. Most of the preceding discussion on E7015 [E4915] electrodes applies equally well to the E7016 [E4916] electrodes. The discussion in A6.13.4 also applies.

A7.6.6.2 Electrodes designated as E7016-1 [E4916-1] have the same usability and weld metal composition as E7016 [E4916] electrodes except that the manganese content is set at the high end of the range. They are intended for welds requiring a lower transition temperature than is normally available from E7016 [E4916] electrodes.

A7.6.7 E6018 [E4318] and E7018 [E4918] Classifications

A7.6.7.1 E7018 [E4918] electrode coverings are similar to E7015 [E4915] coverings, except for the addition of a relatively high percentage of iron powder. The coverings on these electrodes are slightly thicker than those of the E7016 [E4916] electrodes.

A7.6.7.2 E7018 [E4918] low-hydrogen electrodes can be used with either ac or dcep. They are designed for the same applications as the E7016 [E4916] electrodes. As is common with all low-hydrogen electrodes, a short arc length should be maintained at all times.

A7.6.7.3 In addition to their use on carbon steel, the E7018 [E4918] electrodes are also used for joints involving high-strength, high-carbon, or low-alloy steels (see also A6.13). The fillet welds made in the horizontal and flat welding positions have a slightly convex weld face, with a smooth and finely rippled surface. The electrodes are characterized by a smooth, quiet arc, very low spatter, and medium arc penetration. E7018 [E4918] electrodes can be used at high travel speeds.

A7.6.7.4 Electrodes designated as E7018-1 [E4918-1] have the same usability and weld metal composition as E7018 [E4918] electrodes, except that the manganese content is set at the high end of the range. They are intended for welds requiring a lower transition temperature than is normally available from E7018 [E4918] electrodes.

A7.6.7.5 E6018 [E4318] electrodes possess operating and mechanical property characteristics similar to E7018 [E4918] except at a lower strength level. The electrode covering and low hydrogen characteristics are also similar. This electrode is desirable where matching or undermatching weld deposit is required. Electrodes that meet this classification may also be suitable for buffer layer application in cladding operations.

A7.6.8 E7018M [E4918M] Classification

A7.6.8.1 E7018M [E4918M] electrodes are similar to E7018-1H4R [E4918-1H4R] electrodes, except that the testing for mechanical properties and for classification is done on a groove weld that has a 60° included angle and, for electrodes up to 5/32 in [4.0mm], welded in the vertical position with upward progression. The impact test results are evaluated using all five test values and higher values are required at -20 °F [-30 °C]. The maximum allowable moisture-in-coating values in the “as-received” or reconditioned state are more restrictive than that required for E7018R [E4918R]. This classification closely corresponds to MIL-7018-M in the United States military standard MIL-E-22200/10 specification, with the exception that the absorbed moisture limits on the electrode covering and the diffusible hydrogen limits on the weld metal are not as restrictive as those in MIL-E-22200/10.

A7.6.8.2 E7018M [E4918M] is intended to be used with dcep type current in order to produce the optimum mechanical properties. However, if the manufacturer desires, the electrode may also be classified as E7018 [E4918] provided all the requirements of E7018 [E4918] are met.

A7.6.8.3 In addition to their use on carbon steel, the E7018M [E4918M] electrodes are used for joining carbon steel to high-strength low-alloy steels and higher carbon steels. Fillet welds made in the horizontal and flat welding positions have a slightly convex weld face, with a smooth and finely rippled surface. The electrodes are characterized by a smooth, quiet arc, very low spatter, and medium arc penetration.

A7.6.9 E7028 [E4928] Classification

A7.6.9.1 E7028 [E4928] electrodes are very much like the E7018 [E4918] electrodes. However, E7028 [E4928] electrodes are suitable for fillet welds in the horizontal welding position and groove welds in the flat welding position only, whereas E7018 [E4918] electrodes are suitable for all positions.

A7.6.9.2 The E7028 [E4928] electrode coverings are much thicker. They make up approximately 50% of the weight of the electrodes. The iron content of E7028 [E4928] electrodes is higher (approximately 50% of the weight of the coverings). Consequently, on fillet welds in the horizontal position and groove welds in the flat welding position, E7028 [E4928] electrodes give a higher deposition rate than the E7018 [E4918] electrodes for a given size of electrode.

A7.6.10 E7048 [E4948] Classification. Electrodes of the E7048 [E4948] classification have the same usability, composition, and design characteristics as E7018 [E4918] electrodes, except that E7048 [E4948] electrodes are specifically designed for exceptionally good vertical welding with downward progression (see Table 1).

A7.7 E6019 [E4319] Classification

A7.7.1 E6019 [E4319] electrodes, although very similar to E6013 and E6020 [E4313 and E4320] electrodes in their coverings, have distinct differences. E6019 [E4319] electrodes, with a rather fluid slag system, provide deeper arc penetration and produce weld metal that meets a 22% minimum elongation requirement, meets the Grade 1 radiographic standards, and meets an average impact *energy* of 20 ft-lbf [27J] when tested at 0 °F [-20 °C].

A7.7.2 E6019 [E4319] electrodes are suitable for multipass welding of up to 1 in [25 mm] thick steel. They are designed for use with ac, dcen, or dcep. While 3/16 in [5.0 mm] and smaller diameter electrodes can be used for all welding positions (except vertical welding position with downward progression), the use of larger diameter electrodes should be limited to the flat or horizontal fillet welding positions. When welding in the vertical welding position with upward progression, weaving should be limited to minimize undercut.

A7.8 E6020 [E4320] Classification

A7.8.1 E6020 [E4320] electrodes have a high iron oxide covering. They are characterized by a spray type arc, produce a smooth and flat or slightly concave weld face, and have an easily removable slag.

A7.8.2 A low viscosity slag limits their usability to horizontal fillets and flat welding positions. With arc penetration ranging from medium to deep (depending upon welding current), E6020 [E4320] electrodes are best suited for thicker base metal.

A7.9 E6022 [E4322] Classification. Electrodes of the E6022 [E4322] classification are recommended for single-pass, high-speed, high-current welding of groove welds in the flat welding position, lap joints in the horizontal welding position, and fillet welds on sheet metal. The weld face tends to be more convex and less uniform, especially since the welding speeds are higher. *The common usage of E6022 is for burn-thru spot welding, such as connecting floor decking to beams. These electrodes provide deep penetration with little slag interference with the arc.*

A7.10 E7024 [E4924] Classification

A7.10.1 E7024 [E4924] electrode coverings contain large amounts of iron powder in combination with ingredients similar to those used in E6012 and E6013 [E4312 and E4313] electrodes. The coverings on E7024 [E4924] electrodes are very thick and usually amount to about 50% of the weight of the electrode, resulting in higher deposition efficiency.

A7.10.2 The E7024 [E4924] electrodes are well suited for making fillet welds in the flat or horizontal position. The weld face is slightly convex to flat, with a very smooth surface and a very fine ripple. These electrodes are characterized by a smooth, quiet arc, very low spatter, and low arc penetration. They can be used with high travel speeds. Electrodes of these classifications can be operated on ac, dcep, or dcen.

A7.10.3 Electrodes designated as E7024-1 [E4924-1] have the same general usability characteristics as E7024 [E4924] electrodes. They are intended for use in situations requiring greater ductility and a lower transition temperature than normally is available from E7024 [E4924] electrodes. *These electrodes have less stringent radiographic requirements than other classifications.*

A7.11 E6027 [E4327] Classification

A7.11.1 E6027 [E4327] electrode coverings contain large amounts of iron powder in combination with ingredients similar to those found in E6020 [E4320] electrodes. The coverings on E6027 [E4327] electrodes are also very thick and usually amount to about 50% of the weight of the electrode.

A7.11.2 The E6027 [E4327] electrodes are designed for fillet or groove welds in the flat welding position with ac, dcep, or dcen, and will produce a flat or slightly concave weld face on fillet welds in the horizontal position with either ac or dcen.

A7.11.3 E6027 [E4327] electrodes have a spray-type arc. They will operate at high travel speeds. Arc penetration is medium. Spatter loss is very low. E6027 [E4327] electrodes produce a heavy slag which is honeycombed on the underside. The slag is friable and easily removed.

A7.11.4 Welds produced with E6027 [E4327] electrodes have a flat to slightly concave weld face with a smooth, fine, even ripple, and good wetting along the sides of the joint. The weld metal may be slightly inferior in radiographic soundness to that from E6020 [E4320] electrodes. High amperages can be used, since a considerable portion of the electrical energy passing through the electrode is used to melt the covering and the iron powder it contains. These electrodes are well suited for thicker base metal.

A7.12 E7027 [E4927] Classification. E7027 [E4927] electrodes have the same usability and design characteristics as E6027 [E4327] electrodes, except they are intended for use in situations requiring slightly higher tensile and yield strengths than are obtained with E6027 [E4327] electrodes. They must also meet chemical composition requirements (see Table 6). In other respects, all previous discussions for E6027 [E4327] electrodes also apply to E7027 [E4927] electrodes.

A8. Special Tests

It is recognized that supplementary tests may be necessary for certain applications. In such cases, tests to determine specific properties such as hardness, corrosion resistance, mechanical properties at elevated or cryogenic temperatures, wear resistance, and suitability for welding different carbon and low-alloy steels, may be required. AWS A5.01M/A5.01 contains provisions for ordering such tests. This clause is included for the guidance of those who desire to specify such special tests. Those tests may be conducted as agreed upon between the purchaser and supplier.

A8.1 Diffusible Hydrogen Test.

A8.1.1 Hydrogen-induced cracking of weld metal or the heat affected zone generally is not a problem with carbon steels containing 0.3% or less carbon, or with lower-strength alloy steels. However, the electrodes classified in this specification are sometimes used to join higher carbon steels or low-alloy, high-strength steels where hydrogen-induced cracking may be a serious problem.

A8.1.2 Since the available diffusible hydrogen level strongly influences the tendency towards hydrogen-induced cracking, it may be desirable to measure the diffusible hydrogen content resulting from welding with a particular electrode. This specification has, therefore, included the use of optional designators for diffusible hydrogen to indicate the maximum average value obtained under a clearly defined test condition in AWS A4.3.

A8.1.3 The user of this information is cautioned that actual fabrication conditions may result in different diffusible hydrogen values than those indicated by the designator.

A8.1.4 The use of a reference atmospheric condition during welding is necessitated because the arc is subject to atmospheric contamination due to imperfect shielding. Moisture from the air, distinct from that in the electrode, can enter the arc and subsequently the weld pool, contributing to the resulting observed diffusible hydrogen. This effect can be minimized by maintaining as short an arc length as possible consistent with a steady arc. Experience has shown that the effect of arc length is minor at the H16 level, but can be very significant at the H4 level. An electrode meeting the H4 requirements under the reference atmospheric conditions may not do so under conditions of high humidity at the time of welding, especially if a long arc length is maintained.

A8.1.5 Low-hydrogen electrodes can absorb significant moisture if stored in a humid environment in damaged or open packages, or especially if unprotected for long periods of time. In the worst cases of high humidity, even exposure of unprotected electrodes for as little as two hours can lead to a significant increase of diffusible hydrogen. In the event the electrodes have been exposed, the manufacturer should be consulted regarding probable damage to low hydrogen characteristics and possible reconditioning of the electrodes.

A8.1.6 Not all classifications may be available in H16, H8, and H4 diffusible hydrogen levels. The manufacturer of a given electrode should be consulted for availability of products meeting these limits.

A8.2 Aging of Tensile Specimens. Weld metals may contain significant quantities of hydrogen for some time after they have been made. Most of this hydrogen gradually escapes over time. This may take several weeks at room temperature or several hours at elevated temperatures. As a result of this eventual change in hydrogen level, ductility of the weld metal increases toward its inherent value, while yield, tensile and impact properties remain relatively unchanged. The A5.1 and A5.1M specifications permit the aging of the test specimens or weld test assembly for non-low hydrogen electrodes at elevated temperatures not exceeding 220 °F [105 °C] for up to 48 hours before cooling them to room temperature and subjecting them to testing. The purpose of this treatment is to facilitate removal of hydrogen from the test specimen in order to narrow the variation in the test results.

Aging treatments are sometimes used for low-hydrogen electrode deposits, especially when testing high-strength deposits. Note that aging may involve holding test specimens at room temperature for several days or holding at a higher temperature for a shorter period of time. Consequently, users are cautioned to employ adequate preheat and interpass temperatures to avoid the deleterious effects of hydrogen in production welds. It should be kept in mind that aging test assemblies may not remove as much diffusible hydrogen as aging the individual specimens. The purchaser may, by mutual agreement with the supplier, have the thermal aging of specimens prohibited for all mechanical testing done to schedule I or J of AWS A5.01M/A5.01.

A8.3 Absorbed Moisture Test. The development of low-hydrogen electrode coverings that resist moisture absorption during exposure to humid air is a more recent improvement in covered electrode technology. Not all commercial low-hydrogen electrodes possess this characteristic. To assess this characteristic, the absorbed moisture test described in Clause 17 was devised. The exposure conditions selected for the test are arbitrary. Other conditions may yield quite different results.

A task group of the AWS A5A Subcommittee evaluated this test and concluded that it can successfully differentiate moisture resistant electrodes from those which are not. The task group also observed considerable variability of covering moisture results after exposure of electrodes in cooperative testing among several laboratories. The precision of the test is such that, with moisture resistant electrodes from a single lot, the participating laboratories could observe exposed

covering moisture values ranging, for example, from 0.15% or less, to 0.35% or more. The task group concluded that the variability was due to both variations in the exposure conditions and the variability inherent in the application of the moisture test procedure. Therefore, it is not realistic to set a limit for covering moisture of exposed moisture resistant electrodes lower than 0.4% at that time.

A9. Discontinued Classifications

Some classifications have been discontinued from one revision of this specification to another. This results either from changes in commercial practice or changes in the classification system used in the specification. The classifications that have been discontinued are listed in Table A.2, along with the year in which they were last included in the specification.

A10. General Safety Considerations

A10.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Annex Clause A5. Safety and health information is available from other sources, including, but not limited to AWS Safety and Health Fact Sheets and ANSI Z49.1 and applicable federal and state regulations.

A10.2 Safety and Health Fact Sheets. The Safety and Health Fact Sheets are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

Table A.1
Typical Storage and Drying Conditions for Covered Arc Welding Electrodes

AWS Classification		Storage Conditions ^{a, b}		Drying Conditions ^c
A5.1	A5.1M	Ambient Air	Holding Ovens	
E6010, E6011	E4310, E4311	Ambient Temperature	Not Recommended	
E6012, E6013, E6019, E6020, E6022, E6027, E7014, E7024, E7027	E4312, E4313, E4319, E4320, E4322, E4327, E4914, E4924, E4927	80 °F ± 20 °F [30 °C ± 10 °C] 50% max. relative humidity	20 °F to 40 °F [10 °C to 20 °C] above ambient temperature	275 °F ± 25 °F [135 °C ± 15 °C] 1 hour at temperature
E6018, E7015, E7016, E7018, E7028 E7018M, E7048	E4318, E4915, E4916, E4918, E4928, E4918M, E4948	Not Recommended	50 °F to 250 °F [30 °C to 140 °C] above ambient temperature	500 °F to 800 °F [260 °C to 425 °C] 1 to 2 hours at temperature
E60-G, E70-G	E43-G, E49-G	Manufacturer should be consulted for specific storage and drying recommendations	Manufacturer should be consulted for specific storage and drying recommendations	Manufacturer should be consulted for specific storage and drying recommendations

^a After removal from manufacturer's packaging.

^b Some of these electrode classifications may be designated as meeting low moisture absorbing requirements. This designation does not imply that storage in ambient air is recommended.

^c Because of inherent differences in covering composition, the manufacturers should be consulted for the exact drying conditions.

Table A.2
Discontinued Electrode Classifications^a

AWS Classification	Last A5.1 (ASTM A-233) Publication Date	AWS Classification	Last A5.1 (ASTM A-233) Publication Date
E4511	1943	E9030	1945
E4521	1943	E10010 ^b	1945
E7010 ^b	1945	E10011 ^b	1945
E7011 ^b	1945	E10012	1945
E7012	1945	E10020	1945
E7020 ^b	1945	E10030	1945
E7030	1945	E4510	1958
E8010 ^b	1945	E4520	1958
E8011 ^b	1945	E6014	1958
E8012	1945	E6015	1958
E8020 ^b	1945	E6016	1958
E8030	1945	E6018 ^c	1958
E9010 ^b	1945	E6024	1958
E9011 ^b	1945	E6028	1958
E9012	1945	E6030	1958
E9020	1945		

^a See Clause A9 for information on discontinued classifications.

^b These electrode classifications were transferred from the ASTM A233-45T to the new AWS A5.5-48T. They were later discontinued from that specification and replaced with the new "G" classifications in order to permit a single classification system with weld metal chemical composition requirements in AWS A5.5-58T.

^c This classification was reintroduced in the 2004 revision of AWS A5.1/A5.1M with revised classification requirements.

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

B6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

AWS Filler Metal Specifications by Material and Welding Process

	OFW	SMAW	GTAW GMAW PAW	FCAW	SAW	ESW	EGW	Brazing
Carbon Steel	A5.2	A5.1, A5.35	A5.18	A5.20	A5.17	A5.25	A5.26	A5.8, A5.31
Low-Alloy Steel	A5.2	A5.5	A5.28	A5.29	A5.23	A5.25	A5.26	A5.8, A5.31
Stainless Steel		A5.4, A5.35	A5.9, A5.22	A5.22	A5.9, A5.22, A5.39	A5.9, A5.22, A5.39	A5.9	A5.8, A5.31
Cast Iron	A5.15	A5.15	A5.15	A5.15				A5.8, A5.31
Nickel Alloys		A5.11, A5.35	A5.14, A5.34	A5.34	A5.14, A5.34, A5.39	A5.14, A5.34, A5.39		A5.8, A5.31
Aluminum Alloys		A5.3	A5.10					A5.8, A5.31
Copper Alloys		A5.6	A5.7					A5.8, A5.31
Titanium Alloys			A5.16					A5.8, A5.31
Zirconium Alloys			A5.24					A5.8, A5.31
Magnesium Alloys			A5.19					A5.8, A5.31
Tungsten Electrodes			A5.12					
Brazing Alloys and Fluxes								A5.8, A5.31
Surfacing Alloys	A5.21	A5.13	A5.21	A5.21	A5.21			
Consumable Inserts			A5.30					
Shielding Gases			A5.32	A5.32			A5.32	

AWS Filler Metal Specifications and Related Documents

Designation	Title
A4.2M (ISO 8249 MOD)	Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal
A4.3	Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding
A4.4M	Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings
A4.5M/A4.5 (ISO 15792-3 MOD)	Standard Methods for Classification Testing of Positional Capacity and Root Penetration of Welding Consumables in a Fillet Weld
A5.01M/A5.01 (ISO 14344 MOD)	Welding Consumables—Procurement of Filler Materials and Fluxes
A5.02/A5.02M	Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes
A5.1/A5.1M	Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding
A5.2/A5.2M	Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding
A5.3/A5.3M	Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding
A5.4/A5.4M	Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding
A5.5/A5.5M	Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding
A5.6/A5.6M	Specification for Copper and Copper-Alloy Electrodes for Shielded Metal Arc Welding
A5.7/A5.7M	Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes
A5.8M/A5.8	Specification for Filler Metals for Brazing and Braze Welding
A5.9/A5.9M (ISO 14343 MOD)	Specification for Bare Stainless Steel Welding Electrodes and Rods
A5.10/A5.10M (ISO 18273 MOD)	Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods
A5.11/A5.11M	Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding
A5.12M/A5.12 (ISO 6848 MOD)	Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting
A5.13/A5.13M	Specification for Surfacing Electrodes for Shielded Metal Arc Welding
A5.14/A5.14M	Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods
A5.15	Specification for Welding Electrodes and Rods for Cast Iron
A5.16/A5.16M (ISO 24034 MOD)	Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods
A5.17/A5.17M	Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding
A5.18/A5.18M	Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding
A5.19	Specification for Magnesium-Alloy Welding Electrodes and Rods
A5.20/A5.20M	Specification for Carbon Steel Electrodes for Flux Cored Arc Welding
A5.21/A5.21M	Specification for Bare Electrodes and Rods for Surfacing
A5.22/A5.22M	Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods
A5.23/A5.23M	Specification for Low-Alloy and High Manganese Steel Electrodes and Fluxes for Submerged Arc Welding
A5.24/A5.24M	Specification for Zirconium and Zirconium-Alloy Welding Electrodes and Rods
A5.25/A5.25M	Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding
A5.26/A5.26M	Specification for Carbon and Low-Alloy Steel Electrodes for Electrogas Welding
A5.28/A5.28M	Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding
A5.29/A5.29M	Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding
A5.30/A5.30M	Specification for Consumable Inserts
A5.31M/A5.31	Specification for Fluxes for Brazing and Braze Welding
A5.32M/A5.32 (ISO 14175 MOD)	Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes
A5.34/A5.34M	Specification for Nickel-Alloy Flux Cored and Metal Cored Welding Electrodes
A5.35/A5.35M-AMD1	Specification for Covered Electrodes for Underwater Wet Shielded Metal Arc Welding
A5.39/A5.39M	Specification for Flux and Electrode Combinations for Submerged Arc and Electroslag Joining and Surfacing of Stainless Steel and Nickel Alloys

SPECIFICATION FOR CARBON AND LOW-ALLOY STEEL RODS FOR OXYFUEL GAS WELDING



SFA-5.2/SFA-5.2M



(Identical with AWS Specification A5.2/A5.2M:2018. In case of dispute, the original AWS text applies.)

Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding

1. Scope

1.1 This specification prescribes requirements for the classification of carbon and low-alloy steel rods for oxyfuel gas welding.

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to material properties. The specification designated A5.2 uses U.S. Customary Units. The specification designated A5.2M uses SI Units. The latter units are shown within brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing of filler metal or packaging or both under A5.2 and A5.2M specifications.

1.3 *Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in Annexes A5 and A10.*

Safety and Health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets*
- (3) Other safety and health information on AWS website*

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers*
- (2) Operating Manuals supplied by equipment manufacturers*

Applicable federal and state regulations.

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

2.1 The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

2.2 The following AWS standards are referenced in the normative clauses of this document:

- (1) AWS A3.0M/A3.0, *Standard Welding Terms and Definitions; Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*
- (2) A5.01M/A5.01 (ISO 14344 MOD), *Welding Consumables—Procurement of Filler Metals and Fluxes*
- (3) AWS B4.0, *Standard Methods for Mechanical Testing of Welds*
- (4) AWS B4.0M, *Standard Methods for Mechanical Testing of Welds*.

2.3 The following ANSI standard is referenced in the normative clauses of this document:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*.

2.4 The following ASTM standards are referenced in the normative clauses of this document:

- (1) ASTM A36/A36M, *Standard Specification for Carbon Structural Steel*
- (2) ASTM A285/A285M, *Standard Specification for Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength*
- (3) ASTM A514/A514M, *Standard Specification for High-Yield-Strength, Quenched and Tempered Alloy Steel Plate, Suitable for Welding*
- (4) ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*
- (5) ASTM E350, *Standard Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron*

2.5 The following ISO standard is referenced in the normative clauses of this document:

- (1) ISO 544, *Welding consumables—Technical delivery conditions for welding filler materials and fluxes—Type of product, dimensions, tolerances and markings*
- (2) ISO 80000-1, *Quantities and Units—Part 1: General (Corrected by ISO 80000-1:2009/Cor 1:2011)*

3. Classification

3.1 The welding rods covered by this A5.2 specification utilize a classification system based on U.S. Customary Units and are classified according to the mechanical properties of the weld metal in the as-welded condition, as shown in Table 1.

3.1M The welding rods covered by this A5.2M specification utilize a classification system based on the International System of Units (SI) and are classified according to the mechanical properties of the weld metal in the as-welded condition, as shown in Table 1.

3.2 Welding rods classified under one classification shall not be classified under any other classification in this specification. A welding rod may be classified under both A5.2 and A5.2M providing it meets the requirements of both specifications.

3.3 The welding rods classified under this specification are intended for oxyfuel gas welding, but that is not to prohibit their use with any other process for which they are found suitable.

4. Acceptance

Acceptance¹ of the welding rods shall be in accordance with the provisions of AWS A5.01M/A5.01 (ISO 14344 MOD).

¹ See Annex Clause A3 for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01 (ISO 14344 MOD).

Table 1
Tension Test Requirements

AWS Classification		Minimum Tensile Strength ^a		Elongation in 1 in [25 mm] Percent, Min.
A5.2	A5.2M	ksi	MPa	
R45	RM30	Not Specified		Not Specified
R60	RM40	60	400	20
R65	RM45	65	450	16
R100	RM69	100	690	14
R(X)XX-G ^b	RMXX-G ^c	(X)XX ^b	XX ^c	Not Specified

^a Specimens shall be tested in the as-welded condition.

^b For specification A5.2, classifications R(X)XX-G should be based on minimum tensile strength of all-weld-metal tension test of the test assembly, expressed in multiples of 1000 psi. These designators shall be limited to 45, 60, 65, and 100.

^c For specification A5.2M, classification RMXX-G shall be based on minimum tensile strength of all-weld-metal tension test of the test assembly, expressed in multiples of 10 MPa. These designators shall be limited to 30, 40, 45, and 69.

5. Certification

By affixing the AWS specification and classification designations to the packaging, or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification.²

6. Rounding Procedure

For the purpose of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest 1000 psi (1 ksi) for tensile strength for A5.2, and to the nearest 10 MPa for tensile strength for A5.2M, and to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfill the requirements for the classification under test.

7. Summary of Tests

The tests required for each classification are specified in Table 2. The purpose of these tests is to determine the chemical composition of the welding rod and the mechanical properties of the weld metal. The base metal for the preparation of test samples, the testing procedures to be employed, and the results required are given in Clauses 9 through 11.

Table 2
Required Tests

AWS Classification		Chemical Analysis	Tension Test
A5.2	A5.2M		
R45	RM30	Required	Not required
R60	RM40	Required	Required
R65	RM45	Required	Required
R100	RM69	Required	Required
R(X)XX-G	RMXX-G	Not required	Required

² See Annex Clause A4 for further information concerning certification and the testing called for to meet this requirement.

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Specimens or samples for retest may be taken from the original test assembly or sample, or from a new test assembly or sample. For chemical analysis, the retest need be only for those specific elements that failed to meet the test requirement. If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that, during preparation or after completion of any test, it is clearly determined that specified or proper procedures were not followed in preparing the weld test assembly, or in conducting the test, the test shall be considered invalid, without regard to whether the test was actually completed, or whether the test results met, or failed to meet, the requirement. That test shall be repeated, following proper specified procedures. In this case, the requirement for doubling the number of test specimens does not apply.

9. Weld Test Assembly

9.1 Except for the R45 [RM30] classification, one weld test assembly is required. It is the groove weld for mechanical properties in Figure 1.

9.2 Preparation of the weld test assembly shall be as specified in Figure 1. The base metal for the assembly shall be as required in Table 3 and shall meet the requirements of the appropriate ASTM specification shown there or an equivalent specification. Testing of the assembly shall be as prescribed in Clause 11.

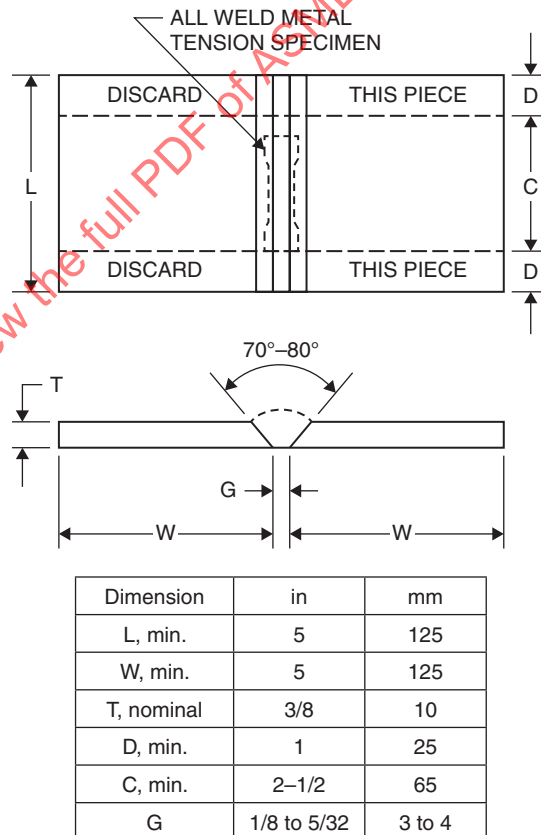


Figure 1—Groove Weld Test Assembly for Mechanical Properties

Table 3
Base Metal Required for Test Assemblies

AWS Classification		Base Metal		
A5.2	A5.2M	Type	ASTM Specification	UNS Number ^a
R60	RM40	Carbon Steel	A36, A285, grade C, or equivalent	K02600
R65	RM45	Carbon Steel	A36, A285, grade C, or equivalent	K02600
R100	RM69	Low-Alloy Steel	Any grade of A514 or equivalent	K11630
R(X)XX-G	RMXX-G	Material shall have tensile strength and chemical composition similar to that of the rod being classified.		

^a SAE HS-1086/ASTM DS-56 *Metals & Alloys in the Unified Numbering System*.

9.3 A test assembly shall be prepared as specified in 9.2. It shall be preheated to between 60°F [15°C] and 200°F [95°C], and the assembly shall be welded using a 3/32 in or 1/8 in [2.5 mm or 3.2 mm] diameter welding rod, and using a maximum of five layers. No layer shall exceed 1/8 in [3 mm] in thickness. The filler metal shall be deposited using backhand welding with a neutral or slightly reducing flame. After welding each layer, the assembly shall be allowed to cool in still air until the interpass temperature drops below 350°F [180°C] before proceeding with the next layer. The joint shall be completely welded without treatment of the reverse side (root surface). Maximum weld reinforcement shall be 1/8 in [3 mm]. After the last pass has been completed, the assembly shall be allowed to cool in still air to ambient temperature. The assembly shall be tested in the as-welded condition.

10. Chemical Analysis

10.1 A sample of the welding rod or the rod stock from which it is made shall be prepared for chemical analysis. Welding rod, when analyzed for elements that are present in the coating (e.g., copper flashing), shall be analyzed without removing the coating. When the welding rod is analyzed for elements other than those in the coating, the coating must be removed if its presence affects the results of the analysis for the other elements. Rod stock analyzed for elements not in the coating may be analyzed prior to applying the coating.

10.2 The sample shall be analyzed by accepted analytical methods. The referee method shall be ASTM E350.

10.3 The results of the analysis shall meet the requirements of Table 4 for the classification of the rod under test.

11. Tension Test

11.1 One all-weld-metal tension test specimen, as specified in the Tension Test Clause of AWS B4.0 or B4.0M, shall be machined from the groove weld described in Clause 9 and shown in Figure 1. The all-weld-metal tension test specimen shall have a nominal diameter of 0.250 in [6.5 mm] and a nominal gage length-to-diameter ratio of 4:1.

11.2 The specimen shall be tested in the manner described in the Tension Test Clause of AWS B4.0 or B4.0M.

11.3 The results of the tension test shall meet the requirements specified in Table 1.

12. Method of Manufacture

The welding rods classified according to this specification may be manufactured by any method that will produce welding rods that meet the requirements of this specification.

Table 4
Chemical Composition Requirements for Welding Rods and Rod Stock

AWS Classification		UNS Number ^a	Amount, wt % ^b									
A5.2	A5.2M		C	Mn	Si	P	S	Cu	Cr	Ni	Mo	Al
R45	RM30	K00045	0.08	0.50	0.10	0.035	0.040	0.30	0.20	0.30	0.20	0.02
R60	RM40	K00060	0.15	0.90 to 1.40	0.10 to 0.35	0.035	0.035	0.30	0.20	0.30	0.20	0.02
R65	RM45	K00065	0.15	0.90 to 1.60	0.10 to 0.70	0.035	0.035	0.30	0.40	0.30	0.20	0.02
R100	RM69	K12147	0.18 to 0.23	0.70 to 0.90	0.20 to 0.35	0.025	0.025	0.15	0.40 to 0.60	0.40 to 0.70	0.15 to 0.25	0.02
R(X)XX-G ^c	RMXX-G ^d	Not Specified										

^a SAE HS-1086/ASTM DS-56 *Metals & Alloys in the Unified Numbering System*.

^b Single values are maxima.

^c Designators "(X)XX" correspond to minimum tensile strength of weld metal in ksi. See Note "b" of Table 1.

^d Designators "XX" correspond to minimum tensile strength of weld metal in multiples of 10 MPa. See Note "c" of Table 1.

13. Standard Sizes and Lengths

Standard sizes and lengths for welding rods shall be as shown in Table 5.

14. Finish and Uniformity

14.1 All welding rods shall have a smooth finish that is free from slivers, depressions, scratches, scale, seams, laps, and foreign matter that would adversely affect the welding characteristics or the properties of the weld metal.

14.2 A suitable protective coating may be applied to any welding rod in this specification.

14.3 The welding rods may be coated with the minimum amount of oil necessary to prevent rusting, but not sufficient to adversely affect weld properties, except that oil is not permitted when copper or other suitable coatings are used to prevent rusting.

15. Filler Metal Identification

Each bare straight length filler rod shall be durably marked with identification traceable to the unique product type of the manufacturer or supplier. Suitable methods of identification could include stamping, coining, embossing, imprinting, flag-tagging, or color coding. (If color coding is used, the choice of color shall be as agreed upon between the purchaser and supplier, and the color shall be identified on the packaging.) When the AWS classification is used for identification, it shall be used in its entirety; for example, "R65" or "RM45" would be used for an R65 [RM45] welding rod. Additional identification shall be as agreed upon between the purchaser and supplier.

16. Packaging

Welding rods shall be suitably packaged to ensure against damage during shipment and storage under normal conditions.

Table 5
Standard Filler Metal Sizes^a

Standard Package Form	Diameter		Tolerance	
	A5.2 (in)	A5.2M (mm)	in	mm
Straight lengths ^b	1/16	(0.062)	1.6	
	3/32	(0.094)	2.4	
	—	(0.098)	2.5	
	1/8	(0.125)	3.2	
	5/32	(0.156)	4.0	
	3/16	(0.188)	4.8 ^c	
	—	(0.197)	5.0	
	—	(0.236)	6.0	
	1/4	(0.250)	6.4 ^c	
			± 0.002	± 0.05

^a Other sizes may be supplied as agreed upon between the purchaser and supplier.

^b The standard length of the welding rod shall be 36 in +0, -1/2 in [900 mm +15 mm, -0 mm]. Other lengths may be supplied as agreed upon between the purchaser and supplier.

^c All sizes in mm are standard in ISO 544 except 4.8 mm and 6.4 mm.

17. Marking of Packages

17.1 The following product information (as a minimum) shall be legibly marked so as to be visible from the outside of each unit package:

- (1) AWS Specification and classification designations (year of issue may be excluded)
- (2) Supplier's name and trade designation
- (3) Size and net weight
- (4) Lot, control, or heat number.

17.2 The appropriate precautionary information³ as given in ANSI Z49.1, latest edition (as a minimum), or its equivalent, shall be prominently displayed in legible print on all packages of welding rods, including individual unit packages enclosed within a larger package.

³ Typical examples of "warning labels" and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

Annex A (Informative)

Guide to AWS Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding

This annex is not part of this standard, but is included for informational purposes only.

A1. Introduction

The purpose of this guide is to correlate the rod classifications with their intended applications so the specification can be used effectively. Appropriate base metal specifications are referred to whenever that can be done and when it would be helpful. Such correlations are intended only as examples rather than complete listings of the materials for which each filler metal is suitable.

A2. Classification System

A2.1 The system for identifying the rod classifications in this specification follows the standard pattern used in other AWS filler metal specifications.

A2.2 The prefix “R [RM]” designates a rod. For A5.2, the numbers (45, 60, 65, and 100) indicate the required minimum tensile strength, as a multiple of 1000 psi, of the weld metal in a test weld made in accordance with specification A5.2. Similarly, for A5.2M, the numbers (30, 40, 45, and 69) indicate the required minimum tensile strength, as a multiple of 10 MPa, of the weld metal in a test weld made in accordance with specification A5.2M.

A2.3 “G” Classification

A2.3.1 This specification includes filler metals classified as R(X)XX-G [RMXX-G]. The “G” indicates that the filler metal is of a *general* classification. It is general because not all of the particular requirements specified for each of the other classifications are specified for this classification. The intent in establishing this classification is to provide a means by which filler metals that differ in one respect or another (e.g., chemical composition) from all other classifications (meaning that the composition of the filler metal, in the case of the example, does not meet the composition specified for any of the classifications in the specification) can still be classified according to the specification. The purpose is to allow a useful filler metal—one that otherwise would have to await a revision of the specification—to be classified immediately under the existing specification. This means, then, that two filler metals, each bearing the same “G” classification, may be quite different in some certain respect (e.g., chemical composition).

A2.3.2 The point of difference (although not necessarily the amount of that difference) referred to above will be readily apparent from the use of the words *not required* and *not specified* in the specification. The use of these words is as follows:

Not Specified is used in those areas of the specification that refer to the results of some particular test. It indicates that the requirements for that test are not specified for that particular classification.

Not Required is used in those areas of the specification that refer to the test that must be conducted in order to classify a filler metal. It indicates that the test is not required because the requirements (results) for the test have not been specified for that particular classification.

Restating the case, when a requirement is not specified, it is not necessary to conduct the corresponding test in order to classify a filler metal to that classification. When a purchaser wants the information provided by that test in order to consider a particular product of that classification for a certain application, the purchaser will have to arrange for that information with the supplier of that product. The purchaser will also have to establish with that supplier just what the testing procedure and the acceptance requirements are to be, for that test. They may want to incorporate that information (via AWS A5.01M/A5.01 (ISO 14344 MOD) in the purchase order.

A2.4 Request for Filler Metal Classification

(1) When a filler metal cannot be classified other than as a “G” classification, a manufacturer may request that a new classification be established. The manufacturer shall do this using the following procedure:

If a manufacturer elects to use a “G” classification, the AWS A5 Committee on Filler Metals and Allied Materials recommends that the manufacturer still request that a new classification be established, as long as the filler metal is commercially available.

(2) A request to establish a new filler metal classification must be submitted in writing. The request needs to provide sufficient detail to permit the AWS A5 Committee on Filler Metals and Allied Materials and the relevant Subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

- (a) A declaration that the new classification will be offered for sale commercially;
- (b) All classification requirements as given for existing classifications, such as, chemical composition ranges, mechanical property requirements, and usability test requirements;
- (c) Any conditions for conducting the tests used to demonstrate that the filler metal meets the classification requirements (it would be sufficient, for example, to state that welding conditions are the same as for other classifications);
- (d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the Annex);
- (e) *Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.*

A request for a new classification without the above information listed in (a) through (e) will be considered incomplete. The Secretary will return the request to the requester for further information.

(3) *In order to comply with the AWS Policy on Patented Items, Trademarks, and Restraint of Trade, if the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester shall disclose this. The affected classification shall be identified in all drafts and eventually the published standard identifying the patent owner. The requester shall also provide written assurance to AWS that:*

[Name of the requester] has filed a patent application [patent application number] for alloy [classification number]. [Name of the requester] does not hold and does not currently intend holding any essential patent claims.

or

[Name of the requester] has filed a patent application [patent application number] for alloy [classification number]. [Name of the requester] will make a license available to such essential patent claims to applicants desiring to utilize the license for the purpose of implementing the standard. The license will be under reasonable terms and conditions that are demonstrably free of any unfair discrimination.

or

[Name of the requester] has filed a patent application [patent application number] for alloy [classification number]. [Name of the requester] will make a license available to such essential patent claims to applicants desiring to utilize the license for the purpose of implementing the standard. The license will be without compensation and under reasonable terms and conditions that are demonstrably free of any unfair discrimination.

[Name of the requester] indicates that the patent holder (or third party authorized to make above assurances on its behalf) will include in any documents transferring ownership of patents subject to the assurance, provisions sufficient to

ensure that the commitments in the assurance are binding on the transferee, and that the transferee will similarly include appropriate provisions in the event of future transfers with the goal of binding each successor-in-interest.

[Name of the requester] indicates that it is intended to be binding on successors-in-interest regardless of whether such provisions are included in the relevant transfer documents.

The status for the patent shall be checked before publication of the document and the patent information included in the document will be updated as appropriate.

Neither AWS, nor the AWS Committee on Filler Metals and Allied Materials, nor the relevant Subcommittee is required to consider the validity of any patent or patent application.

The published standard shall include a note as follows:

NOTE: The user's attention is called to the possibility that compliance with this standard may require use of an invention covered by patent rights. By publication of this standard, no position is taken with respect to the validity of any such claim(s) or of any patent rights in connection therewith. If a patent holder has filed a statement of willingness to grant a license under these rights on reasonable and nondiscriminatory terms and conditions to applicants desiring to obtain such a license, then details may be obtained from the standards developer.

(4) The request should be sent to the Secretary of the AWS A5 Committee on Filler Metals and Allied Materials at AWS Headquarters.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01M/A5.01 (ISO 14344 MOD), as the specification states. Any testing a purchaser requires of the supplier, for material shipped in accordance with this specification, needs to be clearly stated in the purchase order according to the provisions of AWS A5.01M/A5.01 (ISO 14344 MOD). In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing the supplier normally conducts on material of that classification, as specified in Schedule F, Table 1, of AWS A5.01M/A5.01 (ISO 14344 MOD). Testing in accordance with any other schedule in that table must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product, or the classification on the product itself, constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification. The only testing requirement implicit in this *certification* is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped, and that material met the requirements of the specification. Representative material, in this case, is material from any production run of that classification using the same formulation. *Certification* is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been made. The basis for the *certification* required by the specification is the classification test of "*representative material*" cited above, and the "Manufacturer's Quality Assurance Program" in AWS A5.01M/A5.01 (ISO 14344 MOD).

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes in the atmosphere to which welders and welding operators are exposed during welding:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling)
- (2) Number of welders and welding operators working in that space
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes used

(4) The proximity of welders or welding operators to the fumes as these fumes issue from the welding zone, and to the gases and dusts in the space in which they are working

(5) The ventilation provided to the space in which the welding is done.

A5.2 American National Standard ANSI Z49.1 (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the clause on Ventilation in that document. *See also AWS F3.2, Ventilation Guide for Weld Fume, for more detailed descriptions of ventilation options.*

A6. Welding Considerations

A6.1 The test assembly required in this specification is welded according to established techniques of the oxyfuel gas welding process.

A6.2 The oxyfuel gas supplied to the torch should be adjusted to give a neutral or slightly reducing flame. This assures the absence of the oxidizing flame that could adversely influence weld quality. The extent of the excess fuel gas is measured by the length of the streamer (the so-called “feather”) of unburned fuel gas visible at the extremity of the inner cone. This streamer should measure about 1/8 to 1/4 the length of the inner cone of the flame. Excessively long streamers should be avoided, since they may add carbon to the weld metal.

A6.3 In forehand welding, the torch flame points ahead in the direction of welding, and the welding rod precedes the torch flame. To distribute the heat and molten weld metal, it is necessary to use opposing oscillating motions for the flame and welding rod. This may cause excessive melting of the base metal and mixing of base metal and weld metal. Weld metal properties may be altered.

A6.4 In backhand welding, the torch flame points back at the molten metal, and the welding rod is interposed between the flame and molten metal. There is significantly less manipulation of the flame, the welding rod, and the molten metal. Therefore, a backhand weld is more likely to approach the chemical composition of undiluted weld metal.

A7. Description and Intended Use of Carbon and Low-Alloy Steel Rods

A7.1 Oxyfuel gas welding rods have no coverings to influence usability of the rod. Thus, the ability to weld in the vertical or overhead position is essentially a matter of welder skill and can be affected to some degree by the chemical composition of the rod.

A7.2 Class R45 [RM30] welding rods are used for the oxyfuel gas welding of steels, where the minimum tensile strength requirement of the steel does not exceed 45 ksi [300 MPa]. Class R45 [RM30] rods have a low carbon steel composition.

A7.3 Class R60 [RM40] welding rods are used for the oxyfuel gas welding of carbon steels, where the minimum tensile strength requirement of the steel does not exceed 60 ksi [400 MPa]. Class R60 [RM40] rods have a carbon steel composition.

A7.4 Class R65 [RM45] welding rods are used for the oxyfuel gas welding of carbon and low-alloy steels, where the minimum tensile strength requirement of the steel does not exceed 65 ksi [450 MPa]. Class R65 [RM45] welding rods may have either a low-alloy or an unalloyed carbon steel composition.

A7.5 Class R100 [RM69] welding rods are used for the oxyfuel gas welding of low-alloy steels, where the minimum tensile strength requirement of the steel does not exceed 100 ksi [690 MPa] in the as-welded condition. Users are cautioned that response of the weld metal and base metal to postweld heat treatment may be different.

A8. Special Tests

It is recognized that supplementary tests may be required for certain applications. In such cases, tests to determine specific properties such as corrosion resistance, mechanical properties at elevated or cryogenic temperatures, wear

resistance, and suitability for welding combinations of dissimilar metals may be required. AWS A5.01M/A5.01 (ISO 14344 MOD) contains provisions for ordering such tests, which may be conducted as agreed upon between the purchaser and supplier.

A9. Discontinued Classifications

Some classifications have been discontinued from one revision of this specification to another. Discontinued classifications result from changes in commercial practice or changes in the classification system used in the specification. The classifications that have been discontinued are listed in Table A.1, along with the year in which they were last included in the specification.

Table A.1 Discontinued Classifications	
AWS Classification	Last Published Date
GA 50	1946
GA 60	1946
GA 65	1946
GB 45	1946
GB 60	1946
GB 65	1946
RG 45	1969
RG 60	1969
RG 65	1969

A10. General Safety Considerations

A10.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Annex Clause A5. Safety and health information is available from other sources, including, but not limited to, Safety and Health Fact Sheets listed in A10.3, ANSI Z49.1, and applicable federal and state regulations.

A10.2 Safety and Health Fact Sheets. The Safety and Health Fact Sheets listed below are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <https://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

A10.3 AWS Safety and Health Fact Sheets Index (SHF)

No.	Title
1	<i>Fumes and Gases</i>
2	<i>Radiation</i>
3	<i>Noise</i>
4	<i>Chromium and Nickel in Welding Fume</i>
5	<i>Electrical Hazards</i>
6	<i>Fire and Explosion Prevention</i>
7	<i>Burn Protection</i>
8	<i>Mechanical Hazards</i>

- 9 *Tripping and Falling*
- 10 *Falling Objects*
- 11 *Confined Spaces*
- 12 *Contact Lens Wear*
- 13 *Ergonomics in the Welding Environment*
- 14 *Graphic Symbols for Precautionary Labels*
- 15 *Style Guidelines for Safety and Health Documents*
- 16 *Pacemakers and Welding*
- 17 *Electric and Magnetic Fields (EMF)*
- 18 *Lockout/Tagout*
- 19 *Laser Welding and Cutting Safety*
- 20 *Thermal Spraying Safety*
- 21 *Resistance Spot Welding*
- 22 *Cadmium Exposure from Welding & Allied Processes*
- 23 *California Proposition 65*
- 24 *Fluxes for Arc Welding and Brazing: Safe Handling and Use*
- 25 *Metal Fume Fever*
- 26 *Arc Viewing Distance*
- 27 *Thoriated Tungsten Electrodes*
- 28 *Oxyfuel Safety: Check Valves and Flashback Arrestors*
- 29 *Grounding of Portable and Vehicle Mounted Welding Generators*
- 30 *Cylinders: Safe Storage, Handling, and Use*
- 31 *Eye and Face Protection for Welding and Cutting Operations*
- 33 *Personal Protective Equipment (PPE) for Welding and Cutting*
- 34 *Coated Steels: Welding and Cutting Safety Concerns*
- 35 *Welding Safety in Education and Schools*
- 36 *Ventilation for Welding and Cutting*
- 37 *Selecting Gloves for Welding and Cutting*
- 38 *Respiratory Protection Basics for Welding Operations*
- 40 *Asbestos Hazards Encountered in the Welding and Cutting Environment*
- 41 *Combustible Dust Hazards in the Welding and Cutting Environment*

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard, but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standards users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered “yes” or “no”. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

B6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

SPECIFICATION FOR ALUMINUM AND ALUMINUM-ALLOY ELECTRODES FOR SHIELDED METAL ARC WELDING



SFA-5.3/SFA-5.3M



(25)

(Identical with AWS Specification A5.3/A5.3M:2023. In case of dispute, the original AWS text applies.)

Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding

1. Scope

1.1 This specification prescribes requirements for the classification of aluminum and aluminum-alloy electrodes for shielded metal arc welding.

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to weld metal properties. The specification with the designation A5.3 uses U.S. Customary Units. The specification A5.3M uses SI units. The latter are shown within brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing electrodes, packaging or both under A5.3 or A5.3M specifications.

1.3 Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in Annex A, Clauses A5 and A10.

Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. Unless otherwise defined in this document, welding terms are as defined in AWS A3.0M/A3.0. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

2.1 American Welding Society (AWS) documents:

- (1) AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*
- (2) AWS A5.01M/A5.01, *Welding Consumables—Procurement of Filler Metals and Fluxes*

(3) AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*

(4) AWS B4.0, *Standard Methods for Mechanical Testing of Welds*

2.2 American National Standards Institute (ANSI) document:

(1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

2.3 ASTM International (ASTM) documents:

(1) ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

(2) ASTM E34, *Standard Test Methods for Chemical Analysis of Aluminum and Aluminum-Base Alloys*

(3) ASTM B209, *Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate*

2.4 International Organization for Standardization (ISO) document:

(1) ISO 80000-1:2022, *Quantities and units—Part 1: General*

3. Classification

3.1 The electrodes covered by the A5.3/A5.3M specification are classified using a system that is independent of U.S. Customary Units and the International System of Units (SI). Classification is according to the chemical composition of the core wire, as specified in Table 1 and mechanical properties of a groove weld.

3.2 An electrode classified under one classification shall not be classified under any other classification in this specification.

4. Acceptance

Acceptance of the electrode shall be in accordance with the provisions of AWS A5.01M/A5.01 and the tests and requirements of this specification. See A3 (in Annex A) for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

Table 1
Chemical Composition Requirements for Core Wire

Weight Percent ^{a,b}												
AWS Classification	UNS Designation ^c	Si	Fe	Cu	Mn	Mg	Zn	Ti	Be	Other Elements		Al
										Each	Total	
E1100	A91100	(d)	(d)	0.05–0.20	0.05	—	0.10	—	0.0003	0.05	0.15	99.00 min ^e
E3003	A93003	0.6	0.7	0.05–0.20	1.0–1.5	—	0.10	—	0.0003	0.05	0.15	Remainder
E4043	A94043	4.5–6.0	0.8	0.30	0.05	0.05	0.10	0.20	0.0003	0.05	0.15	Remainder
EG	—	As Agreed between Supplier and Purchaser										

^a The core wire, or the stock from which it is made, shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of work, the amount of those elements shall be determined to ensure that they do not exceed the limits specified for “Other Elements.”

^b Single values are maximum, except where otherwise specified.

^c SAE-HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System*.

^d Silicon plus iron shall not exceed 0.95%.

^e The aluminum content for unalloyed aluminum is the difference between 100% and the sum of all other metallic elements present in amounts of 0.010% or more each, expressed to the second decimal before determining the sum.

5. Certification

By affixing the AWS specification and classification designations to the packaging, or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification. See A4 (in Annex A) for further information concerning certification and the testing called for to meet this requirement.

6. Rounding Procedure

For the purpose of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest 1000 psi (1 ksi) for tensile strength for A5.3 [to the nearest 5 MPa for tensile strength for A5.3M] and to the nearest unit in the last right-hand place of figures used for expressing the limiting values for other quantities. The rounded results shall fulfil the requirements for the classification under test.

7. Summary of Tests

The tests required for each classification are specified in Table 2. The purpose of these tests is to determine the chemical composition of the core wire and the mechanical properties of the weldment. The base metal for the weld test assemblies, the welding and testing procedures to be employed, and the results required are given in Clauses 9 through 12.

Table 2
Required Tests

AWS Classification	Electrode Size		Chemical Analysis ^a	Tension Test ^b	Bend Test ^{c,d}
	in	mm			
All classifications	3/32	2.4	Required	Not Required ^e	Not Required ^e
	—	2.5	Required	Not Required ^e	Not Required ^e
	1/8	3.2	Required	Not Required ^e	Not Required ^e
	5/32	4.0	Required	Required ^f	Required ^f
	3/16	4.8	Required	Not Required ^e	Not Required ^e
	—	5.0	Required	Not Required ^e	Not Required ^e
	—	6.0	Required	Required ^g	Required ^g
	1/4	6.4	Required	Required ^g	Required ^g
	5/16	8.0	Required	Not Required ^e	Not Required ^e
	3/8	9.5	Required	Not Required ^e	Not Required ^e

^a Chemical analysis of the core wire or the stock from which it is made.

^b See Clause 11.

^c See Clause 12.

^d For electrodes classified as EG, bend testing shall be as agreed upon between the supplier and the purchaser and may be omitted.

^e If the product is not produced in the sizes listed for required tensile tests and bend tests, then the size closest but not greater than the size specified to be tested, shall be subject to the required tests.

^f Electrodes 5/32 in [4.0 mm] and smaller shall be classified on the basis of the results obtained with the 5/32 in [4.0 mm] size of the same classification.

^g Electrodes 3/16 in [4.8 mm] and larger shall be classified on the basis of the results obtained with the 1/4 in [6.0 mm or 6.4 mm] size of the same classification.

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Specimens or samples for retest may be taken from the original test assembly or sample, or from one or two new test assemblies or samples. For chemical analysis, retest need be only for those specific elements that failed to meet the test requirement. If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that, during preparation or after completion of any test, it is clearly determined that specified or proper procedures were not followed in preparing the weld test assembly or test specimens or in conducting the test, the test shall be considered invalid, without regard to whether the test was actually completed, or whether the test results met, or failed to meet, the requirement. That test shall be repeated, following the proper specified procedures. In this case the requirement for doubling the number of test specimens does not apply.

9. Weld Test Assembly

9.1 One weld test assembly is required as specified in Table 2. It is the groove weld in Figure 1 [1M] for mechanical properties and soundness (bend) testing.

9.2 A test assembly shall be prepared and welded as specified in Figure 1 [1M], and Table 2 using base metal of the appropriate type specified in Table 3. The test assembly shall be preheated to a temperature between 350 °F and 400 °F [175 °C and 200 °C], and shielded metal arc (SMAW) welded from one side. Welding shall be in the flat position, and the assembly shall be restrained or preset to prevent warpage in excess of 5°. An assembly that is warped more than 5° out of plane shall be discarded. Test assemblies shall not be straightened. Testing of this assembly shall be as specified in Clauses 11 and 12. The assembly shall be tested in the as-welded condition.

10. Chemical Analysis

10.1 A sample of the core wire or the stock from which it is made shall be prepared for chemical analysis.

10.2 The sample shall be analyzed by accepted analytical methods. In case of dispute, the referee method shall be ASTM E34.

10.3 The results of the analysis shall meet the requirements of Table 1, for the classification of electrode under test.

11. Tension Test

11.1 Two transverse rectangular tension test specimens shall be machined from the groove weld described in Clause 9 and shown in Figure 1 [1M]. The dimensions of the specimens shall be as specified in the tension test section of AWS B4.0. All dimensions shall be the same as shown in the AWS B4.0 figure for transverse rectangular tension test specimens (plate) except the reduced section radius shall be 2 in [50 mm].

11.2 The specimens shall be tested in the manner described in the tension test clause of AWS B4.0.

11.3 The results of both of the tension tests shall meet the requirements specified in Table 4.

12. Bend Test

12.1 One transverse face and one transverse root bend specimen, as required in Table 2, shall be machined from the groove weld test assembly described in Clause 9 and shown in Figure 1 [1M]. The dimensions of these bend specimens shall be the same as those shown in the bend test section of AWS B4.0, in the figure for transverse face and transverse root-bend specimens (plate).

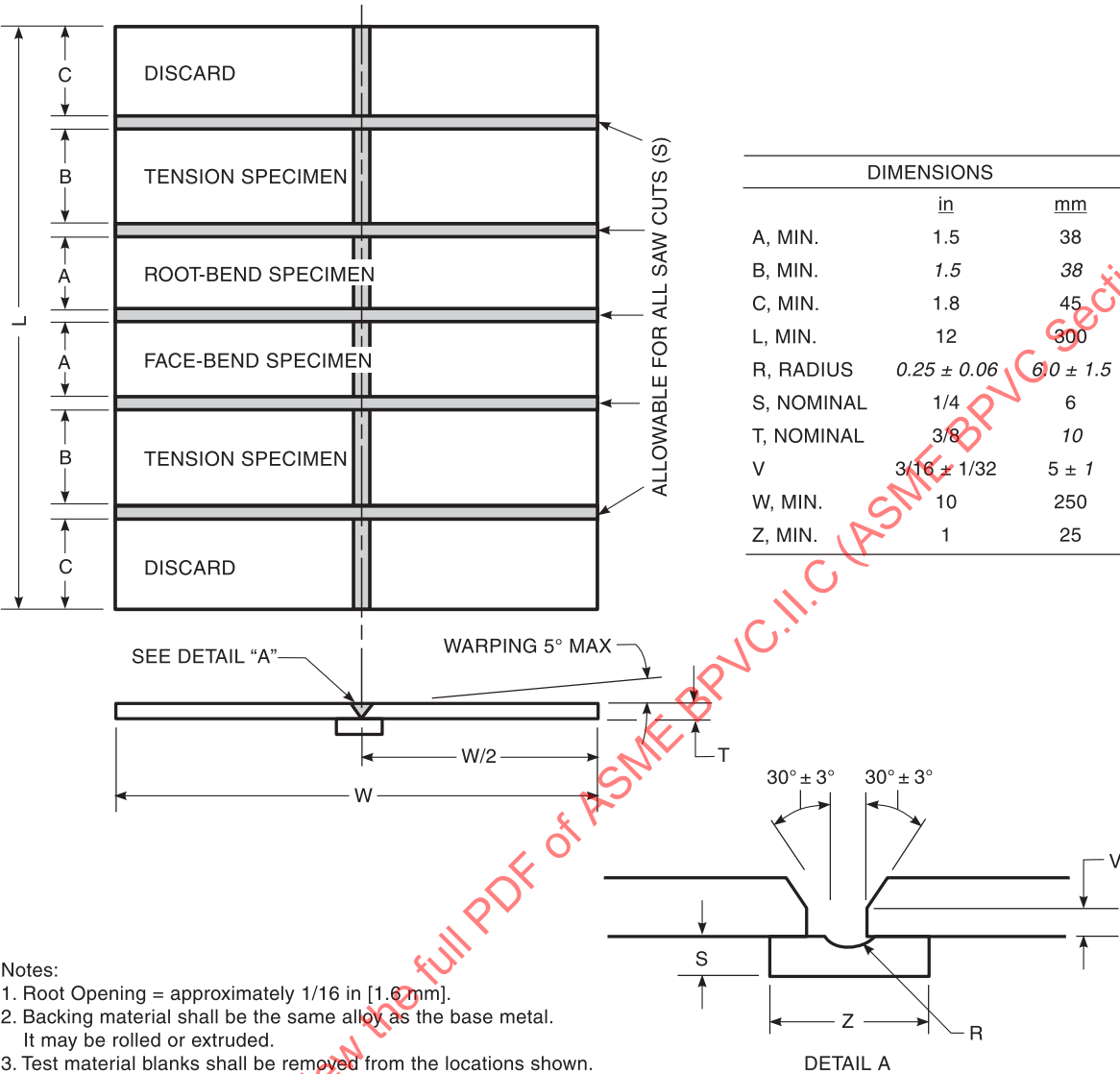


Figure 1 [1M]—Groove Weld Test Assembly for Mechanical Properties

Table 3
Base Metal for Test Assemblies

Electrode		Base Metal	
AWS Classification	Aluminum Alloy ^a	ASTM Specification	UNS Designation
E1100	1100	B209	A91100
E3003, E4043	3003 ^b	B209	A93003
EG		As Agreed between Supplier and Purchaser ^c	

^a Aluminum Association, Inc. registration numbers.
^b When welding 3003 with E4043 electrodes, 3003-0 (annealed temper) plate is preferred.
^c Base metal for which the electrode is recommended by the manufacturer may be used.

Table 4
Tension Test Requirements

AWS Classification	Tensile Strength, min. ^a	
	psi	MPa
E1100	12 000	80
E3003	14 000	95
E4043	14 000	95
EG	As Agreed between Supplier and Purchaser	

^a Fracture may occur in either the base metal or the weld metal.

12.2 The specimens shall be tested in the manner described in the Bend Test clause of AWS B4.0 by bending them uniformly through 180° over a 1-1/4 in [32 mm] radius using any suitable jig, as specified in the Bend Test clause of AWS B4.0. Positioning of the face-bend specimen shall be such that the face of the weld is in tension. Positioning of the root-bend specimen shall be such that the root of the weld is in tension. For both types of transverse bend specimen, the weld shall be at the center of the bend.

12.3 Each specimen, after bending, shall conform to the 1-1/4 in [32 mm] radius, with an appropriate allowance for spring back, and the weld metal shall show no crack or other open defect exceeding 1/8 in [3.2 mm] measured in any direction on the convex surface, when examined with the unaided eye. Cracks that occur on the corners of a specimen during testing and which show no evidence of inclusions or other fusion-type discontinuities shall be disregarded.

13. Method of Manufacture

The electrodes classified according to this specification may be manufactured by any method that will produce electrodes that meet the requirements of this specification.

14. Standard Sizes and Lengths

14.1 Standard sizes (diameter of the core wire) and lengths of electrodes and their respective tolerances are specified in AWS A5.02/A5.02M.

15. Core Wire and Covering

15.1 Requirements for the core wire and covering, including concentricity requirements are specified in AWS A5.02/A5.02M.

15.2 The coverings shall be such that they are not readily damaged by ordinary handling and the coverings shall not blister when heated to 400 °F [200 °C]. They shall be consumed uniformly during welding, and they also shall not blister or melt back from the core wire. The flux residue they produce shall be readily removable.

16. Exposed Core

16.1 Requirements for the grip end of each electrode are specified in AWS A5.02/A5.02M.

16.2 Requirements for the arc end of each electrode are specified in AWS A5.02/A5.02M.

17. Electrode Identification

17.1 All electrodes shall be identified (imprinted) as specified in AWS A5.02/A5.02M.

17.2 In lieu of imprinting, electrodes may be identified by the alternate methods specified in AWS A5.02/A5.02M.

18. Packaging

Electrodes shall be packaged as specified in AWS A5.02/A5.02M.

19. Marking of Packages

19.1 The product information specified in AWS A5.02/A5.02M (as a minimum) shall be legibly marked on the outside of each unit package.

19.2 The appropriate precautionary information as given in ANSI Z49.1 (as a minimum) or its equivalent shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages enclosed within a larger package. Typical examples of “warning labels” and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

Annex A (Informative)

Guide to AWS Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding

This annex is not a part of this standard but is included for informational purposes only.

A1. Introduction

The purpose of this guide is to correlate the electrode classifications with their intended applications so the specification can be used effectively. Appropriate base metal specifications are referred to whenever that can be done and when it would be helpful. Such references are intended only as examples, rather than complete listings of the materials for which each filler metal is suitable.

A2. Classification System

A2.1 The system for identifying the electrode classifications in this specification follows the standard pattern used in other AWS filler metal specifications. The prefix letter E at the beginning of each classification designation stands for electrode. The numerical portion of the designation in this specification conforms to the Aluminum Association registration for the composition of the core wire used in the electrode.

A2.2 “G” Classification

A2.2.1 This specification includes filler metals classified as EG. The “G” indicates that the electrode is of a *general* classification. It is *general* because not all of the particular requirements specified for each of the other classifications are specified for this classification. The intent in establishing this classification is to provide a means by which electrodes that differ in one respect or another (chemical composition, for example) from all other classifications (meaning that the composition of the electrode—in the case of the example—does not meet the composition specified for any of the classifications in the specification) can still be classified according to the specification. The purpose is to allow a useful electrode—one that otherwise would have to await a revision of the specification—to be classified immediately, under the existing specification. This means that two electrodes—each bearing the same “G” classification—may be quite different in some certain respect (chemical composition, again, for example).

A2.2.2 The point of difference (although not necessarily the amount of that difference) between electrodes of a “G” classification and electrodes of a similar classification without the “G” (or even with it, for that matter) will be readily apparent from the use of the words *not required* and *not specified* in the specification. The use of these words is as follows:

Not Required is used in those areas that specify the tests that must be conducted in order to classify an electrode. The words indicate that there is no requirement for that test for that particular classification. When a test is “not required,” it is not necessary to conduct the test in order to classify an electrode to that classification. When a purchaser wants the information provided by that test in order to consider a particular product of that classification for a certain application, the purchaser will have to arrange for that information with the supplier of the product. The purchaser will have to establish with that supplier just what the testing procedure and the acceptance requirements are to be for that test. The purchaser may want to incorporate that information (via AWS A5.01M/A5.01) in the purchase order.

Not Specified is used in those areas of the specification that refer to the results of some particular test. It indicates that the requirements for that test are not specified for that particular classification. If the results from a specific test are listed as “not specified” but the test in question is shown as “required” then the test result must be reported.

A2.2.3 Request for Filler Metal Classification. When a filler metal cannot be classified other than as a “G” classification, a manufacturer may request that a new classification be established. The manufacturer shall do this using the following procedure:

(1) A request to establish a new electrode classification must be submitted in writing. The request needs to provide sufficient detail to permit the Committee on Filler Metals and Allied Materials and the relevant Subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

(a) A declaration that the new classification will be offered for sale commercially.

(b) All classification requirements as given for existing classifications, such as chemical composition ranges, mechanical property requirements, and usability test requirements.

(c) Any conditions for conducting the tests used to demonstrate that the filler metal meets the classification requirements. (It would be sufficient, for example, to state that welding conditions are the same as for other classifications.)

(d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the annex).

(e) Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided.

(f) A request for a new classification without the above information will be considered incomplete. The Secretary will return the request to the requestor for further information.

(2) In order to comply with the AWS Policy on Patented Items, Trademarks, and Restraint of Trade, if the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester shall disclose this. In these cases, the patent holder must allow the use of this technology, such as by license. The Secretary will provide examples of acceptable wording to the patent holder, as required.

(3) The request should be sent to the Secretary of the AWS A5 Committee on Filler Metals and Allied Materials at AWS Headquarters for processing.

A3. Acceptance

Acceptance of electrodes classified under this specification is in accordance with AWS A5.01M/A5.01. Any testing a purchaser requires of the supplier for material shipped in accordance with this specification shall be clearly stated in the purchase order. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing the supplier normally conducts on material of that classification, as specified in Schedule F of AWS A5.01M/A5.01. Testing in accordance with any other Schedule shall be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product, or of placing the classification on the product itself, constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification.

The only testing requirement implicit in this certification is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation. “Certification” is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the certification required by the specification is the classification test of representative material cited above, and the Manufacturer's Quality Assurance Program in AWS A5.01M/A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes in the atmosphere to which welders are exposed during welding. They are:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling);
- (2) Number of welders and welding operators working in that space;
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes used;
- (4) The proximity of the welders to the fumes, as the fumes issue from the welding zone, and to the gases and dusts in the space in which they are working; and
- (5) The ventilation provided to the space in which the welding is done.

A5.2 American National Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the Clause on Ventilation in that document. See also AWS F3.2M/F3.2, *Ventilation Guide for Weld Fume*, for more detailed descriptions of ventilation options.

A6. Welding Considerations

A6.1 Welding aluminum by the shielded metal arc process is a well-established practice. However, development of the gas shielded arc welding processes and the many advantages these processes offer has caused a shift away from the use of covered electrodes for welding aluminum alloys. When shielded metal arc welding, an electrode is held in the standard electrode holder, and welding is usually performed using direct current, electrode positive (DCEP) polarity. Important factors to be considered when welding aluminum with covered electrodes are moisture content of the electrode covering and cleanliness of the electrode and base metal. Preheat is usually required to obtain good fusion and to improve soundness of the weld. Residual flux removal between passes is required to provide improved arc stability and weld fusion. Complete removal of the residual flux after welding is necessary to avoid corrosive attack in service.

A6.2 The presence of moisture in the electrode covering is a major cause of weld porosity. Dirt, grease, or other contamination of the electrode can also contribute to porosity. The absorption of moisture by the covering can be quite rapid, and the covering can deteriorate after only a few hours exposure to a humid atmosphere. For this reason, the electrodes should be stored in a dry, clean location. Electrodes taken from previously opened packages or those exposed to moisture should be "conditioned" by holding them at 350 °F to 400 °F [175 °C to 200 °C], for an hour before welding, or as recommended by the manufacturer. After conditioning, they should be stored in a dry, heated cabinet at 150 °F to 200 °F [65 °C to 95 °C] until used.

A6.3 The minimum base metal thickness recommended for shielded metal arc welding of aluminum is 1/8 in [3.2 mm]. For thicknesses less than 1/4 in [6.4 mm], no edge preparation other than a relatively smooth, square cut is required. Material over 1/4 in [6.4 mm] should be beveled to a single-V-groove with a 60° to 90° included angle. On very thick material, U-grooves may be used. Depending upon base metal gauge, root-face thicknesses may range between 1/16 in and 1/4 in [1.6 mm and 6.4 mm]. A root opening of 1/32 in to 1/16 in [0.8 mm to 1.6 mm] is desirable for all groove welds.

A6.4 Because of the high thermal conductivity of aluminum, preheating to 250 °F to 400 °F [120 °C to 200 °C] is nearly always necessary on thick material to maintain the weld pool and obtain proper fusion. Preheating will also help to avoid porosity due to too rapid cooling of the weld pool at the start of the weld. On complex assemblies, preheating is useful in avoiding distortion. Preheating may be done by torch using oxygen and acetylene or other suitable fuel gas, or by electrical resistance heating. Mechanical properties of 6XXX series aluminum-alloy weldments can be reduced significantly if the higher preheating temperatures, 350 °F [175 °C] or higher, are applied.

A6.5 Single-pass SMAW welds should be made whenever possible. However, where thicker plates require multiple passes, thorough cleaning between passes is essential for optimum results. After the completion of any welding, the weld and work should be thoroughly cleaned of residual flux. The major portion of the residual flux can be removed by mechanical means, such as a rotary wire brush, slag hammer, or peening hammer, and the rest by steaming or a hot-water

rinse. The test for complete removal of residual flux is to swab a solution of 5% silver nitrate on the weld areas. Foaming will occur if residual flux is present.

A6.6 Interruption of the arc when shielded metal arc welding aluminum can cause the formation of a fused flux coating over the end of the electrode. Reestablishing a satisfactory arc is impossible unless this formation is removed.

A7. Description and Intended Use of Electrodes

A7.1 E1100 Classification. Electrodes of the E1100 classification produce weld metal of high ductility, good electrical conductivity, and a minimum tensile strength of 12 000 psi (80 MPa). E1100 electrodes are used to weld 1100, 1350(EC), and other commercially pure aluminum alloys.

A7.2 E3003 Classification. Electrodes of the E3003 classification produce weld metal of high ductility and a minimum tensile strength of 14 000 psi [95 MPa]. E3003 electrodes are used to weld aluminum alloys 1100 and 3003.

A7.3 E4043 Classification. The E4043 classification contains approximately 5% silicon, which provides superior fluidity at welding temperatures, and for this reason is preferred for general purpose welding. The E4043 classification produces weld metal with fair ductility and a minimum tensile strength of 14 000 psi [95 MPa]. E4043 electrodes can be used to weld the 6XXX series aluminum alloys, the 5XXX series aluminum alloys (up to 2.5% Mg content), and aluminum-silicon casting alloys, as well as aluminum base metals 1100, 1350(EC), and 3003.

A7.4 For many aluminum applications, corrosion resistance of the weld is of prime importance. In such cases, it is advantageous to choose an electrode with a composition as close as practical to that of the base metal. For this use, covered electrodes for base metals other than 1100 and 3003 usually are not stocked and must be specially ordered. For applications where corrosion resistance is important, it may be advantageous to use one of the gas shielded arc welding processes for which a wider range of filler metal compositions is available.

A8. Special Tests

It is recognized that supplementary tests may be required for certain applications. In such cases, tests to determine specific properties such as corrosion resistance, electrical conductivity, mechanical properties at elevated or cryogenic temperatures, and suitability for welding different combinations of aluminum base alloys may be required. AWS A5.01M/A5.01 contains provisions for ordering such tests. This clause is included for the guidance of those who desire to specify such special tests. Those tests may be conducted as agreed upon between the purchaser and supplier.

A9. Chemical Analysis

The accepted and most widely used method for chemical analysis is found in ASTM E227, *Optical Emission Spectrometric Analysis of Aluminum and Aluminum Alloy by the Point-to-Plane Technique (now withdrawn)*. This method analyzes a bulk sample and all elements simultaneously. Other established analytical methods are also acceptable. The ASTM E34, *Standard Test Methods for Chemical Analysis of Aluminum and Aluminum-Base Alloys*, prescribes individual test methods by which each element is tested. The ASTM E34 test methods are used as the referee method if a dispute arises concerning a specific elemental analysis.

A10. General Safety Considerations

A10.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Safety and health information is available from other sources, including, but not limited to Safety and Health Fact Sheets and ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations. Safety and Health Fact Sheets may be downloaded and printed directly from the AWS website at <http://www.aws.org>.

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered “yes” or “no”. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

B6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

AWS Filler Metal Specifications by Material and Welding Process

	OFW	SMAW	GTAW GMAW PAW	FCAW	SAW	ESW	EGW	Brazing
Carbon Steel	A5.2	A5.1, A5.35	A5.18	A5.20	A5.17	A5.25	A5.26	A5.8, A5.31
Low-Alloy Steel	A5.2	A5.5	A5.28	A5.29	A5.23	A5.25	A5.26	A5.8, A5.31
Stainless Steel		A5.4, A5.35	A5.9, A5.22	A5.22	A5.9, A5.22, A5.39	A5.9, A5.22, A5.39	A5.9	A5.8, A5.31
Cast Iron	A5.15	A5.15	A5.15	A5.15				A5.8, A5.31
Nickel Alloys		A5.11, A5.35	A5.14, A5.34	A5.34	A5.14, A5.34, A5.39	A5.14, A5.34, A5.39		A5.8, A5.31
Aluminum Alloys		A5.3	A5.10					A5.8, A5.31
Copper Alloys		A5.6	A5.7					A5.8, A5.31
Titanium Alloys			A5.16					A5.8, A5.31
Zirconium Alloys			A5.24					A5.8, A5.31
Magnesium Alloys			A5.19					A5.8, A5.31
Tungsten Electrodes			A5.12					
Brazing Alloys and Fluxes								A5.8, A5.31
Surfacing Alloys	A5.21	A5.13	A5.21	A5.21	A5.21			
Consumable Inserts			A5.30					
Shielding Gases			A5.32	A5.32			A5.32	

AWS Filler Metal Specifications and Related Documents

Designation	Title
A4.2M (ISO 8249 MOD)	<i>Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal</i>
A4.3	<i>Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding</i>
A4.4M	<i>Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings</i>
A4.5M/A4.5 (ISO 15792-3 MOD)	<i>Standard Methods for Classification Testing of Positional Capacity and Root Penetration of Welding Consumables in a Fillet Weld</i>
A5.01M/A5.01 (ISO 14344 MOD)	<i>Welding and Brazing Consumables—Procurement of Filler Metals and Fluxes</i>
A5.02/A5.02M	<i>Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes</i>
A5.1/A5.1M	<i>Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding</i>
A5.2/A5.2M	<i>Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding</i>
A5.3/A5.3M	<i>Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.4/A5.4M	<i>Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding</i>
A5.5/A5.5M	<i>Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding</i>
A5.6/A5.6M	<i>Specification for Copper and Copper-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.7/A5.7M	<i>Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes</i>
A5.8M/A5.8	<i>Specification for Filler Metals for Brazing and Braze Welding</i>
A5.9/A5.9M (ISO 14343 MOD)	<i>Specification for Bare Stainless Steel Welding Electrodes and Rods</i>
A5.10/A5.10M (ISO 18273 MOD)	<i>Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods</i>
A5.11/A5.11M	<i>Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding</i>
A5.12M/A5.12 (ISO 6848 MOD)	<i>Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting</i>
A5.13/A5.13M	<i>Specification for Surfacing Electrodes for Shielded Metal Arc Welding</i>
A5.14/A5.14M	<i>Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods</i>
A5.15	<i>Specification for Welding Electrodes and Rods for Cast Iron</i>
A5.16/A5.16M (ISO 24034 MOD)	<i>Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods</i>
A5.17/A5.17M	<i>Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.18/A5.18M	<i>Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.19	<i>Specification for Magnesium-Alloy Welding Electrodes and Rods</i>
A5.20/A5.20M	<i>Specification for Carbon Steel Electrodes for Flux Cored Arc Welding</i>
A5.21/A5.21M	<i>Specification for Bare Electrodes and Rods for Surfacing</i>
A5.22/A5.22M	<i>Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods</i>
A5.23/A5.23M	<i>Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.24/A5.24M	<i>Specification for Zirconium and Zirconium-Alloy Welding Electrodes and Rods</i>
A5.25/A5.25M	<i>Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding</i>
A5.26/A5.26M	<i>Specification for Carbon and Low-Alloy Steel Electrodes for Electrode Gas Welding</i>
A5.28/A5.28M	<i>Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.29/A5.29M	<i>Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding</i>
A5.30/A5.30M	<i>Specification for Consumable Inserts</i>
A5.31M/A5.31	<i>Specification for Fluxes for Brazing and Braze Welding</i>
A5.32M/A5.32 (ISO 14175 MOD)	<i>Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes</i>
A5.34/A5.34M	<i>Specification for Nickel-Alloy Flux Cored and Metal Cored Welding Electrodes</i>
A5.35/A5.35M-AMD1	<i>Specification for Covered Electrodes for Underwater Wet Shielded Metal Arc Welding</i>
A5.39/A5.39M	<i>Specification for Stainless Steel and Nickel-Alloy Electrodes and Fluxes for Submerged Arc and Electroslag Welding</i>

SPECIFICATION FOR STAINLESS STEEL ELECTRODES FOR SHIELDED METAL ARC WELDING



SFA-5.4/SFA-5.4M



(Identical with AWS Specification A5.4/A5.4M:2012 (R2022). In case of dispute, the original AWS text applies.)

Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding

1. Scope

1.1 This specification prescribes requirements for the classification of covered stainless steel electrodes for shielded metal arc welding.^{1,2}

The chromium content of weld metal deposited by these electrodes is not less than 10.5 percent and the iron content exceeds that of any other element. For purposes of classification, the iron content shall be derived as the balance element when all other elements are considered to be at their minimum specified values.

NOTE: No attempt has been made to classify all grades of filler metals within the limits of the above scope; only the more commonly used grades have been included.

1.2 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Annex Sections A5 and A11. Safety and health information is available from other sources, including, but not limited to ANSI Z49.1, *Safety in Welding, Cutting and Allied Processes*, and applicable state and federal regulations.

1.3 This specification makes use of both U.S. Customary Units and the International System of Units [SI]. The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to material properties. The specification with the designation A5.4 uses U.S. Customary Units. The specification A5.4M uses SI Units. The latter are shown in brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing of filler metal or packaging or both under A5.4 or A5.4M specifications.

2. Normative References

2.1 The following AWS standards³ are referenced in the mandatory section of this document.

1. AWS A5.01M/A5.01 (ISO 14344 MOD). *Procurement Guidelines for Consumables – Welding and Allied Processes – Flux and Gas Shielded Electrical Welding Processes*
2. AWS A5.5, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*
3. AWS B4.0, *Standard Methods for Mechanical Testing of Welds*
4. AWS B4.0M, *Standard Methods for Mechanical Testing of Welds*

2.2 The following ANSI standard is referenced in the mandatory section of this document:

1. ANSI Z49.1⁴, *Safety in Welding, Cutting and Allied Processes*

¹ Due to possible differences in composition, core wire from covered electrodes should not be used as bare filler wire.

² Classifications E502, E505, and E7Cr are no longer specified by this document. They are specified in AWS A5.5/A5.5M:2006, designated as follows: E502 as E801X-B6 and E801X-B6L, E505 as E801X-B8 and E801X-B8L, and E7Cr as E801X-B7 and E801X-B7L.

³ AWS standards are published by the American Welding Society, 8669 Doral Blvd., Suite 130, Doral, FL 33166.

⁴ ANSI Z49.1 is published by the American Welding Society, 8669 Doral Blvd., Suite 130, Doral, FL 33166.

2.3 The following ASTM standards⁵ are referenced in the mandatory section of this document.

1. ASTM A36, *Specification for Structural Steel*
2. ASTM A240, *Specification for Heat-Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels*
3. ASTM A285, *Specification for Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength*
4. ASTM A515, *Specification for Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service*
5. ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*
6. ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*
7. ASTM E353, *Standard Test Methods for Chemical Analysis of Stainless, Heat-Resisting, Maraging, and Other Similar Chromium-Nickel-Iron Alloys*

2.4 The following ISO standard⁶ is referenced in the mandatory section of this document.

ISO 80 000-1 Quantities and Units Part 1: General

3. Classification

3.1 The welding electrodes covered by this A5.4/A5.4M specification are classified using the system that is independent of US customary units and the International System of Units (SI), and are classified according to:

1. Chemical composition requirements for undiluted weld metal (Table 1).
2. Type of welding current and position of welding (Table 2).

3.2 Materials classified under one classification may be classified under any other classification of this specification, provided they meet all the requirements for those classifications, except that a material may not be classified under more than one of the following EXXX-15, EXXX-16, EXXX-17, or EXXX-26 designations. Table 3 lists a number of examples of such dual classification.

NOTE: The test requirements of this specification establish minimum quality levels which will assure suitability of the electrodes for the usual applications. The guide appended to this specification describes the more common applications and suggests testing procedures for those applications which warrant tests that are beyond those included in this specification.

4. Acceptance

Acceptance⁷ of the material shall be in accordance with the provisions of AWS A5.01.

5. Certification

By affixing the AWS specification and classification designations to the packaging, or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification.⁸

⁵ ASTM standards are published by ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

⁶ ISO standards are published by the International Organization of Standardization, 1, chemin de la voie-creuse Case Postale 56 CH-1211 Genève 20 Switzerland.

⁷ See A3, Acceptance (in Annex A) for further information on acceptance, testing of material shipped and AWS A5.01M/A5.01 (ISO 14344 MOD).

⁸ See A4, Certification (in Annex A) for further information concerning certification and the tests called for to meet this requirement.

Table 1
Chemical Composition Requirements for Undiluted Weld Metal

AWS Classification ^c	UNS Number ^d	Weight Percent ^{a,b}											
		C	Cr	Ni	Mo	Nb (Cb) Plus Ta	Mn	Si	P	S	N	Cu	Other ^e
E209-XX	W32210	0.06	20.5–24.0	9.5–12.0	1.5–3.0	—	4.0–7.0	1.00	0.04	0.03	0.10–0.30	0.75	V = 0.10–0.30
E219-XX	W32310	0.06	19.0–21.5	5.5–7.0	0.75	—	8.0–10.0	1.00	0.04	0.03	0.10–0.30	0.75	
E240-XX	W32410	0.06	17.0–19.0	4.0–6.0	0.75	—	10.5–13.5	1.00	0.04	0.03	0.10–0.30	0.75	
E307-XX	W30710	0.04–0.14	18.0–21.5	9.0–10.7	0.5–1.5	—	3.30–4.75	1.00	0.04	0.03	—	0.75	
E308-XX	W30810	0.08	18.0–21.0	9.0–11.0	0.75	—	0.5–2.5	1.00	0.04	0.03	—	0.75	
E308H-XX	W30810	0.04–0.08	18.0–21.0	9.0–11.0	0.75	—	0.5–2.5	1.00	0.04	0.03	—	0.75	
E308L-XX	W30813	0.04	18.0–21.0	9.0–11.0	0.75	—	0.5–2.5	1.00	0.04	0.03	—	0.75	
E308Mo-XX	W30820	0.08	18.0–21.0	9.0–12.0	2.0–3.0	—	0.5–2.5	1.00	0.04	0.03	—	0.75	
E308LMo-XX ^f	W30823	0.04	18.0–21.0	9.0–12.0	2.0–3.0	—	0.5–2.5	1.00	0.04	0.03	—	0.75	
E309-XX	W30910	0.15	22.0–25.0	12.0–14.0	0.75	—	0.5–2.5	1.00	0.04	0.03	—	0.75	
E309H-XX	W30910	0.04–0.15	22.0–25.0	12.0–14.0	0.75	—	0.5–2.5	1.00	0.04	0.03	—	0.75	
E309L-XX	W30913	0.04	22.0–25.0	12.0–14.0	0.75	—	0.5–2.5	1.00	0.04	0.03	—	0.75	
E309Nb-XX ^g	W30917	0.12	22.0–25.0	12.0–14.0	0.75	0.70–1.00	0.5–2.5	1.00	0.04	0.03	—	0.75	
E309Mo-XX	W30920	0.12	22.0–25.0	12.0–14.0	2.0–3.0	—	0.5–2.5	1.00	0.04	0.03	—	0.75	
E309LMo-XX ^f	W30923	0.04	22.0–25.0	12.0–14.0	2.0–3.0	—	0.5–2.5	1.00	0.04	0.03	—	0.75	
E310-XX	W31010	0.08–0.20	25.0–28.0	20.0–22.5	0.75	—	1.0–2.5	0.75	0.03	0.03	—	0.75	
E310H-XX	W31015	0.35–0.45	25.0–28.0	20.0–22.5	0.75	—	1.0–2.5	0.75	0.03	0.03	—	0.75	
E310Nb-XX ^g	W31017	0.12	25.0–28.0	20.0–22.0	0.75	0.70–1.00	1.0–2.5	0.75	0.03	0.03	—	0.75	
E310Mo-XX	W31020	0.12	25.0–28.0	20.0–22.0	2.0–3.0	—	1.0–2.5	0.75	0.03	0.03	—	0.75	
E312-XX	W31310	0.15	28.0–32.0	8.0–10.5	0.75	—	0.5–2.5	1.00	0.04	0.03	—	0.75	
E316-XX	W31610	0.08	17.0–20.0	11.0–14.0	2.0–3.0	—	0.5–2.5	1.00	0.04	0.03	—	0.75	
E316H-XX	W31610	0.04–0.08	17.0–20.0	11.0–14.0	2.0–3.0	—	0.5–2.5	1.00	0.04	0.03	—	0.75	
E316L-XX	W31613	0.04	17.0–20.0	11.0–14.0	2.0–3.0	—	0.5–2.5	1.00	0.04	0.03	—	0.75	
E316LMn-XX	W31622	0.04	18.0–21.0	15.0–18.0	2.5–3.5	—	5.0–8.0	0.90	0.04	0.03	0.10–0.25	0.75	
E317-XX	W31710	0.08	18.0–21.0	12.0–14.0	3.0–4.0	—	0.5–2.5	1.00	0.04	0.03	—	0.75	
E317L-XX	W31713	0.04	18.0–21.0	12.0–14.0	3.0–4.0	—	0.5–2.5	1.00	0.04	0.03	—	0.75	
E318-XX	W31910	0.08	17.0–20.0	11.0–14.0	2.0–3.0	6 × C, min to 1.00 max	0.5–2.5	1.00	0.04	0.03	—	0.75	
E320-XX	W88021	0.07	19.0–21.0	32.0–36.0	2.0–3.0	8 × C, min to 1.00 max	0.5–2.5	0.60	0.04	0.03	—	3.0–4.0	
E320LR-XX	W88022	0.03	19.0–21.0	32.0–36.0	2.0–3.0	8 × C, min to 0.40 max	1.50–2.50	0.30	0.020	0.015	—	3.0–4.0	
E330-XX	W88331	0.18–0.25	14.0–17.0	33.0–37.0	0.75	—	1.0–2.5	1.00	0.04	0.03	—	0.75	
E330H-XX	W88335	0.35–0.45	14.0–17.0	33.0–37.0	0.75	—	1.0–2.5	1.00	0.04	0.03	—	0.75	

(Continued)

Table 1 (Continued)
Chemical Composition Requirements for Undiluted Weld Metal

AWS Classification ^c	UNS Number ^d	Weight Percent ^{a,b}											Other ^e
		C	Cr	Ni	Mo	Nb (Cb) Plus Ta	Mn	Si	P	S	N	Cu	
E347-XX	W34710	0.08	18.0–21.0	9.0–11.0	0.75	8 × C, min to 1.00 max	0.5–2.5	1.00	0.04	0.03	—	0.75	
E349-XX	W34910	0.13	18.0–21.0	8.0–10.0	0.35–0.65	0.75–1.20	0.5–2.5	1.00	0.04	0.03	—	0.75	V = 0.10–0.30 Ti = 0.15 max W = 1.25–1.75
E383-XX	W88028	0.03	26.5–29.0	30.0–33.0	3.2–4.2	—	0.5–2.5	0.90	0.02	0.02	—	0.6–1.5	
E385-XX	W88904	0.03	19.5–21.5	24.0–26.0	4.2–5.2	—	1.0–2.5	0.90	0.03	0.02	—	1.2–2.0	
E409Nb-XX	W40910	0.12	11.0–14.0	0.6	0.75	0.50–1.50	1.0	1.00	0.04	0.03	—	0.75	
E410-XX	W41010	0.12	11.0–13.5	0.7	0.75	—	1.0	0.90	0.04	0.03	—	0.75	
E410NiMo-XX	W41016	0.06	11.0–12.5	4.0–5.0	0.40–0.70	—	1.0	0.90	0.04	0.03	—	0.75	
E430-XX	W43010	0.10	15.0–18.0	0.6	0.75	—	1.0	0.90	0.04	0.03	—	0.75	
E430Nb-XX	W43011	0.10	15.0–18.0	0.6	0.75	0.50–1.50	1.0	1.00	0.04	0.03	—	0.75	
E630-XX	W37410	0.05	16.00–16.75	4.5–5.0	0.75	0.15–0.30	0.25–0.75	0.75	0.04	0.03	—	3.25–4.00	
E16-8-2-XX	W36810	0.10	14.5–16.5	7.5–9.5	1.0–2.0	—	0.5–2.5	0.60	0.03	0.03	—	0.75	
E2209-XX	W39209	0.04	21.5–23.5	8.5–10.5	2.5–3.5	—	0.5–2.0	1.00	0.04	0.03	0.08–0.20	0.75	
E2307-XX	S82371	0.04	22.5–25.5	6.5–10.0	0.8	—	0.4–1.5	1.0	0.030	0.020	0.10–0.20	0.50	
E2553-XX	W39553	0.06	24.0–27.0	6.5–8.5	2.9–3.9	—	0.5–1.5	1.00	0.04	0.03	0.10–0.25	1.5–2.5	
E2593-XX	W39593	0.04	24.0–27.0	8.5–10.5	2.9–3.9	—	0.5–1.5	1.00	0.04	0.03	0.08–0.25	1.5–3.0	
E2594-XX	W39594	0.04	24.0–27.0	8.0–10.5	3.5–4.5	—	0.5–2.0	1.00	0.04	0.03	0.20–0.30	0.75	
E2595-XX	W39595	0.04	24.0–27.0	8.0–10.5	2.5–4.5	—	2.5	1.2	0.03	0.025	0.20–0.30	0.4–1.5	W = 0.4–1.0
E3155-XX	W73155	0.10	20.0–22.5	19.0–21.0	2.5–3.5	0.75–1.25	1.0–2.5	1.00	0.04	0.03	—	0.75	Co = 18.5–21.0 W = 2.0–3.0
E33-31-XX	W33310	0.03	31.0–35.0	30.0–32.0	1.0–2.0	—	2.5–4.0	0.9	0.02	0.01	0.3–0.5	0.4–0.8	

^a Analysis shall be made for the elements for which specific values are shown in the table. If, however, the presence of other elements is indicated in the course of analysis, further analysis shall be made to determine that the total of these other elements, except iron, is not present in excess of 0.50 percent.

^b Single values are maximum percentages.

^c Classification suffix -XX may be -15, -16, -17, or -26. See Clause A8 of Annex A for an explanation.

^d ASTM DS-56H/SAE HS-1086, *Metal & Alloys in the Unified Numbering System*.

^e Analysis for Bi is required to be reported if intentionally added, or if it is known to be present at levels greater than 0.002%.

^f E308L Mo-XX and E309L Mo-XX were formerly named E308MoL-XX and E309MoL-XX, respectively.

^g E309Nb-XX and E310Nb-XX were formerly named E309Cb-XX and E310Cb-XX. The change was made to conform to the worldwide uniform designation of the element niobium.

Table 2
Type of Welding Current and Position of Welding

AWS Classification ^a	Welding Current ^b	Welding Position ^c
EXXX(X)-15	dcep	All ^d
EXXX(X)-16	dcep and ac	All ^d
EXXX(X)-17	dcep and ac	All ^d
EXXX(X)-26	dcep and ac	F, H-fillet

^a See Clause A8, Classification as to Usability, for explanation of positions.

^b dcep = direct current electrode positive (reverse polarity)
ac = alternating current

^c The abbreviations F and H-fillet indicate welding positions as follows:

F = Flat

H-fillet = Horizontal fillet

^d Electrodes 3/16 in [4.8 mm] and larger are not recommended for welding in all positions.

Table 3
Examples of Potentially Occurring Dual Classified Electrodes and Suggested Marking

Primary Classification	Alternate Classification	Suggested Electrode Marking ^a
E308L-XX	E308-XX	E308/E308L-XX
E308H-XX	E308-XX	E308/E308H-XX
E316L-XX	E316-XX	E316/E316L-XX

^a This abbreviated, suggested marking is permitted only on the electrode (the E may be omitted). All packaging and packing labels and certifications must list the complete classification designation for all classifications intended.

6. Rounding-Off Procedure

For purposes of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding-off rules of ASTM E29 or ISO 80000-1, Annex B, Rule A (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding off. If an average value is to be compared to the specified limit, rounding off shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest 1 000 psi (1 ksi) for tensile strength for A5.4, or to the nearest 10 MPa for tensile strength for A5.4M, and to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded-off results shall fulfill the requirements for the classification under test.

7. Summary of Tests

The tests required for each classification are specified in Table 4. The purpose of these tests is to determine the chemical composition, mechanical properties and soundness of the weld metal and the usability of the electrodes. The base metal for the weld test assemblies, the welding and testing procedures to be employed, and the results required are given in Clause 9, Weld Test Assemblies; Clause 10, Chemical Analysis; Clause 11, Radiographic Test; Clause 12, Tension Test; and Clause 13, Fillet Weld Test.

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. For chemical analysis, retest material may be taken from the original test sample or from a new sample. Retest for chemical analysis need be only for those specific elements that failed to meet the test requirement.

If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that, during preparation or after completion of any test, it is clearly determined that specified or proper procedures were not followed in preparing the weld test assembly or test specimen(s) or in conducting the test, the test shall be considered invalid, without regard to whether the test was actually completed, or whether test results met, or failed to meet, the requirement. That test shall be repeated, following proper specified procedures. In this case, the requirement for doubling of the number of test specimens does not apply.

9. Weld Test Assemblies

9.1 One, two, or three weld test assemblies are required depending on electrode diameter as shown in Table 4.

1. The weld pad in Figure 1 for chemical analysis of the undiluted weld metal
2. The groove weld in Figure 2 for Tension and Radiographic tests
3. The fillet weld in Figure 3 for usability of the electrode.

Optionally, the sample for chemical analysis may be taken from the reduced section of the fractured tension specimen or from a corresponding location (or any location above it) in the weld metal in the groove weld in Figure 2 or from the weld pad used for ferrite determination (Figure A.1), thereby avoiding the need to make the weld pad. In the case of dispute, the weld pad of Figure 1 shall be the referee method.

9.2 Preparation of each weld test assembly shall be as prescribed in 9.3, 9.4, and 9.5. Base metal for each assembly shall conform to the following, or an equivalent:

9.2.1 For the chemical analysis pad, the base metal to be used shall be carbon steel, alloy steel, or stainless steel of 0.25 percent carbon maximum for all electrode classifications except E308L, E308LMo, E309L, E309LMo, E316L, E316LMn, E317L, E320LR, E383, E385, E630, E2209, E2307, E2593, E2594, E2595, and E33-31. For chemical analysis of these low-carbon classifications, the base metal shall be steel of 0.03 percent maximum carbon. Other steels having a carbon content of 0.25 percent maximum may be used with the further restrictions specified in 10.6.

9.2.2 For the all-weld-metal tension test and radiographic test, the steel to be used shall be of a matching type or either of the following:

1. For E4XX and E630 classifications—Types 410, 430A, or 430B
2. For all other classifications—Types 304 or 304L.

Optionally, the steel may conform to one of the following specifications or their equivalents, providing two buttering layers of filler metal as shown in Figure 2A, are deposited in stringer beads using electrodes of the same classification as that being classified: ASTM A285, ASTM A36, or ASTM A515.

9.2.3 For the fillet weld test, the steel to be used shall be of a matching type or shall conform to the following specifications:

1. For E4XX and E630 classifications—ASTM A240, Type 410 or Type 430 A or B
2. For all other classifications—ASTM A240, Type 304 or Type 304L.

9.3 Weld Pad. A weld pad shall be prepared as specified in Figure 1 except when one of the alternatives in 9.1 (taking the sample from the broken tension test specimen or from a corresponding location or any location above it in the weld metal in the groove weld in Figure 2 or from the weld pad used for ferrite determination in Figure A.1) is selected. Base metal shall be of any convenient size, of the type specified in 9.2.1. The surface of the base metal on which the filler metal is deposited shall be clean. The pad shall be welded in the flat position, using as short an arc length as practical and at a current as agreed upon between consumer and manufacturer. Multiple layers shall be used to obtain undiluted weld metal. The preheat temperature shall not be less than 60 °F [15 °C] After depositing each layer, the weld pad shall be immersed in water (temperature unimportant) for approximately 30 seconds. The slag shall be removed after each pass. The completed pad shall be as shown in Figure 1 for each size of the electrode. Testing of the assembly shall be as specified in Clause 10, Chemical Analysis.

Table 4
Tests Required For Classification

Classification	Electrode Diameter		Type of Current ^{b,c}	Chemical Analysis	Position of Welding ^a		
	in	mm			Radiographic Test	All Weld Metal Tension Test	Fillet Weld Test
EXXX(X)-15	1/16	1.6	dcep	F	NR	NR	NR
EXXX(X)-15	5/64	2.0	dcep	F	NR	NR	NR
EXXX(X)-15	3/32	2.4	dcep	F	NR	NR	NR
EXXX(X)-15		2.5	dcep	F	NR	NR	NR
EXXX(X)-15	1/8	3.2	dcep	F	F	F	H, V, OH
EXXX(X)-15	5/32	4.0	dcep	F	F	F	H, V, OH
EXXX(X)-15	3/16	4.8	dcep	F	F	F	H
EXXX(X)-15		5.0	dcep	F	F	F	H
EXXX(X)-15	7/32	5.6	dcep	F	F	F	H
EXXX(X)-15		6.0	dcep	F	F	F	H
EXXX(X)-15	1/4	6.4	dcep	F	F	F	H
EXXX(X)-16, -17	1/16	1.6	ac and dcep	F	NR	NR	NR
EXXX(X)-16, -17	5/64	2.0	ac and dcep	F	NR	NR	NR
EXXX(X)-16, -17	3/32	2.4	ac and dcep	F	NR	NR	NR
EXXX(X)-16, -17		2.5	ac and dcep	F	NR	NR	NR
EXXX(X)-16, -17	1/8	3.2	ac and dcep	F	F	F	H, V, OH
EXXX(X)-16, -17	5/32	4.0	ac and dcep	F	F	F	H, V, OH
EXXX(X)-16, -17	3/16	4.8	ac and dcep	F	F	F	H
EXXX(X)-16, -17		5.0	ac and dcep	F	F	F	H
EXXX(X)-16, -17	7/32	5.6	ac and dcep	F	F	F	H
EXXX(X)-16, -17		6.0	ac and dcep	F	F	F	H
EXXX(X)-16, -17	1/4	6.4	ac and dcep	F	F	F	H
EXXX(X)-26	1/16	1.6	ac and dcep	F	NR	NR	NR
EXXX(X)-26	5/64	2.0	ac and dcep	F	NR	NR	NR
EXXX(X)-26	3/32	2.4	ac and dcep	F	NR	NR	NR
EXXX(X)-26		2.5	ac and dcep	F	NR	NR	NR
EXXX(X)-26	1/8	3.2	ac and dcep	F	F	F	H
EXXX(X)-26	5/32	4.0	ac and dcep	F	F	F	H
EXXX(X)-26	3/16	4.8	ac and dcep	F	F	F	H
EXXX(X)-26		5.0	ac and dcep	F	F	F	H
EXXX(X)-26	7/32	5.6	ac and dcep	F	F	F	H
EXXX(X)-26		6.0	ac and dcep	F	F	F	H
EXXX(X)-26	1/4	6.4	ac and dcep	F	F	F	H

^a The abbreviations F, H, OH, and V indicate welding positions as follows:

F = Flat

H = Horizontal

V = Vertical

OH = Overhead

The abbreviation NR indicates that the test is not required.

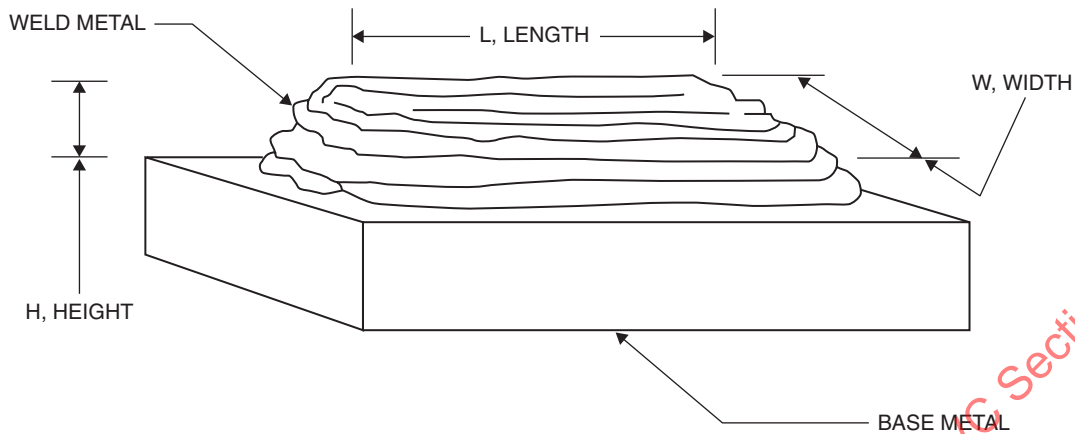
^b ac = alternating current; dcep = direct current, electrode positive (reverse polarity).

^c Where both alternating and direct current are specified, only ac is required for classification testing.

9.4 Groove Weld for Mechanical Properties and Soundness

9.4.1 A test assembly shall be prepared and welded as specified in 9.4.1.1, 9.4.1.2, Figure 2, and the All Weld Metal Tension Test and/or Radiographic Test columns of Table 4 using base material of the appropriate type as specified in 9.2.2. Preheat and interpass temperatures shall be as specified in Table 5. Testing of this assembly shall be as specified in Clause 11, Radiographic Test and Clause 12, Tension Test.

9.4.1.1 The plates shall be welded in the flat position, and they shall be preset or sufficiently restrained during welding to prevent warping more than five degrees. A test plate that has warped more than five degrees shall be discarded. Test assemblies shall not be straightened.



Electrode Size		Weld Pad Size, minimum						Minimum Distance of Sample from Surface of Base Plate	
		L		W		H			
in	mm	in	mm	in	mm	in	mm	in	mm
1/16	1.6	1-1/2	38	1/2	13	1/2	13	3/8	10
5/64	2.0								
3/32	2.4								
—	2.5								
1/8	3.2	2	50	1/2	13	5/8	16	1/2	13
5/32	4.0								
3/16	4.8								
—	5.0								
7/32	5.6	2-1/2	64	1/2	13	3/4	19	5/8	16
—	6.0								
1/4	6.4								

Figure 1—Pad for Chemical Analysis of Undiluted Weld Metal

9.4.1.2 The test assembly shall be within the temperature ranges specified in Table 5 before starting each pass, including depositing of any buttering layer, as measured on the assembly at a distance of 1 in [25 mm] from the weld at the midlength of the test plate.

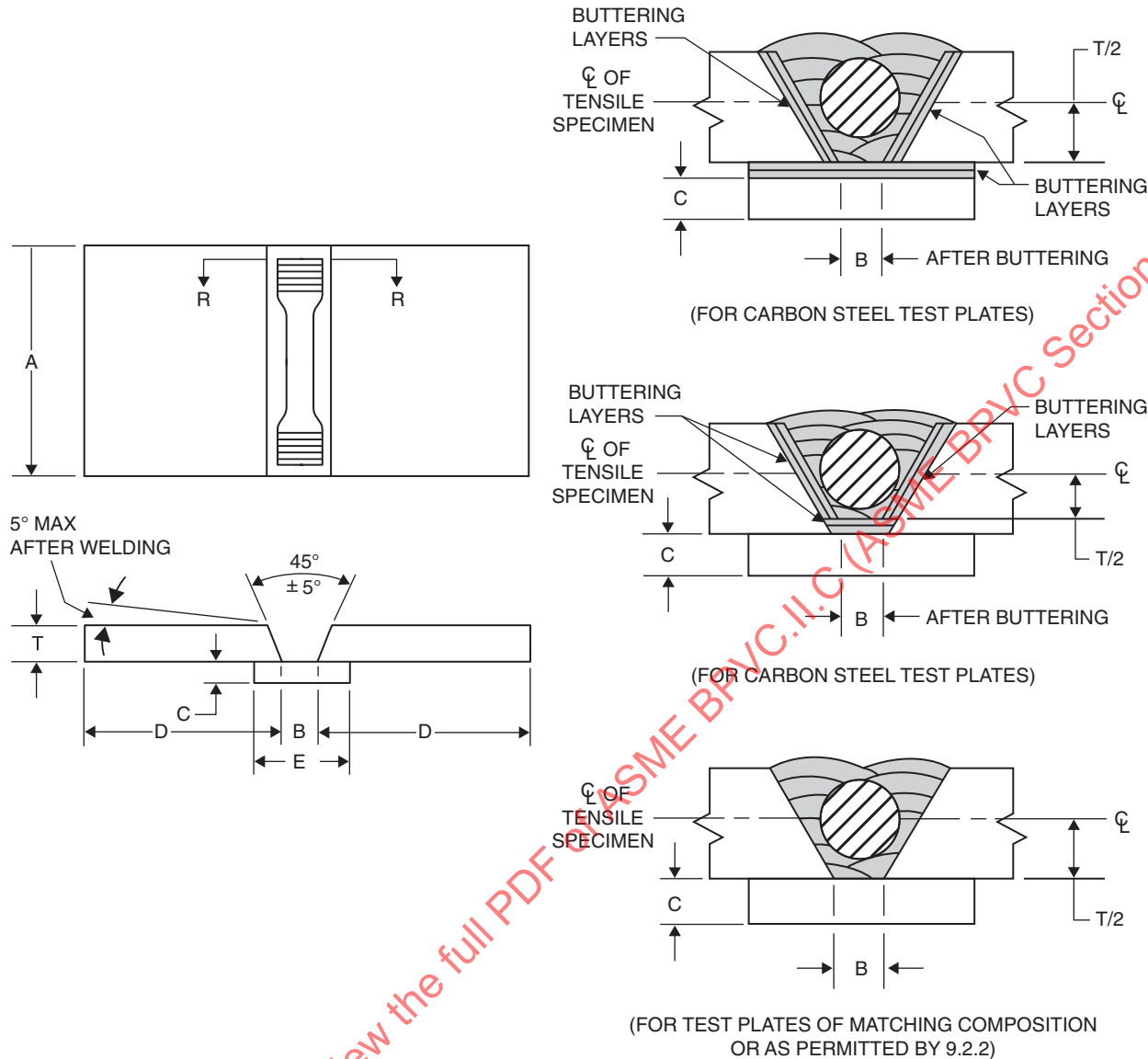
If, after any pass, the maximum temperature specified is exceeded, plates shall be allowed to cool in air (do not cool in water) to a temperature within the range shown.

The assembly shall be tested in the as-welded or postweld heat-treated condition as specified in Table 6.

9.5 Fillet Weld

9.5.1 A test assembly shall be prepared and welded as shown in Figure 3, using base metal of the appropriate type specified in 9.2.3. The welding position and conditions shall be as specified in the fillet weld column of Table 4 for the different electrode sizes and classifications. Testing of the assembly shall be as specified in Clause 13, Fillet Weld Test.

9.5.2 In preparing the two plates forming the test assembly, the standing member (web) shall have one edge prepared throughout its entire length so that when the web is set upon the base plate (flange), which shall be straight and flat, there will be intimate contact along the entire length of the joint.



SECTION R-R

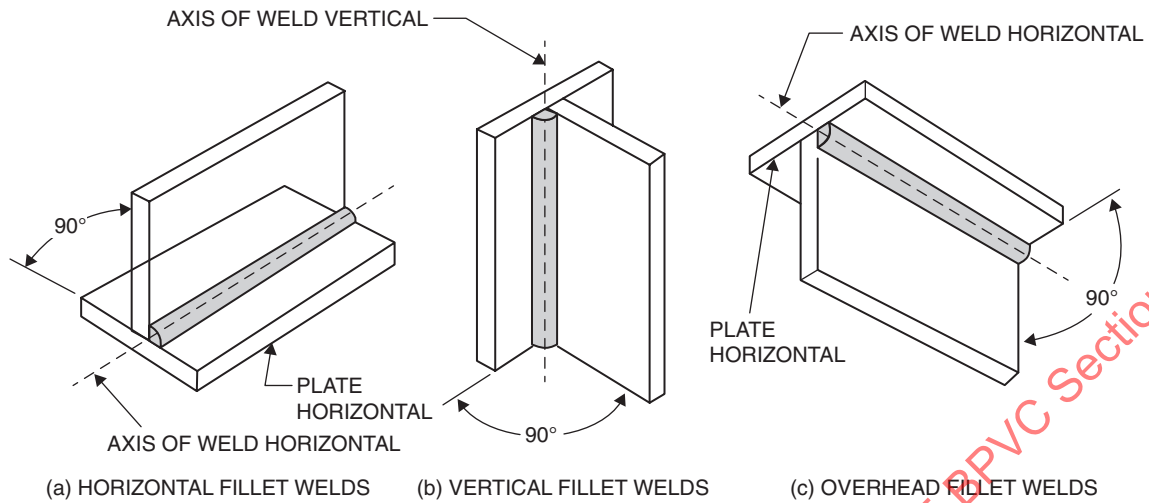
Dimensions of Test Assembly							
Electrode	Diameter	T ^a	A, min. ^b	B ^c	C, min.	D, min.	E, min.
in	1/8	1/2	3-1/2	1/4	3/16	3-1/2	1
mm	3.2	12	90	6.5	5	90	25
in	5/32 to 1/4 incl.	3/4	5-1/2	1/2	1/4	3-1/2	1
mm	4.0 to 6.4 incl.	20	140	12	6.5	90	25

^a For the radiographic test either 1/2 in [12 mm] or 3/4 in [20 mm] plate thickness may be used.

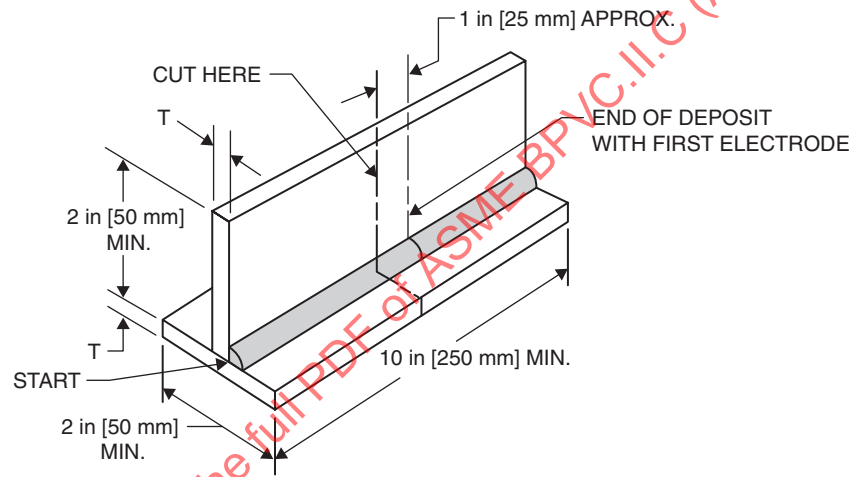
^b Minimum length must be 8 in [200 mm], if being used for radiographic test.

^c Tolerance shall be +1/8 in [3 mm], -0.

Figure 2—Groove Weld Assembly for Tension and Radiographic Tests for Electrodes 1/8 in [3.2 mm] Diameter and Larger



(A) POSITIONS OF TEST PLATES FOR WELDING FILLET-WELD TEST SPECIMENS



(B) PREPARATION OF FILLET-WELD TEST ASSEMBLY

Electrode Diameter		Plate Thickness, T		Position of Welding	Maximum Fillet Size	
in	mm	in	mm		in	mm
1/8	3.2	1/4	6	V	1/4	6.5
1/8 ^a	3.2 ^a	3/8	10	H and OH	3/16	5
				V	3/8	10
				H and OH	1/4	6.5
5/32	4.0	3/8	10	V	5/16	8
				H and OH	1/4	6.5
5/32 ^a	4.0 ^a	1/2	12	V	1/2	13
				H and OH	5/16	8
3/16	4.8 or 5.0	3/8	10	H	5/16	8
7/32	5.6	3/8	10	H	3/8	10
1/4	6.0 or 6.4	3/8	10	H	3/8	10

^a For EXXX-17 electrodes only.

Figure 3—Fillet Weld Test Assembly

Table 5
Welding Conditions for Preparation of
the Groove Weld

AWS Classification	Preheat and Interpass Temperature			
	Minimum		Maximum	
	°F	°C	°F	°C
E409Nb E410NiMo E430 E430Nb E630	300	150	500	260
E410	400	200	600	315
All Others	60	15	300	150

9.5.3 A single-pass fillet weld shall be deposited on one side of the joint. The first electrode shall be continuously consumed to within the maximum permissible stub length of 2 in [50 mm]. Additional electrodes, if necessary, shall then be used to complete the weld for the full length of the joint, consuming each electrode completely as stated above, insofar as permitted by the length of the assembly.

9.5.4 When welding in the vertical position, the welding shall progress upward.

10. Chemical Analysis

10.1 The top surface of the weld pad described in 9.3 and shown in Figure 1 shall be removed and discarded and a sample for analysis shall be obtained from the underlying metal by any appropriate mechanical means. The sample shall be free of slag.

10.2 Weld pads, which are too hard for sample removal in the as-welded condition, may be given an annealing heat treatment.

10.3 Alternatively, the sample taken from the reduced section of the fractured tension specimen or from the groove weld (see 9.1) may be prepared for analysis by any suitable mechanical means. A sample taken from the weld pad used for ferrite determination (A6.9.1 through A6.9.4) shall be taken after draw filing, or grinding, and the height above the base plate for sample removal shall be consistent with the requirements of Figure 1 for the standard weld pad.

10.4 The sample shall be analyzed by accepted analytical methods. In case of dispute, the referee method shall be ASTM E353.

10.5 The results of the analysis shall meet the requirements of Table 1 for the classification of the electrode under test.

10.6 If steel base metal other than those that have 0.03 percent maximum carbon are used for the low-carbon electrodes,⁹ the sample shall come from material above the eighth layer.

11. Radiographic Test

11.1 When required in Table 4, the groove weld described in 9.4 and shown in Figure 2 shall be radiographed to evaluate the soundness of the weld metal. In preparation for radiography, the backing shall be removed and both surfaces of the weld shall be machined or ground smooth and flush with the original surfaces (except as noted) of the base metal or with a uniform reinforcement not exceeding 3/32 in [2.5 mm]. It is permitted on both sides of the test assembly to remove base

⁹ Low-carbon electrodes are as follows: E308L, E308LMo, E309L, E309LMo, E316L, E316LMn, E317L, E320LR, E383, E385, E630, E2209, E2307, E2593, E2594, E2595, and E33-31.

Table 6
All-Weld-Metal Mechanical Property Requirements

AWS Classification	Tensile Strength, min		Elongation min. Percent	Heat Treatment
	ksi	MPa		
E209-XX	100	690	15	None
E219-XX	90	620	15	None
E240-XX	100	690	15	None
E307-XX	85	590	30	None
E308-XX	80	550	30	None
E308H-XX	80	550	30	None
E308L-XX	75	520	30	None
E308Mo-XX	80	550	30	None
E308LMo-XX ^a	75	520	30	None
E309-XX	80	550	30	None
E309H-XX	80	550	30	None
E309L-XX	75	520	30	None
E309Nb-XX ^a	80	550	30	None
E309Mo-XX	80	550	30	None
E309LMo-XX ^a	75	520	30	None
E310-XX	80	550	30	None
E310H-XX	90	620	10	None
E310Nb-XX ^a	80	550	25	None
E310Mo-XX	80	550	30	None
E312-XX	95	660	22	None
E316-XX	75	520	30	None
E316H-XX	75	520	30	None
E316L-XX	70	490	30	None
E316LMn-XX	80	550	20	None
E317-XX	80	550	30	None
E317L-XX	75	520	30	None
E318-XX	80	550	25	None
E320-XX	80	550	30	None
E320LR-XX	75	520	30	None
E330-XX	75	520	25	None
E330H-XX	90	620	10	None
E347-XX	75	520	30	None
E349-XX	100	690	25	None
E383-XX	75	520	30	None
E385-XX	75	520	30	None
E409Nb-XX	65	450	20	d
E410-XX	75	520	20	b
E410NiMo-XX	110	760	15	c
E430-XX	65	450	20	d
E430Nb-XX	65	450	20	d
E630-XX	135	930	7	e
E16-8-2-XX	80	550	35	None
E2209-XX	100	690	20	None
E2307-XX	100	690	20	None
E2553-XX	110	760	15	None
E2593-XX	110	760	15	None
E2594-XX	110	760	15	None
E2595-XX	110	760	15	None
E3153-XX	100	690	20	None
E33-31-XX	105	720	25	None

^a E308LMo-XX, E309LMo-XX, E309Nb-XX, and E310Nb-XX were formerly named E308MoL-XX, E309MoL-XX, E309Cb-XX, and E310Cb-XX, respectively. The change was made to conform to the worldwide uniform designation of the element niobium.

^b Heat to 1350 °F to 1400 °F [730 °C to 760 °C], hold for one hour (–0, +15 minutes), furnace cool at a rate not to exceeding 200 °F [110 °C] per hour to 600 °F [315 °C] and air cool to ambient.

^c Heat to 1100 °F to 1150 °F [595 °C to 620 °C], hold for one hour (–0, +15 minutes), and air cool to ambient.

^d Heat to 1400 °F to 1450 °F [760 °C to 790 °C], hold for two hours (–0, +15 minutes), furnace cool at a rate not exceeding 100 °F [55 °C] per hour to 1100 °F [595 °C] and air cool to ambient.

^e Heat to 1875 °F to 1925 °F [1025 °C to 1050 °C], hold for one hour (–0, +15 minutes), and air cool to ambient, and then precipitation harden at 1135 °F to 1165 °F [610 °C to 630 °C], hold for four hours (–0, +15 minutes), and air cool to ambient.

metal to a depth of 1/16 in [1.5 mm] nominal below the original base metal surface in order to facilitate backing and/or buildup removal. Thickness of the weld metal shall not be reduced by more than 1/16 in [1.5 mm] less than the normal base metal thickness. Both surfaces of the test assembly, in the area of the weld, shall be smooth enough to avoid difficulty in interpreting the radiograph.

11.2 The weld shall be radiographed in accordance with ASTM E1032. The quality level of inspection shall be 2-2T.

11.3 The soundness of the weld metal meets the requirements of this specification if the radiograph shows:

1. no cracks, no incomplete fusion, and no incomplete penetration.
2. no slag in excess of the following:
 - a. in any 6 in [150 mm] length of the 1/2 in [12 mm] thick test assembly: no individual slag inclusion longer than 7/32 in [5.6 mm] and a maximum total length of 7/16 in [11 mm] for all slag inclusions
 - b. in any 6 in [150 mm] length of the 3/4 in [20 mm] thick test assembly: no individual slag inclusion in excess of 9/32 in [7.1 mm] and a maximum total length of 15/32 in [12 mm] for all slag inclusions.
3. no rounded indications in excess of those permitted by the radiographic standards in Figure 5A, or 5B as applicable.

In evaluating the radiograph, 1 in [25 mm] of the weld on each end of the test assembly shall be disregarded.

11.3.1 A rounded indication is an indication (on the radiograph) whose length is no more than three times its width. Rounded indications may be circular or irregular in shape, and they may have tails. The size of a rounded indication is the largest dimension of the indication, including any tail that may be present. The indications may be porosity, or slag inclusions.

11.3.2 Indications whose largest dimension does not exceed 1/64 in [0.4 mm] shall be disregarded. Test assemblies with indications in excess of the sizes permitted in the radiographic standards do not meet the requirements of this specification.

12. Tension Test

12.1 One all-weld metal round tension specimen as specified in the Tension Test section of AWS B4.0 or AWS B4.0M shall be machined from the groove weld described in 9.4 and shown in Figure 2. For a test plate thickness of 1/2 in [12 mm], the all-weld-metal tension test specimen shall have a nominal diameter of 0.250 in [6.25 mm]. For a test plate thickness of 3/4 in [20 mm], the all-weld-metal tension test specimen shall have a nominal diameter of 0.500 [12.5 mm]. For all plate thicknesses, the gage length-to-diameter ratio shall be 4:1.

12.2 The specimen shall be tested in the manner described in the tension test section of AWS B4.0 or AWS B4.0M.

12.3 The results of the tension test shall meet the requirements specified in Table 6.

13. Fillet Weld Test

13.1 The fillet weld test, when required in Table 4, shall be made in accordance with 9.5 and Figure 3. The entire face of the completed fillet weld shall be examined visually. The weld shall be free from cracks or other open defects that would affect the strength of the weld. After the visual examination, a cross section shall be taken from the portion of the weld made with the first electrode at approximately 1 in [25 mm] from the end of that weld bead, as shown in Figure 3. The cross-sectional surface shall be polished and etched, and then examined as required in 13.2.

13.2 Scribe lines shall be placed on the prepared surface, as shown in Figure 4, and the leg length and the convexity shall be determined to the nearest 1/64 in [0.5 mm] by actual measurement.

13.2.1 The fillet weld shall have complete fusion to the joint root.

13.2.2 Both legs of the fillet weld shall be equal in length within 1/16 in [1.5 mm].

13.2.3 Convexity of the fillet weld shall be within the limits shown in Figure 4.

13.2.4 The fillet weld shall show no evidence of cracks.

13.2.5 The fillet weld shall be reasonably free from undercutting, overlap, trapped slag, and porosity.

14. Method of Manufacture

The welding electrodes classified according to this specification may be manufactured by any method that will produce electrodes conforming to the requirements of this specification.

15. Standard Sizes and Lengths

Standard sizes (diameter of the core wire), standard lengths, and tolerances of electrodes shall be as shown in Table 7.

16. Core Wire and Covering

16.1 The core wire and covering shall be free of defects that would interfere with uniform deposition of the weld metal.

16.2 The core wire and the covering shall be concentric to the extent that the maximum core-plus-one-covering dimension does not exceed the minimum core-plus-one-covering dimension by more than the following:

1. Seven percent of the mean dimension in sizes 3/32 in [2.5 mm] and smaller
2. Five percent of the mean dimension in sizes 1/8 in [3.2 mm] and 5/32 in [4.0 mm]
3. Four percent of the mean dimension in sizes 3/16 in [4.8 mm] and larger

The concentricity may be measured by any suitable means.

17. Exposed Core

17.1 The grip end of each electrode shall be bare (free of covering) for a distance of not less than 1/2 in [12 mm], nor more than 1-1/4 in [30 mm] for electrodes 5/32 in [4.0 mm] and smaller, and not less than 3/4 in [19 mm], nor more than 1-1/2 in [38 mm] for electrodes 3/16 in [4.8 mm] and larger, to provide for electrical contact with the electrode holder.

17.2 The arc end of each electrode shall be sufficiently bare and the covering sufficiently tapered to permit easy striking of the arc. The length of the bare portion (measured from the end of the core wire to the location where the full cross section of the covering is obtained) shall not exceed 1/8 in [3 mm] or the diameter of the core wire, whichever is less. Electrodes with chipped coverings near the arc end, baring the core wire no more than the lesser of 1/4 in [6 mm] or twice the diameter of the core wire, meet the requirements of this specification, provided no chip uncovers more than 50 percent of the circumference of the core.

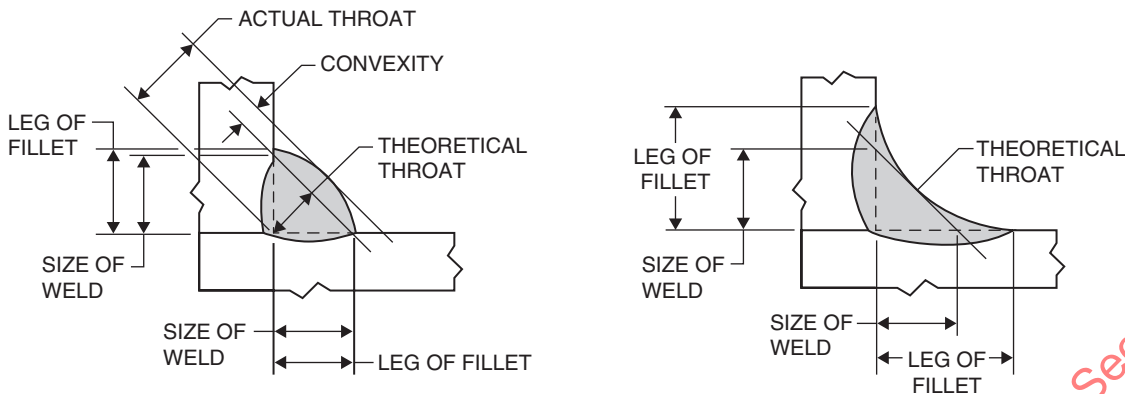
18. Electrode Identification

All electrodes shall be identified as follows:

18.1 At least one imprint of the electrode classification shall be applied to the electrode covering starting within 2-1/2 in [65 mm] of the grip end of the electrode. The prefix letter "E" in the electrode classification may be omitted from the imprint.

18.2 The numbers and letters of the imprint shall be of bold block type and of a size large enough to be legible.

18.3 The ink used for imprinting shall provide sufficient contrast with the electrode covering so that, in normal use, the numbers and letters are legible both before and after welding.



Measured Fillet Weld Size ^a		Maximum Convexity ^b	
in	mm	in	mm
1/8	3.0	3/64	1.0
9/64	3.5	3/64	1.0
5/32	4.0	3/64	1.0
11/64	4.5	3/64	1.0
3/16	5.0	1/16	1.5
13/64	5.0	1/16	1.5
7/32	5.5	1/16	1.5
15/64	6.0	1/16	1.5
1/4	6.5	1/16	1.5
17/64	6.5	1/16	1.5
9/32	7.0	1/16	1.5
19/64	7.5	1/16	1.5
5/16	8.0	5/64	2.0
21/64	8.5	5/64	2.0
11/32	8.5	5/64	2.0
23/64	9.0	5/64	2.0
3/8	9.5	5/64	2.0

^a Size of fillet weld = leg length of largest inscribed isosceles right triangle.

^b Fillet weld size, convexity, and leg lengths of fillet welds shall be determined by actual measurement (nearest 1/64 in [0.5 mm]) on a section laid out with scribed lines shown.

Figure 4—Fillet Weld Test Specimen

19. Packaging

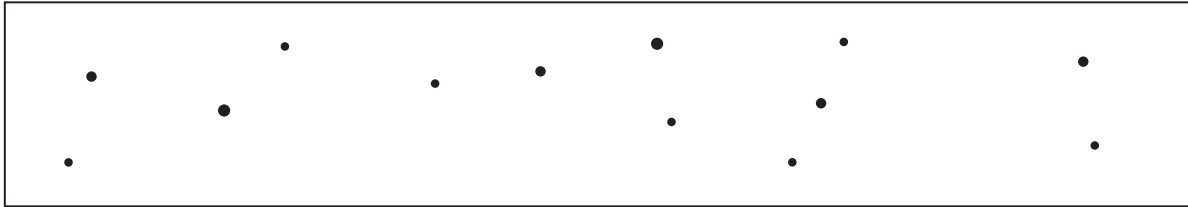
19.1 Electrodes shall be suitably packaged to protect them from damage during shipment and storage under normal conditions.

19.2 Standard package weights shall be as agreed between purchaser and supplier.

20. Marking of Packages

20.1 The following product information (as a minimum) shall be legibly marked on the outside of each unit package:

1. AWS specification and classification designations (year of issue may be excluded)
2. Supplier's name and trade designation
3. Standard size and net weight
4. Lot, control, or heat number.

**(A) ASSORTED ROUNDED INDICATIONS**

SIZE 1/64 in TO 1/16 in [0.4 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 13 WITH THE FOLLOWING RESTRICTIONS:

MAXIMUM NUMBER OF LARGE 3/64 in TO 1/16 in [1.2 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 2.

MAXIMUM NUMBER OF MEDIUM 1/32 in TO 3/64 in [0.8 mm TO 1.2 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 4.

MAXIMUM NUMBER OF SMALL 1/64 in TO 1/32 in [0.4 mm TO 0.8 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 7.

**(B) LARGE ROUNDED INDICATIONS**

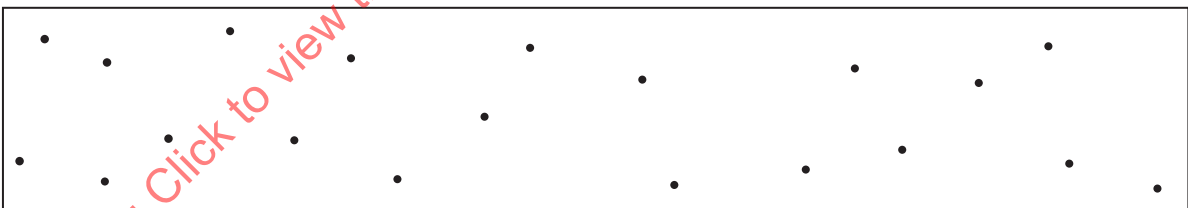
SIZE 3/64 in TO 1/16 in [1.2 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 6.

**(C) MEDIUM ROUNDED INDICATIONS**

SIZE 1/32 in TO 3/64 in [0.8 mm TO 1.2 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 10.

**(D) SMALL ROUNDED INDICATIONS**

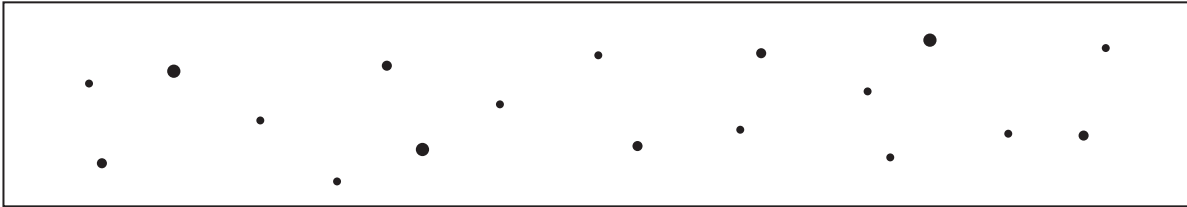
SIZE 1/64 in TO 1/32 in [0.4 mm TO 0.8 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 20.

Notes:

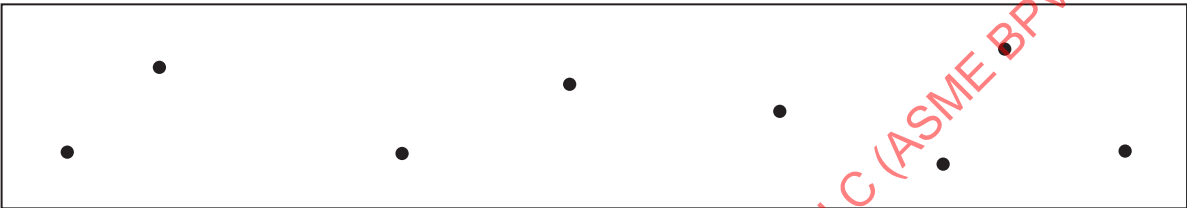
1. In using these standards, the chart which is most representative of the size of the rounded indications present in the test specimen radiograph shall be used for determining conformance to these radiographic standards.
2. Since these are test welds specifically made in the laboratory for classification purposes, the radiographic requirements for these test welds are more rigid than those which may be required for general fabrications.

Figure 5A—Rounded Indication Standards for Radiograph Test—1/2 in [12 mm] Plate



(A) ASSORTED ROUNDED INDICATIONS

SIZE 1/64 in TO 1/16 in [0.4 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH.
MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 18 WITH THE FOLLOWING RESTRICTIONS:
MAXIMUM NUMBER OF LARGE 3/64 in TO 1/16 in [1.2 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 3.
MAXIMUM NUMBER OF MEDIUM 1/32 in TO 3/64 in [0.8 mm TO 1.2 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 5.
MAXIMUM NUMBER OF SMALL 1/64 in TO 1/32 in [0.4 mm TO 0.8 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 10.



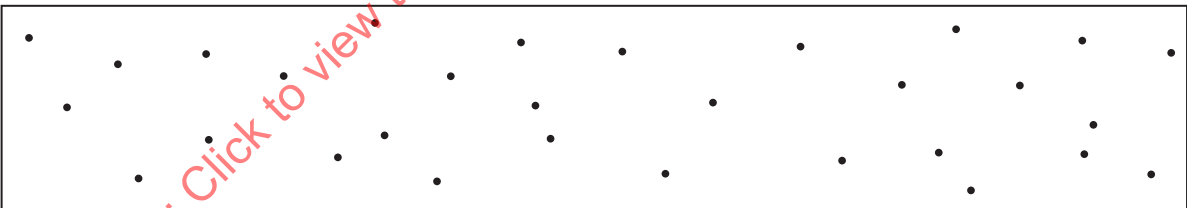
(B) LARGE ROUNDED INDICATIONS

SIZE 3/64 in TO 1/16 in [1.2 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH.
MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 8.



(C) MEDIUM ROUNDED INDICATIONS

SIZE 1/32 in TO 3/64 in [0.8 mm TO 1.2 mm] IN DIAMETER OR IN LENGTH.
MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 15.



(D) SMALL ROUNDED INDICATIONS

SIZE 1/64 in TO 1/32 in [0.4 mm TO 0.8 mm] IN DIAMETER OR IN LENGTH.
MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 30.

- Notes:
1. In using these standards, the chart which is most representative of the size of the rounded indications present in the test specimen radiograph shall be used for determining conformance to these radiographic standards.
 2. Since these are test welds specifically made in the laboratory for classification purposes, the radiographic requirements for these test welds are more rigid than those which may be required for general fabrications.

Figure 5B—Rounded Indication Standards for Radiograph Test—3/4 in [20 mm] Plate

Table 7
Standard Sizes and Lengths

Electrode Size (Diameter of Core Wire) ^a		Standard Lengths ^{b,c}	
in	mm	in	mm
1/16	1.6	9,10	225, 250
5/64	2.0	9,10	225, 250
3/32	2.4 ^e	9, 10, 12, 14 ^d	225, 250, 300, 350 ^d
	2.5	9, 10, 12, 14 ^d	225, 250, 300, 350 ^d
1/8	3.2	14, 18 ^d	350, 450 ^d
5/32	4.0	14, 18 ^d	350, 450 ^d
3/16	4.8 ^e	14, 18 ^d	350, 450 ^d
	5.0	14, 18 ^d	350, 450 ^d
7/32	5.6 ^e	14, 18 ^d	350, 450 ^d
	6.0	14, 18 ^d	350, 450 ^d
1/4	6.4 ^e	14, 18 ^d	350, 450 ^d

^a Tolerance on the diameter shall be ± 0.002 in [± 0.05 mm].

^b Tolerance on length shall be $\pm 1/4$ in [± 6 mm].

^c Other sizes and lengths shall be as agreed upon between purchaser and supplier.

^d These lengths are intended only for the EXXX-26 type.

^e These sizes are not standard in ISO 544.

20.2 The appropriate precautionary information¹⁰ as given in ANSI Z49.1, latest edition (as a minimum), or its equivalent, shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages enclosed within a larger package.

¹⁰ Typical examples of “warning labels” and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

Annex A (Informative)

Guide to AWS Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding

This annex is not part of AWS A5.4/A5.4M:2012, *Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding*, but is included for informational purposes only.

A1. Introduction

The purpose of this guide is to correlate the electrode classifications with their intended applications so that the specification can be used effectively. Appropriate base metal specifications or welding processes are referred to whenever that can be done and when it would be helpful. Such references are intended only as examples rather than complete listings of the materials or welding processes for which each welding material is suitable.

A2. Classification System

A2.1 The system for identifying the electrode classification in this specification follows the standard pattern used in other AWS filler metal specifications. The prefix letter “E” at the beginning of each classification designation stands for electrode. The first three digits designate the classification as to its composition. (Occasionally, a number of digits other than three is used and letters may follow the digits to indicate a specific composition.) The last two digits designate the classification as to usability with respect to position of welding and type of current as described in A8. The smaller sizes of EXXX(X)-15, EXXX(X)-16, or EXXX(X)-17 electrodes up to and including 5/32 in [4.0 mm] included in this specification are used in all welding positions.

A2.1.1 The mechanical tests measure strength and ductility. In corrosive and high-temperature applications where there may be no load-carrying or pressure-retaining requirement, mechanical properties are often of lesser importance than the corrosion and heat-resisting properties. These mechanical test requirements, however, provide an assurance of freedom from weld metal flaws, such as check cracks and serious dendritic segregation which, if present, may cause failure in service.

A2.1.2 It is recognized that for certain applications, supplementary tests may be required. In such cases, additional tests to determine specific properties, such as corrosion resistance, scale resistance, or strength at elevated temperatures, may be required as agreed upon between supplier and purchaser (see A9).

A2.2 Request for New Classification

1. When a new classification that is different from those in this specification achieves commercial significance, the manufacturer, or the user, of this new classification may request that a classification be established for it and that it be included in this specification.
2. A request to establish a new classification must be a written request, and it needs to provide sufficient detail to permit the Committee on Filler Metals and Allied Materials or the Subcommittee on Stainless Steel Filler Metals to determine whether the new classification or the modification of an existing classification is more appropriate, and whether either is necessary to satisfy the need. In particular, the request needs to include:
 - a. All classification requirements as given for existing classifications, such as chemical composition ranges, mechanical property requirements, and usability test requirements.

b. Any testing conditions for conducting the tests used to demonstrate that the product meets the classification requirements. (It would be sufficient, for example, to state that welding conditions are the same as for other classifications.)

c. Information on Description and Intended Use, which parallels that for existing classifications, for that section of the annex.

A request for a new classification without the above information will be considered incomplete. The Secretary will return the request to the requestor for further information.

3. The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters. Upon receipt of the request, the Secretary will:

- a. Assign an identifying number to the request. This number will include the date the request was received.
- b. Confirm receipt of the request and give the identification number to the person who made the request.
- c. Send a copy of the request to the Chair of the Committee on Filler Metals and Allied Materials, and to the Chair of the Subcommittee on Stainless Steel Filler Metals.
- d. File the original request.
- e. Add the request to the log of outstanding requests.

4. All necessary action on each request will be completed as soon as possible. If more than 12 months lapse, the Secretary shall inform the requestor of the status of the request, with copies to the Chairs of the Committee and the Subcommittee. Requests still outstanding after 18 months shall be considered not to have been answered in a timely manner and the Secretary shall report these to the Chair of the Committee on Filler Metals and Allied Materials for action.

5. The Secretary shall include a copy of the log of all requests pending and those completed during the preceding year with the agenda for each Committee on Filler Metals and Allied Materials meeting. Any other publication of requests that have been completed will be at the option of the American Welding Society, as deemed appropriate.

A2.3 International Classification System. Table A.1 shows the classifications of welding filler metals in ISO 3581:2003 corresponding to those in this specification. In accordance with the generic system being adopted in many ISO specifications, the initial letter "E" designates a covered electrode, and the letter "S" the alloy system. The subsequent designators follow the AWS system. This system applies to classifications in ISO 3581B. The designations used in Europe for the closely corresponding classifications in ISO 3581A appear in Table A.1.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01, *Filler Metal Procurement Guidelines*, as the specification states. Any testing a purchaser requires of the supplier, for material shipped in accordance with this specification, must be clearly stated in the purchase order, according to the provisions of AWS A5.01. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing is normally conducted on material of that classification, as specified in Schedule F, Table 1, of AWS A5.01. Testing in accordance with any other Schedule in that Table must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product, or the classification on the product itself, constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification. The only testing requirement implicit in this certification is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation. "Certification" is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted.

The basis for the certification required by the specification is the classification test of “representative material” cited above, and the “Manufacturer’s Quality Assurance Program” in AWS A5.01M/A5.01(ISO 14344 MOD).

A5. Ventilation

A5.1 Five major factors govern the quantity of fumes in the atmosphere to which welders and welding operators are exposed during welding. They are:

1. Dimensions of the space in which the welding is done (with special regard to the height of the ceiling)
2. Number of welders and welding operators working in that space
3. Rate of evolution of fumes, gases, or dust, according to the materials and processes used
4. The proximity of the welders or welding operators to the fumes, as these fumes issue from the welding zone, and to the gases and dusts in the space in which they are working
5. The ventilation provided to the space in which the welding is done.

A5.2 American National Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the section on Ventilation in that document.

A6. Ferrite in Weld Deposits

A6.1 Ferrite is known to be very beneficial in reducing the tendency for cracking or fissuring in weld metals; however, it is not essential. Millions of pounds of fully austenitic weld metal have been used for years and provided satisfactory service performance. Generally, ferrite is helpful when the welds are restrained, the joints are large, and when cracks or fissures adversely affect service performance. Ferrite increases the weld strength level. Ferrite may have a detrimental effect on corrosion resistance in some environments. It also is generally regarded as detrimental to toughness in cryogenic service, and in high-temperature service where it can transform into the brittle sigma phase.

A6.2 Ferrite can be measured on a relative scale by means of various magnetic instruments. However, work by the Subcommittee for Welding of Stainless Steel of the High-Alloys Committee of the Welding Research Council (WRC) established that the lack of a standard calibration procedure resulted in a very wide spread of readings on a given specimen when measured by different laboratories. A specimen averaging 5.0 percent ferrite based on the data collected from all the laboratories was measured as low as 3.5 percent by some and as high as 8.0 percent by others. At an average of 10 percent, the spread was 7.0 to 16.0 percent.

In order to substantially reduce this problem, the WRC Subcommittee published on July 1, 1972, *Calibration Procedure for Instruments to Measure the Delta Ferrite Content of Austenitic Stainless Steel Weld Metal*.¹¹ In 1974, the American Welding Society extended this procedure and prepared AWS A4.2, *Standard Procedure for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic Steel Weld Metal*. All instruments used to measure the ferrite content of AWS classified stainless electrode products are to be traceable to this AWS standard.

A6.3 The WRC Subcommittee also adopted the term *Ferrite Number* (FN) to be used in place of percent ferrite, to clearly indicate that the measuring instrument was calibrated to the WRC procedure. The Ferrite Number, up to 10 FN, is to be considered equal to the *percent ferrite* term previously used. It represents a good average of commercial U.S. and world practice on the percent ferrite. Through the use of standard calibration procedures, differences in readings due to instrument calibration are expected to be reduced to about ± 5 percent, or at the most, ± 10 percent of the measured ferrite value.

A6.4 In the opinion of the WRC Subcommittee, it has been impossible, to date, to accurately determine the true absolute ferrite content of weld metals.

¹¹ WRC documents are published by Welding Research Council, P.O. Box 201547, Shaker Heights, OH 44120.

Table A.1
Comparison of Classification in ISO 3581:2003

AWS A5.4/A5.4M	ISO 3581A	ISO 3581B
E209	—	ES209
E219	—	ES219
E240	—	ES240
E307	E18 9 Mn Mo	ES307
E308	E19 9	ES308
E308H	E19 9 H	ES308H
E308L	E19 9 L	ES308L
E308Mo	E20 10 3	ES308Mo
E308LMo	—	ES308LMo
E309	E22 12	ES309
E309H	—	ES309H
E309L	E22 12 L	ES309L
E309Nb	E23 12 Nb	ES309Nb
E309Mo	—	ES309Mo
E309LMo	E23 12 2 L	ES309LMo
E310	E25 20	ES310
E310H	E25 20H	ES310H
E310Nb	—	ES310Nb
E310Mo	—	ES310Mo
E312	E29 9	ES312
E316	E19 12 2	ES316
E316H	—	ES316H
E316L	E19 12 3 L	ES316L
E316LMn	E20 16 3 Mn N L	ES316LMn
E317	—	ES317
E317L	—	ES317L
E318	E 19 2 3 Nb	ES318
E320	—	ES320
E320LR	—	ES320LR
E330	E18 36	ES330
E330H	—	ES330H
E347	E19 9 Nb	ES347
E349	—	ES349
E409Nb	—	ES409Nb
E410	E13	ES410
E410NiMo	E13 4	ES410NiMo
E430	E17	ES430
E430Nb	—	ES430Nb
E630	—	ES630
E16-8-2	E16 8 2	ES16-8-2
E2209	E22 9 3 N L	ES2209
E2307	E23 7 NL	—
E2553	—	ES2553
E2593	E25 9 3 Cu N L	—
E2594	E25 9 4 N L	—
E2595	—	—
E3155	—	—
E33-31	—	—

A6.5 Even on undiluted pads, ferrite variations from pad to pad must be expected due to slight changes in welding and measuring variables. On a large group of pads from one heat or lot and using a standard pad welding and preparation procedure, two sigma values indicate that 95 percent of the tests are expected to be within a range of approximately ± 2.2 FN at about 8 FN. If different pad welding and preparation procedures are used, these variations will increase.

A6.6 Even larger variations may be encountered if the welding technique allows excessive nitrogen pickup, in which case the ferrite can be much lower than it should be. High nitrogen pickup can cause a typical 8 FN deposit to drop to 0 FN. A nitrogen pickup of 0.10 percent will typically decrease the FN by about 8.

A6.7 Plate materials tend to be balanced chemically to have inherently lower ferrite content than matching weld metals. Weld metal diluted with plate metal will usually be somewhat lower in ferrite than the undiluted weld metal, though this does vary depending on the amount of dilution and the composition of the base metal.

A6.8 In the E3XX classifications, many types such as E310, E310Mo, E310Nb, E316LMn, E320, E320LR, E330, E383, E385, and E3155, and E31-33 are fully austenitic. The E316 group can be made with little or no ferrite and generally is used in that form because it has better corrosion resistance in certain media. It also can be obtained in a higher ferrite form, usually over 4 FN, if desired. Many of the other E3XX classifications can be made in low-ferrite versions, but commercial practice usually involves ferrite control above 4 FN. Because of composition limits covering these grades and various manufacturing limits, most lots will be under 10 FN and they are unlikely to go over 15 FN. E308LMo and E309L can have ferrite levels in excess of 15 FN. E16-8-2 generally is controlled at a low-ferrite level, under 5 FN; E309LMo, E312, E2209, E2307, E2553, E2593, and E2594, and E2595 generally are quite high in ferrite, usually over 20 FN.

A6.9 When it is desired to measure ferrite content, the following procedure is recommended to minimize variation in measured ferrite content and avoid false low or false high values.

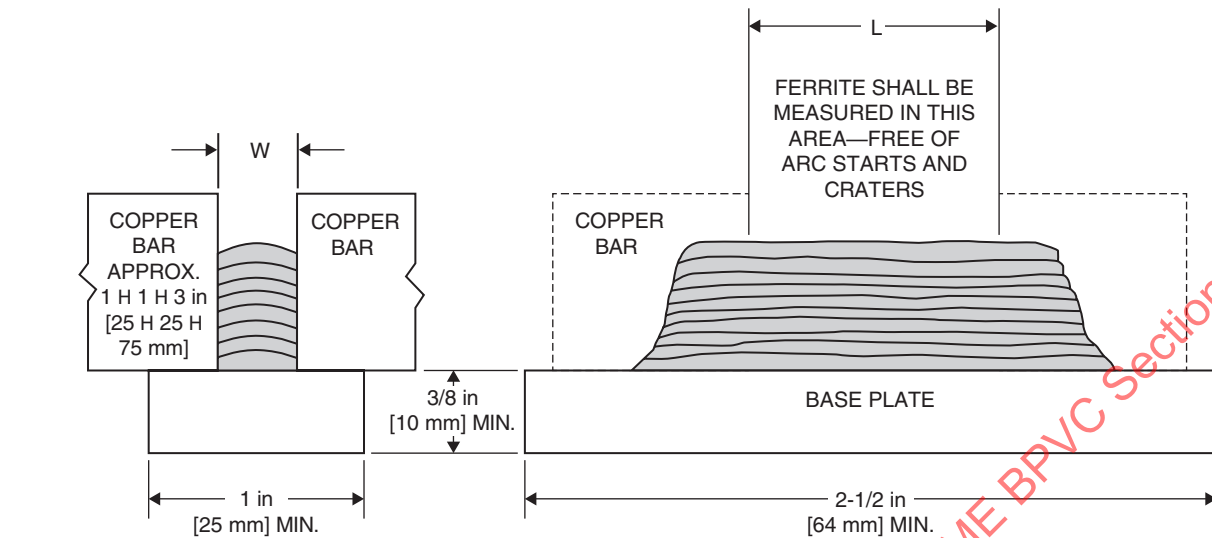
A6.9.1 Weld pads as detailed in Figure A.1 are prepared as described in A6.9.2 through A6.9.4. The base plate should be Type 301, 302, or 304 conforming to ASTM Specification A167 or A240. Carbon steel may be used provided that the weld pad is built up to the minimum height specified in A6.9.2.

A6.9.2 The weld pad should be built up between two copper bars laid parallel on the base plate by depositing single weld bead layers, one on top of the other to a minimum height of 1/2 in [13 mm]. The spacing between the copper bars for the size of the electrode being tested should be as specified in Figure A.1. An optional welding fixture is shown in Figure A.2. If carbon steel is used as the base plate, the weld pad should be built up to a minimum height of 5/8 in [16 mm].

A6.9.3 Typical welding currents used for the size of the electrode being tested are shown in Figure A.1. The arc length should be as short as practicable. The weld bead layers may be deposited with a weave, if necessary, to fill the space between the copper bars. The arc should not be allowed to impinge on the copper bars. The welding direction should be alternated from pass to pass. The weld stops and starts should be located at the ends of the weld buildup. Each pass should be cleaned prior to depositing the next weld bead. The maximum interpass temperatures should be 200 °F [95 °C]. Between passes, the weld pad may be cooled by quenching in water not sooner than 20 seconds after the completion of each pass. The last pass should be air cooled to below 800 °F [430 °C] prior to quenching in water.

A6.9.4 The completed weld pad when the anticipated ferrite is 30 FN or less should be draw filed to provide sufficient finished surface to make the required ferrite readings. Draw filing should be performed with a 14 in [360 mm] mill bastard file held on both sides of the weld with the long axis of the file perpendicular to the long axis of the weld. (Other methods of surface preparation have been shown to result in work hardening and/or overheating, causing false measurements.) Files should either be new or should have been used only on austenitic stainless steel. Filing should be accomplished by smooth draw filing strokes (one direction only) along the length of the weld while applying a firm downward pressure. Cross filing, that is, filing in two different directions, should not be permitted. The finished surface should be smooth with all traces of weld ripple removed and should be continuous in length where measurements are to be taken. The width of the prepared surface should not be less than 1/8 in [3 mm]. For anticipated ferrite levels greater than 30 FN, the surface should be ground with successfully finer abrasives to 600 grit or finer. Care should be taken during grinding to prevent overheating or burning. The completed weld pad should have the surface prepared so that it is smooth with all traces of weld ripple removed and should be continuous in length where measurements are to be taken. This can be accomplished by any suitable means providing the surface is not heated in excess during the machining operation (excessive heating may affect the final ferrite reading). The width of the prepared surface should not be less than 1/8 in [3 mm].

A6.9.5 A total of at least six ferrite readings should be taken on the finished surface along the longitudinal axis of the weld pad with an instrument calibrated in accordance with the procedures specified in AWS A4.2M, *Standard Procedures*



Electrode Size		Welding Current Amperes ^a	Approximate Dimensions of Deposit			
			Width, W		Length, L	
in	mm	-15,-16,-17,-26	in	mm	in	mm
1/16	1.6	35–50	0.25	6.5	1-1/4	32
5/64	2.0	45–60	0.25	6.5	1-1/4	32
3/32	2.4, 2.5	65–90	0.3	7.5	1-1/2	38
1/8	3.2	90–120	0.4	10	1-1/2	38
5/32	4.0	120–150	0.5	13	1-1/2	38
3/16	4.8, 5.0	160–200	0.6	15	1-1/2	38
7/32	5.6	200–240	0.7	18	1-1/2	38
	6.0	220–260	0.7	18	1-1/2	38
1/4	6.4	240–280	0.7	18	1-1/2	38

^a Recommended welding current will vary widely depending on the type of core wire employed. Consult the manufacturer for specific recommendations. Welding current used to produce the test specimen should be reported.

Figure A.1—Weld Pad for Ferrite Test

for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal (latest edition). The readings obtained should be averaged to a single value.

A6.10 The ferrite content of welds may be calculated from the chemical composition of the weld deposit. This can be done from the WRC-1992 Diagram (Figure A.3).

A6.10.1 The WRC-1992 Diagram¹² (Figure A.3) predicts the ferrite content in Ferrite Number (FN). It is a slight modification of the WRC-1988 Diagram¹³ to take into account the effect of copper as originally proposed by Lake. Studies within the WRC Subcommittee on Welding of Stainless Steel and within Commission II of the International Institute of Welding show a closer agreement between measured and predicted ferrite contents using the WRC-1988 Diagram than when using the previously used DeLong Diagram. The WRC-1992 Diagram may not be applicable to compositions having greater than 0.3 percent nitrogen, one percent silicon, or greater than ten percent manganese. For stainless steel compositions not alloyed with Cu, the predictions of the 1988 and 1992 diagrams are identical.

¹² Kotecki, D. J. and Siewert, T. A. 1992. WRC-1992 Constitution Diagram for Stainless Steel Weld Metals: A Modification of the WRC-1988 Diagram, *Welding Journal* 71(5): 171-s to 178-s.

¹³ McCowan, C. N., Siewert, T. A., and Olson, D. L. 1989. WRC Bulletin 342, *Stainless Steel Weld Metal: Prediction of Ferrite Content*, New York, NY: Welding Research Council.

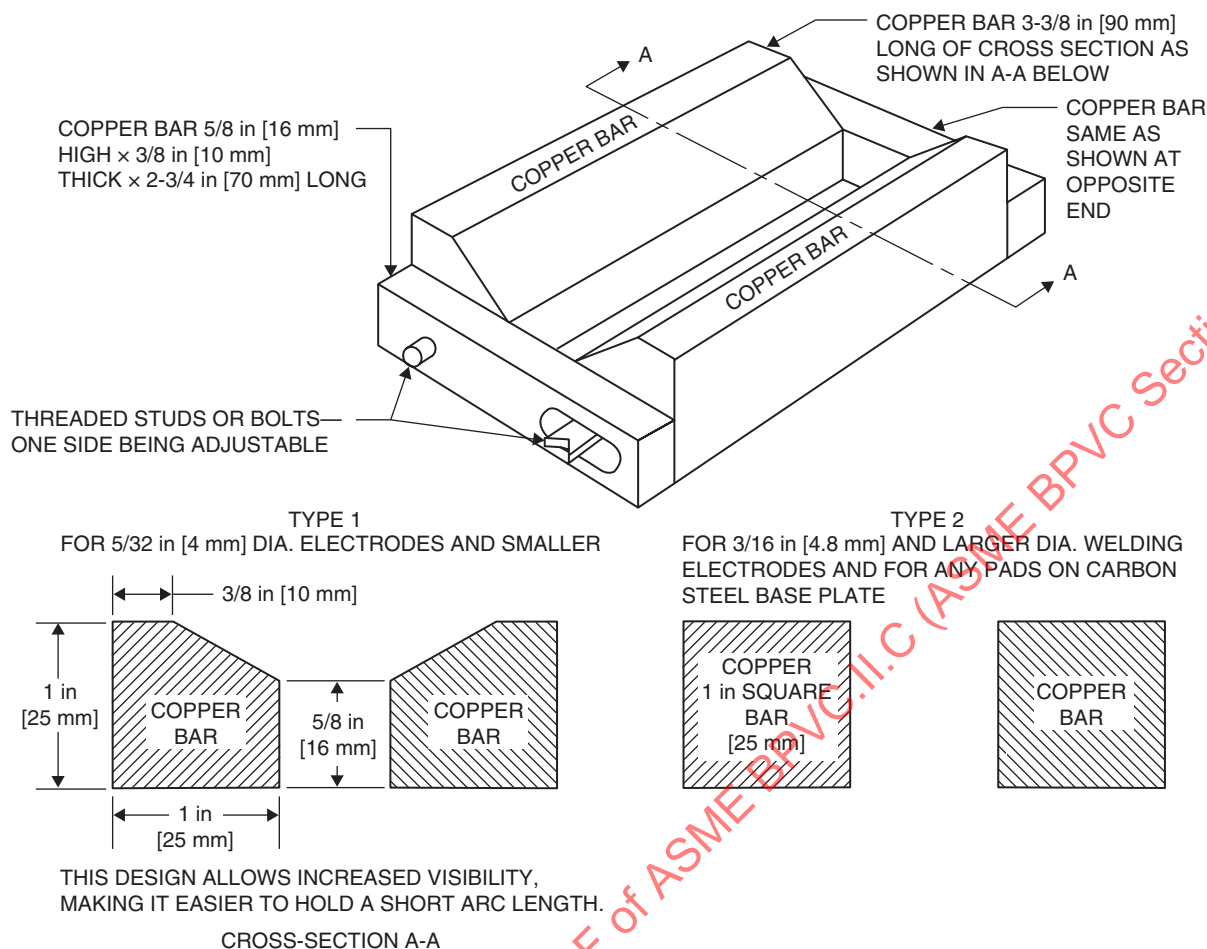


Figure A.2—Optional Welding Fixture for Welding Ferrite Test Pads

A6.10.2 The differences between measured and calculated ferrite are somewhat dependent on the ferrite level of the deposit, increasing as the ferrite level increases. The agreement between the calculated and measured ferrite values is also strongly dependent on the quality of the chemical analysis. Variations in the results of the chemical analyses encountered from laboratory to laboratory can have significant effects on the calculated ferrite value, changing it as much as 4 to 8 FN.

A7. Description and Intended Use of Filler Metals

A7.1 E209. The nominal composition (wt %) of this weld metal is 22 Cr, 11 Ni, 5.5 Mn, 2 Mo, and 0.20 N. Electrodes of this composition are most often used to weld AISI Type 209 (UNS S20910) base metals. The alloy is a nitrogen-strengthened austenitic stainless steel exhibiting high strength with good toughness over a wide range of temperatures. Nitrogen alloying reduces the tendency for intergranular carbide precipitation in the weld area by inhibiting carbon diffusion and thereby increasing resistance to intergranular corrosion. Nitrogen alloying coupled with the molybdenum content provides superior resistance to pitting and crevice corrosion in aqueous chloride-containing media. Type E209 electrodes have sufficient total alloy content for use in joining dissimilar alloys, like mild steel and the stainless steels, and also for direct overlay on mild steel for corrosion applications.

A7.2 E219. The nominal composition (wt %) of this weld metal is 20 Cr, 6 Ni, 9 Mn, and 0.20 N. Electrodes of this composition are most often used to weld AISI Type 219 (UNS S21900) base metals. This alloy is a nitrogen-strengthened austenitic stainless steel exhibiting high strength with good toughness over a wide range of temperatures. Nitrogen alloying reduces the tendency for intergranular carbide precipitation in the weld area by inhibiting carbon diffusion, and



Figure A.3—WRC-1992 (FN) Diagram for Stainless Steel Weld Metal

thereby increases resistance to intergranular corrosion. Nitrogen alloying also improves resistance to pitting and crevice corrosion in aqueous chloride-containing media. The E219 electrodes have sufficient total alloy content for use in joining dissimilar alloys like mild steel and the stainless steels, and also for direct overlay on mild steel for corrosion applications.

A7.3 E240. The nominal composition (wt %) of this weld metal is 18 Cr, 5 Ni, 12 Mn, and 0.20 N. Electrodes of this composition are most often used to weld AISI Type 240 and 241 base metals. These alloys are nitrogen-strengthened austenitic stainless steels exhibiting high strength with good toughness over a wide range of temperatures. Significant improvement in resistance to wear in particle-to-metal and metal-to-metal (galling) applications is a desirable characteristic when compared to the more conventional austenitic stainless steels like Type 304. Nitrogen alloying reduces the tendency for intergranular carbide precipitation in the weld area by inhibiting carbon diffusion and thereby increasing resistance to intergranular corrosion. Nitrogen alloying also improves resistance to pitting and crevice corrosion in aqueous chloride-containing media. In addition, weldments in Alloys AISI 240 and AISI 241 when compared to Type 304, exhibit improved resistance to transgranular stress corrosion cracking in hot aqueous chloride-containing media. The E240 electrodes have sufficient total alloy content for use in joining dissimilar alloys like mild steel and the stainless steels, and also for direct overlay on mild steel for corrosion and wear applications.

A7.4 E307. The nominal composition (wt %) of this weld metal is 19.8 Cr, 9.8 Ni, 4 Mn and 1 Mo. Electrodes of this composition are used primarily for moderate strength welds with good crack resistance between dissimilar steels such as austenitic manganese steel and carbon steel forgings or castings.

A7.5 E308. The nominal composition (wt %) of this weld metal is 19.5 Cr, and 10 Ni. Electrodes of this composition are most often used to weld base metal of similar composition such as AISI Types 301, 302, 304, and 305.

A7.6 E308H. These electrodes are the same as E308 except that the allowable weld metal carbon content has been restricted to eliminate the lowest carbon levels. Carbon content in the range of 0.04 to 0.08 percent provides higher tensile and creep strengths at elevated temperatures. These electrodes are used for welding Type 304H base metal. Weld metal ferrite content is normally targeted for 5 FN to minimize the effect of sigma embrittlement in high-temperature service.

A7.7 E308L. The composition of the weld metal is the same as E308, except for the carbon content. The 0.04 percent maximum carbon content of weld metal deposited by these electrodes reduces the possibility of intergranular carbide precipitation and thereby increases the resistance to intergranular corrosion without the use of stabilizers such as niobium or titanium. A carbon content of 0.04 percent maximum has been shown to be adequate in weld metal, even though it is recognized that similar base metal specifications require a 0.03 percent limitation. This low-carbon alloy, however, is not as strong at elevated temperature as E308H or E347.

A7.8 E308Mo. These electrodes are the same as E308, except for the addition of molybdenum. E308Mo electrodes are recommended for welding ASTM CF8M stainless steel castings, as they match the base metal with regard to chromium, nickel, and molybdenum. They may also be used for welding wrought materials such as Type 316 stainless when increased ferrite is desired beyond that attainable with E316 electrodes.

A7.9 E308LMo. These electrodes are recommended for welding ASTM CF3M stainless steel castings, as they match the base metal with regard to chromium, nickel, and molybdenum. E308LMo electrodes may also be used for welding wrought materials such as Type 316L stainless when increased ferrite is desired beyond that attainable with E316L electrodes.

A7.10 E309. The nominal composition (wt %) of this weld metal is 23.5 Cr, 13 Ni with carbon levels allowed up to 0.15 percent and typical ferrite levels from 3 to 20 FN. Electrodes of this composition are used for welding similar compositions in wrought or cast form. They are also used for welding dissimilar steels, such as joining Type 304 to carbon or low-alloy steel, welding the clad side of Type 304-clad steels, making the first layer of a 308 weld cladding and applying stainless steel sheet linings to carbon steel shells. Embrittlement or cracking can occur if these dissimilar steel welds are subjected to a postweld heat treatment or to service above 700 °F [370 °C]. Occasionally, they are used to weld Type 304 and similar base metals where severe corrosion conditions exist requiring higher alloy weld metal. Essentially, there are two electrodes contained within this specification, E309H and E309L, and for critical applications their use is encouraged. See below for their specific applications.

A7.11 E309H. These electrodes are the same as E309, except that the allowable weld metal carbon content has been restricted to eliminate the lowest carbon levels. The carbon restriction will provide higher tensile and creep strengths at elevated temperatures. This together with a typical ferrite content of about 6 FN make these electrodes suitable for the welding of 24 Cr 12 Ni wrought and cast steels designed for corrosion and oxidation resistance. High-carbon castings to ACI's HH grade should be welded with an electrode that is similar to the casting composition.

A7.12 E309L. The composition of this weld metal is the same as that deposited by E309 electrodes, except for the lower carbon content. The 0.04 percent maximum carbon content of these weld deposits ensures a higher ferrite content than the E309H, usually greater than 8 FN and reduces the possibility of intergranular carbide precipitation. This thereby increases the resistance to intergranular corrosion without the use of niobium (columbium). E309L deposits are not as strong at elevated temperature as the niobium-stabilized alloy or E309H deposits. E309L electrodes are commonly used for welding dissimilar steels, such as joining Type 304 to mild or low-alloy steel, welding the clad side of Type 304-clad steels, welding the first layer of E308L weld cladding and applying stainless steel sheet linings to carbon steel. Embrittlement or cracking can occur if these dissimilar steel welds are subjected to a postweld heat treatment or to service above 700 °F [370 °C]. If postweld heat treatment of the carbon steel is essential, the total procedure, welding and heat treatment, should be proven prior to implementation.

A7.13 E309Nb. The composition of this weld metal is the same as Type 309, except for the addition of niobium and a reduction in the carbon limit. The niobium provides resistance to carbide precipitation and thus increases intergranular corrosion resistance, and also provides higher strength in elevated-temperature service. E309Nb electrodes are used also for welding Type 347 clad steels or for the overlay of carbon steel.

A7.14 E309Mo. The composition of this weld metal is the same as that deposited by E309 electrodes, except for the addition of molybdenum and a small reduction in the carbon limit. These electrodes are used for welding Type 316 clad steels or for the overlay of carbon steels.

A7.15 E309LMo. The composition of this weld metal is the same as that deposited by E309Mo electrodes, except for the restricted carbon content. The lower carbon content of the weld metal reduces the possibility of intergranular corrosion and increases the ferrite content. This in turn reduces the potential for solidification cracking when deposited onto carbon or low-alloy steels.

A7.16 E310. The nominal composition (wt %) of this weld metal is 26.5 Cr, 21 Ni. Electrodes of this composition are most often used to weld base metals of similar composition.

A7.17 E310H. The composition of this weld metal is the same as that deposited by E310 electrodes, except that carbon ranges from 0.35 to 0.45 percent. These electrodes are used primarily for welding or repairing high-alloy heat and corrosion-resistant castings of the same general composition which are designated as Type HK by the Alloy Castings Institute. The alloy has high strength at temperatures over 1700 °F [930 °C]. It is not recommended for high-sulfur atmospheres or where severe thermal shock is present. Long time exposure to temperatures in the approximate range of 1400 °F to 1600 °F [760 °C to 870 °C] may induce formation of sigma and secondary carbides which may result in reduced corrosion resistance, reduced ductility, or both. The composition of this electrode should not be confused with the stainless steel wrought alloy 310H which has a lower carbon content of 0.04–0.10 percent.

A7.18 E310Nb. The composition of this weld metal is the same as that deposited by E310 electrodes, except for the addition of niobium and a reduction in carbon limit. These electrodes are used for the welding of heat-resisting castings, Type 347 clad steels, or the overlay of carbon steels.

A7.19 E310Mo. The composition of this weld metal is the same as that deposited by E310 electrodes, except for the addition of molybdenum and a reduction in carbon limit. These electrodes are used for the welding of heat-resisting castings, Type 316 clad steels, or for the overlay of carbon steels.

A7.20 E312. The nominal composition (wt %) of this weld metal is 30 Cr, 9 Ni. These electrodes were originally designed to weld cast alloys of similar composition. They have been found to be valuable in welding dissimilar metals, especially if one of them is a stainless steel, high in nickel. This alloy gives a two-phase weld deposit with substantial amounts of ferrite in an austenitic matrix. Even with considerable dilution by austenite-forming elements, such as nickel, the microstructure remains two-phase and thus highly resistant to weld metal cracks and fissures. Applications should be limited to service temperature below 800 °F [420 °C] to avoid formation of secondary brittle phases.

A7.21 E316. The nominal composition (wt %) of this weld metal is 18.5 Cr, 12.5 Ni, 2.5 Mo. These electrodes are used for welding Type 316 and similar alloys. They have been used successfully in certain applications involving special base metals for high-temperature service. For these high-temperature applications in the past, the carbon level would have been about 0.06%. For similar current or future applications, the use of E316H would ensure similar carbon levels. The presence of molybdenum provides creep resistance and increased ductility at elevated temperatures. Rapid corrosion of Type 316 weld metal may occur when the following three factors coexist:

1. The presence of a continuous or semi-continuous network of ferrite in the weld metal microstructure
2. A composition balance of the weld metal giving a chromium-to-molybdenum ratio of less than 8.2 to 1
3. Immersion of the weld metal in a corrosive medium.

Attempts to classify the media in which accelerated corrosion will take place by attack on the ferrite phase have not been entirely successful. Strong oxidizing and mildly reducing environments have been present where a number of corrosion failures were investigated and documented. The literature should be consulted for latest recommendations.

A7.22 E316H. These electrodes are the same as E316, except that the allowable weld metal carbon content has been restricted to eliminate the lowest carbon levels. Carbon content in the range of 0.04 to 0.08 percent provides higher tensile and creep strengths at elevated temperatures. These electrodes are used for welding 316H base metal.

A7.23 E316L. This composition is the same as E316, except for the carbon content. The 0.04 percent maximum carbon content of weld metal deposited by these electrodes reduces the possibility of intergranular carbide precipitation and thereby increases the resistance to intergranular corrosion without the use of stabilizers such as niobium or titanium. These electrodes are used principally for welding low-carbon, molybdenum-bearing austenitic alloys. Tests have shown that 0.04 percent carbon limit in the weld metal gives adequate protection against intergranular corrosion in most cases. This low-carbon alloy, however, is not as strong at elevated temperatures as Type E316H. This classification with maximum ferrite content of 2 FN has traditionally been the choice for welding Types 304 and 316 stainless steels for cryogenic service at temperatures down to –452 °F [–269 °C].

A7.24 E316LMn. The nominal composition (wt %) of this weld metal is 19.5 Cr, 16.5 Ni, 6.5 Mn, 3 Mo, 0.2 N. This is normally a fully austenitic alloy with a maximum ferrite content of 0.5 FN. In critical applications for cryogenic and corrosion-resistant service, the purchaser should specify the maximum ferrite allowable. One of the primary uses of this electrode is for the joining of similar and dissimilar cryogenic steels for applications down to –452 °F [–269 °C]. Similar steels include stainless steels such as UNS S30453 and S31653. This electrode also exhibits good corrosion resistance in acids and seawater, and is particularly suited to the corrosion conditions found in urea synthesis plants. It is also

nonmagnetic. The high Mn-content of the alloy helps to stabilize the austenitic microstructure and aids in hot cracking resistance.

A7.25 E317. The alloy content of weld metal deposited by these electrodes is somewhat higher than that of Type E316 electrodes, particularly in molybdenum. These electrodes are usually used for welding alloys of similar composition and are utilized in severely corrosive environments (such as those containing halogens) where crevice and pitting corrosion are of concern.

A7.26 E317L. The composition of this weld metal is the same as that deposited by E317 electrodes, except for the carbon content. The 0.04 percent maximum carbon content of weld metal deposited by these electrodes reduces the possibility of intergranular carbide precipitation and thereby increases the resistance to intergranular corrosion without the use of stabilizers such as niobium or titanium. This low-carbon alloy, however, is not as strong at elevated temperatures as the niobium-stabilized alloys or the standard Type 317 weld metal with higher carbon content.

A7.27 E318. The composition of this weld metal is the same as that deposited by E316 electrodes, except for the addition of niobium. Niobium provides resistance to intergranular carbide precipitation and thus increased resistance to intergranular corrosion. These electrodes are used primarily for welding base metals of similar composition.

A7.28 E320. The nominal composition (wt %) of this weld metal is 20 Cr, 34 Ni, 2.5 Mo, 3.5 Cu, with Nb added to improve resistance to intergranular corrosion. These electrodes are primarily used to weld base metals of similar composition for applications where resistance to severe corrosion is required for a wide range of chemicals including sulfuric and sulfurous acids and their salts. These electrodes can be used to weld both castings and wrought alloys of similar compositions without postweld heat treatment.

A modification of this grade without niobium, not classified herein, is available for repairing castings which do not contain niobium. With this modified composition, solution annealing is required after welding.

A7.29 E320LR (Low Residuals). Weld metal deposited by E320LR electrodes has the same basic composition as that deposited by E320 electrodes; however, the elements C, Si, P, and S are specified at lower maximum levels, and Nb and Mn are controlled within narrower ranges. These changes reduce the weld metal fissuring (while maintaining the corrosion resistance) frequently encountered in fully austenitic stainless steel weld metals. Consequently, welding practices typically used to deposit ferrite-containing austenitic stainless steel weld metals can be used. Type 320LR weld metal has a lower minimum tensile strength than Type 320 weld metal.

A7.30 E330. The nominal composition (wt %) of this weld metal is 35 Ni, 15.5 Cr. These electrodes are commonly used where heat- and scale-resisting properties above 1800 °F [980 °C] are required. However, high-sulfur environments may adversely affect performance at elevated temperature. Repairs of defects in alloy castings and the welding of castings and wrought alloys of similar compositions are the most common applications.

A7.31 E330H. The composition of this weld metal is the same as that deposited by E330 electrodes, except that carbon ranges from 0.35 to 0.45 percent. These electrodes are used primarily for the welding and repairing of high-alloy heat and corrosion-resistant castings of the same general composition which are designated HT by the Alloy Castings Institute. This composition can be used to 2100 °F [1150 °C] in oxidizing atmospheres and at 2000 °F [1090 °C] in reducing atmospheres. However, high-sulfur environments may adversely affect performance at elevated temperature.

A7.32 E347. The nominal composition (wt %) of this weld metal is 19.5 Cr, 10 Ni with Nb or Nb plus Ta added as a stabilizer. Either of these additions reduces the possibility of intergranular chromium carbide precipitation and thus increases resistance to intergranular corrosion.

These electrodes are usually used for welding chromium-nickel alloys of similar compositions stabilized either with niobium or titanium. Electrodes depositing titanium as a stabilizing element are not commercially available because titanium is not readily transferred across the arc in shielded metal arc welding. Although niobium is the stabilizing element usually specified in Type 347 alloys, it should be recognized that tantalum also is present. Tantalum and niobium are almost equally effective in stabilizing carbon and in providing high-temperature strength. This specification recognizes the usual commercial practice of reporting niobium as the sum of niobium plus tantalum. If dilution by the base metal produces a low-ferrite or fully austenitic weld metal deposit, crack sensitivity of the weld may increase substantially.

Some applications, especially those involving high-temperature service, are adversely affected if the ferrite content is too high. Consequently, a high-ferrite content should not be specified unless tests prove it to be absolutely necessary.

A7.33 E349. The normal composition (wt %) of this weld metal is 19.5 Cr, 9 Ni, 1 Nb, 0.5 Mo, 1.4 W. These electrodes are used for welding steels of similar composition such as AISI Type 651 or 652. The combination of niobium, molybdenum, and tungsten with chromium and nickel gives good high-temperature rupture strength. The chemical composition of the weld metal results in an appreciable content of ferrite which increases the crack resistance of the weld metal.

A7.34 E383. The nominal composition (wt %) of this weld metal is 28 Cr, 31.5 Ni, 3.7 Mo, 1 Cu. These electrodes are used to weld base metal of a similar composition to itself and to other grades of stainless steel. Type E383 weld metal is recommended for sulfuric and phosphoric acid environments. The elements C, Si, P, and S are specified at low maximum levels to minimize weld metal hot cracking and fissuring (while maintaining the corrosion resistance) frequently encountered in fully austenitic stainless steel weld metals.

A7.35 E385. The nominal composition (wt %) of this weld metal is 20.5 Cr, 25 Ni, 5 Mo, 1.5 Cu. These electrodes are used primarily for welding of Type 904L materials for the handling of sulfuric acid and many chloride-containing media. Type E385 electrodes also may be used to join Type 317L material where improved corrosion resistance in specific media is needed. E385 electrodes also can be used for joining Type 904L base metal to other grades of stainless. The elements C, Si, P, and S are specified at lower maximum levels to minimize weld metal hot cracking and fissuring (while maintaining corrosion resistance) frequently encountered in fully austenitic weld metals.

A7.36 E409Nb. The composition of this weld metal is very similar to that deposited by E410 electrodes, except that niobium has been added which produces a ferritic microstructure with fine grains. These electrodes are used for the welding of ferritic stainless steels such as Types 405 and 409. They are also used for the second and/or additional layers in the welding of Type 410 clad stainless steel and for the overlay of carbon and low-alloy steels. Preheat and postweld heat treatments are required to achieve welds of adequate ductility for many engineering purposes. This weld deposit cannot be expected to develop the strength and hardness of a fully hardened martensitic stainless steel alloy such as Type 410.

A7.37 E410. This 12 Cr alloy is an air-hardening steel. Preheat and postheat treatments are required to achieve welds of adequate ductility for many engineering purposes. The most common application of these electrodes is for welding alloys of similar compositions. They are also used for surfacing of carbon steels to resist corrosion, erosion, or abrasion.

A7.38 E410NiMo. These electrodes are used for welding ASTM CA6NM (CA-6NM) castings or similar materials, as well as light-gauge Type 410, 410S, and 405 base metals. Weld metal deposited by these electrodes is modified to contain less chromium and more nickel than weld metal deposited by E410 electrodes. The objective is to eliminate ferrite in the microstructure, as ferrite has a deleterious effect on mechanical properties of this alloy. Final postweld heat treatment should not exceed 1150 °F [620 °C]. Higher temperatures may result in rehardening due to untempered martensite in the microstructure after cooling to room temperature.

A7.39 E430. The weld metal deposited by these electrodes contains between 15 and 18 Cr (wt %). The composition is balanced by providing sufficient chromium to give adequate corrosion resistance for the usual applications and yet retain sufficient ductility in the heat-treated condition to meet the mechanical requirements of the specification. (Excessive chromium will result in lowered ductility.) Welding with E430 electrodes usually requires preheat and postheat. Optimum mechanical properties and corrosion resistance are obtained only when the weldment is heat treated following the welding operation.

A7.40 E430Nb. The composition of this weld metal is the same as that deposited by E430 electrodes, except for the addition of niobium. The weld deposit is a ferritic microstructure with fine grains. Preheat and postweld heat treatments are required to achieve welds of adequate ductility for many engineering purposes. These electrodes are used for the welding of Type 430 stainless steel. They are also used for the first layer in the welding of Type 405 and 410 clad steels.

A7.41 E630. The nominal composition (wt %) of these electrodes is 16.4 Cr, 4.7 Ni, 3.6 Cu. These electrodes are primarily designed for welding ASTM A 564, Type 630, and some other precipitation-hardening stainless steels. The weld metal is modified to prevent the formation of ferrite networks in the martensite microstructure which could have a deleterious effect on mechanical properties. Dependent on the application and weld size, the weld metal may be used either as-welded; welded and precipitation hardened; or welded, solution treated, and precipitation hardened.

A7.42 E16-8-2. The nominal composition (wt %) of this weld metal is 15.5 Cr, 8.5 Ni, 1.5 Mo. These electrodes are used primarily for welding stainless steel, such as Types 16-8-2, 316, and 347, for high-pressure, high-temperature piping systems. The weld deposit usually has a Ferrite Number no higher than 5 FN. The deposit also has good, hot ductility properties which offer relative freedom from weld or crater cracking even under high-restraint conditions. The

weld metal is usable in either the as-welded or solution-treated condition. These electrodes depend on a very carefully balanced chemical composition to develop their fullest properties. Corrosion tests indicate that Type 16-8-2 weld metal may have less corrosion resistance than Type 316 base metal depending on the corrosive media. Where the weldment is exposed to severely corrosive agents, the surface layers should be deposited with a more corrosion-resistant weld metal.

A7.43 E2209. The nominal composition (wt %) of this weld metal is 22.5 Cr, 9.5 Ni, 3 Mo, 0.15 N. Electrodes of this composition are used primarily to weld duplex stainless steel such as UNS S31803 and S32205. They are also used for lean duplex stainless steel such as UNS S32101 and S32304. Weld metal deposited by these electrodes has “duplex” microstructure consisting of an austenite-ferrite matrix. Weld metal deposited by E2209 electrodes combines increased tensile strength with improved resistance to pitting corrosive attack and to stress corrosion cracking. If postweld annealing is required this weld metal will require a higher annealing temperature than that required by the duplex base metal.

A7.44 E2307. The nominal composition (wt %) of this weld metal is 24 Cr, 8 Ni, 0.15 N. Electrodes of this classification are used primarily for the welding of lean, low-molybdenum duplex stainless steels which include UNS S32101 and UNS S32304. Weld metal deposited by these electrodes has a “duplex” microstructure consisting of an austenite-ferrite matrix. Weld metal deposited with E2307 electrodes combines increased strength and improved resistance to stress corrosion cracking as compared to these properties in E308L and similar austenitic stainless steel weld metals.

A7.45 E2553. The nominal composition (wt %) of this weld metal is 25.5 Cr, 7.5 Ni, 3.4 Mo, 2 Cu, and 0.17 N. These electrodes are used primarily to weld duplex stainless steels which contain approximately 25 percent of chromium. Weld metal deposited by these electrodes has a “duplex” microstructure consisting of an austenite-ferrite matrix. Weld metal deposited by E2553 electrodes combines increased tensile strength with improved resistance to pitting corrosive attack and to stress corrosion cracking.

A7.46 E2593. The nominal composition (wt %) of this weld metal is 25 Cr, 9.5 Ni, 3.4 Mo, 2.5 Cu, and 0.2 N. These electrodes are used primarily to weld duplex stainless steels which contain approximately 25 percent chromium. Weld metal deposited by these electrodes has a “duplex” microstructure consisting of an austenite-ferrite matrix. Weld metal deposited by E2593 electrodes combines increased tensile strength with improved resistance to pitting corrosive attack and to stress corrosion cracking. If postweld annealing is required this weld metal will require a higher annealing temperature than that required by the E2553 classification or the duplex base metal.

A7.47 E2594. The nominal composition (wt %) of this weld metal is 25.5 Cr, 10 Ni, 4 Mo, and 0.25 N. The sum of the $Cr + 3.3(Mo + 0.5W) + 16N$, known as the Pitting Resistance Equivalent Number (PRE_N), is at least 40, thereby allowing the weld metal to be called a “super-duplex stainless steel.” This number is a semi-quantitative indicator of resistance to pitting in aqueous chloride-containing environments. It is designed for the welding of Type 2507 super-duplex stainless steels UNS S32750 (wrought) and UNS J93404 (cast), and similar compositions. It can also be used for the welding of carbon and low-alloy steels to duplex stainless steels as well as to weld “standard” duplex stainless steels such as Type 2205 although the weld metal impact toughness may be inferior to that from E2209 electrodes. If postweld annealing is required, this weld metal will require a higher annealing temperature than that required by the duplex base metal.

A7.48 E2595. The nominal composition (wt %) of this weld metal is 25.5 Cr, 9 Ni, 3.8 Mo, 0.7 Cu, 0.7 W, and 0.25 N. The sum of the $Cr + 3.3(Mo + 0.5W) + 16N$, known as the Pitting Resistance Equivalent Number (PRE_N), is at least 40, thereby allowing the weld metal to be called a “superduplex stainless steel.” This number is a semi-quantitative indicator of resistance to pitting in aqueous chloride-containing environments. It is designed for the welding of superduplex stainless steels UNS S32550, S32750, and S32760 (wrought), and UNS J93370, J93380, J93404, CD4MCuN (cast), and similar compositions. It can also be used for the welding of carbon and low-alloy steels to duplex stainless steels as well as to weld “standard duplex stainless steel” such as UNS S31803 and UNS S32205.

A7.49 E3155. The nominal chemical composition of this weld metal is 21.25 Cr, 19.75 Co, 20 Ni, 3.0 Mo, 2.5 W. These electrodes are used primarily for welding parts fabricated from material of similar or dissimilar composition, particularly when the weld zone is required to have corrosion and heat resistance comparable to that of the parent metal. It is used in aerospace applications including tailpipes and tail cones, afterburner parts, exhaust manifolds, combustion chambers, turbine blades, buckets, and nozzles. Its high-temperature properties are inherent and are not dependent upon age hardening.

A7.50 E33-31. The nominal chemical composition (wt %) of weld metal produced by electrodes of this classification is 31 Ni, 32 Fe, 33 Cr, 1.6 Mo, and low carbon. The filler materials are used for welding nickel-chromium-iron alloy (UNS R20033) to itself, and to weld to carbon steel. The ASTM specifications for this alloy are B625, B649, B366, B472, B564, B619, B622, and B626. The electrodes are generally used in the flat position.

A8. Classification as to Usability

A8.1 Four basic usability classifications are provided in this specification, as shown in Table 2.

A8.2 The type of covering applied to a core wire to make a shielded metal arc welding electrode typically determines the usability characteristics of the electrode. The following discussion of covering types is based upon terminology commonly used by the industry; no attempt has been made to specifically define the composition of the different covering types.

A8.3 Usability Designation -15. The electrodes are usable with dcsp (electrode positive) only. While use with alternating current is sometimes accomplished, they are not intended to qualify for use with this type of current. Electrode sizes 5/32 in [4.0 mm] and smaller may be used in all positions of welding.

A8.4 Usability Designation -16. The covering for these electrodes generally contains readily ionizing elements, such as potassium, in order to stabilize the arc for welding with alternating current. Electrode sizes 5/32 in [4.0 mm] and smaller may be used in all positions of welding.

A8.5 Usability Designation -17. The covering of these electrodes is a modification of the -16 covering, in that considerable silica replaces some of the titania of the -16 covering. Since both the -16 and the -17 electrode coverings permit ac operation, both covering types were classified as -16 in the past because there was no classification alternative until the 1992 revision of AWS A5.4. However, the operational differences between the two types have become significant enough to warrant a separate classification.

On horizontal fillet welds, electrodes with a -17 covering tend to produce more of a spray arc and a finer rippled weld-bead surface than do those with the -16 coverings. A slower freezing slag of the -17 covering also permits improved handling characteristics when employing a drag technique. The bead shape on horizontal fillets is typically flat to concave with -17 covered electrodes as compared to flat to slightly convex with -16 covered electrodes. When making fillet welds in the vertical position with upward progression, the slower freezing slag of the -17 covered electrodes requires a slight weave technique to produce the proper bead shape. For this reason, the minimum leg-size fillet that can be properly made with a -17 covered electrode is larger than that for a -16 covered electrode. While these electrodes are designed for all-position operation, electrode sizes 3/16 in [4.8 mm] and larger are not recommended for vertical or overhead welding.

A8.6 Usability Designation -26. This designation is for those electrodes that are designed for flat and horizontal fillet welding and that have limited out of position characteristics. In practice, most of these electrodes give higher deposition rates than their all-positional counter-parts owing to their thicker coatings that contain higher levels of metal powders. The thicker coating gives larger fillet welds that are typically flat to concave. It also reduces the effects of core wire overheating, making 18 inch long electrodes possible for the larger electrodes, even with stainless steel core wire. Higher currents are usually required to achieve the necessary penetration compared to the all-positional types.

The slag system of these electrodes is similar to those of the -16 and -17 designations. The resulting slag may be more fluid and even slower freezing than that from electrodes with a -17 designation. Core wire compositions are typically either Type 304L stainless steel or low-carbon mild steel. Electrodes with the latter tend to have thicker coatings to accommodate the necessary alloys in order to attain the required weld metal composition. Such electrodes require even higher currents to compensate for the additional coating to be melted and the lower resistance of the core wire.

Electrodes with the -26 designation are recommended for welding only in the flat and horizontal fillet positions. The manufacturer's suggested operating currents should be consulted. Out of position welding may be possible with electrode sizes up to 1/8 in [3.2 mm] diameter.

A9. Special Tests

A9.1 Corrosion or Scaling Resistance Tests

A9.1.1 Although welds made with electrodes covered by this specification are commonly used in corrosion-resisting or heat-resisting applications, it is not practical to require tests for corrosion or scale resistance on welds or weld metal specimens. Such special tests which are pertinent to the intended application may be conducted as agreed upon between supplier and purchaser. This section is included for the guidance of those who desire to specify such special tests.

A9.1.2 Corrosion or scaling tests of joint specimens have the advantage that the joint design and welding procedure can be made identical to those being used in fabrication. They have the disadvantage of being a test of the combined properties of the weld metal, the heat-affected zone of the base metal, and the unaffected base metal. Furthermore, it is difficult to obtain reproducible data if a difference exists between the corrosion or oxidation rates of the various metal structures (weld metal, heat-affected zone, and unaffected base metal). Test samples cannot be readily standardized if welding procedure and joint design are to be considered variables. Joint specimens for corrosion tests should not be used for qualifying the electrode but may be used for qualifying welding procedures using approved materials.

A9.1.3 All-weld-metal specimens for testing corrosion or scale resistance are prepared by following the procedure outlined for the preparation of pads for chemical analysis (see Clause 10). The pad size should be at least $3/4$ in [19 mm] in height by $2-1/2$ in [65 mm] wide by $1 + 5/8n$ in [$25 + 16n$ mm] long, where “n” represents the number of specimens required from the pad. Specimens measuring $1/2 \times 2 \times 1/4$ in [$13 \times 50 \times 6.4$ mm] are machined from the top surface of the pad in such a way that the 2 in [50 mm] dimension of the specimen is parallel to the $2-1/2$ in [65 mm] width dimension of the pad and the $1/2$ in [13 mm] dimension is parallel to the length of the pad.

A9.1.4 The heat treatments, surface finish, and marking of the specimens prior to testing should be in accordance with standard practices for tests of similar alloys in the wrought or cast forms. The testing procedure should correspond to the ASTM G4, *Standard Method for Conducting Corrosion Tests in Plant Equipment*, or ASTM A262, *Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels*, or ASTM G48, *Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution*.

A9.2 Mechanical Properties Tests for Dissimilar Metal Welds

A9.2.1 Tests for mechanical properties of joint specimens may be desired when the intended application involves the welding of dissimilar metals. Procedures for the mechanical testing of such joints should be in accordance with the latest edition of AWS B4.0 [AWS B4.0M], *Standard Methods for Mechanical Testing of Welds*.

A9.2.2 Tests of joint specimens may be influenced by the properties of the base metal and welding procedures and may not provide adequate tests of the weld metal. Such tests should be considered as tests for qualifying welding procedures using approved materials rather than tests for qualifying the electrodes.

A9.2.3 Where fabrication codes require tests of welds in heat-treated conditions other than those specified in Table 6, all-weld-metal tests of heat-treated specimens may be desired. For the preparation of such specimens, the procedures outlined in Clause 12, Tension Test, and Clause 13, Fillet Weld Test, should be followed.

A9.3 Impact Property Tests for Welds Intended for Cryogenic Service

A9.3.1 Fully austenitic stainless steel weld metals are known to possess excellent toughness at cryogenic temperatures such as -320 °F [-196 °C]. To ensure freedom from brittle failure, Section VIII of the ASME *Boiler and Pressure Vessel Code* requires weldments intended for cryogenic service be qualified by Charpy V-notch testing. The criterion for acceptability is the attainment of a lateral expansion opposite the notch of not less than 15 mils (0.015 in) [0.38 mm] for each of three specimens.

A9.3.2 Austenitic stainless steel weld metals usually are not fully austenitic but contain some delta ferrite. Delta ferrite is harmful to cryogenic toughness. However, fully austenitic weld metal has a greater susceptibility to hot cracking (see A6). It has been found that such weld metals require judicious compositional balances to meet the 15 mils [0.38 mm] lateral expansion criterion even at moderately low temperatures such as -150 °F [-100 °C].

A9.3.3 Electrode classifications which can be used if special attention is given to the weld deposit composition content to maximize toughness are E308L-XX, E316L-XX, and E316LMn-XX. Published studies of the effect of composition changes on weldment toughness properties for these types have shown the following:

A9.3.3.1 Both carbon and nitrogen contents have strong adverse effects on weld metal toughness so that their contents should be minimized. Low-carbon weld metals with nitrogen content below 0.06 percent are preferred.

A9.3.3.2 Nickel appears to be the only element whose increased content in weld metal improves weld metal toughness.

A9.3.3.3 Delta ferrite is harmful; therefore, minimizing ferrite in weld metal (3 FN maximum) is recommended. Weld metal free of ferrite (fully austenitic) is preferred; the more austenitic, the better.

A9.3.3.4 Fully austenitic E316L weld metal appears to be the preferred composition because of the ease in achieving ferrite-free weld metal, while compositionally conforming to AWS A5.4 and retaining crack resistance.

A9.3.3.5 Lime-covered, typically the -15 classification type, electrodes tend to produce weldments having slightly superior lateral expansion values for Charpy V-notch impact specimens than titania-covered, typically -16, -17, and -26 classification type, electrodes when weld metal composition factors are essentially the same. This appears to be due to two factors:

A9.3.3.5.1 Lime-covered SMAW electrodes usually provide better protection from nitrogen incursion into the weld metal than that provided by titania-covered electrodes. Nitrogen, as noted above, has significantly adverse effects on weld toughness.

A9.3.3.5.2 Lime-covered SMAW electrodes appear to produce weld metals of lower oxygen levels and inclusion population, i.e., cleaner weld metal, or both. The above suggestions are particularly important when the intended application involves very-low temperatures such as -320°F [-196°C].

A9.3.4 Limited SMAW electrode weld metal data have indicated that welding in the vertical position, as compared to flat position welding, does not reduce toughness properties, providing good operator's technique is employed.

A9.3.5 Where cryogenic service below -150°F [-100°C] is intended, it is recommended that each lot of electrodes be qualified with Charpy V-notch impact tests. When such tests are required, the test specimens must be taken from a test plate prepared in accordance with Figure 2. The impact specimens must be located in the test plate as shown in Figure A.4. The specimens must be prepared and tested in accordance with the impact test sections of the latest edition of AWS B4.0 [AWS B4.0M], *Standard Methods for Mechanical Testing of Welds*. The test temperature must be selected on the basis of intended service.

A10. Discontinued Classifications

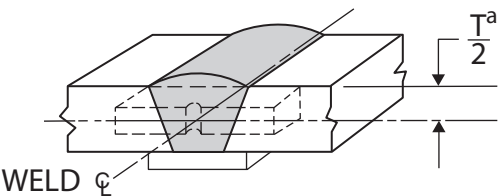
Some classifications have been discontinued from one revision of this specification to another. This results either from changes in commercial practice or changes in the classification system used in the specification. The Classifications that have been discontinued are listed in Table A.2 along with the year in which they were last included in this specification.

A11. General Safety Considerations

A11.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Annex Clause A5. Safety and health information is available from other sources, including, but not limited to Safety and Health Fact Sheets listed in A11.3, ANSI Z49.1 *Safety in Welding, Cutting, and Allied Processes*,¹⁴ and applicable federal and state regulations.

A11.2 Safety and Health Fact Sheets. The Safety and Health Fact Sheets listed below are published by the American Welding Society (AWS). They may be down-loaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

¹⁴ ANSI Z49.1 is published by the American Welding Society, 8669 Doral Blvd., Suite 130, Doral, FL 33166.



Note: Specimen size to be in accordance with AWS B4.0 or AWS B4.0M, *Standard Methods for Mechanical Testing of Welds*.

^a If buttering is used in preparation of the test plate (see Figure 2) the T/2 dimension may need to be reduced to assure that none of the buttering becomes part of the notch area of the impact specimen.

Figure A.4—Orientation and Location of Optional Impact Specimen

Table A.2
Discontinued Classifications^a

AWS Classification	Last A5.4 Publication Date
EXXX-25	1948, 1992 ^b
EXXX-26	1948 ^c
E308ELC-XX	1955 ^d
E316ELC-XX	1955 ^d
E502-XX	1992 ^e
E505-XX	1992 ^f
E7Cr-XX	1992 ^g
E308MoL-XX	1992 ^h
E309MoL-XX	1992 ^h
E309Cb-XX	1992 ⁱ
E310Cb-XX	1992 ⁱ

^a See A10, Discontinued Classifications (in Annex A).

^b The -25 classifications were discontinued with the publication of the 1955 edition of A5.4, included again in the 1992 edition, and then discontinued again in the 2006 edition.

^c The -26 classifications were discontinued with the publication of the 1955 edition of A5.4 and then were included again in the 1992 edition.

^d Starting with the 1962 edition of A5.4, the designator suffix for the low-carbon classifications was changed from “ELC” to “L.” Thus the E308ELC-XX and E316ELC-XX classifications were not really discontinued; they became E308L-XX and E316L-XX, respectively.

^e This classification was transferred to ANSI/AWS A5.5 in 1996 with the new designation E801X-B6 and E801X-B6L.

^f This classification was transferred to ANSI/AWS A5.5 in 1996 with the new designation E801X-B8 and E801X-B8L.

^g This classification was transferred to ANSI/AWS A5.5 in 1996 with the new designation E801X-B7 and E801X-B7L.

^h These two classifications were not really discontinued but were changed to E308LMo-XX and E309LMo-XX to reflect that the “L” for low carbon is the principal modifying suffix.

ⁱ These two classifications were not really discontinued but were changed to E309Nb-XX and E310Nb-XX to reflect the adoption of Nb for niobium instead of Cb for columbium.

A11.3 AWS Safety and Health Fact Sheets Index (SHF)¹⁵

No.	Title
1	<i>Fumes and Gases</i>
2	<i>Radiation</i>
3	<i>Noise</i>
4	<i>Chromium and Nickel in Welding Fume</i>
5	<i>Electric Hazards</i>
6	<i>Fire and Explosion Prevention</i>
7	<i>Burn Protection</i>
8	<i>Mechanical Hazards</i>
9	<i>Tripping and Falling</i>
10	<i>Falling Objects</i>
11	<i>Confined Space</i>
12	<i>Contact Lens Wear</i>
13	<i>Ergonomics in the Welding Environment</i>
14	<i>Graphic Symbols for Precautionary Labels</i>
15	<i>Style Guidelines for Safety and Health Documents</i>
16	<i>Pacemakers and Welding</i>
17	<i>Electric and Magnetic Fields (EMF)</i>
18	<i>Lockout/Tagout</i>
19	<i>Laser Welding and Cutting Safety</i>
20	<i>Thermal Spraying Safety</i>
21	<i>Resistance Spot Welding</i>
22	<i>Cadmium Exposure from Welding & Allied Processes</i>
23	<i>California Proposition 65</i>
24	<i>Fluxes for Arc Welding and Brazing: Safe Handling and Use</i>
25	<i>Metal Fume Fever</i>
26	<i>Arc Viewing Distance</i>
27	<i>Thoriated Tungsten Electrodes</i>
28	<i>Oxyfuel Safety: Check Valves and Flashback Arrestors</i>
29	<i>Grounding of Portable and Vehicle Mounted Welding Generators</i>
30	<i>Cylinders: Safe Storage, Handling, and Use</i>
31	<i>Eye and Face Protection for Welding and Cutting Operations</i>
33	<i>Personal Protective Equipment (PPE) for Welding & Cutting</i>
34	<i>Coated Steels: Welding and Cutting Safety Concerns</i>
36	<i>Ventilation for Welding & Cutting</i>
37	<i>Selecting Gloves for Welding & Cutting</i>

¹⁵ AWS standards are published by the American Welding Society, 8669 Doral Blvd., Suite 130, Doral, FL 33166.

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of AWS A5.4/A5.4M:2012, *Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding*, but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered “yes” or “no”. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the Welding Journal, and post it on the AWS website.

B6. AWS Technical Committees

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

INTENTIONALLY LEFT BLANK

SPECIFICATION FOR LOW-ALLOY STEEL ELECTRODES FOR SHIELDED METAL ARC WELDING



SFA-5.5/SFA-5.5M



(Identical with AWS Specification A5.5/A5.5M:2022. In case of dispute, the original AWS text applies.)

Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding

1. Scope

1.1. This specification prescribes requirements for the classification of low-alloy steel electrodes for shielded metal arc welding of carbon and low-alloy steels. The weld metal deposited by these electrodes are steel alloys in which no single alloying element exceeds 10.5 percent.

In addition to the low-alloy steel electrodes above, this specification also prescribes the requirements for the classification of austenitic, high manganese steel electrodes having weld metal with nominally 20% Mn.

1.2. This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to material properties. The specification designated A5.5 uses U.S. Customary Units. The specification designated A5.5M uses SI Units. The latter units are shown within brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing of filler metal or packaging or both under A5.5 or A5.5M specification.

1.3. Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in Annex A, Clauses A5 and A10.

Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to or revisions of any of these publications do not apply.

American Welding Society (AWS) documents:

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

AWS A4.3 ADD1, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*

AWS A4.4M, *Standard Procedure for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coatings*

AWS A4.5M/A4.5, *Standard Methods for Classification Testing of Positional Capacity and Root Penetration of Welding Consumables in a Fillet Weld*

AWS A5.01M/A5.01, *Welding and Brazing Consumables — Procurement of Filler Metals and Fluxes*

AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*

AWS B4.0, *Standard Methods for Mechanical Testing of Welds*

American National Standards Institute (ANSI) documents:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

ASTM International (ASTM) documents:

ASTM A29/A29M, *Standard Specification for General Requirements for Steel Bars, Carbon and Alloy, Hot-Wrought*

ASTM A36/A36M, *Standard Specification for Carbon Structural Steel*

ASTM A203/A203M, *Standard Specification for Pressure Vessel Plates, Alloy Steel, Nickel*

ASTM A204/A204M, *Standard Specification for Pressure Vessel Plates, Alloy Steel, Molybdenum*

ASTM A242/A242M, *Standard Specification for High-Strength Low-Alloy Structural Steel*

ASTM A283/A283M, *Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates*

ASTM A302/A302M, *Standard Specification for Pressure Vessel Plates, Alloy Steel, Manganese-Molybdenum, and Manganese-Molybdenum-Nickel*

ASTM A352/A352M, *Standard Specification for Steel Castings, Ferritic and Martensitic, for Pressure-Containing Parts, Suitable for Low-Temperature Service*

ASTM A387/A387M, *Standard Specification for Pressure Vessel Plates, Alloy Steel, Chromium-Molybdenum*

ASTM A514/A514M, *Standard Specification for High-Yield-Strength, Quenched and Tempered, Alloy Steel Plate, Suitable for Welding*

ASTM A516/A516M, *Standard Specification for Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service*

ASTM A517/A517M, *Standard Specification for Pressure Vessel Plates, Alloy Steel, High-Strength, Quenched and Tempered*

ASTM A533/A533M, *Standard Specification for Pressure Vessel Plates, Alloy Steel, Quenched and Tempered, Manganese-Molybdenum, and Manganese-Molybdenum-Nickel*

ASTM A537/A537M, *Standard Specification for Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel*

ASTM A543/A543M, *Standard Specification for Pressure Vessel Plates, Alloy Steel, Quenched and Tempered Nickel-Chromium-Molybdenum*

ASTM A588/A588M, *Standard Specification for High-Strength Low-Alloy Structural Steel with 50 ksi [345 MPa] Minimum Yield Point to 4-in. [100-mm] Thick*

ASTM A709/A709M, *Standard Specification for Carbon Structural Steel for Bridges*

ASTM A1106, Standard Specification for Pressure Vessel Plate, Alloy Steel, Austenitic High Manganese for Cryogenic Application

ASTM E23, Standard Test Methods for Notched Bar Impact Testing of Metallic Materials

ASTM E29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

ASTM E350, Standard Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron and Wrought Iron

ASTM E353, Standard Test Methods for Chemical Analysis of Stainless, Heat-Resisting, Maraging, and Other Similar Chromium-Nickel-Iron Alloys

ASTM E1032, Standard Test Method for Radiographic Examination of Weldments

ASTM E2033, Standard Practice for Radiographic Examination Using Computed Radiography (Photostimulable Luminescence Method)

ASTM E2698, Standard Practice for Radiographic Examination Using Digital Detector Arrays

International Organization for Standardization (ISO) documents:

ISO 80000-1, *Quantities and units—Part 1: General*.

United States Department of Defense (DODSSP) publications:

NAVSEA Technical Publication T9074-BD-GIB-010/0300, *Base Materials for Critical Applications: Requirements for Low Alloy Steel Plate, Forgings, Castings, Shapes, Bars, and Heads of HY-80/100/130 and HSLA-80/100*

MIL-E-22200/1, *Military Specification: Electrodes, Welding, Mineral Covered, Iron-Powder, Low-Hydrogen Medium and High Tensile Steel, As Welded or Stress-Relieved Weld Application*

MIL-E-22200/10, *Military Specification: Electrodes, Welding, Mineral Covered, Iron-Powder, Low-Hydrogen Medium, High Tensile and Higher-Strength Low Alloy Steels*

American Petroleum Institute (API) standard:

Specification 5L, *Line Pipe*

3. Classification

3.1 The welding electrodes covered by the A5.5 and A5.5M specifications utilize a classification system (shown in Figure 1) based upon U.S. Customary Units and the International System of Units (SI), respectively, and are classified according to:

- (1) Type of current (Table 1)
- (2) Type of covering (Table 1)
- (3) Welding position (Table 1)
- (4) Chemical composition of the weld metal (Table 2)
- (5) Mechanical properties of the weld metal in the as-welded or postweld heat treated condition (Tables 3 and 4)

3.2 Electrodes classified under one classification shall not be classified under any other classification in this specification, *except that an electrode may be classified with both a defined chemical composition designator and a “-G” composition designator*. Also, an electrode may be classified under both A5.5 and A5.5M specifications.

3.3 Electrodes may be classified under A5.5 using U.S. Customary Units or under A5.5M using the International System of Units (SI), or they may be classified under both systems. Electrodes classified under either classification system must meet all requirements for classification under that system. The classification system is shown in Figure 1.

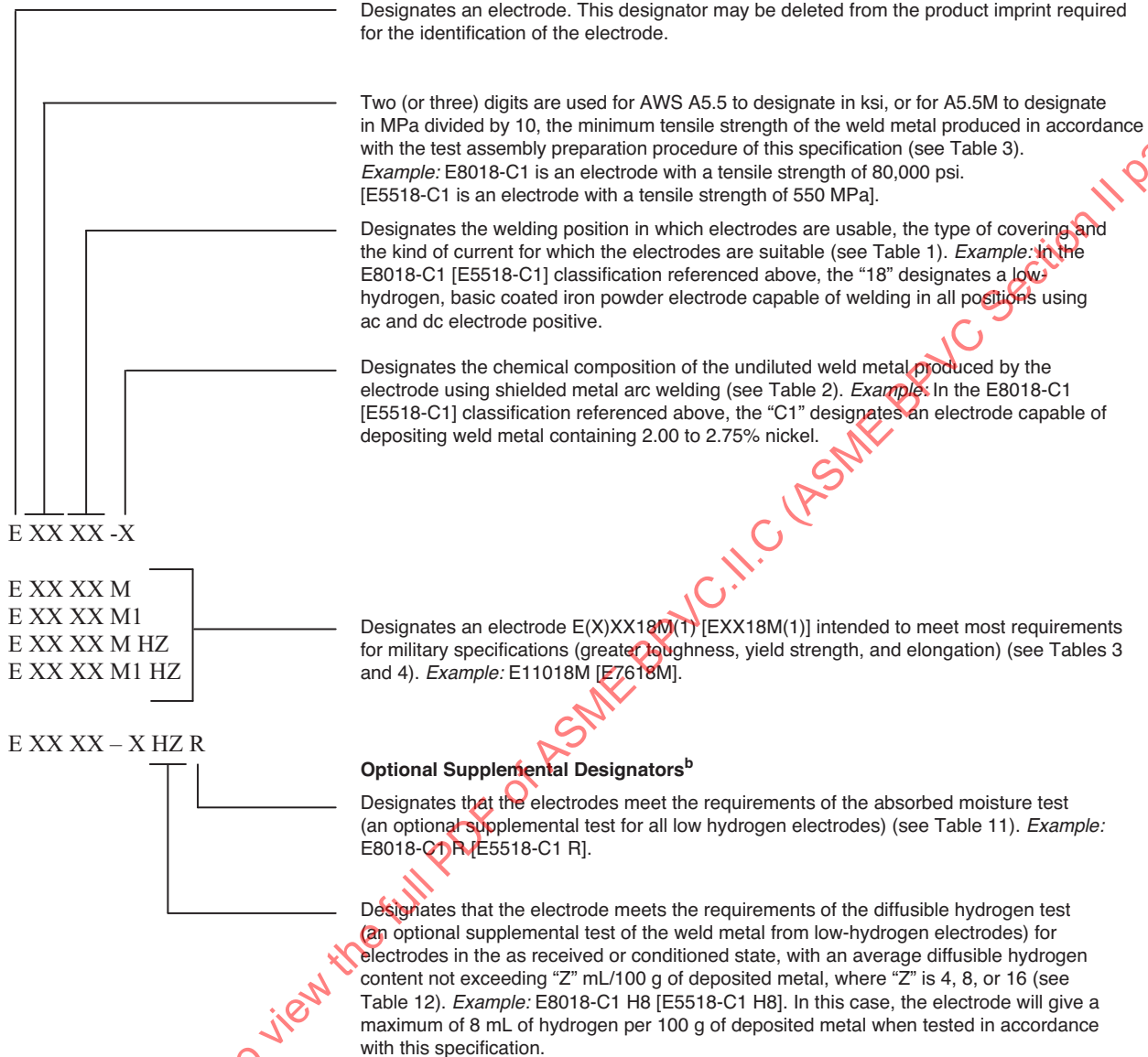
Mandatory Classification Designators^a^a The combination of these designators constitutes the electrode classification.^b These designators are optional and do not constitute a part of the electrode classification.**Figure 1—Order of Electrode Mandatory and Optional Supplemental Designators**

Table 1
Electrode Classification

AWS Classification ^a		Type of Covering	Welding Positions for Classification ^b	Type of Current ^c
A5.5	A5.5M			
E7010-X	E4910-X	High cellulose sodium	F, V, OH, H	dcep
E7011-X	E4911-X	High cellulose potassium	F, V, OH, H	ac, dcep
E7015-X ^{d,e}	E4915-X ^{d,e}	Low hydrogen sodium	F, V, OH, H	dcep
E7016-X ^{d,e}	E4916-X ^{d,e}	Low hydrogen potassium	F, V, OH, H	ac, dcep
E7018-X ^{d,e}	E4918-X ^{d,e}	Low hydrogen potassium, iron powder ^f	F, V, OH, H	ac, dcep
E7020-X	E4920-X	High iron oxide	H-fillets	ac, dcen
			F	ac, dcep, dcen
E7027-X	E4927-X	High iron oxide, iron powder ^f	H-fillet	ac, dcen
			F	ac, dcep, dcen
E8010-X	E5510-X	High cellulose sodium	F, V, OH, H	dcep
E8011-G	E5511-G	High cellulose potassium	F, V, OH, H	ac, dcep
E8013-G	E5513-G	High titania potassium	F, V, OH, H	ac, dcep, dcen
E8015-X ^{d,e}	E5515-X ^{d,e}	Low hydrogen sodium	F, V, OH, H	dcep
E8016-X ^{d,e}	E5516-X ^{d,e}	Low hydrogen potassium	F, V, OH, H	ac, dcep
E8018-X ^{d,e}	E5518-X ^{d,e}	Low hydrogen potassium, iron powder ^f	F, V, OH, H	ac, dcep
E8045-X ^{d,e}	E5545-X ^{d,e}	Low hydrogen sodium	F, OH, H, V-down	dcep
E9010-X	E6210-X	High cellulose sodium	F, V, OH, H	dcep
E9011-G	E6211-G	High cellulose potassium	F, V, OH, H	ac, dcep
E9013-G	E6213-G	High titania potassium	F, V, OH, H	ac, dcep, dcen
E9015-X ^{d,e}	E6215-X ^{d,e}	Low hydrogen sodium	F, V, OH, H	dcep
E9016-X ^{d,e}	E6216-X ^{d,e}	Low hydrogen potassium	F, V, OH, H	ac, dcep
E9018-X ^{d,e}	E6218-X ^{d,e}	Low hydrogen potassium, iron powder ^f	F, V, OH, H	ac, dcep
E9018M ^{d,e}	E6218M ^{d,e}	Iron powder, low hydrogen ^f	F, V, OH, H	dcep
E9045-X ^{d,e}	E6245-X ^{d,e}	Low hydrogen sodium	F, OH, H, V-down	dcep
E10010-G	E6910-G	High cellulose sodium	F, V, OH, H	dcep
E10011-G	E6911-G	High cellulose potassium	F, V, OH, H	ac, dcep
E10013-G	E6913-G	High titania potassium	F, V, OH, H	ac, dcep, dcen
E10015-X ^{d,e}	E6915-X ^{d,e}	Low hydrogen sodium	F, V, OH, H	dcep
E10016-X ^{d,e}	E6916-X ^{d,e}	Low hydrogen potassium	F, V, OH, H	ac, dcep
E10018-X ^{d,e}	E6918-X ^{d,e}	Low hydrogen potassium, iron powder ^f	F, V, OH, H	ac, dcep
E10018M ^{d,e}	E6918M ^{d,e}	Iron powder, low hydrogen ^f	F, V, OH, H	dcep
E10045-X ^{d,e}	E6945-X ^{d,e}	Low hydrogen sodium	F, OH, H, V-down	dcep

(Continued)

Table 1 (Continued)
Electrode Classification

AWS Classification ^a		Type of Covering	Welding Positions for Classification ^b	Type of Current ^c
A5.5	A5.5M			
E11010-G	E7610-G	High cellulose sodium	F, V, OH, H	dcep
E11011-G	E7611-G	High cellulose potassium	F, V, OH, H	ac, dcep
E11013-G	E7613-G	High titania potassium	F, V, OH, H	ac, dcep, dcen
E11015-G ^{d,e}	E7615-G ^{d,e}	Low hydrogen sodium	F, V, OH, H	dcep
E11016-X ^{d,e}	E7616-X ^{d,e}	Low hydrogen potassium	F, V, OH, H	ac, dcep
E11018-X ^{d,e}	E7618-X ^{d,e}	Low hydrogen potassium, iron powder ^f	F, V, OH, H	ac, dcep
E11018M ^{d,e}	E7618M ^{d,e}	Iron powder, low hydrogen ^f	F, V, OH, H	dcep
E12010-G	E8310-G	High cellulose sodium	F, V, OH, H	dcep
E12011-G	E8311-G	High cellulose potassium	F, V, OH, H	ac, dcep
E12013-G	E8313-G	High titania potassium	F, V, OH, H	ac, dcep, dcen
E12015-G ^{d,e}	E8315-G ^{d,e}	Low hydrogen sodium	F, V, OH, H	dcep
E12016-G ^{d,e}	E8316-G ^{d,e}	Low hydrogen potassium	F, V, OH, H	ac, dcep
E12018-G ^{e,e}	E8318-G ^{d,e}	Low hydrogen potassium, iron powder ^f	F, V, OH, H	ac, dcep
E12018M ^{d,e}	E8318M ^{d,e}	Iron powder, low hydrogen ^f	F, V, OH, H	dcep
E12018M1 ^{d,e}	E8318M1 ^{d,e}	Iron powder, low hydrogen ^f	F, V, OH, H	dcep

- a. The letter “X” in the composition designator position (see Figure 1) as used in this table and elsewhere in this specification stands for any allowable value of the designator *not otherwise individually listed*.
- b. The abbreviations F, H, H-fillets, V, V-down, and OH indicate the welding position, as follows:
- F = Flat
 - H = Horizontal
 - H-fillets = Horizontal fillets
 - V = Vertical (For electrodes 3/16 in [5.0 mm] and under, except 5/32 in [4.0 mm] and under for classification E(X)XX15-X, E(X)XX16-X, E(X)XX18-X)
 - V-down = vertical, with downward progression
 - OH = overhead (For electrodes 3/16 in [5.0 mm] and under, except 5/32 in [4.0 mm] and under for classifications E(X)XX15-X, E(X)XX16-X, E(X)XX18-X)
- c. The term “dcep” refers to direct current, electrode positive (dc, reverse polarity). The term “dcen” refers to direct current, electrode negative (dc, straight polarity).
- d. Electrodes classified as E(X)XX15-X, E(X)XX16-X, E(X)XX18-X, E(X)XX18M(1) or E(X)XX45-X which meet the supplemental absorbed moisture requirements in Table 11 may be further identified as shown in Table 11 and Figure 1.
- e. Electrodes classified as E(X)XX15-X, E(X)XX16-X, E(X)XX18-X, E(X)XX18M(1) or E(X)XX45-X which produce weld metal that meets the maximum average level of diffusible hydrogen in Table 12 may be further identified as specified in Table 12 and Figure 1.
- f. Use of the term “iron powder” is intended to include other metal powders added to the covering for alloying of the weld metal (See A6.14).

Table 2
Chemical Composition Requirements for Undiluted Weld Metal

AWS Classifications ^c		UNS Number ^d	Weight Percent ^{a,b}								Other Required Elements ^{e,f}	
			C	Mn	Si	P	S	Ni	Cr	Mo	Element	Amount
A5.5	A5.5M											
Carbon-Molybdenum Steel Electrodes												
E7010-A1	E4910-A1	W17010	0.12	0.60	0.40	0.03	0.03	—	—	0.40–0.65	—	—
E7011-A1	E4911-A1	W17011	0.12	0.60	0.40	0.03	0.03	—	—	0.40–0.65	—	—
E7015-A1	E4915-A1	W17015	0.12	0.90	0.60	0.03	0.03	—	—	0.40–0.65	—	—
E7016-A1	E4916-A1	W17016	0.12	0.90	0.60	0.03	0.03	—	—	0.40–0.65	—	—
E7018-A1	E4918-A1	W17018	0.12	0.90	0.80	0.03	0.03	—	—	0.40–0.65	—	—
E7020-A1	E4920-A1	W17020	0.12	0.60	0.40	0.03	0.03	—	—	0.40–0.65	—	—
E7027-A1	E4927-A1	W17027	0.12	1.00	0.40	0.03	0.03	—	—	0.40–0.65	—	—
Chromium-Molybdenum Steel Electrodes												
E8016-B1	E5516-B1	W51016	0.05–0.12	0.90	0.60	0.03	0.03	—	0.40–0.65	0.40–0.65	—	—
E8018-B1	E5518-B1	W51018	0.05–0.12	0.90	0.80	0.03	0.03	—	0.40–0.65	0.40–0.65	—	—
E8015-B2	E5515-B2	W52015	0.05–0.12	0.90	1.00	0.03	0.03	—	1.00–1.50	0.40–0.65	—	—
E8016-B2	E5516-B2	W52016	0.05–0.12	0.90	0.60	0.03	0.03	—	1.00–1.50	0.40–0.65	—	—
E8018-B2	E5518-B2	W52018	0.05–0.12	0.90	0.80	0.03	0.03	—	1.00–1.50	0.40–0.65	—	—
E7015-B2L	E4915-B2L	W52115	0.05	0.90	1.00	0.03	0.03	—	1.00–1.50	0.40–0.65	—	—
E7016-B2L	E4916-B2L	W52116	0.05	0.90	0.60	0.03	0.03	—	1.00–1.50	0.40–0.65	—	—
E7018-B2L	E4918-B2L	W52118	0.05	0.90	0.80	0.03	0.03	—	1.00–1.50	0.40–0.65	—	—
E9015-B3	E6216-B3	W53015	0.05–0.12	0.90	1.00	0.03	0.03	—	2.00–2.50	0.90–1.20	—	—
E9016-B3	E6216-B3	W53016	0.05–0.12	0.90	0.60	0.03	0.03	—	2.00–2.50	0.90–1.20	—	—
E9018-B3	E6218-B3	W53018	0.05–0.12	0.90	0.80	0.03	0.03	—	2.00–2.50	0.90–1.20	—	—
E8015-B3L	E5515-B3L	W53115	0.05	0.90	1.00	0.03	0.03	—	2.00–2.50	0.90–1.20	—	—
E8018-B3L	E5518-B3L	W53118	0.05	0.90	0.80	0.03	0.03	—	2.00–2.50	0.90–1.20	—	—

(Continued)

Table 2 (Continued)
Chemical Composition Requirements for Undiluted Weld Metal

AWS Classifications ^c		UNS Number ^d	Weight Percent ^{a,b}								Other Required Elements ^{e,f}	
A5.5	A5.5M		C	Mn	Si	P	S	Ni	Cr	Mo	Element	Amount
E8015-B4L	E5515-B4L	W53415	0.05	0.90	1.00	0.03	0.03	—	1.75–2.25	0.40–0.65	—	—
E8016-B5	E5516-B5	W51316	0.07–0.15	0.40–0.70	0.30–0.60	0.03	0.03	—	0.40–0.60	1.00–1.25	V	0.05
E8015-B6	E5515-B6	W50215	0.05–0.10	1.0	0.90	0.03	0.03	0.40	4.0–6.0	0.45–0.65	—	—
E8016-B6	E5516-B6	W50216	0.05–0.10	1.0	0.90	0.03	0.03	0.40	4.0–6.0	0.45–0.65	—	—
E8018-B6	E5518-B6	W50218	0.05–0.10	1.0	0.90	0.03	0.03	0.40	4.0–6.0	0.45–0.65	—	—
E9018-B6	E6218-B6	W50219	0.05–0.10	1.0	0.90	0.03	0.03	0.40	4.0–6.0	0.45–0.65	—	—
E8015-B6L	E5515-B6L	W50205	0.05	1.0	0.90	0.03	0.03	0.40	4.0–6.0	0.45–0.65	—	—
E8016-B6L	E5516-B6L	W50206	0.05	1.0	0.90	0.03	0.03	0.40	4.0–6.0	0.45–0.65	—	—
E8018-B6L	E5518-B6L	W50208	0.05	1.0	0.90	0.03	0.03	0.40	4.0–6.0	0.45–0.65	—	—
E8015-B7	E5515-B7	W50315	0.05–0.10	1.0	0.90	0.03	0.03	0.40	6.0–8.0	0.45–0.65	—	—
E8016-B7	E5516-B7	W50416	0.05–0.10	1.0	0.90	0.03	0.03	0.40	6.0–8.0	0.45–0.65	—	—
E8018-B7	E5518-B7	W50318	0.05–0.10	1.0	0.90	0.03	0.03	0.40	6.0–8.0	0.45–0.65	—	—
E8015-B7L	E5515-B7L	W50305	0.05	1.0	0.90	0.03	0.03	0.40	6.0–8.0	0.45–0.65	—	—
E8016-B7L	E5516-B7L	W50306	0.05	1.0	0.90	0.03	0.03	0.40	6.0–8.0	0.45–0.65	—	—
E8018-B7L	E5518-B7L	W50308	0.05	1.0	0.90	0.03	0.03	0.40	6.0–8.0	0.45–0.65	—	—
E8015-B8	E5515-B8	W50415	0.05–0.10	1.0	0.90	0.03	0.03	0.40	8.0–10.5	0.85–1.20	—	—
E8016-B8	E5516-B8	W50416	0.05–0.10	1.0	0.90	0.03	0.03	0.40	8.0–10.5	0.85–1.20	—	—
E8018-B8	E5518-B8	W50418	0.05–0.10	1.0	0.90	0.03	0.03	0.40	8.0–10.5	0.85–1.20	—	—

(Continued)

Table 2 (Continued)
Chemical Composition Requirements for Undiluted Weld Metal

AWS Classifications ^c		UNS Number ^d	Weight Percent ^{a,b}								Other Required Elements ^{e,f}	
			C	Mn	Si	P	S	Ni	Cr	Mo	Element	Amount
E8015-B8L	E5515-B8L	W50405	0.05	1.0	0.90	0.03	0.03	0.40	8.0–10.5	0.85–1.20	—	—
E8016-B8L	E5516-B8L	W50506	0.05	1.0	0.90	0.03	0.03	0.40	8.0–10.5	0.85–1.20	—	—
E8018-B8L	E5518-B8L	W50408	0.05	1.0	0.90	0.03	0.03	0.40	8.0–10.5	0.85–1.20	—	—
<i>E9016-B9A</i>	<i>E6216-B9A</i>	—	<i>0.04–0.12</i>	<i>1.00–2.00</i>	<i>0.60</i>	<i>0.025</i>	<i>0.025</i>	<i>0.50–1.00</i>	<i>8.0–10.5</i>	<i>0.85–1.20</i>	<i>V</i>	<i>0.15–0.50</i>
											<i>Nb</i>	<i>0.02–0.15</i>
											<i>W</i>	<i>1.50–2.00</i>
											<i>V</i>	<i>0.15–0.30</i>
E9015-B23	E6215-B23										<i>Nb</i>	<i>0.02–0.10</i>
E9016-B23	E6216-B23	K20857	0.04–0.12	1.00	0.60	0.015	0.015	0.50	1.9–2.9	0.30	<i>B</i>	<i>0.006</i>
E9018-B23	E6218-B23										<i>Al</i>	<i>0.04</i>
											<i>Cu</i>	<i>0.25</i>
											<i>N</i>	<i>0.05</i>
											<i>W</i>	<i>1.30–2.00</i>
											<i>V</i>	<i>0.15–0.30</i>
											<i>Nb</i>	<i>0.01–0.10</i>
<i>E8016-B23A</i>	<i>E5516-B23A</i>	—	<i>0.03–0.12</i>	<i>1.00</i>	<i>0.60</i>	<i>0.015</i>	<i>0.015</i>	<i>0.50</i>	<i>1.9–2.9</i>	<i>0.30</i>	<i>B</i>	<i>0.006</i>
											<i>Al</i>	<i>0.04</i>
											<i>Cu</i>	<i>0.25</i>
											<i>N</i>	<i>0.05</i>
E9015-B24	E6215-B24										<i>V</i>	<i>0.15–0.30</i>
E9016-B24	E6216-B24	K20885	0.04–0.12	1.00	0.60	0.020	0.015	0.50	1.9–2.9	0.80–1.20	<i>Nb</i>	<i>0.02–0.10</i>
E9018-B24	E6218-B24										<i>Ti</i>	<i>0.10</i>
											<i>B</i>	<i>0.006</i>
											<i>Al</i>	<i>0.04</i>
											<i>Cu</i>	<i>0.25</i>
											<i>N</i>	<i>0.07</i>

(Continued)

Table 2 (Continued)
Chemical Composition Requirements for Undiluted Weld Metal

AWS Classifications ^c		UNS Number ^d	Weight Percent ^{a,b}								Other Required Elements ^{e,f}	
A5.5	A5.5M		C	Mn	Si	P	S	Ni	Cr	Mo	Element	Amount
											V	0.15–0.30
E9015-B91 ^{g,h}	E6215-B91 ^{g,h}	W50425									Cu	0.25
E9016-B91 ^{g,h}	E6216-B91 ^{g,h}	W50426	0.08–0.13	1.20	0.30	0.01	0.01	0.80	8.0–10.5	0.85–1.20	Al	0.04
E9018-B91 ^{g,h}	E6218-B91 ^{g,h}	W50428									Nb	0.02–0.10
											N	0.02–0.07
											W	1.50–2.00
											V	0.15–0.30
E9015-B92 ^g	E6215-B92 ^g										Nb	0.02–0.08
E9016-B92 ^g	E6216-B92 ^g	W59016	0.08–0.15	1.20	0.60	0.020	0.015	1.00	8.0–10.0	0.30–0.70	B	0.006
E9018-B92 ^g	E6218-B92 ^g										Al	0.04
											Cu	0.25
											N	0.03–0.08
											W	1.50–2.00
											V	0.10–0.40
											Co	1.00–2.00
E9016-B92A	E6216-B92A	—	0.06–0.15	1.20	0.60	0.020	0.015	1.00	8.0–10.5	0.10–0.70	Nb	0.01–0.08
											B	0.006
											Al	0.04
											Cu	0.25
											N	0.03–0.08
											V	0.10–0.30
											Nb	0.02–0.10
E9015-B115	E6215-B115	—	0.08–0.13	0.80	0.50	0.01	0.01	0.50	9.5–12.0	0.40–0.65	Al	0.04
											Cu	0.20
											N	0.02–0.07

(Continued)

Table 2 (Continued)
Chemical Composition Requirements for Undiluted Weld Metal

AWS Classifications ^c		UNS Number ^d	Weight Percent ^{a,b}								Other Required Elements ^{e,f}	
			C	Mn	Si	P	S	Ni	Cr	Mo	Element	Amount
A5.5	A5.5M											
Nickel Steel Electrodes												
E8016-C1	E5516-C1	W22016	0.12	1.25	0.60	0.03	0.03	2.00–2.75	—	—	—	—
E9016-C1	E6216-C1	—	0.12	0.60–1.20	0.80	0.03	0.03	2.00–2.75	—	0.30	—	—
E8018-C1	E5518-C1	W22018	0.12	1.25	0.80	0.03	0.03	2.00–2.75	—	—	—	—
E7015-C1L	E4915-C1L	W22115	0.05	1.25	0.50	0.03	0.03	2.00–2.75	—	—	—	—
E7016-C1L	E4916-C1L	W22116	0.05	1.25	0.50	0.03	0.03	2.00–2.75	—	—	—	—
E7018-C1L	E4918-C1L	W22118	0.05	1.25	0.50	0.03	0.03	2.00–2.75	—	—	—	—
E8016-C2	E5516-C2	W23016	0.12	1.25	0.60	0.03	0.03	3.00–3.75	—	—	—	—
E8018-C2	E5518-C2	W23018	0.12	1.25	0.80	0.03	0.03	3.00–3.75	—	—	—	—
E7015-C2L	E4915-C2L	W23115	0.05	1.25	0.50	0.03	0.03	3.00–3.75	—	—	—	—
E7016-C2L	E4916-C2L	W23116	0.05	1.25	0.50	0.03	0.03	3.00–3.75	—	—	—	—
E7018-C2L	E4918-C2L	W23118	0.05	1.25	0.50	0.03	0.03	3.00–3.75	—	—	—	—
E8016-C3	E5516-C3	W21016	0.12	0.40–1.25	0.80	0.03	0.03	0.80–1.10	0.15	0.35	V	0.05
E8018-C3	E5518-C3	W21018	0.12	0.40–1.25	0.80	0.03	0.03	0.80–1.10	0.15	0.35	V	0.05
E7018-C3L	E4918-C3L	W20918	0.08	0.40–1.40	0.50	0.03	0.03	0.80–1.10	0.15	0.35	V	0.05
E8016-C4	E5516-C4	W21916	0.10	1.25	0.60	0.03	0.03	1.10–2.00	—	—	—	—
E8018-C4	E5518-C4	W21918	0.10	1.25	0.80	0.03	0.03	1.10–2.00	—	—	—	—
E9015-C5L	E6215-C5L	W25018	0.05	0.40–1.00	0.50	0.03	0.03	6.00–7.25	—	—	—	—

(Continued)

Table 2 (Continued)
Chemical Composition Requirements for Undiluted Weld Metal

AWS Classifications ^c		UNS Number ^d	Weight Percent ^{a,b}								Other Required Elements ^{e,f}	
A5.5	A5.5M		C	Mn	Si	P	S	Ni	Cr	Mo	Element	Amount
											V	0.05
E7016-C6	E4916-C6	—	0.12	0.60–1.60	0.25–0.90	0.03	0.03	0.30–1.00	—	0.35	Ti	0.005–0.035
											B	0.0005–0.0045
E8016-C7	E5516-C7	—	0.10	1.00–1.60	0.60	0.03	0.03	1.10–2.00	—	—	Ti	0.005–0.035
											B	0.0005–0.0045
Nickel-Molybdenum Steel Electrodes												
E8018-NM1	E5518-NM1	W21118	0.10	0.80–1.25	0.60	0.02	0.02	0.80–1.10	0.10	0.40–0.65	V	0.02
											Cu	0.10
											Al	0.05
E9018-NM2	E5518-NM2	W21119	0.04–0.15	0.50–1.60	0.70	0.02	0.02	1.40–2.10	0.20	0.20–0.50	V	0.05
											Cu	0.10
											Al	0.05
E10016-NM3	E6916-NM3	—	0.12	1.20–1.70	0.80	0.03	0.03	1.20–1.70	0.10–0.30	0.10–0.30	—	—
E9016-NM4	E6216-NM4	—	0.12	0.70–1.50	0.80	0.03	0.03	0.30–1.00	—	0.10–0.40	—	—
E10016-NM5	E6916-NM5	—	0.12	0.80–1.40	0.80	0.03	0.03	3.00–3.80	0.10–0.40	0.30–0.60	—	—
E11016-NM6	E7616-NM6	—	0.12	1.20–1.80	0.80	0.03	0.03	1.50–2.10	0.10–0.40	0.25–0.55	—	—
E11016-NM7	E7616-NM7	—	0.12	1.40–2.00	0.80	0.03	0.03	2.10–2.80	—	0.50–0.80	—	—
E11018-NM8	E7618-NM8	—	0.12	1.20–1.90	0.20–0.75	0.03	0.03	2.50–3.30	—	0.40–1.00	—	—
Manganese-Molybdenum Steel Electrodes												
E8018-D1	E5518-D1	W18118	0.12	1.00–1.75	0.80	0.03	0.03	0.90	—	0.25–0.45	—	—
E9015-D1	E6215-D1	W19015	0.12	1.00–1.75	0.60	0.03	0.03	0.90	—	0.25–0.45	—	—
E9018-D1	E6218-D1	W19018	0.12	1.00–1.75	0.80	0.03	0.03	0.90	—	0.25–0.45	—	—
E10015-D2	E6915-D2	W10015	0.15	1.65–2.00	0.60	0.03	0.03	0.90	—	0.25–0.45	—	—
E10016-D2	E6916-D2	W10016	0.15	1.65–2.00	0.60	0.03	0.03	0.90	—	0.25–0.45	—	—
E10018-D2	E6918-D2	W10018	0.15	1.65–2.00	0.80	0.03	0.03	0.90	—	0.25–0.45	—	—

(Continued)

Table 2 (Continued)
Chemical Composition Requirements for Undiluted Weld Metal

		Weight Percent ^{a,b}									Other Required Elements ^{e,f}	
AWS Classifications ^c		UNS Number ^d	C	Mn	Si	P	S	Ni	Cr	Mo	Element	Amount
A5.5	A5.5M											
E8016-D3	E5516-D3	W18016	0.12	1.00–1.80	0.60	0.03	0.03	0.90	—	0.40–0.65	—	—
<i>E9016-D3</i>	<i>E6216-D3</i>	—	<i>0.12</i>	<i>1.00–1.80</i>	<i>0.60</i>	<i>0.03</i>	<i>0.03</i>	<i>0.90</i>	—	<i>0.40–0.65</i>	—	—
E8018-D3	E5518-D3	W18018	0.12	1.00–1.80	0.80	0.03	0.03	0.90	—	0.40–0.65	—	—
E9018-D3	E6218-D3	W19118	0.12	1.00–1.80	0.80	0.03	0.03	0.90	—	0.40–0.65	—	—
High Manganese Electrodes												
<i>E10016-Mn2</i>	<i>E6916-Mn2</i>	—	<i>0.25–0.50</i>	<i>16.0–24.0</i>	<i>1.0</i>	<i>0.020</i>	<i>0.015</i>	<i>3.0</i>	<i>1.5–3.5</i>	<i>1.5</i>	<i>Cu</i>	<i>0.5</i>
<i>E10018-Mn2</i>	<i>E6918-Mn2</i>	—	<i>0.25–0.50</i>	<i>16.0–24.0</i>	<i>1.0</i>	<i>0.020</i>	<i>0.015</i>	<i>3.0</i>	<i>1.5–3.5</i>	<i>1.5</i>	<i>Cu</i>	<i>0.5</i>
General Low-Alloy Steel Electrodes												
E(X)XX10-G ⁱ	EXX10-G ⁱ	—	—	1.00 min. ^j	0.80 min. ^j	0.03	0.03	0.50 min. ^j	0.30 min. ^j	0.20 min. ^j	V	0.10 min. ^j
											Cu	0.20 min. ^j
E(X)XX11-G ⁱ	EXX11-G ⁱ	—	—	1.00 min. ^j	0.80 min. ^j	0.03	0.03	0.50 min. ^j	0.30 min. ^j	0.20 min. ^j	V	0.10 min. ^j
											Cu	0.20 min. ^j
E(X)XX13-G ⁱ	EXX13-G ⁱ	—	—	1.00 min. ^j	0.80 min. ^j	0.03	0.03	0.50 min. ^j	0.30 min. ^j	0.20 min. ^j	V	0.10 min. ^j
											Cu	0.20 min. ^j
E(X)XX15-G ⁱ	EXX15-G ⁱ	—	—	1.00 min. ^j	0.80 min. ^j	0.03	0.03	0.50 min. ^j	0.30 min. ^j	0.20 min. ^j	V	0.10 min. ^j
											Cu	0.20 min. ^j
E(X)XX16-G ⁱ	EXX16-G ⁱ	—	—	1.00 min. ^j	0.80 min. ^j	0.03	0.03	0.50 min. ^j	0.30 min. ^j	0.20 min. ^j	V	0.10 min. ^j
											Cu	0.20 min. ^j
E(X)XX18-G ⁱ	EXX18-G ⁱ	—	—	1.00 min. ^j	0.80 min. ^j	0.03	0.03	0.50 min. ^j	0.30 min. ^j	0.20 min. ^j	V	0.10 min. ^j
											Cu	0.20 min. ^j
E(X)XX45-G ⁱ	EXX45-G ⁱ	—	—	1.00 min. ^j	0.80 min. ^j	0.03	0.03	0.50 min. ^j	0.30 min. ^j	0.20 min. ^j	V	0.10 min. ^j
											Cu	0.20 min. ^j
E7020-G	E4920-G	—	—	1.00 min. ^j	0.80 min. ^j	0.03	0.03	0.50 min. ^j	0.30 min. ^j	0.20 min. ^j	V	0.10 min. ^j
											Cu	0.20 min. ^j

(Continued)

Table 2 (Continued)
Chemical Composition Requirements for Undiluted Weld Metal

AWS Classifications ^c		UNS Number ^d	Weight Percent ^{a,b}								Other Required Elements ^{e,f}	
A5.5	A5.5M		C	Mn	Si	P	S	Ni	Cr	Mo	Element	Amount
E7027-G	E4927-G	—		1.00 min. ^j	0.80 min. ^j	0.03	0.03	0.50 min. ^j	0.30 min. ^j	0.20 min. ^j	V	0.10 min. ^j
											Cu	0.20 min. ^j
Military-Similar Electrodes												
E9018M ^k	E6218M ^k	W21218	0.10	0.60–1.25	0.80	0.030	0.030	1.40–1.80	0.15	0.35	V	0.05
E10018M ^k	E6918M ^k	W21318	0.10	0.75–1.70	0.60	0.030	0.030	1.40–2.10	0.35	0.25–0.50	V	0.05
E11018M ^k	E7618M ^k	W21418	0.10	1.30–1.80	0.60	0.030	0.030	1.25–2.50	0.40	0.25–0.50	V	0.05
E12018M ^k	E8318M ^k	W22218	0.10	1.30–2.25	0.60	0.030	0.030	1.75–2.50	0.30–1.50	0.30–0.55	V	0.05
E12018M1 ^k	E8318M1 ^k	W23218	0.10	0.80–1.60	0.65	0.015	0.012	3.00–3.80	0.65	0.20–0.30	V	0.05
Pipeline Steel Electrodes												
E7010-P1	E4910-P1	W17110	0.20	1.20	0.60	0.03	0.03	1.00	0.30	0.50	V	0.10
E8010-P1	E5510-P1	W18110	0.20	1.20	0.60	0.03	0.03	1.00	0.30	0.50	V	0.10
E9010-P1	E6210-P1	W19110	0.20	1.20	0.60	0.03	0.03	1.00	0.30	0.50	V	0.10
E8018-P2	E5518-P2	W18218	0.12	0.90–1.70	0.80	0.03	0.03	1.00	0.20	0.50	V	0.05
E9018-P2	E6218-P2	W19218	0.12	0.90–1.70	0.80	0.03	0.03	1.00	0.20	0.50	V	0.05
E8045-P2	E5545-P2	W18245	0.12	0.90–1.70	0.80	0.03	0.03	1.00	0.20	0.50	V	0.05
E9045-P2	E6245-P2	W19245	0.12	0.90–1.70	0.80	0.03	0.03	1.00	0.20	0.50	V	0.05
E10045-P2	E6945-P2	W10245	0.12	0.90–1.70	0.80	0.03	0.03	1.00	0.20	0.50	V	0.05
Weathering Steel Electrodes												
E7018-W1	E4918-W1	W20018	0.12	0.40–0.70	0.40–0.70	0.025	0.025	0.20–0.40	0.15–0.30	—	V	0.08
											Cu	0.30–0.60
E8018-W2	E5518-W2	W20118	0.12	0.50–1.30	0.35–0.80	0.03	0.03	0.40–0.80	0.45–0.70	—	Cu	0.30–0.75

NOTES:

^a Single values are maxima, except where specified otherwise.

^b Weld metal shall be analyzed for those elements for which specific values are shown. Other elements listed without specified values shall be reported, if intentionally added. The total of these latter unspecified elements and all other elements not intentionally added shall not exceed 0.50%.

^c The suffixes A1, B3, C3, etc. designate the chemical composition of the electrode classification.

^d SAE-HS-1086/ASTM DS-56 *Metals & Alloys in the Unified Numbering System*.

^e Analysis for boron is required to be reported for any weld metal if it has been intentionally added or is known to be present at levels greater than 0.0010%.

^f Analysis for cobalt is required to be reported if intentionally added, or if it is known to be present at levels greater than 0.20%.

^g Mn + Ni shall be 1.40% max.

^h The E90XX-B91 [E62XX-B91] classifications were formerly classified as E90XX-B9 [E62XX-B9] in AWS A5.5/A5.5M.

ⁱ The letters “(X)XX” [“XX”] following the “E” in a classification designation in this table stand for the various strength levels (70, 80, 90, 100, 110, and 120 ksi) [49, 55, 62, 69, 76, and 83 MPa x 10] of weld metals.

^j In order to meet the alloy requirements of the “G” group, the undiluted weld metal shall have the minimum of at least one of the elements listed in this table. Additional chemical requirements may be agreed upon between the purchaser and supplier.

^k These classifications are intended to be similar to types of electrodes covered by military specifications MIL-E-22200/1 and MIL-E-22200/10.

Table 3
Tension Test Requirements^{a,b}

AWS Classification ^c		Tensile Strength		Yield Strength, At 0.2% Offset		Elongation	Postweld Condition ^d
A5.5	A5.5M	ksi	MPa	ksi	MPa	Percent	
E7010-P1	E4910-P1	70	490	60	415	22	AW
E7010-A1	E4910-A1	70	490	57	390	22	PWHT
E7010-G	E4910-G	70	490	57	390	22	AW or PWHT
E7011-A1	E4911-A1	70	490	57	390	22	PWHT
E7011-G	E4911-G	70	490	57	390	22	AW or PWHT
E7015-X	E4915-X	70	490	57	390	22	PWHT
E7015-B2L	E4915-B2L	75	520	57	390	19	PWHT
E7015-G	E4915-G	70	490	57	390	22	AW or PWHT
E7016-X	E4916-X	70	490	57	390	22	PWHT
E7016-B2L	E4916-B2L	75	520	57	390	19	PWHT
E7016-C6	E4916-C6	70	490	57	390	22	AW
E7016-G	E4916-G	70	490	57	390	22	AW or PWHT
E7018-X	E4918-X	70	490	57	390	22	PWHT
E7018-B2L	E4918-B2L	75	520	57	390	19	PWHT
E7018-C3L	E4918-C3L	70	490	57	390	22	AW
E7018-W1	E4918-W1	70	490	60	415	22	AW
E7018-G	E4918-G	70	490	57	390	22	AW or PWHT
E7020-A1	E4920-A1	70	490	57	390	22	PWHT
E7020-G	E4920-G	70	490	57	390	22	AW or PWHT
E7027-A1	E4927-A1	70	490	57	390	22	PWHT
E7027-G	E4927-G	70	490	57	390	22	AW or PWHT
E8010-P1	E5510-P1	80	550	67	460	19	AW
E8010-G	E5510-G	80	550	67	460	19	AW or PWHT
E8011-G	E5511-G	80	550	67	460	19	AW or PWHT
E8013-G	E5513-G	80	550	67	460	16	AW or PWHT
E8015-X	E5515-X	80	550	67	460	19	PWHT
E8015-B3L	E5515-B3L	80	550	67	460	17	PWHT
E8015-G	E5515-G	80	550	67	460	19	AW or PWHT
E8016-X	E5516-X	80	550	67	460	19	PWHT
E8016-C3	E5516-C3	80	550	68 to 80°	470 to 550°	24	AW
E8016-C4	E5516-C4	80	550	67	460	19	AW
E8016-G	E5516-G	80	550	67	460	19	AW or PWHT
E8016-C7	E5516-C7	80	550	67	460	19	AW
E8018-X	E5518-X	80	550	67	460	19	PWHT
E8018-B3L	E5518-B3L	80	550	67	460	17	PWHT
E8018-C3	E5518-C3	80	550	68 to 80°	470 to 550°	24	AW
E8018-C4	E5518-C4	80	550	67	460	19	AW
E8018-NM1	E5518-NM1	80	550	67	460	19	AW
E8018-P2	E5518-P2	80	550	67	460	19	AW
E8018-W2	E5518-W2	80	550	67	460	19	AW
E8018-G	E5518-G	80	550	67	460	19	AW or PWHT
E8045-P2	E5545-P2	80	550	67	460	19	AW
E8045-G	E5545-G	80	550	67	460	19	AW or PWHT
E9010-P1	E6210-P1	90	620	77	530	17	AW
E9010-G	E6210-G	90	620	77	530	17	AW or PWHT
E9011-G	E6211-G	90	620	77	530	17	AW or PWHT
E9013-G	E6213-G	90	620	77	530	14	AW or PWHT
E9015-X	E6215-X	90	620	77	530	17	PWHT
E9015-G	E6215-G	90	620	77	530	17	AW or PWHT
E9016-X	E6216-X	90	620	77	530	17	PWHT
E9016-G	E6216-G	90	620	77	530	17	AW or PWHT
E9018M	E6218M	90	620	78 to 90°	540 to 620°	24	AW

(Continued)

Table 3 (Continued)
Tension Test Requirements^{a,b}

AWS Classification ^c		Tensile Strength		Yield Strength, At 0.2% Offset		Elongation	Postweld Condition ^d
A5.5	A5.5M	ksi	MPa	ksi	MPa	Percent	
E9018-NM2	E6218-NM2	90	620	77	530	17	PWHT
E9018-P2	E6218-P2	90	620	77	530	17	AW
E9018-X	E6218-X	90	620	77	530	17	PWHT
E9018-G	E6218-G	90	620	77	530	17	AW or PWHT
E9045-P2	E6245-P2	90	620	77	530	17	AW
E9045-G	E6245-G	90	620	77	530	17	AW or PWHT
E10010-G	E6910-G	100	690	87	600	16	AW or PWHT
E10011-G	E6911-G	100	690	87	600	16	AW or PWHT
E10013-G	E6913-G	100	690	87	600	13	AW or PWHT
E10015-X	E6915-X	100	690	87	600	16	PWHT
E10015-G	E6915-G	100	690	87	600	16	AW or PWHT
E10016-X	E6916-X	100	690	87	600	16	PWHT
E10016-G	E6916-G	100	690	87	600	16	AW or PWHT
E10016-Mn2	E6916-Mn2	100	690	58	400	22	AW
E10016-NM3	E6916-NM3	100	690	87	600	16	AW
E10016-NM5	E6916-NM5	100	690	87	600	16	AW
E10018M	E6918M	100	690	88 to 100 ^e	610 to 690 ^e	20	AW
E10018-Mn2	E6918-Mn2	100	690	58	400	22	AW
E10018-X	E6918-X	100	690	87	600	16	PWHT
E10018-G	E6918-G	100	690	87	600	16	AW or PWHT
E10045-P2	E6945-P2	100	690	87	600	16	AW
E10045-G	E6945-G	100	690	87	600	16	AW or PWHT
E11016-NM6	E7616-NM6	110	760	97	670	15	AW
E11016-NM7	E7616-NM7	110	760	97	670	15	AW
E11018-NM8	E7618-NM8	110	760	97	670	15	AW
E11010-G	E7610-G	110	760	97	670	15	AW or PWHT
E11011-G	E7611-G	110	760	97	670	15	AW or PWHT
E11013-G	E7613-G	110	760	97	670	13	AW or PWHT
E11015-G	E7615-G	110	760	97	670	15	AW or PWHT
E11016-G	E7616-G	110	760	97	670	15	AW or PWHT
E11018-G	E7618-G	110	760	97	670	15	AW or PWHT
E11018M	E7618M	110	760	98 to 110 ^e	680 to 760 ^e	20	AW
E12010-G	E8310-G	120	830	107	740	14	AW or PWHT
E12011-G	E8311-G	120	830	107	740	14	AW or PWHT
E12013-G	E8313-G	120	830	107	740	11	AW or PWHT
E12015-G	E8315-G	120	830	107	740	14	AW or PWHT
E12016-G	E8316-G	120	830	107	740	14	AW or PWHT
E12018-G	E8318-G	120	830	107	740	14	AW or PWHT
E12018M	E8318M	120	830	108 to 120 ^e	745 to 830 ^e	18	AW
E12018M1	E8318M1	120	830	108 to 120 ^e	745 to 830 ^e	18	AW

NOTES:

a. See Table 5 for sizes to be tested

b. Single values are minima

c. The letter "X" in the composition designator position (See Figure 1), as used in this table, represents the designators not otherwise individually listed which are tested in the PWHT condition only.

d. "AW" signifies as-welded, which may or may not have been aged, at the manufacturer's option (see 12.2). "PWHT" signifies postweld heat treated, as specified in 9.4.1.1 and in Table 7, except that the "G" designated classifications, marked as "AW" or "PWHT" in this table may have weld metal tested with or without PWHT, as agreed upon between the purchaser and supplier.

e. For 3/32 in [2.5 mm] electrodes, the upper value for the yield strength may be 5 ksi [35 MPa] higher than the indicated value.

Table 4
Charpy V-Notch Impact Test Requirements

A5.5 Classification			A5.5M Classification		
AWS Classification ^a	Limits for 3 out of 5 Specimens ^{b, c, d}		AWS Classification	Limits for 3 out of 5 Specimens ^{b, c, d}	
A5.5	A5.5 Average, minimum ^e	A5.5 Single Value, minimum ^e	A5.5M	A5.5M Average, minimum ^e	A5.5M Single Value, minimum ^e
E7018-W1	20 ft•lbf at 0 °F	15 ft•lbf at 0 °F	E4918-W1	27 J at -20 °C	20 J at -20 °C
E8018-W2	20 ft•lbf at 0 °F	15 ft•lbf at 0 °F	E5518-W2	27 J at -20 °C	20 J at -20 °C
E9016-NM4	20 ft•lbf at 0 °F	15 ft•lbf at 0 °F	E6216-NM4	27 J at -20 °C	20 J at -20 °C
E10016-NM3	20 ft•lbf at 0 °F	15 ft•lbf at 0 °F	E6916-NM3	27 J at -20 °C	20 J at -20 °C
E11016-NM6	20 ft•lbf at 0 °F	15 ft•lbf at 0 °F	E7616-NM6	27 J at -20 °C	20 J at -20 °C
E12018M1	50 ft•lbf at 0 °F	40 ft•lbf at 0 °F	E8318M1	67 J at -20 °C	54 J at -20 °C
E7010-P1	20 ft•lbf at -20 °F	15 ft•lbf at -20 °F	E4910-P1	27 J at -30 °C	20 J at -30 °C
E8010-P1	20 ft•lbf at -20 °F	15 ft•lbf at -20 °F	E5510-P1	27 J at -30 °C	20 J at -30 °C
E8018-P2	20 ft•lbf at -20 °F	15 ft•lbf at -20 °F	E5518-P2	27 J at -30 °C	20 J at -30 °C
E8045-P2	20 ft•lbf at -20 °F	15 ft•lbf at -20 °F	E5545-P2	27 J at -30 °C	20 J at -30 °C
E9010-P1	20 ft•lbf at -20 °F	15 ft•lbf at -20 °F	E6210-P1	27 J at -30 °C	20 J at -30 °C
E9018-P2	20 ft•lbf at -20 °F	15 ft•lbf at -20 °F	E6218-P2	27 J at -30 °C	20 J at -30 °C
E9018-NM2	20 ft•lbf at -20 °F ^f	15 ft•lbf at -20 °F ^f	E6218-NM2	27 J at -30 °C ^f	20 J at -30 °C ^f
E9045-P2	20 ft•lbf at -20 °F	15 ft•lbf at -20 °F	E6245-P2	27 J at -30 °C	20 J at -30 °C
E10045-P2	20 ft•lbf at -20 °F	15 ft•lbf at -20 °F	E6945-P2	27 J at -30 °C	20 J at -30 °C
E8018-NM1	20 ft•lbf at -40 °F	15 ft•lbf at -40 °F	E5518-NM1	27 J at -40 °C	20 J at -40 °C
E8016-C3	20 ft•lbf at -40 °F	15 ft•lbf at -40 °F	E5516-C3	27 J at -40 °C	20 J at -40 °C
E8018-C3	20 ft•lbf at -40 °F	15 ft•lbf at -40 °F	E5518-C3	27 J at -40 °C	20 J at -40 °C
E10016-NM5	20 ft•lbf at -40 °F	15 ft•lbf at -40 °F	E6916-NM5	27 J at -40 °C	20 J at -40 °C
E8016-D3	20 ft•lbf at -60 °F ^f	15 ft•lbf at -60 °F ^f	E5516-D3	27 J at -50 °C ^f	20 J at -50 °C ^f
E8018-D1	20 ft•lbf at -60 °F ^f	15 ft•lbf at -60 °F ^f	E5518-D1	27 J at -50 °C ^f	20 J at -50 °C ^f
E8018-D3	20 ft•lbf at -60 °F ^f	15 ft•lbf at -60 °F ^f	E5518-D3	27 J at -50 °C ^f	20 J at -50 °C ^f
E9015-D1	20 ft•lbf at -60 °F ^f	15 ft•lbf at -60 °F ^f	E6215-D1	27 J at -50 °C ^f	20 J at -50 °C ^f
E9018-D1	20 ft•lbf at -60 °F ^f	15 ft•lbf at -60 °F ^f	E6218-D1	27 J at -50 °C ^f	20 J at -50 °C ^f
E9016-D3	20 ft•lbf at -60 °F ^f	15 ft•lbf at -60 °F ^f	E6216-D3	27 J at -50 °C ^f	20 J at -50 °C ^f
E9018-D3	20 ft•lbf at -60 °F ^f	15 ft•lbf at -60 °F ^f	E6218-D3	27 J at -50 °C ^f	20 J at -50 °C ^f
E10015-D2	20 ft•lbf at -60 °F ^f	15 ft•lbf at -60 °F ^f	E6915-D2	27 J at -50 °C ^f	20 J at -50 °C ^f
E10016-D2	20 ft•lbf at -60 °F ^f	15 ft•lbf at -60 °F ^f	E6916-D2	27 J at -50 °C ^f	20 J at -50 °C ^f
E10018-D2	20 ft•lbf at -60 °F ^f	15 ft•lbf at -60 °F ^f	E6918-D2	27 J at -50 °C ^f	20 J at -50 °C ^f
E7018-C3L	20 ft•lbf at -60 °F	15 ft•lbf at -60 °F	E4918-C3L	27 J at -50 °C	20 J at -50 °C
E8016-C4	20 ft•lbf at -60 °F	15 ft•lbf at -60 °F	E5516-C4	27 J at -50 °C	20 J at -50 °C
E8018-C4	20 ft•lbf at -60 °F	15 ft•lbf at -60 °F	E5518-C4	27 J at -50 °C	20 J at -50 °C
E9018M	20 ft•lbf at -60 °F	15 ft•lbf at -60 °F	E6218M	27 J at -50 °C	20 J at -50 °C
E10018M	20 ft•lbf at -60 °F	15 ft•lbf at -60 °F	E6918M	27 J at -50 °C	20 J at -50 °C
E11018M	20 ft•lbf at -60 °F	15 ft•lbf at -60 °F	E7618M	27 J at -50 °C	20 J at -50 °C
E12018M	20 ft•lbf at -60 °F	15 ft•lbf at -60 °F	E8318M	27 J at -50 °C	20 J at -50 °C
E7016-C6	20 ft•lbf at -75 °F	15 ft•lbf at -75 °F	E4916-C6	27 J at -60 °C	20 J at -60 °C
E8016-C7	20 ft•lbf at -75 °F	15 ft•lbf at -75 °F	E5516-C7	27 J at -60 °C	20 J at -60 °C

(Continued)

Table 4 (Continued)
Charpy V-Notch Impact Test Requirements

A5.5 Classification			A5.5M Classification		
AWS Classification ^a	Limits for 3 out of 5 Specimens ^{b, c, d}		AWS Classification	Limits for 3 out of 5 Specimens ^{b, c, d}	
A5.5	A5.5 Average, minimum ^e	A5.5 Single Value, minimum ^e	A5.5M	A5.5M Average, minimum ^e	A5.5M Single Value, minimum ^e
E9016-C1	20 ft•lbf at -75 °F ^f	15 ft•lbf at -75 °F ^f	E6216-C1	27 J at -60 °C ^f	20 J at -60 °C ^f
E11016-NM7	20 ft•lbf at -75 °F	15 ft•lbf at -75 °F	E7616-NM7	27 J at -60 °C	20 J at -60 °C
E11018-NM8	20 ft•lbf at -75 °F	15 ft•lbf at -75 °F	E7618-NM8	27 J at -60 °C	20 J at -60 °C
E8016-C1	20 ft•lbf at -75 °F ^f	15 ft•lbf at -75 °F ^f	E5516-C1	27 J at -60 °C ^f	20 J at -60 °C ^f
E8018-C1	20 ft•lbf at -75 °F ^f	15 ft•lbf at -75 °F ^f	E5518-C1	27 J at -60 °C ^f	20 J at -60 °C ^f
E7015-C1L	20 ft•lbf at -100 °F ^f	15 ft•lbf at -100 °F ^f	E4915-C1L	27 J at -75 °C ^f	20 J at -75 °C ^f
E7016-C1L	20 ft•lbf at -100 °F ^f	15 ft•lbf at -100 °F ^f	E4916-C1L	27 J at -75 °C ^f	20 J at -75 °C ^f
E7018-C1L	20 ft•lbf at -100 °F ^f	15 ft•lbf at -100 °F ^f	E4918-C1L	27 J at -75 °C ^f	20 J at -75 °C ^f
E8016-C2	20 ft•lbf at -100 °F ^f	15 ft•lbf at -100 °F ^f	E5516-C2	27 J at -75 °C ^f	20 J at -75 °C ^f
E8018-C2	20 ft•lbf at -100 °F ^f	15 ft•lbf at -100 °F ^f	E5518-C2	27 J at -75 °C ^f	20 J at -75 °C ^f
E7015-C2L	20 ft•lbf at -150 °F ^f	15 ft•lbf at -150 °F ^f	E4915-C2L	27 J at -100 °C ^f	20 J at -100 °C ^f
E7016-C2L	20 ft•lbf at -150 °F ^f	15 ft•lbf at -150 °F ^f	E4916-C2L	27 J at -100 °C ^f	20 J at -100 °C ^f
E7018-C2L	20 ft•lbf at -150 °F ^f	15 ft•lbf at -150 °F ^f	E4918-C2L	27 J at -100 °C ^f	20 J at -100 °C ^f
E9015-C5L	20 ft•lbf at -175 °F ^f	15 ft•lbf at -175 °F ^f	E6215-C5L	27 J at -115 °C ^f	20 J at -115 °C ^f
E10016-Mn2	0.015 in at -320 °F ^g	0.015 in at -320 °F ^g	E6916-Mn2	0.38 mm at -196 °C ^g	0.38 mm at -196 °C ^g
E10018-Mn2	0.015 in at -320 °F ^g	0.015 in at -320 °F ^g	E6918-Mn2	0.38 mm at -196 °C ^g	0.38 mm at -196 °C ^g
EXXXX-A1	Not specified	Not specified	EXXXX-A1	Not specified	Not specified
EXXXX-BXXX	Not specified	Not specified	EXXXX-BXXX	Not specified	Not specified
EXXXX-BXL	Not specified	Not specified	EXXXX-BXL	Not specified	Not specified
E(X)XXXX-G	Not specified	Not specified	EXXXX-G	Not specified	Not specified

NOTES:

- The letters “(X)XX” [“XX”] following the “E” in a classification designation in this table stand for the various strength levels (70, 80, 90, 100, 110, and 120 ksi) [49, 55, 62, 69, 76, and 83 MPa x 10] of weld metals. The “XXX” and “XL” following the “B” in the composition designator position represent any of the allowed Chromium-Molybdenum electrode composition designators in Table 2.
- The test temperature for the five specimens shall be at or below the temperature listed. The actual temperature used shall be listed on the certification documentation when issued.
- Both the highest and the lowest test values obtained shall be disregarded in computing the average value. Two of the three remaining values shall equal or exceed the minimum average value listed; one of these three remaining values may be lower than minimum average value, but shall not be less than the minimum single value listed. The average of the three remaining values shall not be less than the minimum average value listed.
- Impact test specimens are tested without thermal treatment, except as noted.
- Impact test values shall be recorded to “nearest whole unit” of energy absorbed in accordance with the rounding method specified in Clause 6.
- These classifications are tested in the postweld heat treated condition, as specified in 9.4.1.1 and in Table 7.
- Requirements refer to minimum of lateral expansion, See 13.4.

4. Acceptance

Acceptance of the welding electrodes shall be in accordance with the provisions of AWS A5.01M/A5.01. See A3 (in Annex A) for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

5. Certification

By affixing the AWS specification and classification designations to the packaging, or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification. See A4 (in Annex A) for further information concerning certification and the testing called for to meet this requirement.

6. Rounding Procedure

For the purpose of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest 1 000 psi (1 ksi) for tensile and yield strength for A5.5, to the nearest 10 MPa for tensile and yield strength for A5.5M, and to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfill the requirements for the classification under test.

7. Summary of Tests

The tests required for each classification are specified in Table 5. The purpose of these tests is to determine the chemical composition, mechanical properties, soundness of the weld metal, the usability of the electrode, and the moisture content of the low-hydrogen electrode covering. The base metal for the weld test assemblies, the welding and testing procedures to be employed, and the results required are given in Clauses 9 through 15. The supplemental tests for absorbed moisture (see Clause 16) and for diffusible hydrogen (see Clause 17) are not required for classification of electrodes (see Note k of Table 5).

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Specimens for retest may be taken from the original test assembly or sample or from a new test assembly or sample. For chemical analysis, retest need be only for those specific elements that failed to meet the test requirement. If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that, during preparation or after completion of any test, it is clearly determined that specified or proper procedures were not followed in preparing the weld test assembly or in conducting the test, the test shall be considered invalid, without regard to whether the test was actually completed, or whether test results met, or failed to meet, the requirement. That test shall be repeated, following proper prescribed procedures. In this case, the requirement for doubling the number of test specimens does not apply.

Table 5
Required Tests^a

AWS Classification ^b		Electrode Size ^c		Welding Position for Test Assembly					
A5.5	A5.5M	Type of Current ^d	in	mm	Chemical Analysis ^e	Soundness Test & All Weld Metal Tension Test ^{f,g}	Impact Test ^h	Fillet Weld Test ^{i,j}	Moisture Test ^k
E7010-X	E4910-X	dcep	3/32, 1/8	2.5, 3.2	NR ^l	NR ^l	NR	NR ^l	NR
E8010-X	E5510-X		5/32	4.0	F	F	NR	V, OH	NR
E9010-X	E6210-X		3/16	5.0	NR ^l	F	NR	V, OH	NR
E10010-G	E6910-G		7/32	—	NR ^l	NR ^l	NR	NR ^l	NR
E11010-G	E7610-G		1/4	6.0	F	F	NR	H	NR
E12010-G	E8310-G								
E7011-X	E4911-X	ac and dcep	3/32, 1/8	2.5, 3.2	NR ^l	NR ^l	NR	NR ^l	NR
E8011-G	E5511-G		5/32	4.0	F	F	NR	V, OH	NR
E9011-G	E6211-G		3/16	5.0	NR ^l	F	NR	V, OH	NR
E10011-G	E6911-G		7/32	—	NR ^l	NR ^l	NR	NR ^l	NR
E11011-G	E7611-G		1/4	6.0	F	F	NR	H	NR
E12011-G	E8311-G								
E8013-G	E5513-G	ac, dcen, and dcep	3/32, 1/8	2.5, 3.2	NR ^l	NR ^l	NR	NR ^l	NR
E9013-G	E6213-G		5/32	4.0	F ^m	F ^m	NR	V, OH	NR
E10013-G	E6913-G		3/16	5.0	NR ^l	F ^m	NR	V, OH	NR
E12013-G	E8313-G								
E7015-X	E4915-X	dcep	3/32, 1/8	2.5, 3.2	NR ^l	NR ^l	NR ^l	NR ^l	NR ^l
E8015-X	E5515-X		5/32	4.0	F	F	F	V, OH	R
E9015-X	E6215-X		3/16	5.0	NR ^l	F	F	H	NR ^l
E10015-X	E6915-X		7/32	—	NR ^l	NR ^l	NR ^l	NR ^l	NR ^l
E11015-G	E7615-G		1/4	6.0	F	F	F	H	R
E12015-G	E8315-G								
E7016-X	E4916-X	ac and dcep	3/32, 1/8	2.5, 3.2	NR ^l	NR ^l	NR ^l	NR ^l	NR ^l
E8016-X	E5516-X		5/32	4.0	F	F	F	V, OH	R
E9016-X	E6216-X		3/16	5.0	NR ^l	F	F	H	NR ^l
E10016-X	E6916-X		7/32	—	NR ^l	NR ^l	NR ^l	NR ^l	NR ^l
E11016-G	E7616-G		1/4	6.0	F	F	F	H	R
E12016-G	E8316-G								

(Continued)

Table 5 (Continued)
Required Tests^a

AWS Classification ^b		Electrode Size ^c		Welding Position for Test Assembly					
A5.5	A5.5M	Type of Current ^d	in	mm	Chemical Analysis ^e	Soundness Test & All Weld Metal Tension Test ^{f,g}	Impact Test ^h	Fillet Weld Test ^{i,j}	Moisture Test ^k
E8045-P2	E5545-P2	dcep	3/32, 1/8	2.5, 3.2	NR ^l	NR ^l	NR ^l	NR ^l	NR ^l
E9045-P2	E6245-P2		5/32	4.0	F	F	F	V-down, OH	R
E10045-P2	E6945-P2		—	4.5	F	F	F	V-down, OH	R
E7018-X	E4918-X	ac and dcep	3/32, 1/8	2.5, 3.2	NR ^l	NR ^l	NR ^l	NR ^l	NR ^l
E8018-X	E5518-X		5/32	4.0	F	F	F	V, OH	R
E9018-X	E6218-X		3/16	5.0	NR ^l	F	F	H	NR ^l
E10018-X	E6918-X		7/32	—	NR ^l	NR ^l	NR ^l	NR ^l	NR ^l
E11018-G	E7618-G		1/4	6.0	F	F	F	H	R
E12018-G	E8318-G		—	—	—	—	—	—	—
E7020-X E7027-X	E4920-X E4927-X	For H-fillets: ac and dcen. For flat position: ac, dcen, and dcep	1/8	3.2	NR ^l	NR ^l	NR ^l	NR ^l	NR
			5/32	4.0	F ^m	F ^m	NR	H	NR
			3/16	5.0	NR ^l	F ^m	NR	H	NR
			7/32	—	NR ^l	NR ^{l, n}	NR	NR ^l	NR
			1/4	6.0	F ^m	F ^{m, n}	NR	H	NR
E9018M E10018M E11018M E12018M E12018M1	E6218M E6918M E7618M E8318M E8318M1	dcep	3/32, 1/8	2.5, 3.2	NR ^l	NR ^l	NR	NR ^l	NR ^l
			5/32	4.0	F	F	F	V, OH	R
			3/16	5.0	NR ^l	F	F	H	NR ^l
			7/32	—	NR ^l	NR ^l	NR ^l	NR ^l	NR ^l
			1/4	6.0	F	F	F	H	R
			—	—	—	—	—	—	—

a. *R* means “required”. NR means “not required”.

b. The letter suffix “X” as used in this table is defined in Note a of Table 1.

c. Electrodes manufactured in sizes not shown shall be tested to the requirement of the nearest standard size.

d. The abbreviations F, H, H-fillets, V, V-down, and OH are defined in Note b of Table 1. The terms “dcep” and “dcen” are defined in Note c of Table 1.

e. See Clause 10.

f. See Clause 11.

g. See Clause 12.

h. See Clause 13. Impact tests are required for classifications listed in Table 4.

i. Progression for tests performed in the vertical position shall be upward except for E(X)XX10-X electrodes, which may be tested in either the upward or downward progression and E(X)XX45-X electrodes, which are tested vertically down only.

j. See Clause 14.

k. The moisture test given in Clause 15 is the required test for measurement of moisture content of the covering. The absorbed moisture test in Clause 16 and the diffusible hydrogen test in Clause 17 are supplemental tests required only when their corresponding optional supplemental designators are to be used with the classification designators.

l. Standard electrode sizes not requiring this specific test can be classified provided at least two other sizes of that classification have passed the tests required for them, or the size to be classified meets specification requirements by having been tested in accordance with Clauses 8 through either 13, 14, 15, or 16, depending on the electrode being classified.

m. When dcep and dcen are specified, only dcen need be tested.

n. Electrodes longer than 18 in [450 mm] will require a double length test assembly in accordance with Note 2 of Figure 3, to ensure uniformity of the entire electrode.

9. Weld Test Assemblies

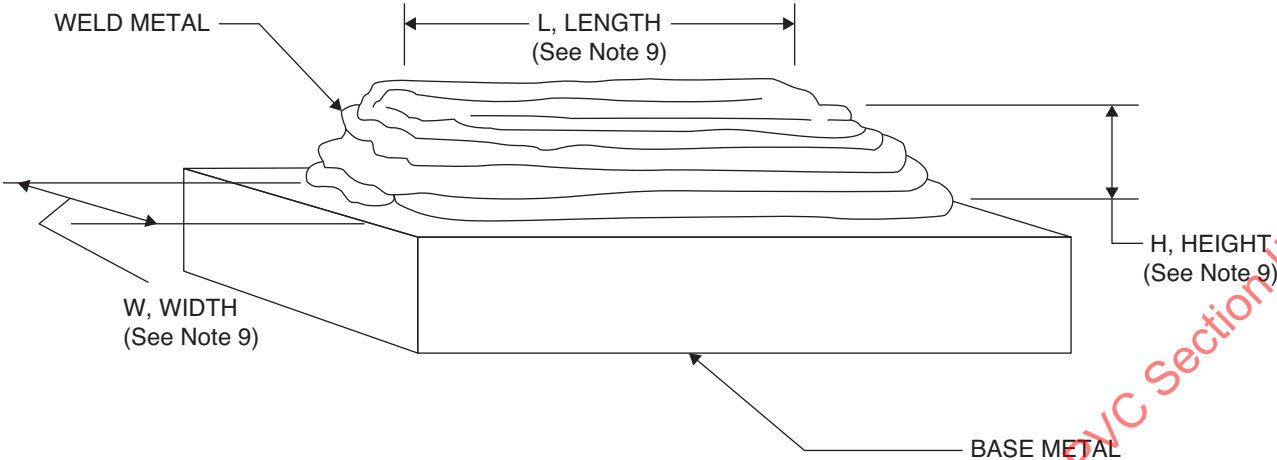
9.1 One or more of the following four weld test assemblies are required for classification testing. They are:

- (1) The weld pad in Figure 2 for chemical analysis of the weld metal.
- (2) The groove weld in Figure 3 for mechanical properties and soundness of the weld metal for all classifications except E(X)XX18M(1).
- (3) The fillet weld in Figure 4 for the usability of the electrode.
- (4) The groove weld in Figure 5 to be used in place of (2) above, for mechanical properties and soundness of the weld metal for E(X)XX18M(1) electrodes.

The sample for chemical analysis may be taken from the reduced section of the fractured tension test specimen or from a corresponding location (or any location above it) along the weld centerline of the weld metal in the groove weld in Figure 3 or Figure 5, thereby avoiding the need to make the weld pad. In case of dispute, the weld pad shall be the referee method.

9.2 Preparation of each weld test assembly shall be as specified in 9.3 through 9.5. The base metal for each assembly shall be as required in Table 6 and shall meet the requirements of the ASTM *or* NAVSEA specification shown there or a chemically equivalent specification. Electrodes other than low-hydrogen electrodes shall be tested without conditioning. Low-hydrogen electrodes, if they have not been adequately protected against moisture pickup in storage, shall be held at a temperature within the range 500 °F to 800 °F [260 °C to 430 °C] for a minimum of one hour prior to testing. Testing of assemblies shall be as prescribed in Clauses 10 through 14.

9.3 Weld Pad. A weld pad shall be prepared as specified in Figure 2, except when one of the alternatives in 9.1 (taking the sample from the broken tension test specimen or from a corresponding location or any location above it along the weld centerline in the weld metal of the groove weld in Figure 3 or Figure 5) is selected. Base metal of any convenient size, of the type specified in Table 6 shall be used as the base for the weld pad. The surface of the base metal on which the filler metal is to be deposited shall be clean. The pad shall be welded in the flat position with multiple layers, to obtain undiluted weld metal. The preheat temperature shall not be less than 60 °F [15 °C] and the interpass temperature shall not exceed 300 °F [150 °C]. The slag shall be removed after each pass. The pad may be quenched in water between passes, *but must be dry before the start of the next pass*. The dimensions of the completed pad shall be as shown in Figure 2. Testing of this assembly shall be as specified in Clause 10, Chemical Analysis.



Notes:

1. Base metal of any convenient size, of the type specified in Table 6, shall be used as the base for the weld pad.
2. The surface of the base metal on which the filler metal is to be deposited shall be clean.
3. The pad shall be welded in the flat position with successive layers to obtain undiluted weld metal.
4. One pad shall be welded for each type of current shown in Table 5 except for those classifications identified by note I in Table 5.
5. The number and size of the beads will vary according to the size of the electrode and the width of the weave, as well as the amperage employed. The width of each weld pass in each weld layer shall be no more than 2-1/2 times the diameter of the core wire.
6. The preheat temperature shall not be less than 60 °F [15 °C] and the interpass temperature shall not exceed 300 °F [150 °C].
7. The slag shall be removed after each pass.
8. The test assembly may be quenched in water between passes to control interpass temperature.
9. The minimum completed pad size shall be at least four layers in height (H) with length (L) and width (W) sufficient to perform analysis. The sample for analysis shall be taken from weld metal that is at least the following distance above the original base metal surface:

Electrode Size		Minimum Distance From Surface of Base Plate	
in	mm	in	mm
3/32	2.5	1/4	6
1/8	3.2		
5/32	4.0	5/16	8
3/16	4.5, 5.0		
7/32	—		
1/4	6.0	3/8	10
5/16	8.0		

Figure 2—Pad for Chemical Analysis of Undiluted Weld Metal

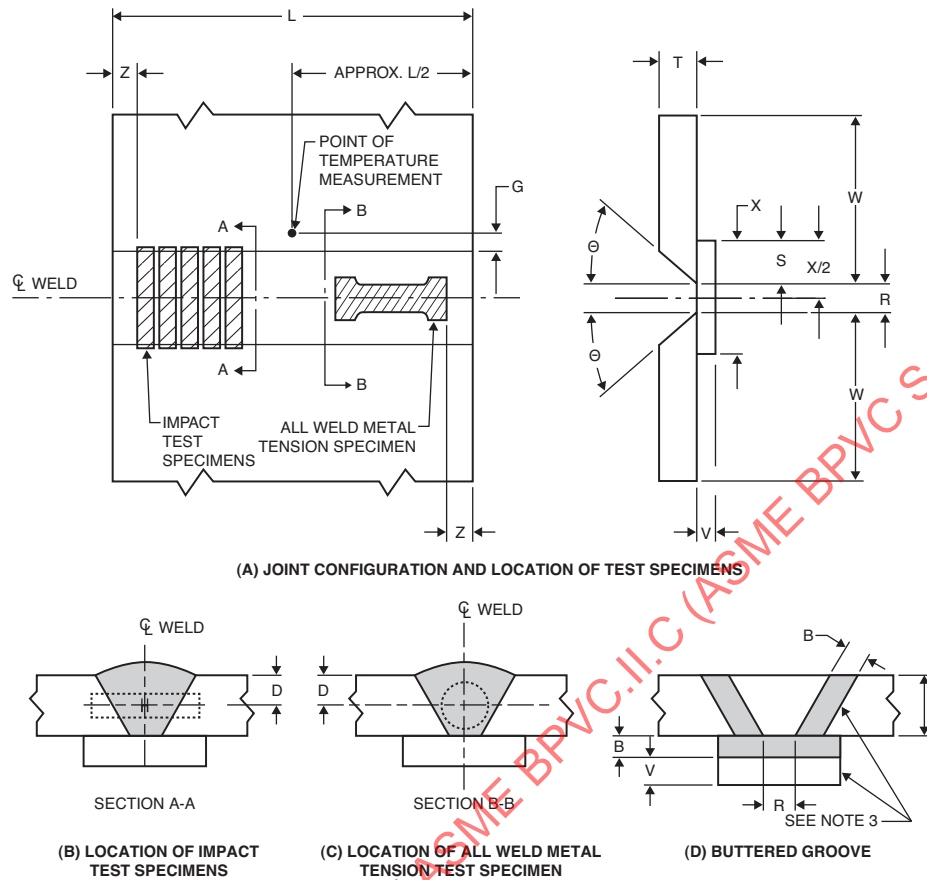


Figure 3—Groove Weld Test Assembly for Mechanical Properties and Soundness of Weld Metal Produced by Using All Electrode Classifications Except E(X)XX18M(1)

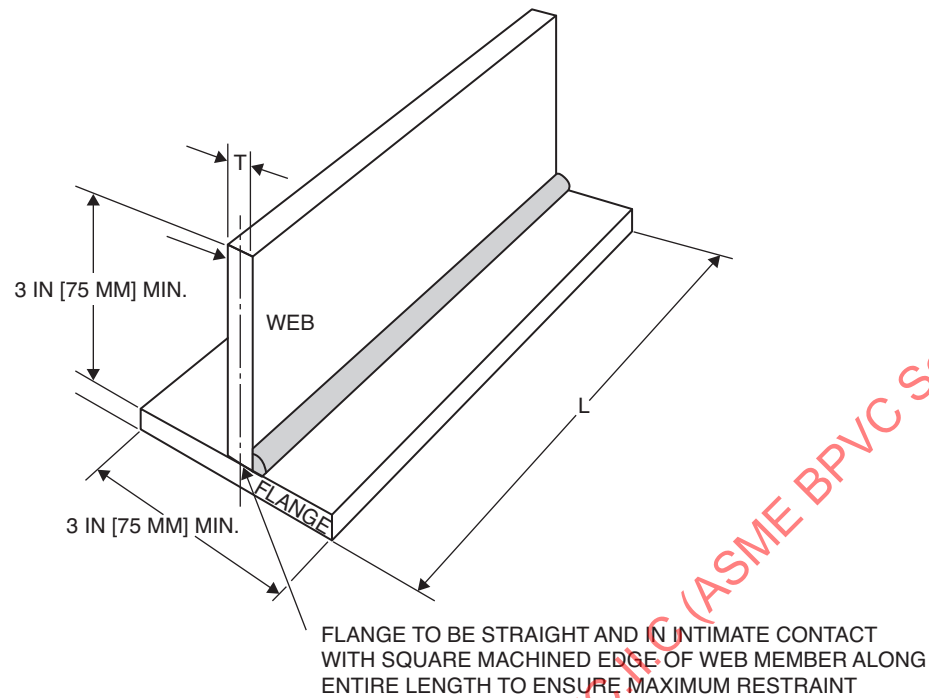
		A5.5						
		Electrode Size, in						
Dimension	Description	3/32	1/8	5/32	3/16	7/32	1/4	5/16
B	Buttering Thickness, min., in	1/8						
G	Point of Temperature Measurement, Offset from Groove Edge, in	1/4 to 1/2						
L	Length, min., in (See Note 1)	10						
S	Backing Overlap, min., in	1/4						
V	Backing Thickness, min., in	1/4						
W	Width, min., in	5						
X	Backing Width, min., in	R + 1/2						
Z	Discard, min., in	1						
T	Nominal Plate Thickness, in	1/2 ± 1/32	1/2 ± 1/32	3/4 ± 1/32	3/4 ± 1/32	3/4 ± 1/32	1 ± 1/32	1 1/4 ± 1/32
D	Specimen Center, in	1/4 ± 1/32	1/4 ± 1/32	3/8 ± 1/32	3/8 ± 1/32	3/8 ± 1/32	1/2 ± 1/32	5/8 ± 1/32
R	Root Opening, in	3/8, -0, +1/16	1/2, -0, +1/16	5/8, -0, +1/16	3/4, -0, +1/16	7/8, -0, +1/16	1, -0, +1/16	1 1/8, -0, +1/16
Θ	Bevel Angle, degrees	10, +2.5, -0						
	Passes per Layer	2	2	2	2	2	2	2
	Total Layers	Not Specified	5 to 7	7 to 9	6 to 8	6 to 8	9 to 11	10 to 12

		A5.5M					
		Electrode Size, mm					
Dimension	Description	2.5	3.2	4	4.5, 5.0	6	8
B	Buttering Thickness, min., mm	3					
G	Point of Temperature Measurement, Offset from Groove Edge, mm	6 to 13					
L	Length, min., mm (See Note 1)	250					
S	Backing Overlap, min., mm	6					
V	Backing Thickness, min., mm	6					
W	Width, min., mm	125					
X	Backing Width, min., mm	R + 12					
Z	Discard, min, mm	25					
T	Nominal Plate Thickness, mm	12 ± 1	12 ± 1	20 ± 1	20 ± 1	25 ± 1	30 ± 1
D	Specimen Center, mm	6 ± 1	6 ± 1	10 ± 1	10 ± 1	12 ± 1	16 ± 1
R	Root Opening, mm	10, -0, +1	13, -0, +1	16, -0, +1	19, -0, +1	25, -0, +1	28, -0, +1
Θ	Bevel Angle, degrees	10, +2.5, -0					
	Passes per Layer	2	2	2	2	2	2
	Total Layers	Not Specified	5 to 7	7 to 9	6 to 8	9 to 11	10 to 12

- For electrodes longer than 18 in [450 mm], a 20 in [500 mm] long test assembly shall be welded.
- The surfaces to be welded shall be clean.
- Base metal shall be as specified in Table 6. For other base metal which does not closely match the composition of the deposit of the electrode under test, the edges of the groove and the contacting face of the backing shall be surfaced as shown, using any size of an electrode having the same composition or classification as the electrode being tested, before welding the joint.
- Prior to welding, the assembly may be preset to yield a welded joint sufficiently flat to facilitate removal of the test specimens. As an alternative, restraint or a combination of restraint and presetting may be used to keep the welded joint within 5 degrees of plane. A completed welded test assembly that is more than 5 degrees out of plane shall be discarded. Straightening of the test assembly is prohibited.
- Welding shall be in the flat position, using each type of current specified in Table 5 except for classifications identified by Note m in Table 5.
- The preheat and interpass temperature shall be as specified in Table 7 for the classification being tested.
- For electrode size larger than 1/8 in [3.2 mm] the joint root may be seal welded with 3/32 or 1/8 in [2.5 or 3.2 mm] electrodes using stringer beads.
- In addition to the stops and starts at the ends, each pass shall contain a stop and start in between the ends.
- The completed weld shall be at least flush with the surface of the test plate.
- The test assemblies shall be post-weld heat treated as specified in Table 7 for the classification being tested.

Source of Details A, C and D: AWS A5.1/A5.1M:2004 ERRATA, Figure 2.

Figure 3 (Continued)—Groove Weld Test Assembly for Mechanical Properties and Soundness of Weld Metal Produced by Using All Electrode Classifications Except E(X)XX18M(1)

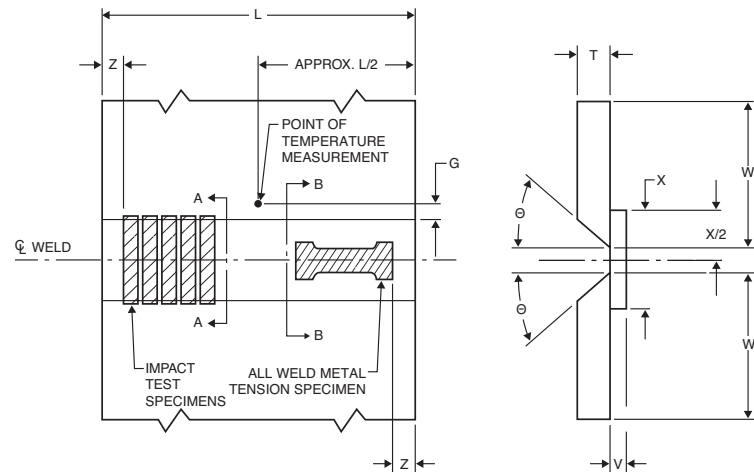


Notes:

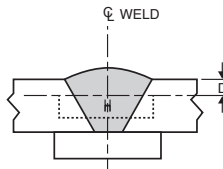
1. See Table 8 for values of T and L.
2. Base metal shall be as specified in Table 6.
3. The surfaces to be welded shall be clean.
4. One assembly shall be welded for each position specified in Table 8 and shown in Figure 6 using each type of current and polarity specified in Table 5.
5. The preheat shall be 60 °F [15 °C] minimum.
6. A single pass fillet weld shall be made on one side of the joint. The first electrode shall be consumed to a stub length of no greater than 2 in [50 mm].
7. Progression in the vertical position shall be upwards, except for E(X)XX10-X electrodes, which may be tested in either upwards or downwards progression, and the E(X)XX45-P2, which is tested vertically down only.
8. Weld cleaning shall be limited to slag chipping, brushing and needle scaling. Grinding or filing of the final weld surface is prohibited.
9. The tests shall be conducted without postweld heat treatment.

Source: AWS A5.5/A5.5M:2006, Figure 3.

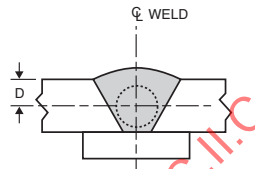
Figure 4—Fillet Weld Test Assembly



(A) JOINT CONFIGURATION AND LOCATION OF TEST SPECIMENS



(B) LOCATION OF IMPACT TEST SPECIMENS



(C) LOCATION OF ALL WELD METAL TENSION TEST SPECIMEN

		A5.5 E(X)XX18M(1)					
		Electrode Size, in					
Dimension	Description	3/32	1/8	5/32	3/16	7/32	1/4
D	Nominal CVN Location, in	1/16					
G	Point of Temperature Measurement, Offset from Groove Edge, in	1/4 to 1/2					
L	Length, min., in	10					
V	Backing Thickness, min., in	As Required					
W	Width, min., in	5					
X	Backing Width, min., in	1					
Z	Discard, min., in	1					
T	Plate Thickness, min., in	1/2	1/2	3/4	3/4	3/4	1
R	Root Opening, max., in	1/4	1/4	1/2	1/2	1/2	1/2
Θ	Bevel Angle, degrees	30					
Total Layers		See Note 1	See Note 1	7 to 9	7 to 9	7 to 8	9 to 11

		A5.5M E(X)XX18M(1)				
		Electrode Size, mm				
Dimension	Description	2.5	3.2	4	5	6
D	Nominal CVN Location, mm	1.5				
G	Point of Temperature Measurement, Offset from Groove Edge, mm	6 to 13				
L	Length, min., mm	250				
V	Backing Thickness, min., mm	As Required				
W	Width, min., mm	125				
X	Backing Width, min., mm	25				
Z	Discard, min., mm	25				
T	Plate Thickness, min., mm	12	12	20	20	25
R	Root Opening, max., mm	6	6	12	12	12
Θ	Bevel Angle, degrees	30				
Total Layers		See Note 1	See Note 1	7 to 9	7 to 9	9 to 11

Figure 5—Groove Weld Test Assembly for Mechanical Properties and Soundness of Weld Metal Produced by Using E(X)XX18M(1)

Notes:

1. Pass and layer sequence shall be reported.
2. Base metal shall be as specified in Table 6.
3. The surfaces to be welded shall be clean.
4. Prior to welding, the assembly may be preset to yield a welded joint sufficiently flat to facilitate removal of the test specimens. As an alternative, restraint or a combination of restraint and presetting may be used to keep the welded joint within 5 degrees of plane. A completed weld test assembly that is more than 5 degrees out of plane shall be discarded. Straightening of the test assembly is prohibited.
5. Welding shall be performed in the flat position using the type of current specified in Table 5 for the classification.
6. The preheat and interpass temperature shall be that specified in Table 7 for the classification being tested.
7. Layers should be approximately 1/8 in [3 mm] thick with each layer being started at the finishing end of the preceding layer.
8. The weld shall be made with stringer beads or with maximum weave no wider than 2-1/2 times the diameter of the core wire.
9. The completed weld shall have a reinforcement of standard proportions, 1/32 in [0.8 mm] minimum; 1/8 in [3.2 mm] maximum. For electrodes larger than 1/8 in [3.2 mm], the root beads may be made with 3/32 in or 1/8 in [2.5 mm or 3.2 mm] electrodes.
10. The number of layers pertains specifically to minimum plate thicknesses. Use of thicker plates may increase the number of layers.

Figure 5 (Continued)—Groove Weld Test Assembly for Mechanical Properties and Soundness of Weld Metal Produced by Using E(X)XX18M(1)

Table 6
Base Metal for Weld Test Assemblies

AWS Classification	Base Metal	
	ASTM Specification Number ^a	UNS Number ^b
EXXXX-A1	A204 Grade A	K11820
EXXXX-B1	A387 Grade 2	K12143
EXXXX-B2, EXXXX-B2L, EXXXX-B5	A387 Grade 11	K11789
EXXXX-B3, EXXXX-B3L, EXXXX-B4L	A387 Grade 22 or 22L	K21590
EXXXX-B6, EXXXX-B6L, EXXXX-B7, EXXXX-B7L	A387 Grade 5	S50200
EXXXX-B8, EXXXX-B8L	A387 Grade 9	K90941
EXXXX-B23, EXXXX-B23A, EXXXX-B24	A29 Grade 1015 or 1020; A283 Grade A, B, C, or D; (Buttering required) ^d	G10150, G10200, K01400, K01702, K02401, K02702
EXXXX-B91, EXXXX-B94	A387 Grade 91	K90901
EXXXX-B92, EXXXX-B92A	A335 Grade P92	K92460
EXXXX-B115	A335 Grade P115, A 387 Grade 91	K91060
EXXXX-C1, EXXXX-C1L	A537 Class 1 or 2; A203 Grade A or B	K12437, K21703, K22103
EXXXX-C2, EXXXX-C2L	A203, Grade D or E	K31718, K32018
EXXXX-C3, EXXXX-C3L, EXXXX-C4	A516 Grade 60, 65, or 70; A537 Class 1 or 2	K02100, K02403, K02700, K12437
EXXXX-C5L	A36 or A131 Grade B (Buttering required) ^d	K02702, K02600
EXXXX-C6	A537 Class 1 or 2	K12437
EXXXX-C7	A537 Class 1 or 2 A516 Grade 65 or 70 A543 Type B or C	K12437, K02403, K02700, K42339
EXXXX-D1, E(X)XXXX-D2, EXXXX-D3	A302 Grade A or B	K12021, K12022
EXXXX-Mn2	A1106	K92594
EXXXX-NM1	A302 Grade C or D; A535 Type B or C A514, A517, A543 Type B or C; NAVSEA Technical Publication T9074-BD-GIB-010/0300 HY80 or HY100	K12039, K12054, K12539, K12554
EXXXX-NM2, E(X)XX18M	A537 Class 1 or 2 A516 Grade 65 or 70 A543 Type B or C	K11630, K42339, K31820, K32045
EXXXX-NM3	A537 Class 1 or 2 A516 Grade 65 or 70 A543 Type B or C	K12437, K02403 K02700, K42339
EXXXX-NM4	A537 Class 1 or 2 A516 Grade 65 or 70	K02403, K02700
EXXXX-NM5	A543 Type B or C	K42339
EXXXX-NM6, EXXXX-NM7, EXXXX-NM8	A517 A 543 Type B or C	K11630, K42339
E12018M1 [E8318M1]	NAVSEA Technical Publication T9074-BD-GIB-010/0300 HY100	K32045
EXX10-P1, EXX18-P2, E(X)XX45-P2, E(X)XX45-X, EXX10-G electrodes intended for pipe welding	API 5L X pipe steel ^e	—
EXX18-W1, EXX18-W2	A588 Grade A, B, or C; A709 Grade 50W	K11947, K12043, K11538
All except E(X)XX18M(1)	A29 Grade 1015 or 1020; A283 Grade A, B, C, or D (Buttering required) ^d	G10150, G10200, K01400, K01702, K02401, K02702
All	A36; A131 Grade B (Buttering required) ^d	K02600, K02102

NOTES:

a. The letters "(X)XX" ["XX"] following the "E" in a classification designation in this table stand for the various strength levels (70, 80, 90, 100, 110, and 120 ksi) [49, 55, 62, 69, 76, and 83 MPa x 10] of weld metals. The letter "X" in the last place is the composition designator.

b. Steel specifications in other national and international specifications that are equivalent to the U.S. specifications shown are acceptable.

c. SAE HS-1086/ASTM DS-56 Metals & Alloys in the Unified Numbering System.

d. Carbon steels as listed may be used for test assemblies, but require buttering as required in 9.4.1 and as shown in Figure 3. Buttering is not required when used for fillet weld test assemblies.

e. Grade shall be appropriate for electrode classification strength level.

9.4 Groove Weld

9.4.1 Mechanical Properties and Soundness. A test assembly shall be prepared and welded as specified in Figure 3 or Figure 5, using matching base metal of the appropriate type (specified in Table 6). Note d to Table 6 and Figure 3(B) allow the use of mild steel base metal with buttering. Welding shall be in the flat position, using each type of current specified in Table 5, except for classifications identified by Note m in Table 5.

Prior to welding, the assembly may be preset to yield a welded joint sufficiently flat to facilitate removal of the test specimens. As an alternative, restraint or a combination of restraint and presetting may be used to keep the welded joint within 5 degrees of plane. A completed welded test assembly that is more than 5 degrees out of plane shall be discarded. Straightening of the test assembly is prohibited.

Preheat and interpass temperatures shall be as specified in Table 7. Testing of this assembly shall be as specified in Clauses 11, 12, and 13. The assembly shall be tested in the as-welded condition or the postweld heat treated condition as specified in Table 3, except for the E(X)XXXX-G classifications, which, when postweld heat treatment (PWHT) is required, shall be tested in the postweld heat treated condition agreed upon between the purchaser and supplier (see Note c of Table 7).

9.4.1.1 When postweld heat treatment is required, the heat treatment shall be applied to the test assembly before the specimens for mechanical testing are removed. This heat treatment may be applied either before or after the radiographic examination.

9.4.1.2 The temperature of the test assembly shall be raised in a suitable furnace at the rate of 150 °F to 500 °F [85 °C to 280 °C] per hour until the postweld heat treatment temperature specified in Table 7, for the electrode classification is attained. This temperature shall be maintained for the time specified in Table 7 (-0, +15 minutes).

9.4.1.3 The test assembly shall then be allowed to *completely* cool in the furnace at a rate not greater than 350 °F [200 °C] per hour or may be removed from the furnace when the temperature of the furnace has reached 600 °F [300 °C] and allowed to cool in still air.

9.5 Fillet Weld. One or more test assemblies shall be prepared and welded as specified in Table 5 and shown in Figure 4 using base metal of the appropriate type as specified in Table 6. The welding positions shall be as specified in Table 8 and Figure 6, according to the size and classification of the electrode. Testing of the assembly shall be as specified in AWS A4.5M/A4.5.

10. Chemical Analysis

10.1 The sample for analysis shall be taken from weld metal produced with the electrode. The sample shall be taken from a weld pad or the reduced section of the fractured tension test specimen (Figure 3 or 5) or from a corresponding location or any location *along the weld centerline* above it in the groove weld in Figure 3 or 5. Areas where arc starts or craters exist shall be avoided.

The top surface of the pad described in 9.3 and shown in Figure 2 shall be removed and discarded, and a sample for analysis shall be obtained from the underlying metal *of this same top layer* by any means *that will not affect the chemical composition*. The sample shall be free of slag and shall be taken from metal that is at least the minimum distance from the original base metal surface as specified in Figure 2.

The sample from the reduced section of the fractured tension test specimen or from a corresponding location (or any location *along the weld centerline* above it) in the groove weld in Figure 3 or 5 shall be prepared for analysis by any means *that will not affect the chemical composition*.

10.2 The sample shall be analyzed by accepted analytical methods. The referee method shall be ASTM E350 or ASTM E353 for 20% Mn electrodes.

10.3 The results of the analysis shall meet the requirements of Table 2 for the classification of electrode under test.

11. Radiographic Test

11.1 When required in Table 5, the groove weld described in 9.4.1 and shown in Figure 3 or 5 shall be radiographed to evaluate the soundness of the weld metal. In preparation for radiography, the backing shall be removed and both surfaces

of the weld shall be machined or ground smooth and flush with the original surfaces of the base metal or with a reasonably uniform reinforcement not exceeding $3/32$ in [2.5 mm].

It is permitted on both sides of the test assembly, to remove base metal to a depth of $1/16$ in [1.5 mm] below the original base metal surface, in order to facilitate backing and/or buildup removal. The thickness of the weld metal shall not be reduced by more than $1/16$ in [1.5 mm] *so the thickness of the prepared radiographic test specimen equals at least the thickness of the base metal minus $1/16$ in [1.5 mm]*. Both surfaces of the test assembly in the area of the weld shall be smooth enough to avoid difficulty in interpreting the radiograph.

11.2 The weld shall be radiographed in accordance with one of the following. The quality level of inspection shall be 2-2T.

(1) *Film Radiology: ASTM E1032*

(2) *Computed Radiology (CR): ASTM E2033 and the requirements of ASTM E1032, except where CR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2033, refers to phosphor imaging plate.*

(3) *Digital Radiology (DR): ASTM E2698 and the requirements of ASTM E1032, except where DR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2698, refers to digital detector array (DDA).*

Table 7
Preheat, Interpass, and Postweld Heat Treatment Temperatures

AWS Classification		Preheat and Interpass		Postweld Heat Treatment		
		Temperature		Temperature		Time ^a
A5.5	A5.5M	°F	°C	°F	°C	Hour(s)
E7010-A1	E4910-A1					
E7011-A1	E4911-A1					
E7015-A1	E4915-A1					
E7016-A1	E4916-A1					
E7018-A1	E4918-A1					
E7020-A1	E4920-A1					
E7027-A1	E4927-A1					
E8018-D1	E5518-D1					
E9015-D1	E6215-D1	200 to 225	95 to 110	1150 ± 25	620 ± 15	1
E9018-D1	E6218-D1					
E10015-D2	E6915-D2					
E10016-D2	E6916-D2					
E10018-D2	E6918-D2					
E8016-D3	E5516-D3					
E8018-D3	E5518-D3					
E9018-D3	E6218-D3					
<i>E9016-D3</i>	<i>E6216-D3</i>					
E8016-B1	E5516-B1					
E8018-B1	E5518-B1					
E8015-B2	E5515-B2					
E8016-B2	E5516-B2					
E8018-B2	E5518-B2					
E7015-B2L	E4915-B2L					
E7016-B2L	E4916-B2L					
E7018-B2L	E4918-B2L	325 to 375	160 to 190	1275 ± 25	690 ± 15	1
E9015-B3	E6215-B3					
E9016-B3	E6216-B3					
E9018-B3	E6218-B3					
E8015-B3L	E5515-B3L					
E8018-B3L	E5518-B3L					
E8015-B4L	E5515-B4L					
E8016-B5	E5516-B5					
E8015-B6	E5515-B6					
E8016-B6	E5516-B6					
E8018-B6	E5518-B6					
E9018-B6	E6218-B6					
E8015-B6L	E5515-B6L					
E8016-B6L	E5516-B6L					
E8018-B6L	E5518-B6L	350 to 450	180 to 230	1375 ± 25	740 ± 15	1
E8015-B7	E5515-B7					
E8016-B7	E5516-B7					
E8018-B7	E5518-B7					
E8015-B7L	E5515-B7L					
E8016-B7L	E5516-B7L					
E8018-B7L	E5518-B7L					
E8015-B8	E5515-B8					
E8016-B8	E5516-B8					
E8018-B8	E5518-B8					
E8015-B8L	E5515-B8L	400 to 500	200 to 250	1375 ± 25	740 ± 15	1
E8016-B8L	E5516-B8L					
E8018-B8L	E5518-B8L					

(Continued)

Table 7 (Continued)
Preheat, Interpass, and Postweld Heat Treatment Temperatures

AWS Classification		Preheat and Interpass		Postweld Heat Treatment		Time ^a
		Temperature		Temperature		
A5.5	A5.5M	°F	°C	°F	°C	Hour(s)
<i>E9016-B9A</i>	<i>E6216-B9A</i>	300 to 500	155 to 255	1350 ±50	735 ±25	2
E9015-B23	E6215-B23	350 to 475	180 to 250	1365 ± 25	740 ± 15	2
E9016-B23	E6216-B23					
E9018-B23	E6218-B23					
<i>E8016-B23A</i>	<i>E5516-B23A</i>					
E9015-B24	E6215-B24					
E9016-B24	E6216-B24					
E9018-B24	E6218-B24	400 to 600	200 to 315	1400 ± 25	760 ± 15	2
E9015-B91	E6215-B91					
E9016-B91	E6216-B91					
E9018-B91	E6218-B91					
E9015-B92	E6215-B92					
E9016-B92	E6216-B92					
E9018-B92	E6218-B92	200 to 225	95 to 110	1125 ± 25	605 ± 15	1
<i>E9016-B92A</i>	<i>E6216-B92A</i>					
<i>E9015-B115</i>	<i>E6215-B115</i>					
E8016-C1	E5516-C1					
E8018-C1	E5518-C1					
<i>E9016-C1</i>	<i>E6216-C1</i>					
E7015-C1L	E4915-C1L	200 to 225	95 to 110	1125 ± 25	605 ± 15	1
E7016-C1L	E4916-C1L					
E7018-C1L	E4918-C1L					
E8016-C2	E5516-C2					
E8018-C2	E5518-C2					
E7015-C2L	E4915-C2L					
E7016-C2L	E4916-C2L	200 to 225	95 to 110	1150 ±25	620 ±15	1
E7018-C2L	E4918-C2L					
<i>E9016-D3</i>	<i>E6216-D3</i>					
E9015-C5L	E6215-C5L					
E9018-NM2	E6218-NM2					
E8010-G	E5510-G					
E8011-G	E5511-G	See Note b		See Note b		
E8013-G	E5513-G					
E9010-G	E6210-G					
E9011-G	E6211-G					
E9013-G	E6213-G					
E10010-G	E6910-G					
E10011-G	E6911-G					
E10013-G	E6913-G					
E11010-G	E7610-G					
E11011-G	E7611-G					
E11013-G	E7613-G					
E12010-G	E8310-G					
E12011-G	E8311-G					
E12013-G	E8313-G					

(Continued)

Table 7 (Continued)
Preheat, Interpass, and Postweld Heat Treatment Temperatures

AWS Classification		Preheat and Interpass		Postweld Heat Treatment		Time ^a					
		Temperature		Temperature							
A5.5	A5.5M	°F	°C	°F	°C	Hour(s)					
E7010-G	E4910-G	See Note b									
E7011-G	E4911-G										
E7015-G	E4915-G										
E7016-G	E4916-G										
E7018-G	E4918-G										
E7020-G	E4920-G										
E7027-G	E4927-G										
E8015-G	E5515-G										
E8016-G	E5516-G										
E8018-G	E5518-G										
E8045-G	E5545-G										
E9015-G	E6215-G										
E9016-G	E6216-G										
E9018-G	E6218-G										
E9045-G	E6245-G										
E10015-G	E6915-G										
E10016-G	E6916-G										
E10018-G	E6918-G										
E11015-G	E7615-G										
E11016-G	E7616-G										
E11018-G	E7618-G										
E10045-G	E7645-G										
E12015-G	E8315-G										
E12016-G	E8316-G										
E12018-G	E8318-G										
E10016-Mn2	E6916-Mn2						50 to 350	10 to 175		Not Specified ^c	
E10018-Mn2	E6918-Mn2										
E7010-P1	E4910-P1	200 to 250	95 to 120		Not Specified ^c						
E7018-C3L	E4918-C3L										
E7018-W1	E4918-W1										
E8016-C3	E5516-C3										
E8018-C3	E5518-C3										
E8016-C4	E5516-C4										
E8018-C4	E5518-C4										
E8018-NM1	E5518-NM1										
E8018-W2	E5518-W2										
E8018-P2	E5518-P2										
E8045-P2	E5545-P2										
E9018-P2	E6218-P2										
E9045-P2	E6245-P2										
E9018M	E6218M										
E10018M	E6918M										
E10045-P2	E6945-P2										
E11018M	E7618M										
E12018M	E8318M										
E12018M1	E8318M1										

(Continued)

Table 7 (Continued)
Preheat, Interpass, and Postweld Heat Treatment Temperatures

AWS Classification		Preheat and Interpass		Postweld Heat Treatment		Time ^a
		Temperature		Temperature		
A5.5	A5.5M	°F	°C	°F	°C	Hour(s)
E7016-C6	E4916-C6					
E8016-C7	E5516-C7					
E9016-NM4	E6216-NM4					
E10016-NM3	E6916-NM3					
E10016-NM5	E6916-NM5	200 to 225	95 to 110			Not Specified ^c
E11016-NM6	E7616-NM6					
E11016-NM7	E7616-NM7					
E11018-NM8	E7618-NM8					
E8010-P1	E5510-P1					
E9010-P1	E6210-P1	325 to 375	160 to 190			Not Specified ^c

NOTES:

a Postweld heat treat at specified time, -0, +15 minutes.

b The need for, and specific values for preheat and interpass temperatures, and postweld heat treatment conditions of weld test assemblies made with “G” electrodes shall be as agreed upon between the purchaser and supplier.

c Postweld heat treatment is not required for those classifications listed as “as-welded” in Table 3.

Table 8
Requirements for Preparation of Fillet Weld Test Assemblies

AWS Classification ^a		Electrode				Plate Sizes ^b				Position of Welding	Size of Fillet Weld	
		Size		Length		Thickness (T)		Length (L) min. ^c			in	mm
A5.5	A5.5M	in	mm	in	mm	in	mm	in	mm			
E(X)XX10-X E(X)XX11-X	EXX10-X EXX11-X	3/32	2.5	12	300	1/8	3	10	250	V, OH	5/32 max.	4 max.
		1/8	3.2	14	350	1/4	6	12	300	V, OH	3/16 max.	5 max.
		5/32	4.0	14	350	3/8	10	12	300	V, OH	1/4 max.	6 max.
		3/16	5.0	14	350	3/8	10	12	300	V, OH	5/16 max.	8 max.
		7/32	—	14 or 18	350 or 450	1/2	12	12 or 16	300 or 400	H	1/4 min.	6 min.
		1/4	6.0	18	450	1/2	12	16	400	H	1/4 min.	6 min.
E(X)XX13-X	EXX13-X	3/32	2.5	12	300	1/8	3	10	250	V, OH	5/32 max.	4 max.
		1/8	3.2	14	350	1/4	6	12	300	V, OH	3/16 max.	5 max.
		5/32	4.0	14	350	3/8	10	12	300	V, OH	1/4 max.	6 max.
		3/16	5.0	14	350	3/8	10	12	300	V, OH	3/8 max.	10 max.
		7/32	—	14 or 18	350 or 450	1/2	12	12 or 16	300 or 400	H	1/4 min.	6 min.
E(X)XX15-X	EXX15-X	3/32	2.5	12 or 14	300 or 350	1/8	3	10 or 12	250 or 300	V, OH	3/16 max.	5 max.
E(X)XX16-X	EXX16-X	1/8	3.2	14	350	1/4	6	12	300	V, OH	1/4 max.	6 max.
E(X)XX18M(1)	EXX18M(1)	5/32	4.0	14	350	3/8	10	12	300	V, OH	5/16 max.	8 max.
E(X)XX18-X	EXX18-X	3/16	5.0	14	350	3/8	10	12	300	H	3/16 min.	5 min.
		7/32	—	14 or 18	350 or 450	1/2	12	12 or 16	300 or 400	H	1/4 min.	6 min.
		1/4	6.0	18	450	1/2	12	16	400	H	5/16 min.	8 min.
		1/8	3.2	14	350	1/4	6	12	300	H	1/8 min.	3 min.
E7020-X	E4920-X	5/32	4.0	14	350	3/8	10	12	300	H	3/16 min.	5 min.
E7027-X	E4927-X	3/16	5.0	14 or 18	350 or 450	3/8	10	12 or 16	300 or 400	H	1/4 min.	6 min.
		7/32	—	18 or 28	450 or 700	1/2	12	16 or 26	400 or 650	H	1/4 min.	6 min.
		1/4	6.0	18 or 28	450 or 700	1/2	12	16 or 26	400 or 650	H	5/16 min.	8 min.
		5/16	8.0	18 or 28	450 or 700	1/2	12	16 or 26	400 or 650	H	5/16 min.	8 min.
E(X)XX45-P2	EXX45-P2	3/32	2.5	14	350	1/8	3	10 or 12	250 or 300	V-down, OH	3/16 max.	5 max.
		1/8	3.2	14	350	1/4	6	12	300	V-down, OH	1/4 max.	6 max.
		5/32	4.0	14	350	3/8	10	12	300	V-down, OH	5/16 max.	8 max.
		—	4.5	14	350	3/8	10	12	300	V-down, OH	1/4 min.	6 min.

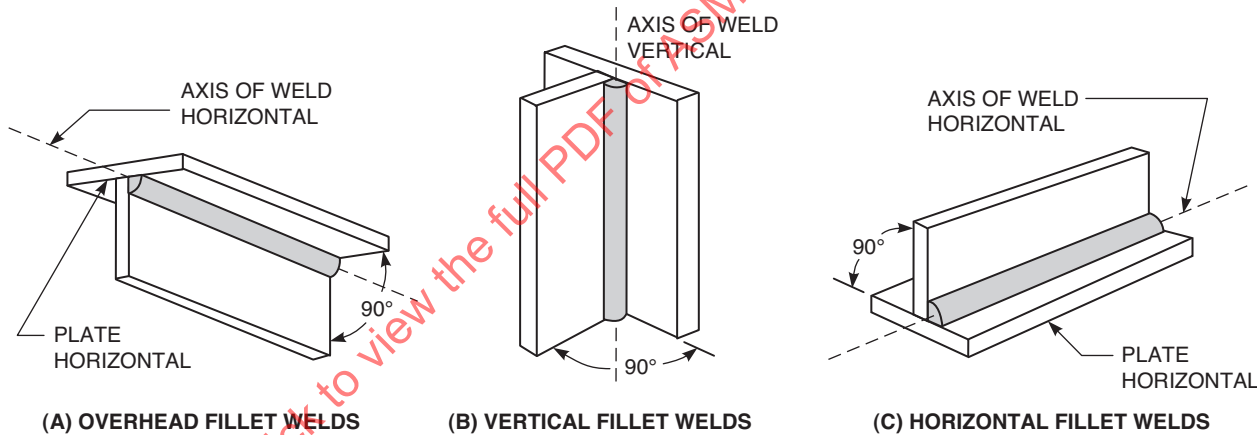
NOTES:

- a. The letters “(X)XX” [“XX”] following the “E” in a classification designation in this table stand for the various strength levels (70, 80, 90, 100, 110, and 120 ksi) [49, 55, 62, 69, 76, and 83 MPa x 10] of weld metals. The letter “X” in the composition designator position used in this table is defined in Note a of Table 1.
- b. See Figure 4.
- c. A starting tab or longer test assembly shall be used to ensure that the end of the first bead is more than 4 in [100 mm] from the end of the test assembly.

Table 9
Radiographic Soundness Requirements

AWS Classification ^a		Radiographic Standard ^{b,c}
A5.5	A5.5M	
E(X)XX15-X	EXX15-X	Grade 1
E(X)XX16-X	EXX16-X	
E(X)XX18-X	EXX18-X	
EXX20-X	EXX20-X	
E(X)XX18M(1)	EXX18M(1)	
E(X)XX45-X	EXX45-X	
E(X)XX10-X	EXX10-X	Grade 2
E(X)XX11-X	EXX11-X	
E(X)XX13-G	EXX13-G	
EXX27-X	EXX27-X	

- a. The letters “(X)XX” [“XX”] following the “E” in a classification designation in this table stand for the various strength levels (70, 80, 90, 100, 110, and 120 ksi) [49, 55, 62, 69, 76, and 83 MPa x 10] of weld metals. The letter “X” in the composition designator position used in this table is defined in Note a of Table 1.
- b. See Figure 7.
- c. The radiographic soundness obtainable under actual industrial conditions employed for various electrode classifications is discussed in A6.11.1 in Annex A.



Source: AWS A5.5/A5.5M:2006, Figure 5.

Figure 6—Welding Positions for Fillet Weld Test Assemblies

11.3 The soundness of the weld metal meets the requirements of this specification if the radiograph shows:

- (1) no cracks, no incomplete fusion, and no incomplete penetration, and
- (2) no slag inclusions longer than 1/4 in [6 mm] or 1/3 of the thickness of the weld, whichever is greater, or no groups of slag inclusions in line that have an aggregate length greater than the thickness of the weld in a length 12 times the thickness of the weld except when the distance between the successive inclusions exceeds six times the length of the longest inclusion in the group, and

(3) no rounded indications in excess of those permitted by the radiographic standards in Figure 7A (Grade 1) or Figure 7B (Grade 2), according to the grade specified in Table 9.

In evaluating the radiograph, one inch [25 mm] of the weld on each end of the test assembly shall be disregarded.

11.4 A rounded indication is an indication on the radiograph whose length is no more than three times its width. Rounded indications may be circular or irregular in shape, and may have tails. The size of a rounded indication is the largest dimension of the indication, including any tail that may be present.

The indication may be of porosity or slag. Indications whose largest dimension does not exceed 1/64 in [0.4 mm] shall be disregarded. Test assemblies with indications larger than the large indications permitted in the radiographic standards do not meet the requirements of this specification.

12. Tension Test

12.1 One all-weld-metal tension test specimen shall be machined from the groove weld described in Clause 9 and shown in Figure 3 or 5. For specimens machined from 3/4 in [20 mm] or thicker weld assemblies, the all-weld-metal tension test specimen shall have a nominal diameter of 0.500 in [12.5 mm]. For specimens machined from 1/2 in [12.5 mm] thick weld assemblies, the all-weld-metal tension test specimen shall have a nominal diameter of 0.250 in [6.5 mm]. The nominal gauge length-to-diameter ratio shall be 4:1 in each case.

12.2 *For classifications to be tested in the as-welded condition (as specified in Table 3), the weld test assembly or tension test specimen may be aged at a temperature not to exceed 220 °F [105 °C] for up to 48 hours then allowed to cool to room temperature. In case of dispute, aging the tensile specimen shall be the referee method. No aging shall be performed prior to radiographic examination.* Refer to A6.3 for a discussion of the purpose of aging. The purchaser may, by mutual agreement with the supplier, have the thermal aging of specimens prohibited for all mechanical testing done to Schedule I or J of AWS A5.01M/A5.01.

12.3 *The tension test specimens shall be tested in the manner described in the Tension Test clause of AWS B4.0.*

12.4 The results of the tension test shall meet the requirements specified in Table 3.

13. Impact Test

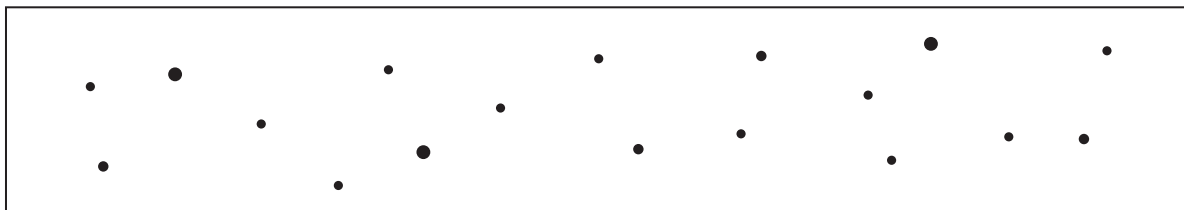
13.1 Five full-size Charpy V-notch impact test specimens shall be machined from the test assembly shown in Figure 3 or 5, for those classifications for which impact testing is required in Table 5. The Charpy V-notch specimens shall have the notched and struck surfaces parallel with each other within 0.002 in [0.05 mm]. The other two surfaces of the specimen shall be square with the notched or struck surfaces within 10 minutes of a degree. The notch shall be smoothly machined and shall be square with the longitudinal edge of the specimen within one degree.

The geometry of the notch shall be measured on at least one specimen in a set of five specimens. Measurement shall be done at a minimum 10X magnification. The correct location of the notch shall be verified by etching before or after machining.

13.2 The five specimens shall be tested in accordance with the Fracture Toughness Test clause of AWS B4.0. The test temperature shall be at or below the temperature specified in Table 4, for the classification under test. The actual temperature used shall be listed on the certification documentation when issued.

13.3 In evaluating the test results, the lowest and the highest values obtained shall be disregarded. Two of the remaining three values shall equal or exceed the specified 20 ft•lbf [27 J] energy level. One of the three may be lower, but not lower than the single value indicated in Table 4, and the average of the three shall be not less than the required average energy level.

13.4 *For the E100xx-Mn2 [E69xx-Mn2] classifications, the lateral expansion of the three Charpy specimens remaining after discarding the specimens with the highest and lowest absorbed energy levels shall be measured in accordance with ASTM E23. All three of these specimens shall exhibit a lateral expansion of at least 0.015 in [0.38 mm]. However, if the average of these three specimens is at least 0.015 in [0.38 mm] and one of the three specimens is lower than 0.015 in [0.38 mm], an additional set of three specimens shall be tested. If all three of the additional set of specimens exhibit a*

**(A) ASSORTED ROUNDED INDICATIONS**

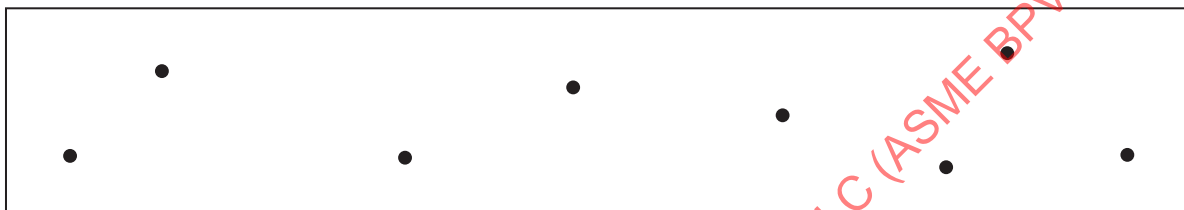
SIZE: 1/64 in [0.4 mm] TO 1/16 in [1.6 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 18, WITH THE FOLLOWING RESTRICTIONS:

MAXIMUM NUMBER OF LARGE (3/64 in [1.2 mm] TO 1/16 in [1.6 mm] IN DIAMETER OR IN LENGTH) INDICATIONS = 3.

MAXIMUM NUMBER OF MEDIUM (1/32 in [0.8 mm] TO 3/64 in [1.2 mm] IN DIAMETER OR IN LENGTH) INDICATIONS = 5.

MAXIMUM NUMBER OF SMALL (1/64 in [0.4 mm] TO 1/32 in [0.8 mm] IN DIAMETER OR IN LENGTH) INDICATIONS = 10.

**(B) LARGE ROUNDED INDICATIONS**

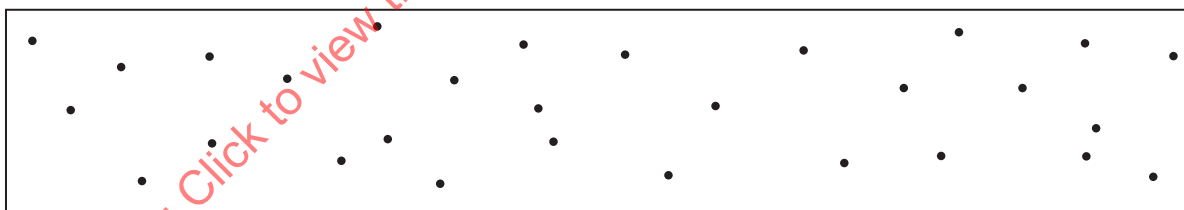
SIZE: 3/64 in [1.2 mm] TO 1/16 in [1.6 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 8.

**(C) MEDIUM ROUNDED INDICATIONS**

SIZE: 1/32 in [0.8 mm] TO 3/64 in [1.2 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 15.

**(D) SMALL ROUNDED INDICATIONS**

SIZE: 1/64 in [0.4 mm] TO 1/32 in [0.8 mm] IN DIAMETER OR IN LENGTH.

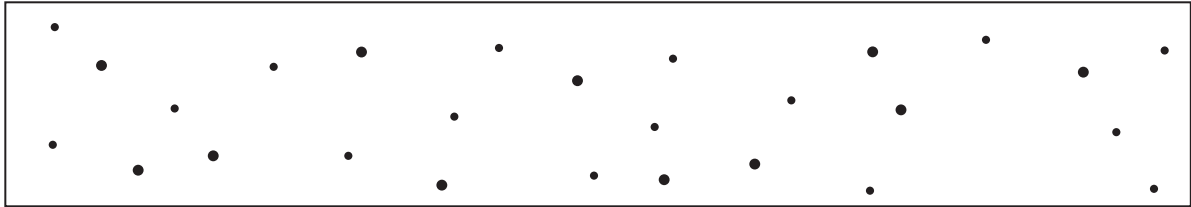
MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 30.

Notes:

1. In using these standards, the chart which is most representative of the size of the rounded indications present in the test specimen radiograph, shall be used for determining conformance to these radiographic standards.
2. Since these are test welds specially made in the laboratory for classification purposes, the radiographic requirements for these test welds are more rigid than those which may be required for general fabrication.
3. Indications whose largest dimension does not exceed 1/64 in [0.4 mm] shall be disregarded.

Source: AWS A5.1/A5.1M:2004, ERRATA, Figure 7 on page 16.

Figure 7A—Radiographic Acceptance Standards for Rounded Indications (Grade 1)

**(A) ASSORTED ROUNDED INDICATIONS**

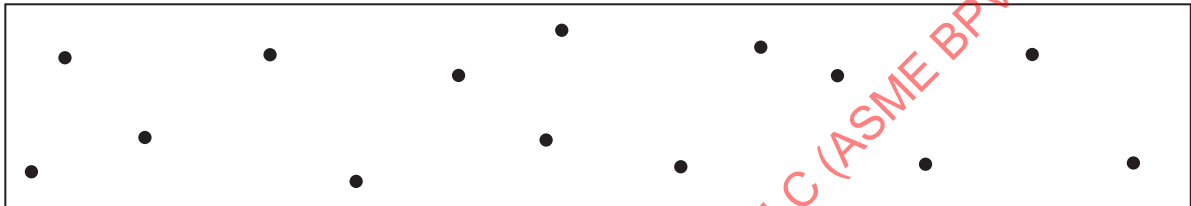
SIZE: 1/64 in [0.4 mm] TO 5/64 in [2.0 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 27, WITH THE FOLLOWING RESTRICTIONS:

MAXIMUM NUMBER OF LARGE (1/16 in [1.6 mm] TO 5/64 in [2.0 mm] IN DIAMETER OR IN LENGTH) INDICATIONS = 3.

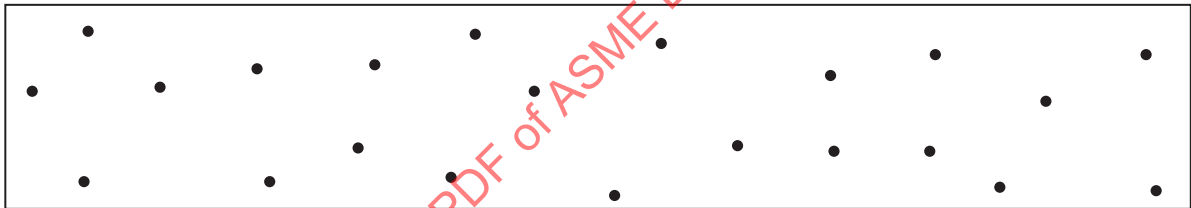
MAXIMUM NUMBER OF MEDIUM (3/64 in [1.2 mm] TO 1/16 in [1.6 mm] IN DIAMETER OR IN LENGTH) INDICATIONS = 8.

MAXIMUM NUMBER OF SMALL (1/64 in [0.4 mm] TO 3/64 in [1.2 mm] IN DIAMETER OR IN LENGTH) INDICATIONS = 16.

**(B) LARGE ROUNDED INDICATIONS**

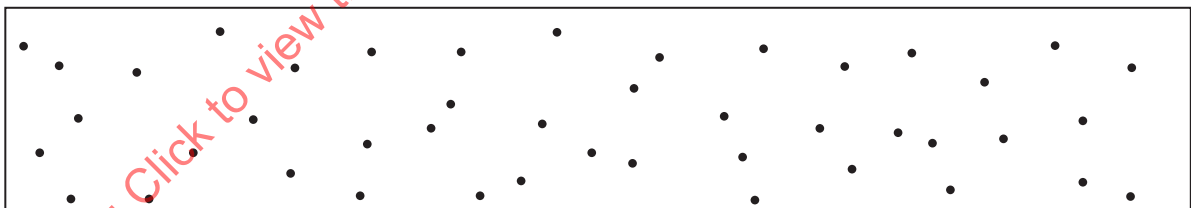
SIZE: 1/16 in [1.6 mm] TO 5/64 in [2.0 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 14.

**(C) MEDIUM ROUNDED INDICATIONS**

SIZE: 3/64 in [1.2 mm] TO 1/16 in [1.6 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 22.

**(D) SMALL ROUNDED INDICATIONS**

SIZE: 1/64 in [0.4 mm] TO 3/64 in [1.2 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 44.

Notes:

1. In using these standards, the chart which is most representative of the size of the rounded indications present in the test specimen radiograph shall be used for determining conformance to these radiographic standards.
2. Since these are test welds specially made in the laboratory for classification purposes, the radiographic requirements for these test welds are more rigid than those which may be required for general fabrication.
3. Indications whose largest dimension does not exceed 1/64 in [0.4 mm] shall be disregarded.

Source: AWS A5.1/A5.1M:2004, ERRATA, Figure 7 on page 17.

Figure 7B—Radiographic Acceptance Standards for Rounded Indications (Grade 2)

lateral expansion of at least 0.015 in [0.38 mm], these results may be reported and used to determine conformity with the classification. The additional set of three specimens may be taken from the original test assembly or from a new test assembly that was welded to the requirements of this standard.

14. Fillet Weld Test

14.1 The fillet weld test assembly, when required in Table 5, shall be made in accordance with the requirements of 9.5, and Figure 4 and AWS A4.5M/A4.5. There shall be no indication of cracks and the weld shall be reasonably free of undercut, overlap, trapped slag, and surface porosity. After the visual examination, the fillet weld size, leg lengths and convexity shall be measured using the methods of AWS A4.5M/A4.5. Fillet weld measurements shall meet the requirements of Table 8 and Table 10 for convexity and permissible difference in the length of the legs.

14.2 A minimum of 10 in [250 mm] of the test assembly shall be broken longitudinally through the fillet weld by a force exerted as shown in AWS A4.5M/A4.5. Cutting of the test assembly into two or more lengths before fracture is permitted, but a sufficient number of segments shall be fractured such that a minimum of 10 in [250 mm] is examined. When necessary, to facilitate fracture through the fillet, one or more of the procedures listed in AWS A4.5M/A4.5 may be used.

Tests in which the weld metal pulls out of the base metal during bending are invalid. Specimens in which this occurs shall be replaced, specimen for specimen, and the test completed. In this case, the doubling of the specimens required for retest in Clause 8 does not apply.

14.3 The fractured surfaces shall be visually examined without magnification. The fracture surface shall be free of cracks. Incomplete fusion at the weld root shall not be greater than 20% of the total length of the weld. There shall be no continuous length of incomplete fusion greater than 1 in [25 mm] as measured along the weld axis, except for electrodes of E(X)XX13-G classifications. Fillet welds made with electrodes of these classifications may exhibit incomplete penetration through the entire weld length. They may also exhibit incomplete fusion, which shall at no point exceed 25% of the smaller leg of the fillet weld.

15. Moisture Test

15.1 The moisture content of the covering of the electrode, when required in Table 5, shall be determined by any suitable method. In case of dispute, the method described in AWS A4.4M shall be the referee method.

15.2 The electrodes shall be tested without conditioning, unless the manufacturer recommends otherwise. Conditioning can be considered to be any special preparation or procedure, such as baking the electrode. If the electrodes are conditioned, that fact, along with the method used for conditioning and the time and temperature involved in the conditioning, shall be noted on the certificate of conformance. The moisture content shall not exceed the limit specified in Table 11 for the classification under test.

Table 10
Dimensional Requirements for Fillet Weld Usability Test Specimens

Measured Fillet Weld Size		Maximum Convexity		Maximum Difference Between Fillet Weld Legs	
in	mm	in	mm	in	mm
1/8 or less	3 or less	1/16	2	1/32	1
5/32	4	1/16	2	1/16	2
3/16	—	1/16	—	1/16	—
—	5	—	2	—	—
7/32	5	1/16	2	3/32	2
1/4	6	1/16	2	3/32	2
9/32	7	1/16	2	1/8	3
5/16	8	3/32	2	1/8	3
11/32	9	3/32	2	5/32	4
3/8 or more	10 or more	3/32	2	5/32	4

16. Absorbed Moisture Test

16.1 In order for a low-hydrogen electrode to be designated as low-moisture-absorbing, with the “R” suffix designator, sufficient electrodes shall be exposed to an environment of 80 °F [27 °C] and 80 percent relative humidity (RH) for a period of not less than nine hours by any suitable method. In case of dispute, the exposure method described in 16.2 through 16.6 shall be the referee method. The moisture content of the electrode covering on the low-moisture-absorbing, low-hydrogen electrodes, for example, E(X)XX15-X R, E(X)XX16-X R, E(X)XX18-X R, E(X)XX45-P2 R, and E(X)XX18M(1) R, shall be determined by any suitable method. In case of dispute, the method described in AWS A4.4M shall be the referee method for the determination of moisture content. The moisture content of the exposed covering shall not exceed the maximum specified moisture content for the designated electrode and classification in Table 11.

16.2 An electrode sample of the smallest and largest sizes of “R” designated electrodes shall be exposed. If the electrodes are conditioned prior to exposure, that fact, along with the method used for conditioning, and the time and temperature involved in conditioning, shall be noted on the *certificate of conformance*. Conditioning of electrodes after exposure is not permitted.

16.3 The electrode sample shall be exposed in a suitably calibrated and controlled environmental chamber for a *minimum* of nine hours at 80 °F to 85 °F [27 °C to 30 °C] and 80 to 85 percent relative humidity.

16.4 The environmental chamber shall meet the following design requirements:

- (1) The apparatus shall be an insulated humidifier which produces the temperature of adiabatic saturation through regenerative evaporation or vaporization of water.
- (2) The apparatus shall have an average air speed of 100 fpm to 325 fpm [0.5 m/s to 1.7 m/s] *within the envelope of air surrounding the covered electrode*.
- (3) The apparatus shall have a drip-free area where the covered electrode up to 18 in [450 mm] in length can be positioned with length as perpendicular as practical to the general air flow.
- (4) The apparatus shall have a calibrated means of continuously measuring and recording the dry bulb temperature and either the wet bulb temperature or the differential between the dry bulb and wet bulb temperature over the period of time required.
- (5) The apparatus shall have an air speed of at least 900 fpm [4.5 m/s] over the wet bulb sensor unless the wet bulb sensor can be shown to be insensitive to air speed or has a known correction factor that will provide for an adjusted wet bulb reading equal to the temperature of adiabatic saturation.
- (6) The apparatus shall have the wet bulb sensor located on the suction side of the fan so that there is an absence of heat radiation on the sensor.

16.5 The exposure procedure shall be as follows:

- (1) The electrode sample, in previously unopened packages or from a reconditioned lot shall be brought to a temperature, −0 °F, +10 °F [−0 °C, +6 °C] above the dew point of the chamber at the time of loading.
- (2) The electrode sample shall be loaded into the chamber without delay after the packages are opened. *Or, in the case of a reconditioned lot, the sample shall be loaded without delay once conditioning is complete and the sample reaches the temperature prescribed in 16.5 (1).*
- (3) The electrodes shall be placed in the chamber in a vertical or horizontal position on 1 in [25 mm] centers, with the length of the electrode as perpendicular as practical to the general air flow.
- (4) Time, temperature, and humidity shall be continuously recorded for the period that the electrodes are in the chamber.
- (5) Counting of the exposure time shall start when the required temperature and humidity in the chamber are established.
- (6) At the end of the exposure time, the electrodes shall be removed from the chamber and a sample of the electrode covering taken for moisture determination, as specified in Clause 15, Moisture Test.

Table 11
Moisture Content Limits for Low-Hydrogen Electrode Coverings

AWS Electrode Designation ^{a, b}		Limit of Moisture Content, % by weight max.	
A5.5	A5.5M	As-Received or Reconditioned ^c	As-Exposed ^d
E70XX-X, E70XX-X HZ	E49XX-X, E49XX-X HZ	0.4	Not specified
E70XX-X R, E70XX-X HZ R	E49XX-X R, E49XX-X HZ R	0.3	0.4
E80XX-X, E80XX-X HZ	E55XX-X, E55XX-X HZ	0.2	Not specified
E80XX-X R, E80XX-X HZ R	E55XX-X R, E55XX HZ R	0.2	0.4
E90XX-X, E90XX-X HZ E9018M, E9018M HZ	E62XX-X, E62XX HZ E6218M, E6218M HZ	0.15	Not specified
E90XX-X R, E90XX-X HZ R E9018M R, E9018M HZ R	E62XX-X R, E62XX-X HZ R E6218M, E6218M HZ R	0.15	0.4
E100XX-X, E100XX-X HZ E10018M, E10018M HZ	E69XX-X, E69XX-X HZ E6918M, E6918M HZ	0.15	Not specified
E100XX-X R, E100XX-X HZ R E10018M R, E10018M HZ R	E69XX-X R, E69XX-X HZ R E69XXM R, E69XXM HZ R	0.15	0.4
E110XX-X, E110XX-X HZ E11018M, E11018M HZ	E76XX-X, E76XX-X HZ E7618M, E7618M HZ	0.15	Not specified
E110XX-G R, E110XX-G HZ R E11018M R, E11018M HZ R	E76XX-G R, E76XX-G HZ R E7618M R, E7618M HZ R	0.15	0.4
E120XX-G, E120XX-G HZ E12018M, E12018M HZ	E83XX-G, E83XX-G HZ E8318M, E8318M HZ	0.15	Not specified
E120XX-G R, E120XX-G HZ R E12018M R, E12018M HZ R	E83XX-G R, E83XX-G HZ R E8318M R, E8318M HZ R	0.15	0.4
E12018M1, E12018M1 HZ	E8318M1, E8318M1 HZ	0.10	Not specified
E12018M1 R, E12018M1 HZ R	E8318M1 R, E8318M1 HZ R	0.10	0.4

^a See Clause 16, Figure 1, and Table 12.

^b The letters "XX" ["XX"] following the tensile strength designator in this table stand for the various designators (15, 16, 18, and 45) indicating suitable welding position, type of covering, and suitable current type of electrodes. The letter "X" in the composition designator position used in this table is defined in Note a of Table 1.

^c As-received or reconditioned electrode coverings shall be tested as specified in Clause 15.

^d As-exposed electrode coverings shall be treated with a moist environment as specified in 16.2 through 16.6 before being tested as specified in 16.1.

16.6 The manufacturer shall control other test variables which are not defined, but which must be controlled to ensure a greater consistency of results.

17. Diffusible Hydrogen Test

17.1 The smallest and largest sizes of an electrode to be identified by an optional supplemental diffusible hydrogen designator shall be tested according to one of the methods given in AWS A4.3. Based upon the average value of test results that satisfy the requirements of Table 12, the appropriate diffusible hydrogen designator may be added at the end of the classification.

17.2 Testing shall be done without conditioning of the electrode, unless the manufacturer recommends otherwise. *Conditioning can be considered to be any special preparation or procedure, such as baking the electrode.* If the electrodes are conditioned, that fact, along with the method used for conditioning, and the time and temperature involved in the conditioning shall be noted on the certificate of conformance.

17.3 For purposes of certifying compliance with diffusible hydrogen requirements, the reference atmospheric condition shall be an absolute humidity of ten (10) grains of moisture/lb [1.43 g/kg] of dry air at the time of welding. See A8.1.4 in

Table 12
Diffusible Hydrogen Requirements for Weld Metal with Optional Supplemental Designators^c

Diffusible Hydrogen Designator ^a	Average, Maximum ^b mL (H ₂)/100 g Deposited Metal
H16	16
H8	8
H4	4

NOTES:

^a Diffusible hydrogen testing is only required when the diffusible hydrogen designator is added to the classification as specified in Figure 1. See Clause 17.

^b The lower average diffusible hydrogen levels (H8 and H4) may not be available in all low hydrogen classifications. *Electrodes meeting requirements for an H4 designator also meet the requirement for an H8 and H16. Electrodes meeting the requirements for an H8 designator also meet the requirements for H16.*

^c Optional diffusible hydrogen designators are applicable for all E(X)XX15(-)X, E(X)XX16(-)X, E(X)XX18(-)X or E(X)XX45(-)X" classifications with the exception of those austenitic manganese classifications as indicated by the Mn2 composition designator.

Annex A. The actual atmospheric conditions shall be reported along with the average value for the tests, according to AWS A4.

17.4 When the absolute humidity equals or exceeds the reference condition at the time of preparation of the test assemblies, the test shall be acceptable as demonstrating compliance with the requirements of this specification provided the actual test results satisfy the diffusible hydrogen requirements for the applicable designator. If the actual test results for an electrode meet the requirements for the lower or lowest hydrogen designator, as specified in Table 12, the electrode also meets the requirements for all higher hydrogen designators in Table 12 without need to retest.

18. Method of Manufacture

The electrodes classified according to this specification may be manufactured by any method that will produce electrodes that meet the requirements of this specification.

19. Standard Sizes and Lengths

Standard sizes (diameter of the core wire) and lengths of electrodes and their respective tolerances are as specified in AWS A5.02/A5.02M.

20. Core Wire and Covering

Requirements for the core wire and covering, including concentricity requirements, are as specified in AWS A5.02/A5.02M.

21. Exposed Core

21.1 Requirements for the grip end of each electrode are as specified in AWS A5.02/A5.02M.

21.2 Requirements for the arc end of each electrode are as specified in AWS A5.02/A5.02M.

22. Electrode Identification

22.1 All electrodes shall be identified (imprinted) as specified in AWS A5.02/A5.02M.

22.2 In lieu of imprinting, electrodes may be identified by the alternate *methods* specified in AWS A5.02/A5.02M.

22.3 *In the case of electrodes that have two classifications, in accordance with 3.2, whether the method of identification in 22.1 or 22.2 is chosen, it is at the manufacturer's discretion to identify electrodes with either of the classifications or both of the classifications. Purchaser can specify a preference for identification using AWS A5.01M/A5.01.*

23. Packaging

Electrodes shall be packaged as specified in AWS A5.02/A5.02M. E(X)XX18M(1) electrodes shall be packaged in hermetically sealed containers. These containers shall be capable of passing the test specified in AWS A5.02/A5.02M *for hermetically sealed containers.*

24. Marking of Packages

24.1 The product information specified in AWS A5.02/A5.02M (as a minimum) shall be legibly marked on the outside of each unit package.

24.2 The appropriate precautionary information as given in ANSI Z49.1 (as a minimum) or its equivalent, shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages enclosed within a larger package. *Typical examples of "warning labels" and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.*

Annex A (Informative)

Guide to AWS Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding

This annex is not part of this standard but is included for informational purposes only.

A1. Introduction

The purpose of this guide is to correlate the electrode classifications with their intended applications, so the specification can be used effectively. Appropriate base metal specifications are referred to whenever that can be done and when it would be helpful. Such references are intended as examples rather than complete listings of the base metals for which each filler metal is suitable.

A2. Classification System

A2.1 The system for identifying the electrode classification in this specification follows the standard pattern used in other AWS filler metal specifications. The prefix letter “E” at the beginning of each classification stands for electrode. The first two (or three) digits, 70 (or 110) [49 (or 76)], for example, designate tensile strength of at least 70 (or 110) ksi [490 (or 760) MPa] of the weld metal, welded and postweld heat treated (if required) in accordance with the test assembly preparation clause of this specification. It should be noted that there are some exceptions to this general rule. For example, in the case of E7015-B2L [E4916-B2L], the minimum tensile strength is 75 ksi [520 MPa]. Therefore, it is important to review the actual requirements listed within this specification. The third (or fourth) digit designates position usability that will allow satisfactory welds to be produced with the electrode.

Thus, the “1,” as in E7018-C2L (or E11018M) [E4918-C2L (or E7618M)], means that the electrode is usable in all positions (flat, horizontal, vertical, and overhead). The “2,” as in E7020-A1 [E4920-A1], designates that the electrode is suitable for use in the flat position and for making fillet welds in the horizontal position. The “4” as in E8045-P2 [E5545-P2], designates that the electrode is usable in the flat, horizontal, and overhead positions, and is especially suitable for vertical welding with downward progression. The last two digits taken together designate the type of current with which the electrode can be used and the type of covering on the electrode, as listed in Table 1.

With the exception of the military-similar electrodes (i.e., E(X)XX18M(1)), the classifications in this specification also include a suffix designator, separated by a hyphen from the tensile strength and usability designators. This composition designator, such as A1, B3, or W1, immediately identifies the classification as different from those in AWS A5.1/A5.1M, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*. The composition designator identifies the chemical composition of the weld metal as specified in Table 2. For example, an “A1” composition designator identifies the electrode as one that produces carbon-molybdenum steel weld metal, when the electrode is deposited using shielded metal arc welding.

A2.2 Optional designators are also used in this specification in order to identify electrodes that have met the mandatory classification requirements and certain supplementary requirements as agreed upon between the purchaser and supplier. Certain low-hydrogen electrodes may have optional designators. An optional supplemental designator “HZ” following the composition designator indicates an average diffusible hydrogen content of not more than “Z” mL/100 g of deposited metal when tested in the “as-received” or conditioned state in accordance with AWS A4.3. Electrodes that are designated as meeting the lower or lowest hydrogen limits, as specified in Table 12, are also understood to be able to meet any higher hydrogen limits even though these are not necessarily designated along with the electrode classification. Therefore, as an

example, an electrode designated as “H4” also meets “H8” and “H16” requirements without being designated as such. See Clause 17, Figure 1, and Table 12.

A letter “R” is a designator used with the low-hydrogen electrode classifications. It is used to identify electrodes that have been exposed to a humid environment for a given length of time and tested for moisture absorption in addition to the standard moisture test required for classification of low hydrogen electrodes. See Clause 16, and Note d to Table 1, as well as Figure 1 and Table 11.

A2.3 “G” Classification

A2.3.1 This specification includes filler metals classified as E(X)XXXX-G. The “G” indicates that the filler metal is of a general classification. It is general because not all of the particular requirements specified for each of the other classifications are specified for this classification. The intent, in establishing this classification, is to provide a means by which filler metals that differ in one respect or another (chemical composition, for example) from all other classifications (meaning that the composition of the filler metal—in the case of the example—does not meet the composition specified for any of the classifications in the specification) can still be classified according to the specification. The purpose is to allow useful filler metal, one that otherwise would have to await a revision of the specification, to be classified immediately, under the existing specification. This means, then, that two filler metals, each bearing the same “G” classification, may be quite different in some certain respect (chemical composition, again, for example).

A2.3.2 The point of difference between filler metal of a “G” classification and filler metal of a similar classification without the “G” (or even with it, for that matter) may be further clarified from the use of the words “not required” and “not specified” in the specification. The use of these words is as follows:

Not Required is used in those areas of the specification that specify the tests that must be conducted in order to classify a welding material. It indicates that that test is not required because the results for the particular test are not a requirement for that particular classification. When a test is “not required”, it is not necessary to conduct the corresponding test in order to classify a filler metal to that classification. When a purchaser wants the information provided by that test in order to consider a particular product of that classification for a certain application, the purchaser will have to arrange for that information with the supplier of the product. The purchaser will have to establish with that supplier just what the testing procedure and the acceptance requirements are to be for that test. The purchaser may want to incorporate that information (via AWS A5.01M/A5.01) in the purchase order.

Not Specified is used in those areas of the specification that refer to the results of some particular test. It indicates that the requirements for that test are not specified for that particular classification. If the required results from a specific test are listed as “not specified” but the test in question is shown as “required” then the test results must be reported.

A2.3.3 Request for Filler Metal Classification. When a filler metal cannot be classified other than as a “G” classification, a manufacturer may request that a new classification be established. The manufacturer shall do this using the following procedure:

(1) A request to establish a new filler metal classification must be submitted in writing. The request needs to provide sufficient detail to permit the Committee on Filler Metals and Allied Materials and the relevant Subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

- (a) Declaration that the new classification will be offered for sale commercially;
- (b) All classification requirements as given for existing classifications, such as, chemical composition ranges, mechanical property requirements, and usability test requirements;
- (c) Any conditions for conducting the tests used to demonstrate that the filler metal meets the classification requirements (It would be sufficient, for example, to state that welding conditions are the same as for other classifications);
- (d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the Annex);
- (e) Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.

A request for a new classification without the above information listed in (a) through (e) will be considered incomplete. The Secretary will return the request to the requester for further information.

(2) In order to comply with the AWS Policy on Patented Items, Trademarks, and Restraint of Trade, if the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester shall disclose this. *In these cases, the patent holder must allow the use of this technology, such as by license. The Secretary will provide examples of acceptable wording to the patent holder, as required.*

(3) The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters for processing.

A2.3.4 *After the fixed classification is established the –G classification may be retained for a period to allow for users to transition existing documents to the fixed classification.*

A2.4 International Classification System

An international system for designating welding filler metals has been developed by ISO. A complete series of ISO standards for filler metals and allied materials, including the vast majority of AWS classifications, but not all, has now been published. Some of these ISO standards have a single way of classification, like AWS standards. A number of the ISO standards dealing with steels are cohabitation standards. A cohabitation standard specifies two parallel systems, roughly corresponding to the European system (the “A” side) and the AWS system (the “B” side). In each case, the “B” side is usually similar to the AWS designation. Annex Table A1 shows the classifications and designations, appearing in ISO specifications, *similar* to filler metal classifications included in this specification.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01M/A5.01 as the specification states. Any testing a purchaser requires of the supplier, for material shipped in accordance with this specification, needs to be clearly stated in the purchase order, according to the provisions of AWS A5.01M/A5.01. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing the supplier normally conducts on material of that classification, as specified in Schedule F, Table 1, of AWS A5.01M/A5.01. Testing in accordance with any other Schedule in that Table must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

Table A1
Comparison of Classifications

ISO						AWS	
2560A ^a	2560B ^a	3580A ^b	3580B ^b	18275A ^c	18275B ^c	A5.5	A5.5M
Carbon-Molybdenum Steels Electrodes							
E38xMo	E49XX-1M3	EMo X	E49XX-MM3			E70XX-A1	E49XX-A1
Manganese Molybdenum Steel Electrodes							
	E55XX-3M2					E8018-D1	E55XX-D1
					E69XX-4M2	E100XX-D2	E69XX-D2
			E550XMnMo	E62XX-3M3		E90XX-D3	E62XX-D3
Chromium-Molybdenum Steel Electrodes							
		ECrMo0.5	E55XX-CM			E80XX-B1	E55XX-B1
		ECrMo1	E55XX-1CM			E80XX-B2	E55XX-B2
		ECrMo1L	E55XX-1CML			E70XX-B2L	E49XX-B2L
		ECrMo1L	E55XX-1CML			E80XX-B2L	E55XX-B2L
		ECrMo2	E62XX-2C1M			E90XX-B3	E62XX-B3
		ECrMo2L	E55XX-2C1ML			E80XX-B3L	E55XX-B3L
			E55XX-2CM1L			E80XX-B4L	E55XX-B4L
			E55XX-C1M			E80XX-B5	E55XX-B5
		ECrMo5	E55XX-5CM			E80XX-B6	E55XX-B6
		ECrMo5	E62XX-5CM			E90XX-B6	E62XX-B6
			E55XX-5CML			E80XX-B6L	E55XX-B6L
			E55XX-7CM			E80XX-B7	E55XX-B7
			E55XX-7CML			E80XX-B7L	E55XX-B7L
		ECrMo9	E55XX-9C1M			E80XX-B8	E55XX-B8
			E55XX-9C1ML			E80XX-B8L	E55XX-B8L
						E90XX-B9A	E62XX-B9A
		—	—			E90XX-B23	E62XX-B23
						E80XX-B23A	E55XX-B23A
		—	—			E90XX-B24	E62XX-B24
		ECrMo91	E62XX-9C1MV			E90XX-B91	E62XX-B91
		—	—			E90XX-B92	E62XX-B92
						E90XX-B92A	E62XX-B92A
						E9015-B115	E6215-B115
Nickel Steel Electrodes							
	E55XX-N5					E80XX-C1	E55XX-C1
					E62XX-N5M1	E90XX-C1	E62XX-C1
	E49XX-N5					E70XX-C1L	E49XX-C1L
	E55XX-N7					E80XX-C2	E55XX-C2
	E49XX-N7					E70XX-C2L	E49XX-C2L
E38X1Ni	E55XX-N2					E80XX-C3	E55XX-C3
	E49XX-N2					E70XX-C3L	E49XX-C3L
	E55XX-N3					E80XX-C4	E55XX-C4
	E6215-N13L					E90XX-C5L	E62XX-C5L
	E49XX-N1					E70XX-C6	E49XX-C6
	E55XX-N3					E80XX-C7	E55XX-C7
Nickel-Molybdenum Steel Electrodes							
E38X1NiMo	E55XX-N2M3					E80XX-NM1	E55XX-NM1
—	—				E62XX-N3M2	E90XX-NM2	E62XX-NM2
					E62XX-N1M1	E90XX-NM4	E62XX-NM4
					E69XX-N3CM1	E100XX-NM3	E69XX-NM3
					E69XX-N7CM3	E100XX-NM5	E69XX-NM5
					E78XX-N4CM2	E110XX-NM6	E76XX-NM6
					E78XX-N5M4	E110XX-NM7	E76XX-NM7
Military-Similar Electrodes							
				E55X1.5NiMo	E6218-N3M1	E9018M	E6218M
					E6918-N3M2	E10018M	E6918M
				E69XMn2NiCrMo	E7618-N4CM2	E11018M	E7618M
				E69XMn2Ni1CrMo	E8318-N4C2M2	E12018M	E8318M

Table A1 (Continued)
Comparison of Classifications

ISO						AWS	
2560A ^a	2560B ^a	3580A ^b	3580B ^b	18275A ^c	18275B ^c	A5.5	A5.5M
						E12018M1	E8318M1
Weathering Alloy Steels							
	E49XX-NCC2					E7018-W1	E49XX-W1
	E5518-NCC1					E8018-W2	E55XX-W2
High Manganese Electrodes							
						E10016-Mn2	E6916-Mn2
						E10018-Mn2	E6918-Mn2

NOTES:

^a ISO 2560, *Welding consumables—Covered electrodes for manual metal arc welding of nonalloy and fine grain steels—Classification.*

^b ISO 3580, *Welding consumables—Covered electrodes for manual metal arc welding of creep-resisting steels—Classification.*

^c ISO 18275, *Welding consumables—Covered electrodes for manual metal arc welding of high-strength steels—Classification.*

A4. Certification

The act of placing the AWS specification and classification designations, and optional designators, if applicable, on the packaging enclosing the product, or the classification on the product itself, constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification. The only testing requirement implicit in this certification is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that the material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation. Certification is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been made. The basis for the certification required by the specification is the classification test of representative material cited above, and the Manufacturer's Quality Assurance Program as defined in AWS A5.01M/A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes in the atmosphere to which welders and welding operators are exposed during welding. They are:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling)
- (2) Number of welders and welding operators working in that space
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes used
- (4) The proximity of welders and welding operators to the fumes, as these fumes issue from the welding zone, and to the gases and dust in the space in which they are working
- (5) The ventilation provided to the space in which the welding is done

A5.2 American National Standard ANSI Z49.1, published by the American Welding Society, discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the clause on Ventilation in that document. See also AWS F3.2, *Ventilation Guide for Weld Fume* for more detailed descriptions of ventilation options.

A6. Welding Considerations

A6.1 Weld metal properties may vary widely, according to size of the electrode and amperage used, size of the weld beads, base metal thickness, joint geometry, preheat and interpass temperatures, surface condition, base metal composi-

tion, dilution, etc. Because of the profound effect of these variables, a test procedure was chosen for this specification that would represent good welding practice and minimize variation of the most potent of these variables.

A6.2 It should be recognized, however, that production practices may be different. The differences encountered may alter the properties of the weld metal. For instance, interpass temperatures may range from subfreezing to several hundred degrees. No single temperature or reasonable range of temperatures can be chosen for classification tests which will be representative of all of the conditions encountered in production work.

Properties of production welds may vary accordingly, depending on the particular welding conditions. Weld metal properties may not duplicate, or even closely approach, the values listed and prescribed for test welds. For example, ductility in single-pass welds in thick base metal made outdoors in cold weather without adequate preheating may drop to little more than half that required herein and normally obtained. This does not indicate that either the electrodes or the welds are below standard. It indicates only that the particular production conditions are more severe than the test conditions prescribed by this specification.

A6.3 Hydrogen is another factor to be considered in welding. Weld metals, other than those from low-hydrogen electrodes {E(X)XX15-X, E(X)XX16-X, E(X)XX18-X, E(X)XX18M(1), and E(X)XX45-X}, contain significant quantities of hydrogen for some period of time after they have been made. Most of this hydrogen gradually escapes. After two to four weeks at room temperature or in 24 to 48 hours at 200 °F to 220 °F [95 °C to 105 °C], most of it has escaped. As a result of this change in hydrogen content, ductility of the weld metal increases towards its inherent value, while yield, tensile, and impact strengths remain relatively unchanged.

This specification permits aging of the weld plate or test specimens of cellulosic electrodes at 200 °F to 220 °F [95 °C to 105 °C] for 48 hours before subjecting them to tension testing. This is done to minimize discrepancies in testing. Aging treatments are sometimes used for low-hydrogen electrodes, especially when testing high-strength deposits. Note that aging may involve holding test specimens at room temperature for several days or holding at a higher temperature for a shorter period of time. Consequently, users are cautioned to employ adequate preheat and interpass temperatures to avoid the deleterious effects of hydrogen in production welds.

A6.4 When weldments are given a postweld heat treatment, the temperature and time at temperature are very important. The tensile and yield strengths are generally decreased as postweld heat treatment temperatures and time at temperature are increased.

A6.5 Welds made with electrodes of the same classification and the same welding procedure may have significantly different tensile and yield strengths in the as-welded and postweld heat-treated conditions. Even weld metal produced from the same classification and the same welding procedure but with different postweld heat-treatment holding temperatures or times at holding temperatures may have different strength levels. With low-alloy steel weld metals produced by the classifications in this specification, postweld heat treatment can produce tempering (softening) or secondary hardening of the weld metal. It is recommended that users conduct their own evaluation of the welding procedure to be used in production in order to verify that the weld metal properties obtained in actual production are those desired.

A6.6 Preheat and interpass minimum temperatures also have a significant effect on the strength levels attained with certain low-alloy steel weld metals. These weld metals are affected by rapid cooling rates which tend to produce more martensitic or bainitic microstructures. These microstructures will often exhibit higher yield and tensile strengths with a decrease in ductility. The cooling rate can be retarded by utilizing a higher preheat and interpass temperature. The preheat and interpass temperature ranges given in Table 7 of this specification are adequate for the preparation of the test assemblies. However, in actual production, users are encouraged to test their own procedures to verify that they have selected preheat and interpass temperatures which will produce desirable results.

A6.7 Heat input usually is measured as Joules per linear inch, J/in [kJ/mm]. However, in this specification the heat input is governed in the preparation of the test assembly by the bead sequence and the total weld layer count upon completion of the groove weld test assembly.

Heat input will have a significant effect on the strength levels attained in many of the higher strength weld metals produced from the electrode classifications in this specification. For instance, weld metal produced with E11018M [E7618M] electrode at a 35 000 J/in [1.38 kJ/mm] heat input may exceed 110 ksi [760 MPa] yield strength in the as-welded condition and 95 ksi [655 MPa] yield strength after postweld heat treatment. On the other hand, if the heat input is raised to 55 000 J/in [2.17 kJ/mm], this same electrode will produce weld metal that does not exceed 110 ksi [760 MPa] as-welded

yield strength and after postweld heat treatment may be below 95 ksi [655 MPa] yield strength. It is, therefore, recommended that, if the user is going to use either lower or higher heat inputs than normally used for classification testing of electrodes, the user should test the welding procedure to be used to determine that the strength levels expected will be attained in production. This is especially true if out-of-position welding is to be performed.

A6.8 *Other than “-G” classifications*, electrodes that meet all the requirements of any given classification may be expected to have similar characteristics. Certain minor differences continue to exist from one brand to another due to differences in preferences that exist regarding specific operating characteristics.

A6.9 Since electrodes within a given classification have similar operating characteristics and mechanical properties, the user can usually limit study of available electrodes to those within a single classification after determining which classification best suits the user’s particular requirements.

A6.10 This specification does not establish values for all characteristics of the electrodes falling within a given classification, but it does establish values to measure those of major importance. In some instances, a particular characteristic is common to a number of classifications and testing for it is not necessary. In other instances, the characteristics are so intangible that no adequate tests are available. This specification does not necessarily provide all the information needed to determine which classification would best fulfill a particular need. The information included in Clause A7 regarding typical applications for each classification supplements information given elsewhere in the specification and is intended to provide assistance in making electrode selections. However, it must be noted that it is the fabricator’s responsibility to ensure that the electrode selected will satisfy all of the performance requirements for the intended applications under the specific fabrication conditions in use.

A6.11 Some important tests for measuring major electrode characteristics are as follows:

A6.11.1 Radiographic Test. Nearly all of the low-alloy steel electrodes covered by this specification are capable of producing welds that meet most radiographic soundness requirements. However, if incorrectly applied, unsound welds may be produced by any of the electrodes. For electrodes of some classifications, the radiographic requirements in Table 9 are not necessarily indicative of the average radiographic soundness to be expected in production use. Electrodes of the E(X)XX10-X, E(X)XX11-X, and E7020-X classifications can be expected to produce acceptable radiographic results. Under certain conditions, notably in welding long, continuous joints in relatively thick base metal, low-hydrogen electrodes of the E(X)XX15-X, E(X)XX16-X, E(X)XX18M(1), E(X)XX18-X, and E(X)XX45-X classifications will often produce even better results.

On the other hand, in joints open to the atmosphere on the root side, at the ends of joints, in joints with many stops and starts, and in welds on small diameter pipe or in small, thin, irregularly-shaped joints, the low-hydrogen electrodes tend to produce welds of poor radiographic soundness. E(X)XX13-X electrodes usually produce the best radiographic soundness in welding small, thin parts.

E7027-X [E4927-X] electrodes produce welds which may be either quite good or rather inferior in radiographic soundness. The tendency is the latter.

A6.11.2 Fillet Weld Test. This test is included as a means of demonstrating the usability of an electrode. This test is concerned with the appearance of the weld (i.e., weld face contour and smoothness, undercut, overlap, size, and resistance to cracking). It also provides an excellent and inexpensive method of determining the adequacy of fusion at the weld root (one of the important considerations for an electrode). Test results may be influenced by the level of welder skill.

A6.11.3 Toughness. Charpy V-notch impact requirements are included in the specification. All classifications of electrodes in the specification can produce weld metal of sufficient toughness for many applications. The inclusion of impact requirements for certain electrode classifications allows the specification to be used as a guide in selecting electrodes where low-temperature toughness is required. There can be considerable variation in the weld-metal toughness unless particular attention is given to the welding procedure and the preparation and testing of the specimens. The impact energy values are for Charpy V-notch specimens and should not be confused with values obtained with other toughness tests.

A6.12 Electrode Covering Moisture Content and Conditioning

A6.12.1 Hydrogen can have adverse effects on welds in some steels under certain conditions. One source of this hydrogen is moisture in the electrode coverings. For this reason, the proper storage, treatment, and handling of electrodes are necessary.

A6.12.2 Electrodes are manufactured to be within acceptable moisture limits, consistent with the type of covering and strength of the weld metal. They are then normally packaged in a container, which has been designed to provide the degree of moisture protection considered necessary for the type of covering involved.

A6.12.3 If there is a possibility that the noncellulosic covered electrodes may have absorbed excessive moisture, they may be reconditioned by rebaking. Some electrodes require rebaking at a temperature as high as 800 °F [425 °C] for approximately 1 to 2 hours. The manner in which the electrodes have been produced and the relative humidity and temperature conditions under which the electrodes are stored determine the proper length of time and temperature used for conditioning. Some typical storage and drying conditions are included in Table A2.

A6.12.4 Cellulosic coverings for E(X)XX10-X and E(X)XX11-X classifications need moisture levels of approximately 3% to 7% for proper operation. Therefore, storage or conditioning above ambient temperature may dry these electrodes too much and adversely affect their operation (see Table A2).

A6.13 Core Wire. The core wire for all the electrodes in this specification is usually (but not always) a mild steel having a typical composition which may differ significantly from that of the weld metal produced by the covered electrode.

A6.14 Coverings

A6.14.1 Electrodes of some classifications have substantial quantities of iron and other metal powders added to their coverings. (Use of the term “iron powder” herein is intended to include metal powders added to the coating for alloying of the weld metal. For example, quite large quantities of chromium and ferro-chromium powders can be added in such alloy designations as B7, B8, and B91.) The iron powder fuses with the core wire as the electrode melts, and is deposited as part of the weld metal, just as is the core wire and other metals in the covering. Relatively high currents can be used since a considerable portion of the electrical energy passing through the electrode is used to melt the thicker covering containing iron powder. The result is that more weld metal may be obtained from a single electrode with iron powder in its covering than from a single electrode of the same size without iron powder.

A6.14.2 Due to the thick covering and deep cup produced at the arcing end of the electrode, iron powder electrodes can be used very effectively with a “drag” technique. This technique consists of keeping the electrode covering in contact with the workpiece at all times, which makes for easy handling. However, a technique using a short arc length is preferable if the 3/32 in [2.5 mm] or 1/8 in [3.2 mm] electrodes are to be used in other than flat or horizontal fillet welding positions or for making groove welds.

Table A2
Typical Storage and Drying Conditions for Covered Arc Welding Electrodes

AWS Classifications		Storage Conditions ^a		
A5.5	A5.5M	Ambient Air	Holding Ovens	Drying Conditions ^b
E(X)XX10-X	EXX10-X	Ambient temperature	Not recommended	Not recommended
E(X)XX11-X	EXX11-X			
E(X)XX13-G	EXX13-G	60°F–100 °F [15 °C–40 °C]	100 °F–120 °F [40 °C–50 °C]	250 °F–300 °F [125 °C–150 °C] 1 hour at temperature
E7020-X	E4920-X	50% max.		
E7027-X	E4927-X	relative humidity		
E(X)XX15-X	EXX15-X	Not recommended ^c	250 °F–300 °F [125 °C–150 °C]	500 °F–800 °F [250 °C–425 °C] 1 hour at temperature
E(X)XX16-X	EXX16-X			
E(X)XX18M(1)	EXX18M(1)			
E(X)XX18-X	EXX18-X			
E(X)XX45-X	EXX45-X			

NOTES:

^a After removal from manufacturer's packaging.

^b Because of inherent differences in covering compositions the manufacturer should be consulted for the exact drying conditions.

^c Some of these electrode classifications may be designated as meeting low moisture absorbing requirements. This designation does not imply that storage in ambient air is recommended.

A6.14.3 The E70XX-X [E49XX-X] electrodes were included in this specification to recognize the lowest strength levels obtained with low-alloy steel electrodes, as well as to recognize the industry demand for low-alloy electrodes with 70 ksi [490 MPa] minimum tensile strength. Unlike the E70XX [E49XX] classifications in AWS A5.1/A5.1M, these electrodes do contain deliberate alloy additions, and some are required to meet minimum tensile properties after postweld heat treatment.

A6.14.4 Low-hydrogen electrodes have mineral coverings, which are high in calcium carbonate and other ingredients that are low in moisture and organic materials and hence “low in hydrogen content.” Low-hydrogen electrodes were developed for welding low-alloy, high-strength steels, some of which were high in carbon content. Electrodes with other than low-hydrogen coverings may produce “hydrogen induced cracking” in those steels. These underbead cracks occur in the base metal, usually just below the weld bead. Weld cracks also may occur. These cracks are caused by the hydrogen absorbed from the arc atmosphere. Although these cracks do not generally occur in carbon steels which have low carbon content, they may occur when welding higher carbon or low-alloy steels with other than low-hydrogen electrodes and without precautions, such as increased preheat temperatures and postweld heating. For more information on special tests for low-hydrogen electrodes, see Clauses 16 and 17 in the specification and A8.1 and A8.3 in this Annex.

Some extra-low hydrogen (H4) electrode coatings may be prone to reduced operability and producing unacceptable porosity. The unacceptable condition is usually associated with varying or excessive arc length and is highly dependent on operator skill level.

A6.15 Welding Parameters. *Appropriate parameters vary by product, polarity, welding position, etc. The electrode manufacturer should be consulted for recommended parameters.*

A7. Description and Intended Use of Electrodes

A7.1 Chemical Composition. The chemical composition of the weld metal produced is often the primary consideration for electrode selection. Together with appropriate heat treatments, each composition can achieve a wide range of corrosion resistance and mechanical properties at various service temperatures. It is usually desirable for weld metal to match the chemical composition and the mechanical properties of the base metal as closely as possible. In fact, many of the electrodes classified to this specification have been developed for specific base metal grades or classes. If an optimum match is not possible, engineering judgment together with weld testing may be required to select the most suitable electrodes.

Table 2 provides detailed weld metal chemical composition requirements for each electrode classification. Tables 3 and 4 list the mechanical properties of the weld metal when the electrode is used in the flat downhand position, and the weldment is subjected to the postweld heat treatment (PWHT) requirements in Tables 3 and 7. It should be noted that changes in welding position, welding variables, or heat treatment can be expected to affect the mechanical properties. However, except for the effects of dilution, the chemical composition can be expected to remain reasonably unchanged.

The suffixes, which are part of each alloy electrode classification, identify the chemical composition of the weld metal produced by the electrode. The following paragraphs highlight the differences between these electrodes and electrode groups and indicate typical applications.

A7.1.1 E70XX-A1 [E49XX-A1] (C-Mo Steel) Electrodes. These electrodes are similar to the E70XX [E49XX] carbon steel electrodes classified in AWS A5.1/A5.1M, except that 0.5% molybdenum has been added. This addition increases the strength of the weld metal, especially at elevated temperatures, and provides some increase in corrosion resistance, however, it may reduce the notch toughness of the weld metal. Typical applications include the welding of C-Mo steel base metals such as ASTM A204 plate and A335-P1 pipe.

A7.1.2 EXXXX-BX and EXXXX-BXL (Cr-Mo Steel) Electrodes. These low-hydrogen electrodes produce weld metal that nominally contains between 0.5% and 10% chromium and up to 1.25% molybdenum. They are designed to produce weld metal for high-temperature service and for matching the properties of the typical Cr-Mo base metals, some of which are shown in Table 6.

For many of these Cr-Mo electrode classifications, low carbon EXXXX-BXL classifications have been established. While regular Cr-Mo electrodes produce weld metal with about 0.08% carbon, the “L-Grades” are limited to a maximum of 0.05% carbon. While the lower percent carbon in the weld metal will improve ductility and lower hardness, it will also reduce the high-temperature strength and creep resistance of the weld metal.

Since all Cr-Mo electrodes produce weld metal which will harden in still air, both preheat and PWHT are required for most applications.

No minimum notch toughness requirements have been established for any of the Cr-Mo electrode classifications. While it is possible to obtain Cr-Mo electrodes with minimum toughness values at ambient temperatures down to 32 °F [0 °C], specific values and testing must be agreed upon between the purchaser and supplier.

A7.1.2.1 E70XX-B2L [E49XX-B2L] and E80XX-B3L [E55XX-B3L] Electrodes. In AWS A5.5-81, and previous revisions, electrodes classified as E70XX-B2L [E49XX-B2L] were classified as E80XX-B2L [E55XX-B2L]. Likewise, electrodes herein classified as E80XX-B3L [E55XX-B3L] were classified as E90XX-B3L [E62XX-B3L]. The composition ranges in AWS A5.5-96, or the present edition, have not been changed from A5.5-81 for the corresponding classifications. The strength designations and room-temperature strength requirements after postweld heat treatment have been reduced to reflect the fact that commercial products had been producing marginal tensile strength results in classification tests over many years. The base metals with which these classifications are generally used have lower strength requirements than were reflected by the former electrode classifications. Therefore, unless the higher strength indicated by the former classifications of these electrodes is specifically necessary for a particular welding procedure, the E70XX-B2L [E49XX-B2L] classifications in this standard should be considered as identical to the corresponding E80XX-B2L [E55XX-B2L] classifications of A5.5-81. Likewise, the E80XX-B3L [E55XX-B3L] classifications in this standard should be considered as identical to the E90XX-B3L [E62XX-B3L] classifications of A5.5-81.

A7.1.2.2 E8015 B6 [E5515-B6] and E8015 B6L [E5515-B6L] Electrodes. The E8015-B6 [E5515-B6] and E8015-B6L [E5515-B6L] electrodes were formerly classified as E502-15 in AWS A5.4-92, *Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding*. The E8016-B6 [E5516-B6] and E8016-B6L [E5516-B6L] were formerly classified as E502-16 in A5.4-92. The E8018-B6 [E5518-B6] and E8018-B6L [E5518-B6L] were not formerly classified, but were produced to the E502 composition ranges in A5.4-92 but with the EXX18 covering of this specification. Similarly, the E80XX-B7(L) [E55XX-B7(L)] classifications were formerly classified as E7Cr-XX in A5.4-92; and the E80XX-B8(L) [E55XX-B8(L)] classifications were formerly classified as E505-XX in A5.4-92.

A7.1.2.3 E8016-B23A [E5516-B23A] and E90XX-B23 [E62XX-B23] Electrodes. E8016-B23A [E5516-B23A] and E90XX-B23 [E62XX-B23] are 2.5% Cr–1.5% W–0.2% Mo–0.20% V–0.04% Nb, low-hydrogen electrodes designed to provide improved creep strength, toughness, fatigue life, and oxidation and corrosion resistance at elevated temperatures. In addition to the classification requirements in this specification, impact toughness or high temperature creep strength properties may be determined. Additional testing requirements must be agreed upon between the purchaser and supplier depending upon the application.

A7.1.2.4 E90XX-B24 [E62XX-B24] Electrodes. E90XX-B24 [E62XX-B24] is a 2.5% Cr–1.0% Mo–0.20% V–0.10% Ti–0.04% Nb, low-hydrogen electrode designed to provide improved creep strength, toughness, fatigue life, and oxidation and corrosion resistance at elevated temperatures. In addition to the classification requirements in this specification, impact toughness or high temperature creep strength properties may be determined. Additional testing requirements must be agreed upon between the purchaser and supplier depending upon the application.

A7.1.2.5 E90XX-B9A [E62XX-B9A] Electrodes. This is a 9%Cr-1%Mo-Nb-V electrode. The niobium (columbium) and vanadium additions are designed to provide increased creep strength and oxidation and corrosion resistance at elevated temperatures. Due to the higher elevated temperature properties of this alloy, components that are now fabricated from stainless and ferritic steels may be fabricated from a single alloy eliminating problems associated with dissimilar welds.

In addition to the classification requirements of this specification, impact toughness and high temperature creep strength properties should be determined. Due to the influence of various levels of carbon and niobium (columbium) specific values and testing must be agreed to by the purchaser and supplier. Thermal treatment of this alloy is critical and must be closely controlled. The temperature at which the microstructure has complete transformation into martensite (M_s) is relatively low. For applications requiring optimum ductility and creep resistance consideration should be given to allowing the weldment to cool to at least 200 °F [95 °C] before PWHT to maximize transformation to martensite.

The maximum allowable temperature for most postweld heat treatment is 1400 °F [760 °C] which is the temperature that can satisfy the requirement of conventional boiler designs. These electrodes have a good resistance to high temperature cracking due to the relatively high content of nickel, which generates a fine microstructure with low amounts of delta ferrite.

A7.1.2.6 E90XX-B91 [E62XX-B91] (formerly E90XX-B9 [E62XX-B9]) Electrodes. This electrode, formerly classified as E90XX-B9 [E62XX-B9], is a 9% Cr-1% Mo, low-hydrogen electrode modified with niobium (columbium) and vanadium, designed to provide improved creep strength, toughness, fatigue life, and oxidation and corrosion resistance at elevated temperatures. Due to the higher elevated temperature properties of this alloy, components that are now fabricated from stainless and ferritic steels may be fabricated from a single alloy, eliminating problems associated with dissimilar welds.

In addition to the classification requirements in this specification, impact toughness or high temperature creep strength properties may be determined. Due to the influence of various levels of carbon and niobium (columbium), testing must be agreed upon between the purchaser and supplier.

Thermal treatment of this alloy is critical and must be closely controlled. The temperature at which the microstructure has complete transformation to martensite (M_s) is relatively low. For applications requiring optimal ductility and creep resistance, consideration should be given to allowing the weldment to cool sufficiently to maximize transformation to martensite.

The maximum allowable temperature for postweld heat treatment is also critical in that the lower transformation temperature (A_{c1}) is also comparably low. To aid in allowing for an adequate postweld heat treatment, the restriction on Mn + Ni has been imposed (see Table 2, note g). The combination of Mn and Ni tends to lower the A_{c1} temperature to the point where the PWHT temperature approaches the A_{c1} , possibly causing partial transformation of the microstructure. By restricting the Mn + Ni, the PWHT temperature will be sufficiently below the A_{c1} to avoid this partial transformation.

A7.1.2.7 E90XX-B92 [E62XX-B92] Electrodes. E90XX-B92 [E62XX-B92] is a 9% Cr-2% W-0.5% Mo-0.20% V-0.05% Nb, low-hydrogen electrode designed to provide improved creep strength, toughness, fatigue life, and oxidation and corrosion resistance at elevated temperatures. Due to the higher elevated temperature properties of this alloy, components that are now fabricated from stainless and ferritic steels may be fabricated from a single alloy, eliminating problems associated with dissimilar welds.

In addition to the classification requirements in this specification, impact toughness or high temperature creep strength properties may be determined. *Significant reductions in ductility of this alloy have been observed after high temperature service, and testing must be agreed upon between the purchaser and supplier.*

Thermal treatment of this alloy is critical and must be closely controlled. The temperature at which the microstructure has complete transformation to martensite (M_s) is relatively low. For applications requiring optimum ductility and creep resistance, consideration should be given to allowing the weldment to cool to at least 200 °F [93 °C] before PWHT to maximize transformation to martensite.

The maximum allowable temperature for PWHT is also critical in that the lower transformation temperature (A_{c1}) is also comparably low. To ensure proper PWHT results, a restriction on Mn + Ni has been imposed (see Table 2, Note g). The combination of Mn and Ni tends to lower the A_{c1} temperature to the point where the PWHT temperature approaches the A_{c1} , possibly causing partial transformation of the microstructure. By restricting the Mn + Ni, the PWHT temperature will be sufficiently below the A_{c1} to avoid this partial transformation.

A7.1.2.8 E9016-B92A [E6216-B92A] Electrodes. This electrode type is similar in applications to the E90XX-B92 [E62XX-B92] shown above. It has been modified with the addition of 1.5% Co.

A7.1.2.9 X-Factor. A major application of the Cr-Mo steels is in the fabrication of pressure vessels for the petrochemical and power generation industries. Where these materials are subjected to elevated temperatures for extended periods of time, temper embrittlement usually occurs. Temper embrittlement is the migration of certain elements within the material matrix to the grain boundaries over time, resulting in a loss of impact toughness. In 1970, Bruscatto developed a formula using only the critical elements affecting temper embrittlement, as follows:

$$\text{X-Factor} = (10 P + 5 \text{ Sb} + 4 \text{ Sn} + \text{As})/100$$

with analytical results for the elements in ppm. The industry X-Factor requirement is less than 15. An X-Factor less than 15, combined with low Mn and Si levels, is recommended in industry to minimize temper embrittlement effects (see Bruscatto, R., Welding Journal Research Supplement, Vol 49, N.4, pp. 148-s-156-s, 1970).

A7.1.3 EXXXX-CX and EXXXX-CXL (Ni Steel) Electrodes. These low-hydrogen electrodes have been designed to produce weld metal with increased strength without being air-hardenable or with increased notch toughness at temperatures as low as -175 °F [-115 °C]. They have been specified with nickel contents which fall into five nominal levels of 1% Ni, 1.5% Ni, 2.5% Ni, 3.5% Ni, and 6.5% Ni in steel.

With carbon levels of up to 0.12%, strength increases and permits these Ni steel electrodes to be classified as E80XX-CX [E55XX-CX]. However, with lower levels of carbon, low-temperature toughness improves to match the base-metal properties of nickel steels, such as ASTM A203 Grade E, and ASTM A352 LC3 and LC4 classifications. Thus, the intended application and the needed mechanical properties determine whether or not “L-Grades” should be selected. *Some of these electrode types are designed with a complex addition of Ti and B to improve the toughness by providing a finer micro-structure.*

Many low-alloy steels require postweld heat treatment to stress relieve the weld or temper the weld metal and heat affected zone to achieve increased ductility. It is often acceptable to exceed the PWHT holding temperatures shown in Table 7. However, for many applications, nickel steel weld metal can be used without postweld heat treatment. If PWHT is to be specified for a nickel steel weldment, the holding temperature should not exceed the maximum temperature given in Table 7 for the classification considered since nickel steels can be embrittled at higher temperatures.

A7.1.4 EXXXX-NMX (Ni-Mo Steel) Electrodes

A7.1.4.1 E8018-NM1 [E5518-NM1] Electrodes. This low-hydrogen electrode, which contains about 1% nickel and 0.5% molybdenum, is similar to the Mn-Mo steel electrodes discussed in A7.1.5. However, this electrode can often be welded without PWHT, but the resulting strength and notch toughness are lower than the values obtained with Mn-Mo electrodes. Some typical applications include the welding of high-strength low-alloy or microalloyed structural steels.

A7.1.4.2 E9018-NM2 [E6218-NM2] Electrodes. This electrode is intended to meet strength requirements after extended postweld heat treatment as required in the construction of nuclear power plants and in the fabrication of components (e.g., steam generators and pressurizers) used in nuclear power plants. In production environments, the length of postweld heat treatments can be as long as 48 hours. Increased carbon aids in achieving desired response to heat treatment. In addition to the requirements listed in this specification, these applications also often require drop weight testing to determine nil ductility temperature as well as measurement of mils of lateral expansion on broken Charpy V-notch specimens.

A7.1.4.3 E10016-NM3 [E6916-NM3] Electrodes. *These low-hydrogen electrodes are similar to the Ni steel electrodes discussed in A7.1.3 except that chromium and molybdenum have been added. Electrodes of this classification produce weld metal which will have a chemical composition of 1.5% nickel, 0.20% chromium and 0.20% molybdenum. These additional alloys increase the strength of the weld metal. This electrode can often be welded without PWHT. Typical applications include the welding of low-alloy, high-strength structural steels.*

A7.1.4.4 E9016-NM4 [E6216-NM4]. *These low-hydrogen electrodes are similar to the Ni steel electrodes discussed in A7.1.3 except that molybdenum has been added. Electrodes of this classification produce weld metal which will have a chemical composition of 0.5% nickel and 0.4% molybdenum. This additional alloy increases the strength of the weld metal.*

This weld metal is often suitable for use in either the as-welded or PWHT condition. Typical applications include the welding of low-alloy, high-strength structural steels.

A7.1.4.5 E10016-NM5 [E6916-NM5] Electrodes. *These low-hydrogen electrodes are similar to the Ni steel electrodes discussed in A7.1.3 except that chromium and molybdenum have been added. Electrodes of this classification produce weld metal which will have a chemical composition of 3.5% nickel, 0.20% chromium and 0.50% molybdenum. These additional alloys increase the strength of the weld metal. This weld metal is often suitable for use in either the as-welded or PWHT condition. Typical applications include the welding of low-alloy, high-strength structural steels.*

A7.1.4.6 E11016-NM6 [E7616-NM6] Electrodes. *These low-hydrogen electrodes are similar to the Ni steel electrodes discussed in A7.1.3 except that chromium and molybdenum have been added. Electrodes of this classification produce weld metal which will have a chemical composition of 2.0% nickel, 0.25% chromium and 0.40% molybdenum. These additional alloys increase the strength of the weld metal. This weld metal is often suitable for use in either the as-welded or PWHT condition. Typical applications include the welding of low-alloy, high-strength structural steels.*

A7.1.4.7 E11016-NM7 [E7616-NM7] Electrodes. *These low-hydrogen electrodes are similar to the Ni steel electrodes discussed in A7.1.3 except that molybdenum has been added. Electrodes of this classification produce weld metal which will have a chemical composition of 2.5% nickel and 0.70% molybdenum. These additional alloys increase the strength of the weld metal. This weld metal is often suitable for use in either the as-welded or PWHT condition. These electrodes are used on many high-strength applications. Typical applications would include the welding of offshore structures and many structural applications where excellent low temperature toughness is required.*

A7.1.4.8 E11018-NM8 [E7618-NM8] Electrodes. These low-hydrogen electrodes are similar to the Ni steel electrodes discussed in A7.1.3 except that molybdenum has been added. Electrodes of this classification produce weld metal which will have a chemical composition of 2.8% nickel and 0.80% molybdenum. These additional alloys increase the strength of the weld metal. This weld metal is often suitable for use in either the as-welded or PWHT condition. These electrodes are used on many high-strength applications. Typical applications would include the welding of offshore structures and many structural applications where excellent low temperature toughness is required.

A7.1.5 E(X)XX1X-DX [EXX1X-DX] (Mn-Mo Steel) Electrodes. These low-hydrogen electrodes produce weld metal that contains about 1.5% manganese and between 0.33% and 0.67% molybdenum. This weld metal provides higher strength and better notch toughness than the C-0.5% Mo and 1% Ni-0.5% Mo steel weld metal discussed in A7.1.1 and A7.1.4, respectively. However, the weld metal from these Mn-Mo steel electrodes is quite air-hardenable and usually requires preheat and PWHT. The individual electrodes classified under this electrode group have been designed to match the mechanical properties and corrosion resistance of the high-strength, low-alloy pressure vessel steels, such as ASTM A302 Grade B.

A7.1.6 E(X)XXXX-G (General Low-Alloy Steel) Electrodes. These electrodes are described in A2.3. These electrode classifications may be either modifications of other discrete classifications or totally new classifications. Purchaser and user should determine from the supplier what the description and intended use of the electrode is.

A7.1.7 E(X)XX18M(1) (Military-Similar) Electrodes. These low-hydrogen electrodes were originally designed for military applications such as welding HY80 and HY100 type steels. To achieve desired weld-metal properties and soundness, these electrodes have small alloy additions (especially some Ni) and require careful control of moisture in the electrode covering. It is important that moisture levels in the coating be maintained during electrode manufacture, packaging, transport, and site storage.

These electrodes are usually employed without subsequent PWHT. However, hydrogen-release treatments at lower temperatures, typically less than 500 °F [260 °C], are often applied. In the as-welded condition, the weld-metal mechanical properties include ultimate tensile strength minima ranging from 90 ksi to 120 ksi [620 MPa to 830 MPa] and good notch toughness at temperatures ranging from 0 °F to -60 °F [-18 °C to -51 °C]. With these properties, the E(X)XX18M(1) type electrodes are suitable for joining many high-strength, low-alloy or microalloyed steels to themselves or to lower strength steels, including carbon steels.

A7.1.8 EXX10-P1 (Pipeline) Electrodes. These electrodes have been designed primarily for welding typical high-strength pipe butt joints in the vertical welding position with downward or upward progression. With their cellulosic coverings, they produce deep penetrating, spray-type welding arcs and thin, easily removable slag. This combination is best suited for achieving full penetration and radiographic quality for the downhill welding of butt joints when the axis of the pipe is in the horizontal position.

While weld metals produced from these electrodes do not have any minimum chemical composition requirements, the supplier must provide sufficient alloying elements to meet the increased mechanical property requirements. Special emphasis must be placed upon the minimum yield strength values, since most transmission pipeline materials and systems are designed to yield strength limits. Typical application for E7010-P1 [E4910-P1], E8010-P1 [E5510-P1], and E9010-P1 [E6210-P1] electrodes is the welding of API-5L-X52, API-5L-X65, and API-5L-X70 piping assemblies, respectively.

A7.1.9 EXX18-P2 Pipe Welding Electrodes. These electrodes have been designed primarily for the welding of the hot, fill, and cap passes in high strength pipe butt joints in the vertical position, in upward progression. Some electrodes of these classifications may also be used on fillet welds with downward progression. The low-hydrogen nature of the coating of these electrodes makes them especially suited for joining crack-sensitive high strength pipe. Typical application for electrodes of these classifications are the welding of API 5L pipe steels up to and including Grade X80, along with many other high strength, medium and high carbon, and low-alloy steels. Electrodes of these classifications are normally not recommended for the root pass (stringer bead) on open gaps.

A7.1.10 E(X)XX45-P2 and E(X)XX45-G Pipe Welding Electrodes. These electrodes have specifically been designed for the welding of hot, fill, and cap passes in high strength pipe butt joints using vertical downward progression. This classification is not recommended for welding with vertical upward progression. While specifically designed for butt welds, electrodes of these classifications can often be used on fillet welds with downward progression, such as repair welding when attaching pipe sleeves. The low hydrogen nature of the coating of these electrodes makes them especially

suiting for downhill welding of butt joints on crack sensitive high strength pipe when the axis of the pipe is horizontal. Typical application for electrodes of these classifications are the welding of API 5L pipe steels using the appropriate strength level electrode, along with many other high strength, medium and high carbon, and low alloy steels. Electrodes of these classifications are normally not recommended for root pass (stringer bead) on open gaps.

A7.1.11 EXX18-WX (Weathering Steel) Electrodes. These low-hydrogen electrodes have been designed to produce weld metal that matches the corrosion resistance and the coloring of the ASTM weathering-type structural steels. These special properties are achieved by the addition of about 0.5% copper to the weld metal. To meet strength, ductility, and notch toughness in the weld metal, some chromium and nickel additions are also made. These electrodes are used to weld the typical weathering steels, such as ASTM A242 and ASTM A588.

A7.1.12 E10016-Mn2 [E6916-Mn2] and E10018-Mn2 [E6918-Mn2]. Weld metal of this composition has been designed for joining austenitic steels of similar composition (such as ASTM A1106) used for containing liquid natural gas and other cryogenic liquids. Weld metal of this composition is also used for welding nickel steels such as 3-1/2% and 9% nickel steels.

A8. Special Tests

It is recognized that supplementary tests may be necessary for certain applications. In such cases, tests to determine specific properties such as hardness, corrosion resistance, mechanical properties at elevated or cryogenic temperatures, wear resistance, and suitability for welding different carbon and low-alloy steels, may be required. AWS A5.01M/A5.01 contains provisions for ordering such tests. This clause is included for the guidance of those who desire to specify such special tests. Those tests may be conducted as agreed upon between the purchaser and supplier.

A8.1 Diffusible Hydrogen Test.

A8.1.1 Hydrogen-induced cracking of weld metal or the heat affected zone generally is not a problem with carbon steels containing 0.3% or less carbon, or with lower-strength alloy steels. However, the electrodes classified in this specification are sometimes used to join higher carbon steels or low-alloy, high-strength steels where hydrogen-induced cracking may be a serious problem.

A8.1.2 Since the available diffusible hydrogen level strongly influences the tendency towards hydrogen-induced cracking, it may be desirable to measure the diffusible hydrogen content resulting from welding with a particular electrode. This specification has, therefore, included the use of optional designators for diffusible hydrogen to indicate the maximum average value obtained under a clearly defined test condition in AWS A4.3.

A8.1.3 The user of this information is cautioned that actual fabrication conditions may result in different diffusible hydrogen values than those indicated by the designator.

A8.1.4 The use of a reference atmospheric condition during welding is necessitated because the arc is subject to atmospheric contamination due to imperfect shielding. Moisture from the air, distinct from that in the electrode, can enter the arc and subsequently the weld pool, contributing to the resulting observed diffusible hydrogen. This effect can be minimized by maintaining as short an arc length as possible consistent with a steady arc. Experience has shown that the effect of arc length is minor at the H16 level, but can be very significant at the H4 level. An electrode meeting the H4 requirements under the reference atmospheric conditions may not do so under conditions of high humidity at the time of welding, especially if a long arc length is maintained.

A8.1.5 Low-hydrogen electrodes can absorb significant moisture if stored in a humid environment in damaged or open packages, or especially if unprotected for long periods of time. In the worst cases of high humidity, even exposure of unprotected electrodes for as little as two hours can lead to a significant increase of diffusible hydrogen. In the event the electrodes have been exposed, the manufacturer should be consulted regarding probable damage to low hydrogen characteristics and possible reconditioning of the electrodes.

A8.1.6 Not all classifications may be available in H16, H8, and H4 diffusible hydrogen levels. The manufacturer of a given electrode should be consulted for availability of products meeting these limits.

A8.2 Aging of Tensile Specimens. Weld metals may contain significant quantities of hydrogen for some time after they have been made. Most of this hydrogen gradually escapes over time. This may take several weeks at room temperature or several hours at elevated temperatures. As a result of this eventual change in hydrogen level, ductility of the weld metal

increases toward its inherent value, while yield, tensile and impact strengths remain relatively unchanged. The A5.5 and A5.5M specifications permit the aging of the test specimens *or weld test assembly* at elevated temperatures *not exceeding* 220 °F [105 °C] for up to 48 hours before *cooling them to room temperature and* subjecting them to testing. The purpose of this treatment is to facilitate removal of hydrogen from the test specimen in order to *narrow the variation in the test results*.

Aging treatments are sometimes used for low-hydrogen electrode deposits, especially when testing high-strength deposits. Note that aging may involve holding test specimens at room temperature for several days or holding at a higher temperature for a shorter period of time. Consequently, users are cautioned to employ adequate preheat and interpass temperatures to avoid the deleterious effects of hydrogen in production welds. *It should be kept in mind that aging test assemblies may not remove as much diffusible hydrogen as aging the individual specimens. The purchaser may, by mutual agreement with the supplier, have the thermal aging of specimens prohibited for all mechanical testing done to schedule I or J of AWS A5.01M/A5.01.*

A8.3 Absorbed Moisture Test. The development of low-hydrogen electrode coverings that resist moisture absorption during exposure to humid air is a recent improvement in covered electrode technology. Not all commercial low-hydrogen electrodes possess this characteristic. To assess this characteristic, the absorbed moisture test described in Clause 16 was devised. The exposure conditions selected for the test are arbitrary. Other conditions may yield quite different results.

A task group of the AWS A5A Subcommittee evaluated this test and concluded that it can successfully differentiate moisture resistant electrodes from those which are not. The task group also observed considerable variability of covering moisture results after exposure of electrodes in cooperative testing among several laboratories. The precision of the test is such that, with moisture resistant electrodes from a single lot, the participating laboratories could observe exposed covering moisture values ranging, for example, from 0.15% or less to 0.35% or more. The task group concluded that the variability was due to both variations in the exposure conditions and the variability inherent in the application of the moisture test procedure. Therefore, it is not realistic to set a limit for covering moisture of exposed moisture resistant electrodes lower than 0.4% at this time.

A9. Discontinued Classifications

Some classifications have been discontinued from one revision of this specification to another. This results either from changes in commercial practice or changes in the classification system used in the specification. The classifications that have been discontinued are listed in Table A.3, along with the year in which they were last included in the specification.

A10. General Safety Considerations

A10.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Annex Clause A5. Safety and health information is available from other sources, including, but not limited to Safety and Health Fact Sheets and ANSI Z49.1 and applicable federal and state regulations.

A10.2 Safety and Health Fact Sheets. The Safety and Health Fact Sheets are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

Table A3
Discontinued Electrode Classifications^a

AWS Classification	Last A5.5 (ASTM A 316 ^b) Publication Date	AWS Classification	Last A5.5 (ASTM A 316 ^b) Publication Date
E7010 ^c	1954	E10026	1948
E7011 ^c	1954	E10030	1948
E7013	1948	E12015 ^c	1954
E7015 ^d	1954	E12016 ^c	1954
E7016 ^d	1954	E7015-C1	1954
E7020 ^c	1954	E7016-C1	1954
E7025	1948	E7015-C2	1954
E7026	1948	E7016-C2	1954
E7030	1948	E9010-B3	1954
E8010 ^c	1954	E9011-B3	1954
E8011 ^c	1954	E9013-B3	1954
E8013 ^c	1954	E8010-B1	1958
E8015 ^c	1954	E8011-B1	1958
E8016 ^c	1954	E8013-B1	1958
E8020	1948	E8015-B1	1958
E8025	1948	E8010-B2	1958
E8026	1948	E8011-B2	1958
E8030	1948	E8013-B2	1958
E9010 ^c	1954	E8015-B4	1958
E9011 ^c	1954	E8016-B4	1958
E9013 ^c	1954	E8018-B4	1958
E9015 ^c	1954	E8015-C1	1958
E9016 ^c	1954	E8015-C2	1958
E9020	1948	E8015-C3	1958
E9025	1948	E9016-D1	1958
E9026	1948	E7018-W ^e	1981
E9030	1948	E8015-B2L ^f	1981
E10010 ^c	1954	E8018-B2L ^f	1981
E10011 ^c	1954	E8018-NM ^g	1981
E10013 ^c	1954	E8018-W ^e	1981
E10015 ^c	1954	E9015-B3L ^f	1981
E10016 ^c	1954	E9018-B3L ^f	1981
E10020	1948	E90XX-B9 [E62XX-B9] ^h	2006
E10025	1948		

^a See Clause A10, Discontinued Classifications (in Annex A), for information on discontinued classifications and how they may be used.

^b ASTM A 316 was withdrawn without replacement in 1969.

^c The higher tensile strength electrode classifications without chemical composition requirements for classifications were discontinued in 1958 and replaced with the “G” classifications in order to permit a single classification system with chemical composition requirements.

^d Both E7015 and E7016 classifications were transferred to AWS A5.1-58T and continue to be included in the current revision of that specification.

^e Both E7018-W and E8018-W classification designations have been changed to E7018-W1 and E8018-W2 in order to permit the suffix designator to differentiate between the two chemical compositions of undiluted weld metal.

^f These Cr-Mo electrode classifications were modified by using a lower strength designator. This reflects a more realistic minimum tensile strength for low-carbon chromium molybdenum steel weld metal. This change may or may not show a corresponding reduction in creep strength of the weld metal depending on how the chemical composition of the weld metal is controlled.

^g The E8018-NM classification has been changed to E8018-NM1 to allow for other possible Ni-Mo steel electrode classifications in future revisions.

^h The E90XX-B9 [E62XX-B9] classification has been changed to E90XX-B91[E62XX-B91] to better conform to industry standards and practices.

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the Welding Journal, and post it on the AWS website.

B6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The AWS Board Policy Manual requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

SPECIFICATION FOR COPPER AND COPPER-ALLOY ELECTRODES FOR SHIELDED METAL ARC WELDING



SFA-5.6/SFA-5.6M



(Identical with AWS Specification A5.6/A5.6M:2008. In case of dispute, the original AWS text applies.)

SPECIFICATION FOR COPPER AND COPPER-ALLOY ELECTRODES FOR SHIELDED METAL ARC WELDING



SFA-5.6/SFA-5.6M



(Identical with AWS Specification A5.6/A5.6M:2008. In case of dispute, the original AWS text applies.)

1. Scope

1.1 This specification prescribes requirements for the classification of covered copper and copper-alloy electrodes for shielded metal arc welding. It includes compositions in which the copper content exceeds that of any other element.¹

1.2 Safety and health issues and concerns are beyond the scope of this standard and are therefore not fully addressed herein. Some safety and health information can be found in the informative Annex Clauses A5 and A10. Safety and health information is available from other sources, including, but not limited to, ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations.

1.3 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to filler metal properties. The specification with the designation A5.6 uses U.S. Customary Units. The specification A5.6M uses SI Units. The latter are shown within brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing of electrodes or packaging or both under A5.6 or A5.6M specifications.

2. Normative References

2.1 The following AWS standards² are referenced in the mandatory section of this document.

- (a) AWS A5.01, *Filler Metal Procurement Guidelines*

¹ No attempt has been made to provide for the classification of all grades of copper and copper-alloy welding electrodes. Only the more commonly used grades have been included.

² AWS standards are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

(b) AWS B4.0 [AWS B4.0M], *Standard Methods for Mechanical Testing of Welds*

2.2 The following ANSI standard³ is referenced in the mandatory section of this document:

- (a) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

2.3 The following ASTM standards⁴ are referenced in the mandatory section of this document.

- (a) ASTM B 96/B 96M, *Standard Specification for Copper-Silicon Alloy Plate, Sheet, Strip, and Rolled Bar for General Purposes and Pressure Vessels*

- (b) ASTM B 103/B 103M, *Standard Specification for Phosphor Bronze Plate, Sheet, Strip, and Rolled Bar*

- (c) ASTM B 122/B 122M, *Standard Specification for Copper-Nickel-Tin Alloy, Copper-Nickel-Zinc Alloy (Nickel Silver) and Copper-Nickel Alloy Plate, Sheet, Strip, and Rolled Bar*

- (d) ASTM B 148, *Standard Specification for Aluminum-Bronze Sand Castings*

- (e) ASTM B 152/B 152M, *Standard Specification for Copper Sheet, Strip, Plate, and Rolled Bar*

- (f) ASTM B 169/B 169M, *Standard Specification for Aluminum Bronze Sheet, Strip, and Rolled Bar*

- (g) ASTM E 29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

- (h) ASTM E 75, *Standard Test Methods for Chemical Analysis of Copper-Nickel and Copper-Nickel-Zinc Alloys*

- (i) ASTM E 478, *Standard Test Methods for Chemical Analysis of Copper Alloys*

- (j) ASTM E 1032, *Standard Test Method for Radiographic Examination of Weldments*

³ This ANSI standard is published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

⁴ ASTM standards are published by the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

2.4 The following ISO standard⁵ is referenced in the mandatory sections of this document.

(a) ISO 544, *Welding consumables—Technical delivery conditions for welding filler materials—Type of product, dimensions, tolerances and markings*

3. Classification

3.1 The welding materials covered by the A5.6/A5.6M specification are classified using the system that is independent of U.S. Customary Units and the International System of Units (SI). Classifications are according to the chemical composition of the undiluted weld metal as specified in Table 1.

3.2 Materials classified under one classification shall be classified under any other classification in this specification. However, material may be classified under both A5.6 and A5.6M.

3.3 The materials classified under this specification are intended for shielding metal arc welding, but that is not to prohibit their use with any other process for which they are found suitable.

4. Acceptance

Acceptance⁶ of the material shall be in accordance with the provisions of AWS A5.01.

5. Certification

By affixing the AWS specification and classification designations to the packaging, or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification.⁷

6. Rounding-Off Procedure

For the purposes of determining conformance with this specification, an observed or calculated value shall be rounded to the nearest 1000 psi [10 MPa] for tensile strength, and to the “nearest unit” in the last right-hand place of figures used in expressing the limiting value for other quantities in accordance with the rounding-off method given in ASTM E 29.

7. Summary of Tests

The tests required for each classification are specified in Table 2. The purpose of these tests is to determine the

⁵ ISO standards are published by the International Organization for Standardization, 1 rue de Varembe, Case postale 56, CH-1211 Geneva 20, Switzerland.

⁶ See A3 in Annex A for further information concerning acceptance, testing of the material shipped, and AWS A5.01, *Filler Metal Procurement Guidelines*.

⁷ See A4 in Annex A for further information concerning certification and the testing called for to meet this requirement.

chemical composition, mechanical properties, and soundness of the weld metal. The base metal for the weld test assemblies, the welding and testing procedures to be employed, and the results required are given in Clauses 9 through 13.

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. For chemical analysis, retest material may be taken from the original test sample or from a new sample. Retest for chemical analysis need be only for those specific elements that failed to meet the test requirement.

If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that, during preparation or after completion of any test, it is clearly determined that specified or proper procedures were not followed in preparing the weld test assembly or test specimen(s) or in conducting the test, the test shall be considered invalid, without regard to whether the test was actually completed, or whether test results met, or failed to meet, the requirement. That test shall be repeated, following proper specified procedures. In this case the requirement for doubling of the number of test specimens does not apply.

9. Weld Test Assemblies

9.1 Two test assemblies are required for all classifications except ECuNi, which may require three test assemblies (see Fig. 3). The three test assemblies are as follows:

- (a) the weld pad in Fig. 1 for chemical analysis of the undiluted weld metal
- (b) the groove weld in Fig. 2 for mechanical properties and soundness of the weld metal
- (c) the groove weld in Fig. 3 for the usability of ECuNi electrodes

The sample for chemical analysis may be taken from the reduced section of the fractured tension specimen or from a corresponding location (or any location above it) in Fig. 2, thereby avoiding the need to make the weld pad. In the case of dispute, the weld pad shall be the referee method.

9.2 Preparation of each weld test assembly shall be as prescribed in 9.3 and 9.4. The base metal for each assembly shall be as required in Table 3 according to the tests to be conducted and shall meet the requirements of the appropriate ASTM specification shown there, or an equivalent

Table 1
Chemical Composition Requirements for Undiluted Weld Metal

Composition, weight-percent ^{a, b}														
AWS Classification	UNS Number ^c	Common Name	Cu Including Ag	Zn	Sn	Mn	Fe	Si	Ni ^d	P	Al	Pb	Ti	Total Other Elements
ECu	W60189	Copper	Remainder	f	f	0.10	0.20	0.10	f	f	0.10	0.01	—	0.50
ECuSi	W60656	Silicon bronze (copper-silicon)	Remainder	f	1.5	1.5	0.50	2.4–4.0	f	f	0.01	0.02	—	0.50
ECuSn-A	W60518	Phosphor bronze (copper-tin)	Remainder	f	4.0–6.0	f	0.25	f	f	0.05–0.35	0.01	0.02	—	0.50
ECuSn-C	W60521		Remainder	f	7.0–9.0	f	0.25	f	f	0.05–0.35	0.01	0.02	—	0.50
ECuNi ^e	W60715	Copper nickel (70/30)	Remainder	f	f	1.00–2.50	0.40–0.75	0.50	29.0–33.0	0.020	—	0.02	0.50	0.50
ECuAl-A2	W60614	Aluminum bronze	Remainder	f	f	f	0.50–5.0	1.5	f	—	6.5–9.5	0.02	—	0.50
ECuAl-B	W60619	Aluminum bronze	Remainder	f	f	f	2.5–5.0	1.5	f	—	9.5–11.5	0.02	—	0.50
ECuNiAl	W60632	Nickel aluminum bronze	Remainder	f	f	0.50–3.5	3.0–6.0	1.5	4.0–6.0	—	8.0–9.5	0.02	—	0.50
ECuMnNiAl	W60633	Manganese-nickel aluminum bronze	Remainder	f	f	11.0–14.0	2.0–4.0	1.5	1.5–3.0	—	6.0–8.5	0.02	—	0.50

^a Analysis shall be made for the elements for which specific values or an “f” are shown in this table. If, however, the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of other elements is not present in excess of the limits specified for “total other elements” in the last column in the table.

^b Single values shown are maximum.

^c ASTM D5-56/SAE HS-1086, *Metals & Alloys in the Unified Numbering System*.

^d Includes cobalt.

^e Sulfur shall be restricted to 0.015% maximum for the ECuNi classification.

^f This element must be included in total other elements.

TABLE 2
REQUIRED TESTS FOR CLASSIFICATION^a

AWS Classification	Chemical Analysis	Tension Test	Transverse Side-Bend Test	Radiographic Test
ECu	Required	Required	Required	Not Required
ECuSi	Required	Required	Required	Not Required
ECuSn-A	Required	Required	Required	Not Required
ECuSn-C	Required	Required	Required	Not Required
ECuNi	Required	Required	Required	Required
ECuAl-A2	Required	Required	Required	Not Required
ECuAl-B	Required	Required	Not Required	Not Required
ECuNiAl	Required	Required	Not Required	Not Required
ECuMnNiAl	Required	Required	Not Required	Not Required

NOTE:

- a. All welding for chemical analysis, all-weld-metal tension tests, and transverse side-bend tests shall be done with the test plates in the flat position.

specification. Testing of the assemblies shall be as prescribed in Clause 10, Chemical Analysis, Clause 11, Radiographic Test, Clause 12, Tension Test, and Clause 13, Bend Test.

9.3 Weld Pad. A weld pad shall be prepared as specified in Fig. 1 except when one of the alternatives in 10.1 (taking the sample from the broken tension test specimen or from a corresponding location in the groove weld) is selected. Base metal of any convenient size, of the type specified in Table 3 (including notes a and b to that table) shall be used as the base for the weld pad. The surface of the base metal on which the filler metal is deposited shall be clean. The pad shall be welded in the flat position with multiple beads to obtain undiluted weld metal. The preheat temperature shall not be less than 60°F [15°C] and the interpass temperature shall not exceed 300°F [150°C]. The slag shall be removed after each pass. The pad may be quenched in water of a temperature above 60°F [15°C] between passes. The dimensions of the completed pad shall be as shown in Fig. 1 for each size of electrode. Testing of this assembly shall be as specified in Clause 10, Chemical Analysis.

9.4 Groove Weld

9.4.1 Mechanical Properties and Soundness. A test assembly shall be prepared and welded as specified in Fig. 2 using base material of the appropriate type as specified in Table 3. Testing of the assembly shall be as specified in Clause 12, Tension Test, and Clause 13, Bend Test. The test specimens shall be tested in the as welded condition.

9.4.2 Usability Test. A test assembly shall be for electrodes of the ECuNi classification and welded as shown in Fig. 3, using base metal of the appropriate type specified in Table 3. The welding position shall be vertical for the $\frac{3}{32}$ in. [2.4 mm or 2.5 mm] and $\frac{1}{8}$ in. [3.2 mm] diameter electrodes or flat for the $\frac{5}{32}$ in. [4.0 mm] and $\frac{3}{16}$ in. [4.8 mm, 5.0 mm, or 6.0 mm] diameter electrodes. Testing

of the assembly shall be as specified in Clause 11, Radiography Test.

10. Chemical Analysis

10.1 The sample for analysis shall be taken from weld metal produced with the electrode. The sample shall be taken from a weld pad (see Fig. 1), from the reduced section of the fractured all-weld-metal tension specimen (see Fig. 2), or from a corresponding location in the groove weld (see Fig. 2 or Fig. 3). The top surface of the weld pad described in 9.3 and shown in Fig. 1 shall be removed and discarded, and a sample for analysis shall be obtained by any appropriate mechanical means. The sample shall be free of slag.

10.2 The sample taken from the reduced section of the fractured tension specimen, or from the corresponding location in the groove weld in Fig. 2 or Fig. 3 shall be prepared for analysis by any suitable mechanical means.

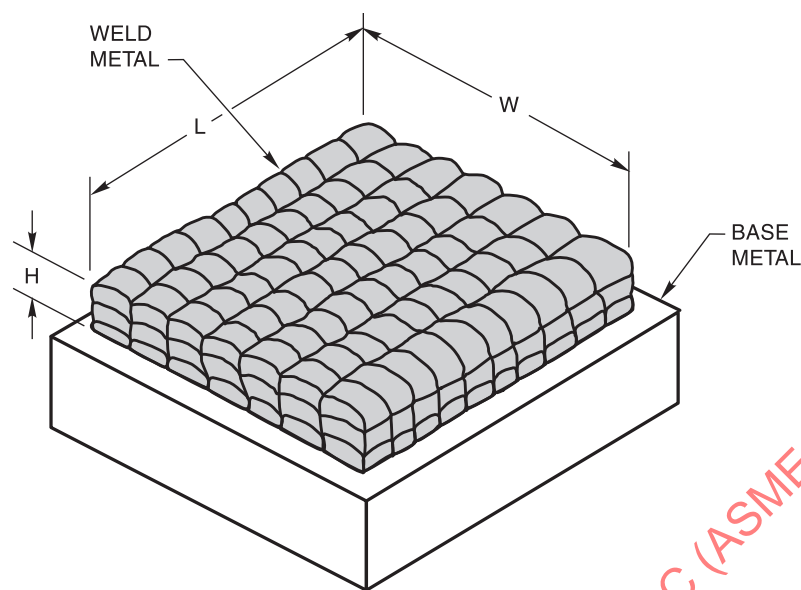
10.3 The sample shall be analyzed by accepted analytical methods. The referee method shall be ASTM E 478. For classification ECuNi, where titanium may be intentionally added up to 0.50%, the element titanium should be analyzed by using ASTM E 75.

10.4 The results of the analysis shall meet the requirements of Table 1 for the classification of electrode under test.

11. Radiographic Test

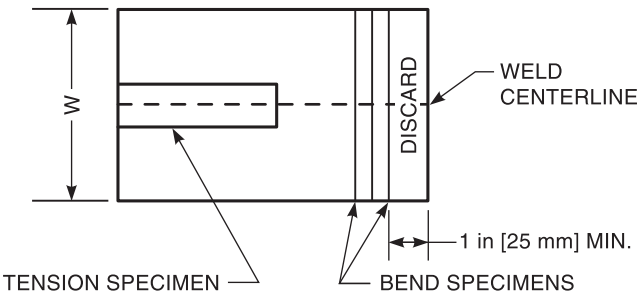
11.1 When required in Table 2, the groove weld described in 9.4.2 and shown in Fig. 3 shall be radiographed to evaluate the soundness of the weld metal and the usability of the electrode. In preparation for radiography, the backing shall be removed and both surfaces of the weld shall be machined or ground smooth and flush with the

FIG. 1 PAD FOR CHEMICAL ANALYSIS OF UNDILUTED WELD METAL

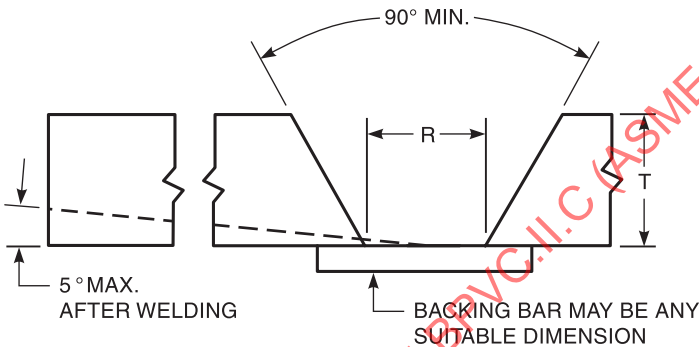


Electrode Size			Weld Pad Size, Minimum		Minimum Distance of Sample From Surface of Base Plate	
in.	mm		in.	mm	in.	mm
$\frac{3}{32}$	2.4	L W H	$1\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$	38 13 13	$\frac{3}{8}$	10
$\frac{3}{32}$	2.5	L W H	$1\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$	38 13 13	$\frac{3}{8}$	10
$\frac{1}{8}$	3.2	L W H	2 $\frac{1}{2}$ $\frac{5}{8}$	50 13 16	$\frac{1}{2}$	13
$\frac{5}{32}$	4.0	L W H	2 $\frac{1}{2}$ $\frac{5}{8}$	50 13 16	$\frac{1}{2}$	13
$\frac{3}{16}$	4.8	L W H	2 $\frac{1}{2}$ $\frac{5}{8}$	50 13 16	$\frac{1}{2}$	13
$\frac{3}{16}$	5.0	L W H	2 $\frac{1}{2}$ $\frac{5}{8}$	50 13 16	$\frac{1}{2}$	13
$\frac{3}{16}$	6.0	L W H	2 $\frac{1}{2}$ $\frac{5}{8}$	50 13 16	$\frac{1}{2}$	13

FIG. 2 TEST ASSEMBLY FOR TENSION AND BEND TEST



LAYOUT OF TEST ASSEMBLY



GROOVE PREPARATION

Electrode Size, in. [mm]	Root Opening, R ^a		Test Plate Thickness T, min.		Number of Layers ^b	Width of Test Plate, W, min.	
	in.	mm	in.	mm		in.	mm
$\frac{1}{8}$ [3.2] and less	$\frac{1}{4}$	6.4	$\frac{1}{2}$	12	...	6	150
$\frac{5}{32}$ [4.0] and larger	$\frac{1}{2}$	13	$\frac{3}{4}$	20	6 to 9	6	150

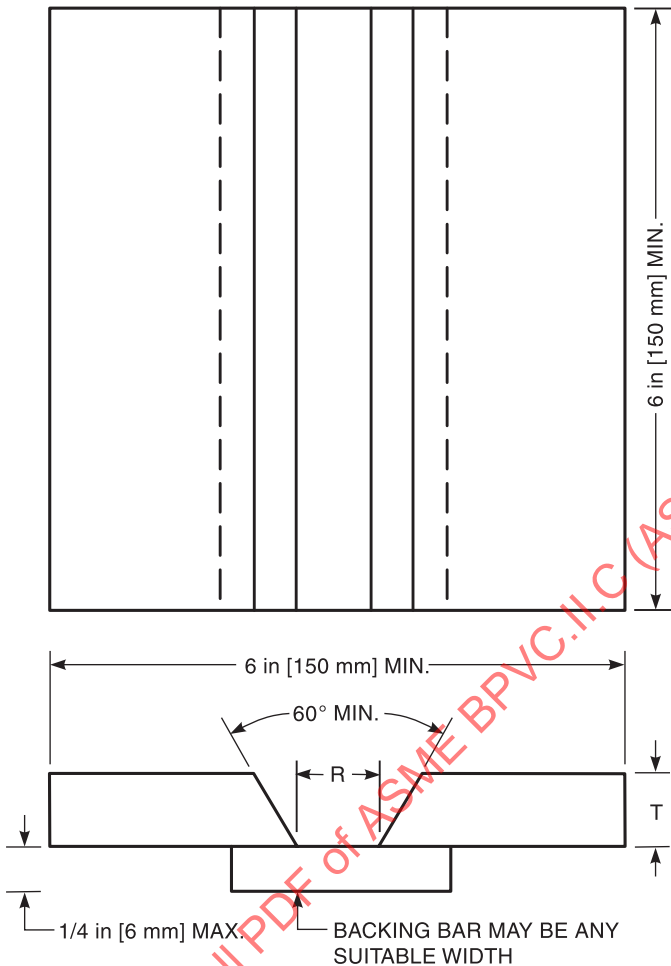
GENERAL NOTES:

1. Weld test plates for all-weld-metal tension and bend specimens shall be prepared using the plate base metal shown in Table 3.
2. The surfaces to be welded shall be clean.
3. Welding shall be performed with the plates in the flat position, using the current values and welding techniques recommended by the electrode manufacturer.
4. Preheat temperature shall be 60°F [15°C] minimum. The interpass temperature shall not exceed 300°F [150°C]. For ECU_{Si} classification, the interpass temperature shall not exceed 150°F [65°C].
5. The weld metal shall have a maximum bead width equal to six (6) times the core wire diameter. The completed weld shall be at least flush with the surface of the test plate.
6. Tests shall be conducted in the as welded condition.

NOTES:

- a. Root opening tolerance is $\pm \frac{1}{16}$ in. [± 1.5 mm].
- b. For the ECU_{Ni} classification, the minimum groove angle shall be 60 deg. For all classifications, the number of layers for the $\frac{1}{8}$ in. [3.2 mm] and smaller electrodes shall be recorded and reported. The $\frac{5}{32}$ in. [4.0 mm] and larger electrodes shall have a minimum of six layers and a maximum of nine layers.

FIG. 3 GROOVE WELD FOR RADIOGRAPHIC TEST (ECuNi ONLY)



Electrode Size		Root Opening ^a		Test Plate Thickness T, min.	
in.	mm	in.	mm	in.	mm
$\frac{3}{32}$	2.4, 2.5	$\frac{1}{4}$	6.4	$\frac{1}{4}$	6
$\frac{1}{8}$	3.2	$\frac{5}{16}$	8	$\frac{3}{8}$	10
$\frac{5}{32}$	4.0	$\frac{3}{8}$	9.5	$\frac{1}{2}$	12
$\frac{3}{16}$	4.8, 5.0, 6.0	$\frac{1}{2}$	12	$\frac{1}{2}$	12

GENERAL NOTES:

1. Welding shall be conducted in the vertical position or flat position as prescribed in 9.4.2.
2. Base metal shall be in accordance with Table 3.
3. The surfaces to be welded shall be clean.
4. Each weld bead shall contain a start in the area to be evaluated. The weld metal shall have a maximum bead width equal to six (6) times the core wire diameter. The root layer for a test of $\frac{5}{32}$ in. [4.0 mm] electrode or larger may be deposited with a $\frac{3}{32}$ in. [2.4 mm or 2.5 mm] or $\frac{1}{8}$ in. [3.2 mm] electrode.
5. The completed weld shall be at least flush with the surface of the test plate.
6. Preheat temperature shall be 60°F [15°C] minimum. The interpass temperature shall not exceed 300°F [150°C].
7. After completion of the weld, the weld reinforcement and backing strip shall be removed flush with the base plate surfaces and the assembly shall be radiographed.

NOTE:

- a. Root opening tolerance is $\pm \frac{1}{16}$ in. [± 1.5 mm].

TABLE 3
BASE METALS FOR TEST ASSEMBLIES

AWS Classification	Base Metal (ASTM Specification and UNS Numbers)			
	UNS Number ^a	Chemical Analysis	All-Weld-Metal Tension Test	Transverse Side-Bend Test
ECu	C12200	B152	B152	B152
ECuSi	C65500	B96	B97	B96
ECuSn-A	C51100	B103	B103	B103
ECuSn-C	C52100	B103	B103	B103
ECuNi ^b	C71500	B122	B122	B122
ECuAl-A2	C61400	B169	B169	B169
ECuAl-B	C95400	B148	B148	...
ECuNiAl	C95800	B148	B148	...
ECuMnNiAl	C95700	B148	B148	...

NOTES:

a. ASTM DS-56/SAE HS-1086, *Metals & Alloys in the Unified Numbering System*.

b. Groove weld usability tests shall be conducted for the ECuNi classification as per Fig. 3 using B122 base metal (UNS C71500).

original surfaces of the base metal or with a uniform reinforcement not exceeding $\frac{3}{32}$ in. [2.5 mm]. It is permitted on both sides of the test assembly to remove base metal to a depth of $\frac{1}{16}$ in. [1.5 mm] nominal below the original base metal surface in order to facilitate backing and/or buildup removal. The thickness of the weld metal shall not be reduced by more than $\frac{1}{16}$ in. [1.5 mm] so that the machined thickness of the radiographic test specimen equals at least the thickness of the base metal minus $\frac{1}{16}$ in. [1.5 mm]. Both surfaces of the test assembly, in the area of the weld, shall be smooth enough to avoid difficulty in interpreting the radiograph.

11.2 The weld shall be radiographed in accordance with ASTM E 1032.

11.3 The soundness of the weld metal and the usability of the electrode meet the requirements of this specification if the radiograph shows

(a) no cracks, no incomplete fusion and no incomplete penetration

(b) no slag inclusions in excess of those permissible in Note 4 in the radiographic standards in Figs. 4A, 4B, 4C, and 4D

(c) no rounded indications in excess of those permitted by the radiographic standards in Figs. 4A, 4B, 4C, and 4D

In evaluating the radiograph, 1 in. [25 mm] of the weld on each end of the test assembly shall be disregarded.

11.3.1 A rounded indication is an indication (on the radiograph) whose length is no more than three times its width. Rounded indications may be circular or irregular in shape, and they may have tails. The size of a rounded indication is the largest dimension of the indication, including any tail that may be present.

11.3.2 The indications may be of porosity or slag. Indications whose largest dimension does not exceed $\frac{1}{64}$ in.

[0.4 mm] shall be disregarded. Test assemblies with indications larger than the large indications permitted in the radiographic standards do not meet the requirements of this specification.

12. Tension Test

12.1 One all-weld metal round tension specimen, as specified in the Tension Test section of AWS B4.0 or AWS B4.0M, shall be machined from the groove weld described in 9.4.1 and shown in Fig. 2. The tensile specimen shall have a nominal diameter of 0.500 in. [12.5 mm] for test assemblies $\frac{3}{4}$ in. [20 mm] thick, or 0.250 in. [6 mm] for test assemblies $\frac{1}{2}$ in. [12 mm] thick. All tensile specimens shall have a nominal gage-length-to-diameter ratio of 4:1. Other dimensions of the tension test specimen shall be as specified in AWS B4.0 or B4.0M.

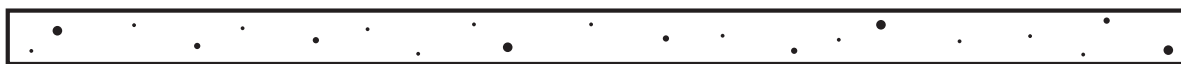
12.2 The specimen shall be tested in the as-welded condition in the manner described in the tension test section of AWS B4.0 or AWS B4.0M.

12.3 The results of the tension test shall meet the requirements specified in Table 4.

13. Bend Test

13.1 Two transverse side bend specimens as required in Table 2 shall be machined from the groove weld described in 9.4.1 and shown in Fig. 2.

13.2 The specimens (in the as-welded condition) shall be tested in the manner described in the bend test section of AWS B4.0 or AWS B4.0M. A $\frac{3}{8}$ in. [10 mm] thick specimen shall be uniformly bent 180 deg over a $\frac{3}{4}$ in. [19 mm] radius. Any suitable fixture, as specified in the Bend Test section of AWS B4.0 or AWS B4.0M, may be used. Positioning of the specimen shall be such that the

FIG. 4A RADIOGRAPHIC ACCEPTANCE STANDARD FOR $\frac{1}{4}$ IN. [6 MM] TEST PLATE**(A) ASSORTED ROUNDED INDICATIONS**

SIZE $\frac{1}{64}$ in TO 0.050 in [0.4 mm TO 1.3 mm] IN DIAMETER OR IN LENGTH

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 21, WITH THE FOLLOWING RESTRICTIONS:

MAXIMUM NUMBER OF LARGE 0.031 in TO 0.050 in [0.8 mm TO 1.3 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 4

MAXIMUM NUMBER OF MEDIUM 0.020 in TO 0.031 in [0.5 mm TO 0.8 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 5

MAXIMUM NUMBER OF SMALL $\frac{1}{64}$ in TO 0.020 in [0.4 mm TO 0.5 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 12

**(B) LARGE ROUNDED INDICATIONS**

SIZE 0.031 in TO 0.050 in [0.8 mm TO 1.3 mm] IN DIAMETER OR IN LENGTH

MAXIMUM NUMBER INDICATIONS IN ANY 6 in [150 mm] OF WELD = 8

**(C) MEDIUM ROUNDED INDICATIONS**

SIZE 0.020 in TO 0.031 in [0.5 mm TO 0.8 mm] IN DIAMETER OR IN LENGTH

MAXIMUM NUMBER INDICATIONS IN ANY 6 in [150 mm] OF WELD = 19

**(D) SMALL ROUNDED INDICATIONS**

SIZE $\frac{1}{64}$ in TO 0.020 in [0.4 mm TO 0.5 mm] IN DIAMETER OR IN LENGTH

MAXIMUM NUMBER INDICATIONS IN ANY 6 in [150 mm] OF WELD = 48

GENERAL NOTES:

- (1) The chart that is most representative of the size of the rounded indications in the radiograph of the test assembly shall be used to determine conformance with this specification. Rounded indications $\frac{1}{64}$ in. [0.4 mm] and smaller shall be disregarded. The largest dimension of the indication (including any tail) is the size of the indication.
- (2) These radiographic requirements are for test welds made in the laboratory specifically for classification purposes. They are more restrictive than those normally encountered in general fabrication.
- (3) When using the alternative method of evaluation described in 11.3.1, the total cross-sectional area of the rounded indications (calculated from measurements taken from the radiograph) shall not exceed 0.015 in.² [10 mm²] in any 6 in. [150 mm] of weld.
- (4) The acceptance standard for slag inclusions in this assembly is the following:
 - (a) Length of each individual slag indication: $\frac{5}{32}$ in. [4.0 mm] maximum
 - (b) Total length of all slag indications: $\frac{1}{4}$ in. [6.4 mm] maximum

FIG. 4B RADIOGRAPHIC ACCEPTANCE STANDARD FOR $\frac{3}{8}$ IN. [10 MM] TEST PLATE**(A) ASSORTED ROUNDED INDICATIONS**

SIZE $\frac{1}{64}$ in TO 0.075 in [0.4 mm TO 1.9 mm] IN DIAMETER OR IN LENGTH

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 17, WITH THE FOLLOWING RESTRICTIONS:

MAXIMUM NUMBER OF LARGE 0.049 in TO 0.075 in [1.3 mm TO 1.9 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 3

MAXIMUM NUMBER OF MEDIUM 0.020 in TO 0.049 in [0.5 mm TO 1.3 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 3

MAXIMUM NUMBER OF SMALL $\frac{1}{64}$ in TO 0.020 in [0.4 mm TO 0.5 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 11

**(B) LARGE ROUNDED INDICATIONS**

SIZE 0.049 in TO 0.075 in [1.3 mm TO 1.9 mm] IN DIAMETER OR IN LENGTH

MAXIMUM NUMBER INDICATIONS IN ANY 6 in [150 mm] OF WELD = 5

**(C) MEDIUM ROUNDED INDICATIONS**

SIZE 0.020 in TO 0.049 in [0.5 mm TO 1.3 mm] IN DIAMETER OR IN LENGTH

MAXIMUM NUMBER INDICATIONS IN ANY 6 in [150 mm] OF WELD = 11

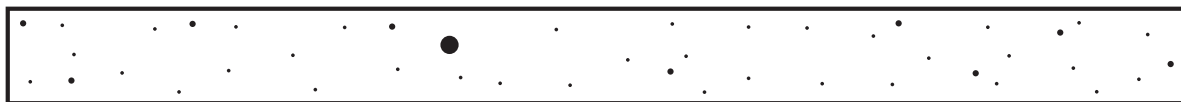
**(D) SMALL ROUNDED INDICATIONS**

SIZE $\frac{1}{64}$ in TO 0.020 in [0.4 mm TO 0.5 mm] IN DIAMETER OR IN LENGTH

MAXIMUM NUMBER INDICATIONS IN ANY 6 in [150 mm] OF WELD = 72

GENERAL NOTES:

- (1) The chart that is most representative of the size of the rounded indications in the radiograph of the test assembly shall be used to determine conformance with this specification. Rounded indications $\frac{1}{64}$ in. [0.4 mm] and smaller shall be disregarded. The largest dimension of the indication (including any tail) is the size of the indication.
- (2) These radiographic requirements are for test welds made in the laboratory specifically for classification purposes. They are more restrictive than those normally encountered in general fabrication.
- (3) When using the alternative method of evaluation described in 11.3.1, the total cross-sectional area of the rounded indications (calculated from measurements taken from the radiograph) shall not exceed 0.023 in.² [15 mm²] in any 6 in. [150 mm] of weld.
- (4) The acceptance standard for slag inclusions in this assembly is the following:
 - (a) Length of each individual slag indication: $\frac{7}{32}$ in. [5.6 mm] maximum
 - (b) Total length of all slag indications: $\frac{3}{8}$ in. [10 mm] maximum

FIG. 4C RADIOGRAPHIC ACCEPTANCE STANDARD FOR $\frac{1}{2}$ IN. [12 MM] TEST PLATE**(A) ASSORTED ROUNDED INDICATIONS**

SIZE $\frac{1}{64}$ in TO 0.10 in [0.4 mm TO 2.5 mm] IN DIAMETER OR IN LENGTH

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 45, WITH THE FOLLOWING RESTRICTIONS:

MAXIMUM NUMBER OF LARGE 0.031 in TO 0.10 in [0.8 mm TO 2.5 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 4

MAXIMUM NUMBER OF MEDIUM 0.020 in TO 0.031 in [0.5 mm TO 0.8 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 9

MAXIMUM NUMBER OF SMALL $\frac{1}{64}$ in TO 0.020 in [0.4 mm TO 0.5 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 35

**(B) LARGE ROUNDED INDICATIONS**

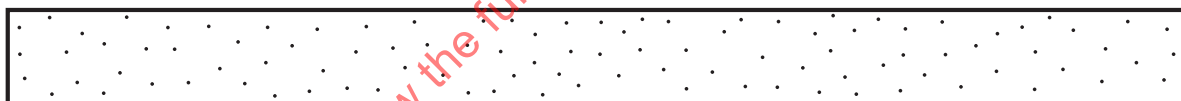
SIZE 0.031 in TO 0.10 in [0.8 mm TO 2.5 mm] IN DIAMETER OR IN LENGTH

MAXIMUM NUMBER INDICATIONS IN ANY 6 in [150 mm] OF WELD = 4

**(C) MEDIUM ROUNDED INDICATIONS**

SIZE 0.020 in TO 0.031 in [0.5 mm TO 0.8 mm] IN DIAMETER OR IN LENGTH

MAXIMUM NUMBER INDICATIONS IN ANY 6 in [150 mm] OF WELD = 40

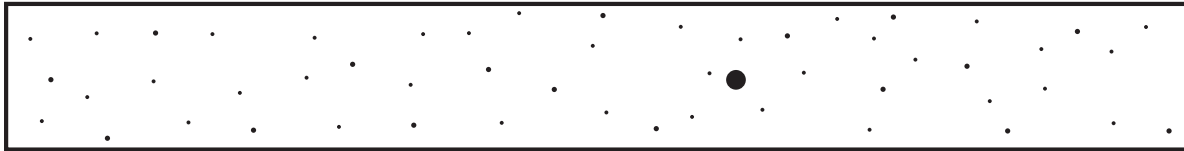
**(D) SMALL ROUNDED INDICATIONS**

SIZE $\frac{1}{64}$ in TO 0.020 in [0.4 mm TO 0.5 mm] IN DIAMETER OR IN LENGTH

MAXIMUM NUMBER INDICATIONS IN ANY 6 in [150 mm] OF WELD = 101

GENERAL NOTES:

- (1) The chart that is most representative of the size of the rounded indications in the radiograph of the test assembly shall be used to determine conformance with this specification. Rounded indications $\frac{1}{64}$ in. [0.4 mm] and smaller shall be disregarded. The largest dimension of the indication (including any tail) is the size of the indication.
- (2) These radiographic requirements are for test welds made in the laboratory specifically for classification purposes. They are more restrictive than those normally encountered in general fabrication.
- (3) When using the alternative method of evaluation described in 11.3.1, the total cross-sectional area of the rounded indications (calculated from measurements taken from the radiograph) shall not exceed 0.030 in.² [20 mm²] in any 6 in. [150 mm] of weld.
- (4) The acceptance standard for slag inclusions in this assembly is the following:
 - (a) Length of each individual slag indication: $\frac{7}{32}$ in. [5.6 mm] maximum
 - (b) Total length of all slag indications: $\frac{7}{16}$ in. [11 mm] maximum

FIG. 4D RADIOGRAPHIC ACCEPTANCE STANDARD FOR $\frac{3}{4}$ IN. [20 MM] TEST PLATE**(A) ASSORTED ROUNDED INDICATIONS**

SIZE $\frac{1}{64}$ in TO 0.125 in [0.4 mm TO 3.2 mm] IN DIAMETER OR IN LENGTH

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 53, WITH THE FOLLOWING RESTRICTIONS:

MAXIMUM NUMBER OF LARGE 0.034 in TO 0.125 in [0.9 mm TO 3.2 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 1

MAXIMUM NUMBER OF MEDIUM 0.024 in TO 0.034 in [0.6 mm TO 0.9 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 17

MAXIMUM NUMBER OF SMALL $\frac{1}{64}$ in TO 0.024 in [0.4 mm TO 0.6 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 35

**(B) LARGE ROUNDED INDICATIONS**

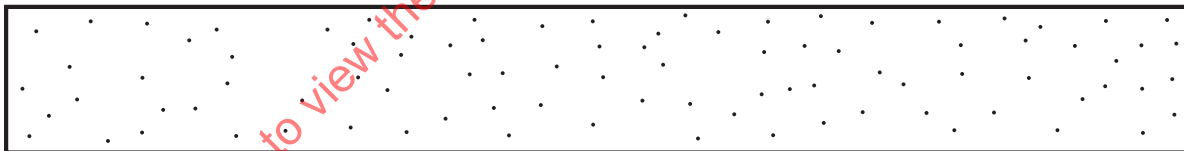
SIZE 0.034 in TO 0.1 in [0.9 mm TO 2.5 mm] IN DIAMETER OR IN LENGTH

MAXIMUM NUMBER INDICATIONS IN ANY 6 in [150 mm] OF WELD = 4

**(C) MEDIUM ROUNDED INDICATIONS**

SIZE 0.024 in TO 0.034 in [0.6 mm TO 0.9 mm] IN DIAMETER OR IN LENGTH

MAXIMUM NUMBER INDICATIONS IN ANY 6 in [150 mm] OF WELD = 50

**(D) SMALL ROUNDED INDICATIONS**

SIZE $\frac{1}{64}$ in TO 0.024 in [0.4 mm TO 0.6 mm] IN DIAMETER OR IN LENGTH

MAXIMUM NUMBER INDICATIONS IN ANY 6 in [150 mm] OF WELD = 90

GENERAL NOTES:

- (1) The chart that is most representative of the size of the rounded indications in the radiograph of the test assembly shall be used to determine conformance with this specification. Rounded indications $\frac{1}{64}$ in. [0.4 mm] and smaller shall be disregarded. The largest dimension of the indication (including any tail) is the size of the indication.
- (2) These radiographic requirements are for test welds made in the laboratory specifically for classification purposes. They are more restrictive than those normally encountered in general fabrication.
- (3) When using the alternative method of evaluation described in 11.3.1, the total cross-sectional area of the rounded indications (calculated from measurements taken from the radiograph) shall not exceed 0.045 in.² [30 mm²] in any 6 in. [150 mm] of weld.
- (4) The acceptance standard for slag inclusions in this assembly is the following:
 - (a) Length of each individual slag indication: $\frac{5}{16}$ in. [7.9 mm] maximum
 - (b) Total length of all slag indications: $\frac{15}{32}$ in. [11.9 mm] maximum

TABLE 4
MECHANICAL PROPERTY REQUIREMENTS

AWS Classification	Tensile Strength, min.		Elongation Percent, min.
	ksi	MPa	
ECu	25	170	20
ECuSi	50	350	20
ECuSn-A	35	240	20
ECuSn-C	40	280	20
ECuNi	50	350	20
ECuAl-A2	60	410	20
ECuAl-B	65	450	20
ECuNiAl	72	500	10
ECuMnNiAl	75	520	15

side of the specimen with the greater discontinuities, if any, is in tension.

13.3 Each specimen, after bending, shall conform to the specified radius, with appropriate allowance for spring back, and the weld metal shall show no cracks or open discontinuities exceeding $\frac{1}{8}$ in. [3.2 mm] measured in any direction. Small checks or cracks at the edges of the test specimen shall be disregarded.

14. Method of Manufacture

The electrodes classified according to this specification may be manufactured by any method that will produce material that meets the requirements of this specification.

15. Standard Sizes and Lengths

15.1 Standard sizes and lengths of electrodes are shown in Table 5. Other sizes shall be as agreed upon between the purchaser and manufacturer.

15.2 Diameter of the core wire shall not vary more than ± 0.003 in. [± 0.1 mm] from the diameter specified. Length shall not vary more than $\pm \frac{1}{4}$ in. [$\pm 2\%$ of the nominal mm length].

16. Core Wire and Covering

16.1 The core wire and covering shall be free of defects that would interfere with uniform deposition of the weld electrode.

16.2 The core wire and the covering shall be concentric to the extent that the maximum core-plus-one covering dimension does not exceed the minimum core-plus-one covering dimension by more than:

(a) 7% of the mean dimension for $\frac{3}{32}$ in. [2.4 mm and 2.5 mm]

(b) 5% of the mean dimension for sizes $\frac{1}{8}$ in. and $\frac{5}{32}$ in. [3.2 mm and 4.0 mm]

(c) 4% of the mean dimension for $\frac{3}{16}$ in. [4.8 mm, 5.0 mm, and 6.0 mm]

Concentricity may be measured by any suitable means.

17. Exposed Core

17.1 The grip end of each electrode shall be bare (free of covering) for a distance of not less than $\frac{1}{2}$ in. [12 mm], nor more than $1\frac{1}{4}$ in. [30 mm] for electrodes $\frac{5}{32}$ in. [4.0 mm] and smaller, and not less than $\frac{3}{4}$ in. [19 mm], nor more than $1\frac{1}{2}$ in. [38 mm] for electrodes $\frac{3}{16}$ in. [4.8 mm] and larger, to provide for electrical contact with the electrode holder.

17.2 The arc end of each electrode shall be sufficiently bare, and the covering sufficiently tapered, to permit easy striking of the arc. The length of the bare portion (measured from the end of the core wire to the location where the full cross section of the covering is obtained) shall not exceed $\frac{1}{8}$ in. [3 mm] or the diameter of the core wire, whichever is less. Electrodes with chipped coverings near the arc end, baring the core wire no more than the lesser of $\frac{1}{4}$ in. [6 mm] or twice the diameter of the core wire, meet the requirement of this specification provided no chip uncovers more than 50% of the circumference of the core.

18. Electrode Identification

All electrodes shall be identified as follows:

18.1 At least one imprint of the electrode classification shall be applied to the electrode covering beginning within $2\frac{1}{2}$ in. [65 mm] of the grip end of the electrode. The prefix letter "E" in the classification may be omitted from the imprint.

18.2 The numbers and letters of the imprint shall be of bold block type a size large enough to be legible.

18.3 The ink used for imprinting shall provide sufficient contrast with the electrode covering so that, in normal use, the numbers and letters are legible, both before and after welding.

19. Packaging

19.1 Electrodes shall be suitably packaged to protect them against damage during shipment and storage under normal conditions.

19.2 Standard package weights shall be as agreed upon by the supplier and purchaser.

20. Marking of Packages

20.1 The following product information (as a minimum) shall be legibly marked on the outside of each unit package:

TABLE 5
STANDARD SIZES AND LENGTHS

Standard Size (Core Wire Diameter)		Standard Length ^{a, b}			
		Classification			
		ECuAl-B, ECuNiAl		All Others	
in.	mm	in.	mm	in.	mm
$\frac{3}{32}$	2.4 ^c	...	...	9 or 12	250 or 300
...	2.5	...	...	9 or 12	250 or 300
$\frac{1}{8}$	3.2	14	350	14	350
$\frac{5}{32}$	4.0	14 or 18	350 or 450	14 or 18	350 or 450
$\frac{3}{16}$	4.8 ^c	14 or 18	350 or 450	14 or 18	350 or 450
...	5.0	14 or 18	350 or 450	14 or 18	350 or 450
...	6.0	14 or 18	350 or 450	14 or 18	350 or 450

NOTES:

- a. Lengths other than these shall be as agreed upon between purchaser and supplier.
b. In all cases, end-gripped electrodes are standard.
c. Not included in ISO 544.

(a) AWS specification and classification designations
(year of issue may be excluded)

(b) Supplier's name and trade designation

(c) Size and net weight

(d) Lot, control, or heat number

20.2 The appropriate precautionary information⁸ given in ANSI Z49.1, latest edition (as a minimum), or its equivalent, shall be prominently displayed in legible print on all packages, including individual unit packages within a larger package.

⁸ Typical examples of "warning labels" are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

Annex A (Informative)

Guide to AWS Specification for Copper and Copper-Alloy Electrodes for Shielded Metal Arc Welding

(This annex is not part of AWS A5.6/A5.6M:2008, *Specification for Copper and Copper-Alloy Electrodes for Shielded Metal Arc Welding*, but is included for informational purposes only.)

A1. Introduction

The purpose of this guide is to correlate the electrode classifications with their intended applications so the specification can be used effectively. Appropriate base metal specifications are referred to whenever that can be done and when it would be helpful. Such references are intended only as examples rather than complete listings of the materials for which each electrode is suitable.

A2. Classification System

A2.1 The system for identifying the electrode classification in this specification follows the standard pattern used in other AWS filler metal specifications, namely:

(a) The letter E at the beginning of each classification designation indicates a covered electrode.

(b) The chemical symbol Cu is used to identify the electrodes as copper-base alloys, and the additional chemical symbol, such as Si in ECuSi, Sn in ECuSn, etc., indicates the principal alloying element of each classification or group of similar classifications. Where more than one classification is included in a basic group, the individual classifications in the group are identified by the letters A, B, C, etc., as in ECuSn-A. Further subdividing is done by using a 1, 2, etc., after the last letter, as the 2 in ECuAl-A2.

A2.2 Request for Filler Metal Classification

A2.2.1 A request to establish a new electrode classification must be written, and it needs to provide sufficient detail to permit the A5 Committee on Filler Metals and Allied Materials or the Subcommittee to determine whether a new classification or a modification of an existing classification is more appropriate, and whether either is necessary to satisfy the need.

In particular, the request needs to include:

(a) all classification requirements as given for existing classifications, such as chemical composition ranges, mechanical property requirements, and usability test requirements.

(b) any testing conditions for conducting the tests used to demonstrate that the product meets the classification requirements. (It would be sufficient, for example, to state that welding conditions are the same as the other classifications.)

(c) Information on Descriptions and Intended Use, which parallels existing classifications for that section in the Annex.

A request for a new classification without the above information will be considered incomplete. The Secretary will return the request to the requestor for further information.

A2.2.2 The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters. Upon receipt of the request, the Secretary will:

(a) assign an identifying number to the request. This number will include the date the request was received.

(b) confirm receipt of the request and give the identification number to the person who made the request.

(c) send a copy of the request to the Chair of the Committee on Filler Metals and Allied Materials and the Chair of the particular Subcommittee involved.

(d) file the original request.

(e) add the request to the log of outstanding requests.

A2.2.3 All necessary action on each request will be completed as soon as possible. If more than 12 months lapse, the Secretary shall inform the requestor of the status of the request, with copies to the Chairs of the Committee and the Subcommittee. Requests still outstanding after 18 months shall be considered not to have been answered in a timely manner, and the Secretary shall report these to the Chair of the A5 Committee on Filler Metals and Allied Materials for action.

A2.2.4 The Secretary shall include a copy of the log of all requests pending and those completed during the preceding year with the agenda for each A5 Committee on Filler Metals and Allied Materials meeting. Any other

TABLE A1
COMPARISON OF SPECIFICATIONS

Covered Electrodes A5.6/A5.6M	Bare Rods and Electrodes A5.7/A5.7M ^a	Proposed ISO Designations ^b
ECu	ERCu	EC1898
ECuSi	ERCuSi-A	EC6560
ECuSn-A	ERCuSn-A	EC5180
ECuSn-C	ERCuSn-C	EC5210
ECuNi	ERCuNi	EC7158
...	ERCuAl-A1	EC6100
ECuAl-A2	ERCuAl-A2	EC6180
...	ERCuAl-A3	EC6240
ECuAl-B	...	EC6220
ECuNiAl	ERCuNiAl	EC6328
ECuMnNiAl	ERCuMnNiAl	EC6338

NOTES:

- AWS A5.7/A5.7M, *Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes*.
- AWS Publication IFS:2002, *International Index of Filler Metal Classifications*, Table 12A. Also, Table 12B of that document covers bare welding materials which carry the initial letter, "SC," in place of "EC" for the comparable guide.

publication of requests that have been completed will be at the option of the American Welding Society, as deemed appropriate.

A2.3 Compositions of bare welding filler metal in AWS A5.7 similar to those in this specification are shown in Table A1.

A2.4 An international system for designating welding filler metals is under development by the International Institute of Welding (IIW) for use in future specifications to be issued by the International Standards Organization (ISO). Table A1 shows the proposed designations for copper-alloy filler metals. To understand the proposed international designation system, refer to Table 12A and the Annex of AWS publication IFS 2002, *International Index of Welding Filler Metal Classifications*.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01, *Filler Metal Procurement Guidelines*, as the specification states. Any testing a purchaser requires of the supplier, for material shipped in accordance with this specification, needs to be clearly stated in the purchase order, according to the provisions of AWS A5.01. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing the supplier normally conducts on material of that classification, as specified in Schedule F, Table 1, of AWS A5.01. Testing in accordance with any other Schedule in that Table must be specifically

required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product or the classification on the product itself, constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification. The only testing requirement implicit in this "certification" is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that the tested material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation. "Certification" is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the "certification" required by the specification is the classification test of "representative material" cited above, and the "Manufacturer's Quality Assurance System" in AWS A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes in the atmosphere to which welders and welding operators are exposed during welding. These are:

- dimensions of the space in which welding is done (with special regard to the height of the ceiling)
- number of welders working in that space
- rate of evolution of fumes, gases, or dust, according to the materials and processes used
- the proximity of the welders to the fumes, as these fumes issue from the welding zone, and to the gases and dusts in the space in which they are working
- the ventilation provided to the space in which the welding is performed

A5.2 American National Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding, and should be referred to for details. Attention is drawn particularly to the Section on Ventilation in that document. Further information concerning ventilation in welding can be found in AWS F3.2, *Ventilation Guide for Weld Fume*.

A6. Welding Considerations

A6.1 Before welding or heating any copper-base alloy, the base metal should be clean. Oil, grease, paint, lubricants, marking pencils, temperature indicating materials,

threading compounds, and other such materials frequently contain sulfur, lead, or silver, that may cause cracking (embrittlement) of the base metal or the weld metal if present during welding or heating.

A6.2 Electrodes of some of the classifications are used for dissimilar metal welds. When making such welds, it is important to obtain as little dilution as possible from the dissimilar metal member (steels, for example). This can be done by traveling slowly to deposit a thicker bead and to dissipate the energy of the arc against the molten weld metal or the copper base metal, rather than the dissimilar metal member.

A6.3 Most of the electrodes in this specification are intended to be used with direct current, electrode positive (dcep) polarity. Some electrodes may be designated to operate also on alternating current, which makes them desirable for minimizing arc blow. The electrode manufacturer should be consulted to determine if the particular product is designed to be used with alternating current.

A7. Description and Intended Use of Electrodes

A7.1 Copper and copper-alloy electrodes generally operate with DCEP and the coverings often are hygroscopic.

A7.1.1 The supplier should be consulted regarding the following:

- (a) specific operating parameters and positions
- (b) recommended storage conditions and reconditioning temperatures

A7.1.2 The weld area should be free from moisture and other contaminants.

A7.2 ECU Classification (Copper Electrodes). ECU electrodes are generally manufactured from deoxidized copper wire (essentially pure copper with small amounts of deoxidizers added) and may be used for shielded metal arc welding (SMAW) of deoxidized coppers, oxygen-free coppers, and tough pitch (electrolytic) coppers.

The electrodes are also used to repair or surface these base metals as well as to surface steel and cast iron. Mechanically and metallurgically sound joints can best be made in deoxidized coppers.

Reactions with hydrogen in oxygen-free copper, and the segregation of copper oxide in tough pitch copper may detract from joint efficiency. However, when highest quality is not required, ECU electrodes may be successfully used on these base metals.

The high thermal conductivity of unalloyed coppers in thick sections may require preheat and interpass temperatures up to 1000°F [540°C].

A7.3 ECU_{Si} Classification (Silicon Bronze). ECU_{Si} electrodes contain approximately 3% silicon plus small percentages of manganese and tin. They are used primarily for welding copper-silicon alloys. ECU_{Si} electrodes are occasionally used for the joining of copper, dissimilar metals, and some iron base metals. Silicon bronze weld metal seldom is used to surface bearing surfaces, but often is used to surface areas subject to corrosion.

A7.4 ECU_{Sn} Classification (Phosphor Bronze). ECU_{Sn} electrodes are used to join phosphor bronzes of similar compositions. They are also useful for joining brasses and, in some cases, for welding them to cast iron and carbon steel. ECU_{Sn} weld metals tend to flow sluggishly, requiring preheat and interpass temperatures of at least 400°F [200°C] on heavy sections. Postweld heat treatment may not be necessary, but it is desirable for maximum ductility, particularly if the weld metal is to be cold worked.

A7.4.1 ECU_{Sn}-A electrodes are used primarily to join base metals of similar composition. They also may be used to weld copper if the resultant weld metal has adequate electrical conductivity and corrosion resistance for the specific application.

A7.4.2 ECU_{Sn}-C electrodes have higher tin content resulting in weld metals of higher hardness, tensile strength, and yield strength compared to ECU_{Sn}-A weld metal.

A7.5 ECU_{Ni} Classification (Copper-Nickel). Electrodes of the ECU_{Ni} classification are used for shielded metal arc welding (SMAW) of wrought or cast ⁷⁰/₃₀, ⁸⁰/₂₀, and ⁹⁰/₁₀ copper-nickel alloys to themselves or to each other. They also are used for welding the clad side of copper-nickel clad steel. Preheating generally is not necessary.

A7.6 ECU_{Al} Classification (Aluminum Bronze)

A7.6.1 The copper-aluminum electrodes are used only in the flat position. For butt joints, a 90 deg single V-groove is recommended for plate thicknesses up to and including ⁷/₁₆ in. [10 mm]. A modified U- or double V-groove is recommended for heavier plate thicknesses. Preheat and interpass temperature should be as follows:

- (a) For iron-base materials, 200°F to 300°F [100°C to 150°C]
- (b) For bronzes, 300°F to 400°F [150°C to 200°C]
- (c) For brasses, 500°F to 600°F [250°C to 300°C]

A7.6.2 ECU_{Al}-A2 electrodes are used in joining aluminum bronzes of similar composition, high strength copper-zinc alloys, silicon bronzes, manganese bronzes, some nickel alloys, many ferrous metals and alloys, and combinations of dissimilar metals. The weld metal is also suitable for surfacing wear- and corrosion-resistant bearing surfaces.

TABLE A2
HARDNESS OF COPPER AND COPPER-ALLOY WELD
METAL

AWS Classification	Hardness ^a			
	Brinell		Vickers	
	HBS	Load, kgf	HV	Load, kgf
ECu	25 ^b	...	38	1
ECuSi	80–100	500	94–110	1
ECuSn-A	70–85	500	76–98	1
ECuSn-C	85–100	500	98–110	1
ECuNi	60–80	20	64–94	1
ECuAl-A2	130–150	3000	130–150	10
ECuAl-B	130–180	3000	140–184	10
ECuNiAl	160–200	3000	163–205	10
ECuMnNiAl	160–200	3000	163–205	10

NOTES:

- These values are average values for an as-welded deposit made with the filler metal specified. This table is for information only.
- Rockwell F-scale (HRF).

A7.6.3 ECuAl-B electrodes deposit weld metal having a higher tensile strength, yield strength, and hardness (with a correspondingly lower ductility) than ECuAl-A2 weld metal. ECuAl-B electrodes are used for repairing aluminum bronze and other copper-alloy castings. ECuAl-B weld metal also is used for wear- and corrosion-resistant bearing surfaces.

A7.6.4 ECuNiAl electrodes are used to join or repair cast or wrought nickel-aluminum bronze materials. These weld metals also may be used for applications requiring high resistance to corrosion, erosion, or cavitation in salt and brackish water.

A7.6.5 ECuMnNiAl electrodes are used to join or repair cast or wrought manganese-nickel-aluminum bronze materials. These weld metals exhibit excellent resistance to corrosion, erosion, and cavitation.

A8. Special Testing

A8.1 It is recognized that supplementary tests may be necessary to determine the suitability of these electrodes for applications involving properties not considered in this specification. In such cases, additional tests to determine such specific properties as corrosion resistance, mechanical properties at low and high temperatures, and suitability for welding combinations of dissimilar metals may be required upon agreement between the purchaser and supplier.

A8.2 Tests for hardness are not included in this specification. For reference, however, a chart of typical hardness values is included as Table A2.

A9. Discontinued Classifications

Some classifications have been discontinued from one revision of this specification to another. This results either

TABLE A3
DISCONTINUED CLASSIFICATIONS

Discontinued Classifications	Last Year Published
ECuAl-A ^a	1948
ECuAl-C ^b	1948
ECuAl-D ^c	1948
ECuAl-E ^d	1948
ECuAl-A1 ^a	1969

NOTES:

- This electrode classification was reclassified as ECuAl-A1 with a wider aluminum content by dropping the minimum allowable. That classification was later discontinued in 1977.
- This older electrode classification, together with the old version of ECuAl-B, was reclassified into a new single electrode classification ECuAl-A2 with a combined wider range of aluminum, and is currently listed in this current revision. This older classification continues in the A5.13 specification, but with a higher aluminum content than was specified in A5.6-48T.
- This older electrode classification became the newer version of ECuAl-B and still continues in the current specification. This older classification continues in the A5.13 specification, but with a higher aluminum content than was specified in A5.6-48T.
- This older electrode classification was reclassified as ECuAl-C in the A5.13-56T specification. This older classification continues in the A5.13 specification, but with a higher aluminum content than was specified in A5.6-48T.

from changes in commercial practice or changes in the classification system used in the specification. The classifications that have been discontinued are listed in Table A3, along with the year in which they were last included in the specification.

A10. General Safety Considerations

A10.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Annex Clause A5. Safety and health information is available from other sources, including, but not limited to, Safety and Health Fact Sheets listed in A10.3, ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations.

A10.2 Safety and Health Fact Sheets. The Safety and Health Fact Sheets listed below are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

A10.3 AWS Safety and Health Fact Sheets Index (SHF)⁹

No.	Title
1	Fumes and Gases
2	Radiation
3	Noise
4	Chromium and Nickel in Welding Fume
5	Electric Hazards
6	Fire and Explosion Prevention
7	Burn Protection
8	Mechanical Hazards
9	Tripping and Falling
10	Falling Objects
11	Confined Spaces
12	Contact Lens Wear

⁹ AWS standards are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

13	Ergonomics in the Welding Environment
14	Graphic Symbols for Precautionary Labels
15	Style Guidelines for Safety and Health Documents
16	Pacemakers and Welding
17	Electric and Magnetic Fields (EMF)
18	Lockout/Tagout
19	Laser Welding and Cutting Safety
20	Thermal Spraying Safety
21	Resistance Spot Welding
22	Cadmium Exposure from Welding & Allied Processes
23	California Proposition 65
24	Fluxes for Arc Welding and Brazing: Safe Handling and Use
25	Metal Fume Fever
26	Arc Viewing Distance
27	Thoriated Tungsten Electrodes
28	Oxyfuel Safety: Check Valves and Flashback Arrestors
29	Grounding of Portable and Vehicle Mounted Welding Generators
30	Cylinders: Safe Storage, Handling, and Use
31	Eye and Face Protection for Welding and Cutting Operations

SPECIFICATION FOR COPPER AND COPPER-ALLOY BARE WELDING RODS AND ELECTRODES



SFA-5.7/SFA-5.7M



(Identical with AWS Specification A5.7/A5.7M:2007. In case of dispute, the original AWS text applies.)

SPECIFICATION FOR COPPER AND COPPER-ALLOY BARE WELDING RODS AND ELECTRODES



SFA-5.7/SFA-5.7M



(Identical with AWS Specification A5.7/A5.7M:2007. In case of dispute, the original AWS text applies.)

1. Scope

1.1 This specification prescribes requirements for the classification of copper and copper-alloy bare welding rods and electrodes for plasma arc, gas metal arc, and gas tungsten arc welding. It includes compositions in which the copper content exceeds that of any other element.¹

1.2 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in the informative Annex Clauses A5 and A10. Safety and health information is available from other sources, including, but not limited to, ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations.

1.3 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to material properties. The specification with the designation A5.7 uses U.S. Customary Units. The specification A5.7M uses SI Units. The latter are shown within brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing of filler metal or packaging or both under A5.7 or A5.7M specification.

2. Normative References

The following standards contain provisions which, through reference in this text, constitute provisions of this AWS standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreement based on this AWS

standard are encouraged to investigate the possibility of applying the most recent editions of the documents shown below. For undated references, the latest edition of the standard referred to applies.

2.2 The following AWS standard² is referenced in the normative clauses of this document:

(1) AWS A5.01, *Filler Metal Procurement Guidelines*.

2.3 The following ANSI standard³ is referenced in the normative clauses of this document:

(1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*.

2.4 The following ASTM International standards⁴ are referenced in the normative clauses of this document:

(1) ASTM E 29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*.

(2) ASTM E 75, *Test Methods for Chemical Analysis of Copper-Nickel and Copper-Nickel-Zinc Alloys*.

(3) ASTM E 478, *Standard Test Methods for Chemical Analysis of Copper Alloys*.

2.5 The following ISO standard⁵ is referenced in the normative clauses of this document:

(1) ISO 544: *Welding consumables — Technical delivery conditions for welding filler materials — Type of product, dimensions, tolerances and markings*.

² AWS standards are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

³ This ANSI standard is published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

⁴ ASTM International standards are published by the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

⁵ ISO standards are published by the International Organization for Standardization, 1 rue de Varembe, Case postale 56, CH-1211 Geneva 20, Switzerland.

¹ No attempt has been made to provide for classification of all grades of copper and copper-alloy filler metals; only the more commonly used have been included.

3. Classification

3.1 The welding materials covered by the AWS A5.7/A5.7M specification are classified using a system that is independent of U.S. Customary Units and the International System of Units (SI). Classification is according to the chemical composition of the filler metal or rod stock from which it was made, as specified in Table 1.

3.2 Material classified under one classification shall not be classified under any other classification of this specification.

3.3 The materials classified under this specification are intended for plasma arc, gas metal arc, and gas tungsten arc welding, but that does not prohibit their use with other welding processes for which they are found suitable.

4. Acceptance

Acceptance⁶ of the material shall be in accordance with the provisions of AWS A5.01.

5. Certification

By affixing the AWS specification and classification designations to the packaging or the AWS classification to the product, the manufacturer certifies that the product meets the requirements of this specification.⁷

6. Rounding-Off Procedure

For purposes of determining conformance with this specification, an observed or calculated value shall be rounded to the "nearest unit" in the last right-hand place of figures used in expressing the limiting value in accordance with the rounding-off method given in ASTM E 29.

7. Summary of Tests

Chemical analysis of the filler metal, or the stock from which it was made, is the only test required for classification of a product under this specification.

8. Retest

If the results of any test fail to meet its requirement, that test shall be repeated twice. The results of both tests shall meet the requirements. Specimens for retest may be taken from the original test sample or from a new test sample. For chemical analysis, retest need be only for those specific elements that failed to meet their requirement. If

the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that, during preparation or after completion of any test, it is clearly determined that prescribed or proper procedures were not followed in preparing the test specimens or in conducting the test, the test shall be considered invalid without regard to whether the test was actually completed, or whether test results met, or failed to meet, the requirement. That test shall be repeated, following prescribed procedures. In this case the requirement for doubling of the number of test specimens does not apply.

9. Chemical Analysis

9.1 A sample of the filler metal or the stock from which it is made shall be prepared for chemical analysis.

9.2 The sample shall be analyzed by accepted analytical methods. The referee method shall be ASTM E 478, and ASTM E 75 for copper-nickel alloys, as appropriate.

9.3 The results of the analysis shall meet the requirements of Table 1 for the classification of filler metal under test.

10. Method of Manufacture

The welding materials classified according to this specification may be manufactured by any method that will produce material that meets the requirements of this specification.

11. Standard Sizes and Shapes

Standard sizes for filler metal in the different package forms (straight lengths, coils with support, coils without support, and spools) are shown in Table 2.

12. Finish and Uniformity

12.1 All filler metal shall have a smooth finish that is free from slivers, depressions, scratches, scale, seams, laps, and foreign matter that would adversely affect the welding characteristics, the operation of the welding equipment, or the properties of the weld metal.

12.2 Each continuous length of filler metal shall be from a single heat or lot of material, and welds, when present, shall have been made so as not to interfere with the uniform, uninterrupted feeding of the filler metal on automatic or semiautomatic equipment.

13. Standard Package Forms

13.1 Standard package forms are straight lengths, coils with support, coils without support, and spools. Standard

⁶ See Clause A3 (in Annex A) for further information concerning acceptance, testing of the material shipped, and AWS A5.01.

⁷ See Clause A4 (in Annex A) for further information concerning certification and the testing called for to meet this requirement.

TABLE 1
CHEMICAL COMPOSITION REQUIREMENTS, PERCENT

AWS Classification	UNS Number ^c	Common Name	Composition, Weight Percent ^{a,b}											Total Other Elements
			Cu Including Ag ^e	Zn	Sn	Mn	Fe	Si	Ni Including Co ^f	P	Al	Pb	Ti	
ERCu	C18980	Copper	98.0 min	—	1.0	0.50	—	0.50	—	0.15	0.01	0.02	—	0.50
ERCuSi-A	C65600	Silicon bronze (copper-silicon)	Remainder	1.0	1.0	1.5	0.50	2.8– 4.0	—	—	0.01	0.02	—	0.50
ERCuSn-A	C51800	Phosphor bronze (copper-tin)	Remainder	—	4.0– 6.0	—	—	—	—	0.10– 0.35	0.01	0.02	—	0.50
ERCuSn-C	C52100	Phosphor bronze (copper-tin)	Remainder	0.20	7.0– 9.0	—	0.10	—	—	0.10– 0.35	0.01	0.02	—	0.50
ERCuNi ^d	C71581	Copper-nickel	Remainder	—	—	1.0	0.40– 0.75	0.25	29.0– 32.0	0.02	—	0.02	0.20 to 0.50	0.50
ERCuAl-A1	C61000	Aluminum bronze	Remainder	0.20	—	0.50	—	0.10	—	—	6.0– 8.5	0.02	—	0.50
ERCuAl-A2	C61800	Aluminum bronze	Remainder	0.02	—	—	0.5–1.5	0.10	—	—	8.5– 11.0	0.02	—	0.50
ERCuAl-A3	C62400	Aluminum bronze	Remainder	0.10	—	—	2.0– 4.5	0.10	—	—	10.0– 11.5	0.02	—	0.50
ERCuNiAl	C63280	Nickel-aluminum bronze	Remainder	0.10	—	0.60– 3.50	3.0– 5.0	0.10	4.0– 5.5	—	8.50– 9.50	0.02	—	0.50
ERCuMnNiAl	C63380	Manganese-nickel aluminum bronze	Remainder	0.15	—	11.0– 14.0	2.0– 4.0	0.10	1.5– 3.0	—	7.0– 8.5	0.02	—	0.50

NOTES:

- Analysis shall be made for the elements for which specific values are shown in this table. If, however, the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements is not present in excess of the limits specified for 'Total other elements' in the last column in this table.
- Single values shown are maximum, unless otherwise noted.
- ASTM D5-56/SAE HS-1086, *Metals & Alloys in the Unified Numbering System*.
- Sulfur shall be 0.01% maximum for the ERCuNi classification.
- Ag may or may not be present.
- Co may or may not be present.

TABLE 2
STANDARD SIZES

Standard Package Form	Diameter			Tolerance ^b	
	in.	in.	mm	in.	mm
Straight lengths ^c	$\frac{1}{16}$	(0.062)	1.6	± 0.002	± 0.1
	$\frac{5}{64}$	(0.078)	2.0	± 0.002	± 0.1
	$\frac{3}{32}$	(0.094)	2.4	± 0.002	± 0.1
	...	(0.097)	2.5	± 0.002	± 0.1
	$\frac{1}{8}$	(0.125)	3.2	± 0.002	± 0.1
	$\frac{5}{32}$	(0.156)	4.0	± 0.002	± 0.1
	$\frac{3}{16}$	(0.187)	4.8 ^d	± 0.002	± 0.1
	...	(0.197)	5.0	± 0.002	± 0.1
Coils, with or without support	$\frac{1}{4}$	(0.250)	6.4 ^d	± 0.002	± 0.1
	$\frac{1}{8}$	(0.125)	3.2	± 0.002	± 0.01
					-0.07
	$\frac{5}{32}$	(0.156)	4.0	± 0.002	± 0.01
					-0.07
	$\frac{3}{16}$	(0.187)	4.8 ^d	± 0.002	± 0.01
					-0.07
	...	(0.197)	5.0	± 0.002	± 0.01
Spools					-0.07
					-0.07
					-0.07
					-0.07
					-0.07
					-0.07
					-0.07
					-0.07
Spools	0.020		0.5	± 0.002	± 0.01
					-0.04
	0.030		0.8	± 0.002	± 0.01
					-0.04
	0.035		0.9	± 0.002	± 0.01
					-0.04
	...		1.0	± 0.002	± 0.01
					-0.04
	0.045		—	± 0.002	± 0.01
					-0.04
	...	(0.047)	1.2	± 0.002	± 0.01
					-0.04
Spools	$\frac{1}{16}$	(0.062)	1.6	± 0.002	± 0.01
					-0.04
	$\frac{5}{64}$	(0.078)	2.0	± 0.002	± 0.01
					-0.04
	$\frac{3}{32}$	(0.094)	2.4	± 0.002	± 0.01
					-0.04
Spools	...	(0.097)	2.5	± 0.002	± 0.01
					-0.04

NOTES:

- Dimensions, tolerances, and package forms other than those shown shall be as agreed upon between purchaser and supplier.
- Out of roundness (the difference between the major and minor diameters) shall not exceed one-half of the tolerance.
- Length shall be 36 in. $+0$, $-\frac{1}{2}$ in. [900 mm $\pm 2\%$].
- Not included in ISO 544.

TABLE 3
STANDARD PACKAGE DIMENSIONS AND WEIGHT^a

Package Form	Net Weight ^b		Width, max.		Diameter			
					Inside		Outside	
	lb	kg	in.	mm	in.	mm	in.	mm
Coils without support	As agreed by the purchaser and supplier							
Coils with support	25	12	2½	65	12 ± ⅛	305 + 10, -0	17½	445
	50	25	4⅝	120	12 ± ⅛	305 + 10, -0	17	430
	60	30	4⅝	120	12 ± ⅛	305 + 10, -0	17	430
Spools ^c	2 ^d	1 ^d	...	...	...	...	4	100
	10 ^d	5 ^d	...	...	...	...	8	200
	25 ^e	12 ^e	...	...	...	...	12	300
Straight lengths	5	2.5	...	...	...	...	...	...
	10	5	...	...	...	...	...	...
	25	12	...	...	...	...	...	...
	50	25	...	...	...	...	...	...

NOTES:

- Weights, dimensions, and package forms other than these shall be as agreed upon between purchaser and supplier.
- Net weight may vary ±10% from the nominal weight, except as provided in Notes d and e.
- Dimensions of the standard spools are specified in Figure 1.
- ±20%.
- ±20%, except that 20% of any lot may contain spools that vary in weight from 12½ lb to 20 lb [5 kg to 10 kg].

package dimensions and weights for each form are given in Table 3. Dimensions for standard spools are given in Fig. 1. Package forms, sizes, and weights other than these shall be as agreed upon between purchaser and supplier.

13.2 The liners in coils with support shall be designed and constructed to prevent distortion of the coil during normal handling and use, and shall be clean and dry enough to maintain the cleanliness of the filler metal.

13.3 Spools shall be designed and constructed to prevent distortion of the spool and the filler metal during normal handling and use, and shall be clean and dry enough to maintain the cleanliness of the filler metal. Spools shall electrically insulate the filler metal from the spindle.

14. Winding Requirements

14.1 The electrode on spools and in coils shall be closely wound so that kinks, waves, sharp bends, overlapping, or wedging are not encountered, leaving the filler metal free to unwind without restriction. The outside end of the filler metal (the end with which welding is to begin) shall be identified so that it can be located readily and shall be fastened to avoid unwinding. The outermost layer of electrode or rod on spools shall be at least ⅛ in. [3 mm] from the rim (the O.D.) of the flanges of the spool.

14.2 The cast and helix of the filler metal in coils and spools shall be such that the filler metal will feed in an uninterrupted manner in automatic and semi-automatic equipment.

14.3 The cast and helix of filler metal on 4 in. [100 mm] spools shall be such that a specimen long enough to produce a single loop, when cut from the spool and laid unrestrained on a flat surface, will:

- (1) form a circle not less than 4 in. [100 mm], nor more than 15 in. [380 mm] in diameter; and
- (2) rise above the flat surface no more than ½ in. [13 mm] at any location.

14.4 The cast and helix of filler metal on 8 in. [200 mm] spools shall be such that a specimen long enough to produce a single loop, when cut from the spool and laid unrestrained on a flat surface, will:

- (1) form a circle not less than 10 in. [250 mm] nor more than 30 in. [760 mm] in diameter, and
- (2) rise above the flat surface no more than ¾ in. [19 mm] at any location.

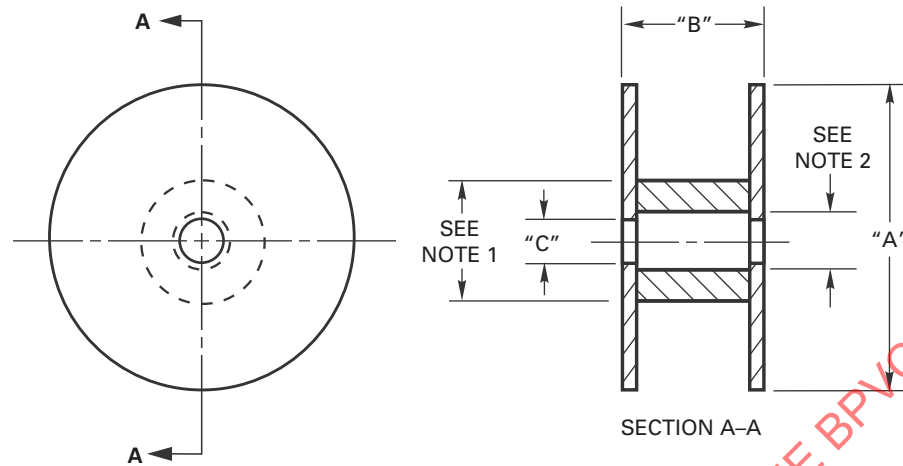
14.5 The cast and helix of filler metal on 12 in. [300 mm] spools shall be such that a specimen long enough to produce a single loop, when cut from the spool and laid unrestrained on a flat surface, will:

- (1) form a circle not less than 15 in. [380 mm] nor more than 50 in. [1 250 mm] in diameter, and
- (2) rise above the flat surface no more than 1 in. [25 mm] at any location.

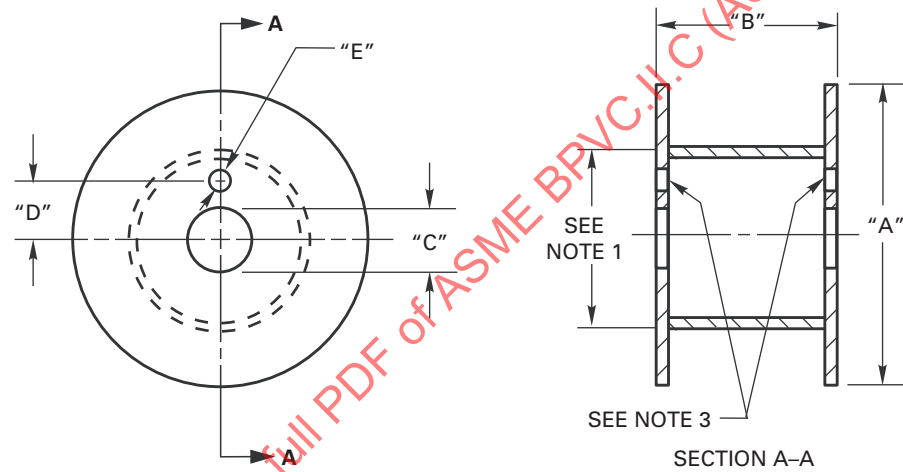
15. Filler Metal Identification

15.1 The product information and precautionary information required in 17.1 and 17.2 for marking each package shall also appear on each coil and spool.

FIG. 1 DIMENSIONS OF 4 IN., 8 IN., AND 12 IN. [100 MM, 200 MM, AND 300 MM] SPOOLS



DIMENSIONS OF STANDARD 4 in. [100 mm] SPOOL



DIMENSIONS OF STANDARD 8 in. AND 12 in. [200 mm AND 300 mm] SPOOLS

		DIMENSIONS					
		4 in. [100 mm] Spools		8 in. [200 mm] Spools		12 in. [300 mm] Spools	
		in.	mm	in.	mm	in.	mm
A	Diameter, max. (Note 4)	4.0	102	8.0	203	12	305
B	Width	1.75	46	2.16	56	4.0	103
	Tolerance	± 0.03	$+0, -2$	± 0.03	$+0, -3$	± 0.06	$+0, -3$
C	Diameter	0.63	16 $+1, -0$	2.03	50.5	2.03	50.5
	Tolerance	$+0.01, -0$	-0	$+0.06, -0$	$+2.5, -0$	$+0.06, -0$	$+2.5, -0$
D	Distance between axes	—	—	1.75	44.5	1.75	44.5
	Tolerance	—	—	± 0.02	± 0.5	± 0.02	± 0.5
E	Diameter (Note 3)	—	—	0.44	10	0.44	10
	Tolerance	—	—	$+0, -0.06$	$+1, -0$	$+0, -0.06$	$+1, -0$

NOTES:

1. Outside diameter of barrel shall be such as to permit proper feeding of the filler metals.
2. Inside diameter of the barrel shall be such that swelling of the barrel or misalignment of the barrel and flanges will not result in the inside of the diameter of the barrel being less than the inside diameter of the flanges.
3. Holes are provided on each flange, but they need not be aligned. No driving holes required for 4 in. [100 mm] spools.
4. Metric dimensions and tolerances conform to ISO 544 except that "A" specifies $\pm$ tolerances on the nominal diameter, rather than a plus tolerance only, which is shown here as a maximum.

15.2 Coils without support shall have a tag containing this information securely attached to the inside end of the coil.

15.3 Coils with support shall have the information securely affixed in a prominent location on the support.

15.4 Spools shall have the information securely affixed in a prominent location on the outside of at least one flange of the spool.

15.5 Each bare straight length filler rod shall be durably marked with identification traceable to the unique product type of the manufacturer or supplier. Suitable methods of identification could include stamping, coining, embossing, imprinting, flag-tagging, or color coding. (If color coding is used, the choice of color shall be as agreed upon between supplier and purchaser and the color shall be identified on the packaging.) When the AWS classification designation is used, the “ER” may be omitted; for example, “CuAl-A2” for classification ERCuAl-A2. Additional identification shall be as agreed upon between supplier and purchaser.

16. Packaging

Filler metal shall be suitably packaged to ensure against damage during shipment and storage under normal conditions.

17. Marking of Packages

17.1 The following product information (as a minimum) shall be legibly marked so as to be visible from the outside of each unit package.

(1) AWS specification and classification designations (year of issue may be excluded).

(2) Supplier’s name and trade designation.

(3) Size and net weight.

(4) Lot, control, or heat number

17.2 The appropriate precautionary information⁸ as given in ANSI Z49.1, latest edition, (as a minimum) or its equivalent, shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages enclosed within a larger package.

⁸ Typical example of “warning labels” are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

Annex A (Informative)

Guide to AWS Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes

(This annex is not part of AWS A5.7/A5.7M:2007, *Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes*, but is included for informational purposes only.)

A1. Introduction

The purpose of this guide is to correlate the filler metal classifications with their intended applications so the specification can be used effectively. Appropriate base metal specifications are referred to whenever that can be done and when it would be helpful. Such references are intended only as examples rather than complete listings of the materials for which each filler metal is suitable.

A2. Classification System

A2.1 The system for identifying the filler metal classification in this specification follows the standard pattern used in other AWS filler metal specifications. The prefix letters ER at the beginning of each classification designation stand for electrode and rod, indicating that the filler metal may be used either way. The chemical symbol Cu is used to identify the electrodes as copper-base alloys. The additional chemical symbol, such as Si for silicon in ERCuSi, Sn for tin in ERCuSn, etc., indicates the principal alloying element of each classification or group of classifications. Where more than one classification is included in a basic group, the individual classifications in the group are identified by using letters (A, B, C, etc.), as in ERCuSn-A and ERCuSn-C. Further subdividing is done by using digits (1, 2, etc.) following the letter, as in ERCuAl-A1, ERCuAl-A2, and ERCuAl-A3.

A2.2 An international system for designating welding filler metals, developed by the International Institute of Welding (IIW), is being adopted in many ISO specifications. Table A1 shows the designations for bare copper-alloy filler metals in ISO 24373 corresponding to those in this specification.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01, *Filler Metal Procurement Guidelines*, as the specification states.

Any testing a purchaser requires of the supplier, for material shipped in accordance with this specification, needs to be clearly stated in the purchase order, according to the provisions of AWS A5.01. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing normally is conducted on material of that classification, as specified in Schedule F, Table 1, of AWS A5.01. Testing in accordance with any other Schedule in that table must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS Specification and classification designations on the packaging enclosing the product or the classification on the product itself constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification.

The only testing requirement implicit in this "certification" is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that the material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation. "Certification" is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the "certification" required by the specification is the classification test of "representative material" cited above, and the "Manufacturer's Quality Assurance System" in AWS A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes to which welders and welding operators can be exposed during welding. These are:

TABLE A1
COMPARISON OF SPECIFICATIONS

Bare Rods and Electrodes A5.7/A5.7M	Covered Electrodes A5.6/A5.6M ^a	ISO 24373 Designations ^b
ERCu	ECu	SCu 1898
ERCuSi-A	ECuSi	SCu 6560
ERCuSn-A	ECuSn-A	SCu 5180
ERCuSn-C	ECuSn-C	SCu 5210
ERCuNi	ECuNi	SCu 7158
ERCuAl-A1	...	SCu 6100
ERCuAl-A2	ECuAl-A2	SCu 6180
ERCuAl-A3	...	SCu 6240
ERCuNiAl	ECuNiAl	SCu 6328
ERCuMnNiAl	ECuMnNiAl	SCu 6338

NOTES:

- a. AWS A5.6/A5.6M, *Specification for Copper and Copper-Alloy Electrodes for Shielded Metal Arc Welding*.
b. ISO 24373, *Welding consumables — Solid wires and rods for fusion welding of copper and copper alloys — Classification*.

(1) dimensions of the space in which welding is done (with special regard to the height of the ceiling).

(2) number of welders and welding operators working in that space.

(3) rate of evolution of fumes, gases, or dust according to the materials and processes used.

(4) the proximity of the welders or welding operators to the fumes as they issue from the welding zone, and to the gases and dusts in the space in which the welders or welding operators are working.

(5) the ventilation provided to the space in which the welding is done.

A5.2 ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the clause on Health Protection and Ventilation in that document. Further details about ventilation can be found in AWS F3.2, *Ventilation Guide for Welding Fume*.

A6. Welding Considerations

A6.1 The filler metals in this specification can be used with any of a variety of welding processes. Most notable of them are the gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW) processes.

A6.2 Before welding or heating any copper-base alloy, the base metal must be clean. Oil, grease, paint, lubricants, marking pencils, temperature indicating materials, threading compounds and other such materials frequently contain sulfur or lead that may cause cracking (embrittlement) of the base metal or the weld metal if present during welding or heating.

A6.3 For GTAW, direct current-electrode negative (dcen) is used. High purity grades of either argon or helium (or a combination of the two) are used as a shielding gas.

A6.4 For GMAW, direct current-electrode positive (dcep) is employed. Argon shielding gas is most often used, but mixtures of argon and helium are also commonly used when welding high conductivity copper.

A7. Description and Intended Use of Electrodes and Rods

A7.1 General Characteristics

A7.1.1 Gas tungsten arc welding normally employs dcen current.

A7.1.2 Gas metal arc welding normally employs dcep current.

A7.1.3 Shielding gas for use with either process normally is argon, helium, or a mixture of the two, with or without hydrogen. Oxygen-bearing gases normally are not recommended.

A7.1.4 Base metal should be free from moisture and all other contaminants, including surface oxides.

A7.2 ERCu (Copper) Filler Metal Classification

A7.2.1 ERCu filler metals are made of deoxidized copper, but also may contain one or more of the following elements: phosphorus, silicon, tin, manganese, and silver. Phosphorus and silicon are added primarily as deoxidizers. The other elements add either to the ease of welding or to the properties of the final weldment. ERCu filler metals generally are used for the welding of deoxidized and electrolytic tough pitch (ETP) copper. Reactions with hydrogen in oxygen-free copper, and the segregation of copper oxide in tough pitch copper may detract from joint efficiency. ERCu welding electrodes and rods may be used to weld these base metals when the highest quality is not required.

A7.2.2 Preheating is desirable on most work; on thick base metal it is essential. Preheat temperatures of 400°F to 1000°F [200°C to 500°C] are suitable.

A7.2.3 For thick base metals, gas metal arc welding is preferred. Conventional joint designs consistent with good welding practice are generally satisfactory. An external source of preheating generally is not needed when welding base metal $\frac{1}{4}$ in. [6 mm] and less in thickness. Preheating in the range of 400°F to 1000°F [200°C to 500°C] is desirable when welding base metal thicker than $\frac{1}{4}$ in. [6 mm] if high-quality welds are to be obtained.

A7.3 ERcusi (Silicon Bronze) Filler Metal Classification

A7.3.1 ERcusi filler metals are copper-base alloys containing approximately three percent silicon; they may also contain small percentages of manganese, tin, or zinc. They are used for gas tungsten and gas metal arc welding of copper-silicon and copper-zinc base metals, to themselves and also to steel.

A7.3.2 When gas metal arc welding with ERcusi filler metals, it generally is best to keep the weld pool small and the interpass temperature below 150°F [65°C] to minimize hot cracking. The use of narrow weld passes reduces contraction stresses and also permits faster cooling through the hot-short temperature range.

A7.3.3 When gas tungsten arc welding with ERcusi filler metals, best results are obtained by keeping the weld pool small. Preheating is not required. Welding can be done in all positions, but the flat position is preferred.

A7.4 ERcuSn-x (Phosphor Bronze) Filler Metal Classification

A7.4.1 ERcuSn-A filler metals contain about five percent tin and up to 0.35% phosphorus added as a deoxidizer. Tin increases wear resistance of the weld metal and slows the rate of solidification by broadening the temperature differential between the liquidus and solidus. This slower solidification increases the tendency to hot shortness. To minimize this effect, the weld pool should be kept small and welding time as short as possible. ERcuSn-A filler metals can be used to weld bronze and brass. They also can be used to weld copper if the presence of tin in the weld metal is not objectionable.

A7.4.2 ERcuSn-C filler metal contains about 8% tin and up to 0.35% phosphorus. The higher tin increases strength and wear resistance and increases the solidification temperature range during deposition of the weld metal.

A7.4.3 When gas tungsten arc welding with ERcuSn filler metals, preheating is desirable. Welding is done in the flat position only.

A7.5 ERcuNi (Copper-Nickel) Filler Metal Classification

A7.5.1 ERcuNi electrodes and rods are used for the welding of wrought or cast 70/30, 80/20, and 90/10

copper-nickel alloys to themselves or to each other. These filler metals also are used for welding the clad side of copper-nickel clad steel. Preheating generally is not necessary.

A7.5.2 When gas tungsten or gas metal arc welding with ERcuNi filler metals, preheating is not required. Welding is done in all positions. The arc should be kept as short as possible to assure adequate shielding gas coverage and thus minimize porosity. This filler metal may also be used for surfacing applications where high resistance to corrosion, erosion, or cavitation is required.

A7.6 ERcuAl (Aluminum Bronze) Filler Metal Classification

A7.6.1 ERcuAl-A1 filler metal is an iron-free aluminum bronze. It is recommended for use as a surfacing metal for wear-resistant surfaces having relatively light loads, for resistance to corrosive media such as salt or brackish water, and for resistance to many commonly used acids in varying concentrations and temperatures. This alloy is not recommended for joining.

A7.6.2 ERcuAl-A2 filler metal is iron-bearing aluminum bronze and is generally used for joining aluminum bronzes of similar composition, manganese bronze, silicon bronze, and some copper-nickel alloys, ferrous metals and dissimilar metals. The most common dissimilar metal combinations are aluminum bronze to steel and copper to steel. This alloy is also used to provide wear-and corrosion-resistant surfaces.

A7.6.3 ERcuAl-A3 is a higher strength aluminum bronze filler metal used for joining and repair welding of aluminum bronze castings of similar composition, and for depositing bearing surfaces and wear- and corrosion-resistant surfaces.

A7.6.4 ERcuNiAl is a nickel-aluminum bronze filler metal used for joining and repairing of cast and wrought nickel-aluminum bronze base metals.

A7.6.5 ERcuMnNiAl is a manganese-nickel-aluminum bronze filler metal used for joining or repairing of cast or wrought base metals of similar composition. This filler metal may also be used for surfacing applications where high resistance to corrosion, erosion, or cavitation is required.

A7.6.6 Because of the formation of aluminum oxide in the molten weld pool, aluminum bronze filler metals are not recommended for use with the oxyfuel gas welding process.

A7.6.7 Copper-aluminum weld metals are characterized by relatively high tensile strength, yield strength, and hardness. Depending upon the thickness or composition of the base metal, preheat may or may not be necessary.

TABLE A2
HARDNESS AND TENSILE STRENGTH OF COPPER AND COPPER-ALLOY WELD METAL

AWS Classification	Hardness				Minimum Tensile Strength	
	Brinell		Vickers			
	HBW	Load, kgf	HV	Load, Kgf	psi	MPA
ERCu	25 ^b	...	38	...	25 000	170
ERCuSi-A	80–100	500	94–110	1	50 000	345
ERCuSn-A	70–85	500	76–98	1	35 000	240
ERCuSn-C	85–100	500	98–110	1	55 000	380
ERCuNi	60–80	500	64–94	1	50 000	345
ERCuAl-A1	80–110	500	94–115	10	55 000	380
ERCuAl-A2 ^a	130–150	3000	130–150	10	60 000	415
ERCuAl-A3 ^a	140–180	3000	140–184	10	65 000	450
ERCuNiAl ^a	160–200	3000	163–205	10	72 000	480
ERCuMnNiAl ^a	160–200	3000	163–205	10	75 000	515

GENERAL NOTE: Hardness values as listed above are average values for an as-welded deposit made with the filler metal specified. This table is included for information only.

NOTES:

- a. Gas tungsten arc process only.
b. Rockwell F.

A7.6.8 Welding in the flat position is preferred. Welding in other positions can be done successfully with pulsed arc welding equipment and welder technique.

A8. Special Tests

It is recognized that supplementary tests may be required for certain applications. In such cases, tests to determine specific properties (such as corrosion resistance, scaling resistance, or strength at elevated or cryogenic temperatures) may be required. AWS A5.01, *Filler Metal Procurement Guidelines*, contains provisions for ordering such tests. This clause is included for the guidance of those who desire to specify such special tests. Those tests may be conducted as agreed upon between purchaser and supplier.

Tests for tensile strength and hardness are not included in this specification. A chart of strength and hardness is included in Table A2. When tests for mechanical properties are specified, the procedures should be in accordance with AWS B4.0 or AWS B 4.0M, *Standard Methods for Mechanical Testing of Welds*.

It should be noted that the variables in the procedure (current, voltage, and welding speed), variables in shielding medium (the specific gas mixture or the flux), variables in the composition of the base metal and the filler metal influence the results which may be obtained. When these variables are properly controlled, however, the filler metal should give sound welds whose strengths (determined by

all-weld-metal tension tests) should meet or exceed the minimums shown in Table A2.

A9. Discontinued

A9.1 Classifications. Some classifications have been discontinued from one revision of this specification to another. This results either from changes in commercial practice or changes in the classification system used in the specification. The classifications that have been discontinued are listed in Table A3, along with the year in which they were last included in the specification.

A10. General Safety Considerations

A10.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in annex Clause A5 and below. Safety and health information is available from other sources, including but not limited to Safety and Health Fact Sheets listed in A10.3, ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations.

A10.2 Safety and Health Fact Sheets. The Safety and Health Fact Sheets listed below are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

TABLE A3
DISCONTINUED CLASSIFICATIONS

Discontinued Classifications	Last Year Published
RCuAl-A1	1952
RCuSn ^a	1952
RCuSi-B	1957
RCu ^b	1969
RCuSi-A ^b	1969
RCuSn-A ^b	1969
RCuNi ^b	1969
RCuAl-A2 ^b	1969
RBCuZn-A ^c	1969
RCuZn-B ^c	1969
RCuZn-C ^c	1969
RBCuZn-D ^c	1969
RCuAl-B	1969

NOTES:

- This rod classification was reclassified as RCuSn-A with a wider range listed for phosphorus.
- These classifications were redesignated as ERxx-x in A5.7-77 to indicate both electrode and rod materials and continue in the current specification.
- These classifications were transferred to A5.27 where they became RBxx-x rod for braze welding. The A5.27 specification was later withdrawn, and these classifications moved to the current A5.8 specification.

A10.3 AWS Safety and Health Fact Sheets Index
(SHF)⁹

No.	Title
1	Fumes and Gases
2	Radiation
3	Noise
4	Chromium and Nickel in Welding Fume
5	Electric Hazards
6	Fire and Explosion Prevention
7	Burn Protection
8	Mechanical Hazards
9	Tripping and Falling
10	Falling Objects
11	Confined Space
12	Contact Lens Wear
13	Ergonomics in the Welding Environment
14	Graphic Symbols for Precautionary Labels
15	Style Guidelines for Safety and Health Documents
16	Pacemakers and Welding
17	Electric and Magnetic Fields (EMF)
18	Lockout/Tagout
19	Laser Welding and Cutting Safety
20	Thermal Spraying Safety
21	Resistance Spot Welding
22	Cadmium Exposure from Welding & Allied Processes
23	California Proposition 65
24	Fluxes for Arc Welding and Brazing: Safe Handling and Use
25	Metal Fume Fever
26	Arc Viewing Distance
27	Thoriated Tungsten Electrodes
28	Oxyfuel Safety: Check Valves and Flashback Arrestors
29	Grounding of Portable and Vehicle Mounted Welding Generators
30	Cylinders: Safe Storage, Handling, and Use
31	Eye and Face Protection for Welding and Cutting Operations

⁹ AWS standards are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

INTENTIONALLY LEFT BLANK

SPECIFICATION FOR FILLER METALS FOR BRAZING AND BRAZE WELDING



SFA-5.8/SFA-5.8M



(Identical with AWS Specification A5.8/A5.8M:2011. In case of dispute, the original AWS text applies.)

Specification for Filler Metals for Brazing and Braze Welding

1. General Requirements

1.1 Scope. This specification prescribes requirements for the classification of brazing filler metals for brazing and braze welding. It includes brazing filler metals for brazing with or without a flux and in all protective atmospheres for various applications, including those for vacuum service.¹ The prefix “RB” indicates that the brazing filler metal is suitable for use both as brazing rod for braze welding and as a brazing filler metal.

1.2 Units of Measurement. This specification makes use of both the International System of Units (SI) and U.S. Customary Units. The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to material properties. The specification with the designation A5.8M uses the International System of Units. The specification A5.8 uses U.S. Customary Units. The latter are shown within brackets ([]) or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for the sizing or packaging of brazing filler metal, or both, under A5.8M or A5.8 specifications.

1.3 Safety. Safety issues and concerns are addressed in this standard, although health issues and concerns are beyond the scope of this standard. Some safety and health information can be found in nonmandatory Annex Clauses B5 and B10.

Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets (see Annex Clause B10)
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Material Safety Data Sheets supplied by the materials manufacturers
- (2) Operating manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

¹ Filler metals for vacuum service are for devices operating in vacuum service, regardless of the atmosphere used in making the joint.

2. Normative References

The standards listed below contain provisions that, through reference in this text, constitute mandatory provisions of this AWS standard. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

2.1 American Welding Society (AWS) standards:²

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

AWS A5.01M/A5.01 (ISO 14344:2002 MOD), *Procurement Guidelines for Consumables—Welding and Allied Processes—Flux and Gas Shielded Electrical Welding Processes*

2.2 American National Standards Institute (ANSI) standard:³

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

2.3 ASTM International standards:⁴

ASTM B214, *Standard Method for Sieve Analysis of Metal Powders*

ASTM E11-01, *Standard Specification for Wire Cloth and Sieves for Testing Purposes*

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

ASTM E1371-05, *Standard Test Method for Gravimetric Determination of Phosphorus in Phosphorus–Copper Alloys or Phosphorus–Copper–Silver Alloys*

Annual Book of ASTM Standards, Section 03—Metals Test Methods and Analytical Procedures, Volume 5—Analytical Chemistry for Metals, Ores, and Related Materials

2.4 International Organization for Standardization (ISO) standard:⁵

ISO 80000-1 *Quantities and units—Part 0: General Principles*

2.5 SAE International standard:⁶

SAE HS-1086, *Metals & Alloys in the Unified Numbering System*

3. Classification⁷

3.1 The brazing filler metals covered by the A5.8M/A5.8 specification are classified using a system that is independent of the International System of Units (SI) and U.S. Customary Units. Their classification is according to the chemical composition as specified in Tables 1 through 7.

3.2 Brazing filler metal classified under one classification shall not be classified under any other classification in this specification. However, material may be classified under both A5.8M and A5.8 specifications.

4. Acceptance

Acceptance⁸ of the brazing filler metal shall be in accordance with the provisions of AWS A5.01M/A5.01 (ISO 14344 MOD).

² AWS standards are published by the American Welding Society, 8669 Doral Blvd., Suite 130, Doral, FL 33166.

³ This ANSI standard is published by the American Welding Society, 8669 Doral Blvd., Suite 130, Doral, FL 33166.

⁴ ASTM International standards are published by ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

⁵ ISO standards are published by the International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56 CH-1211 Geneva 20, Switzerland.

⁶ SAE International standards are published by SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

⁷ An explanation of the method of classification of the filler metals is included in B2 (in Annex B).

⁸ See B3 (in Annex B) for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01 (ISO 14344 MOD).

5. Certification

By affixing the AWS specification and classification designations to the packaging, or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification.⁹

6. Rounding-Off Procedure

For purposes of determining compliance with the requirements of this standard, the actual test values shall be subjected to the rounding-off rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding off. If an average value is to be compared to the specified limit, rounding off shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest 10 MPa [1000 psi] for tensile and yield strength and to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded-off results shall fulfill the requirements for the classification under test.

7. Summary of Tests

7.1 The tests required for each classification or product form are as follows:

7.1.1 Chemical analysis of the brazing filler metal is required for all classifications.

7.1.2 Brazing filler metals for vacuum service require a melt cleanliness test and a spatter test in addition to chemical analysis.

7.1.3 Sieve analysis is required for all powdered brazing filler metals.

7.1.4 A binder content test for transfer tape used in conjunction with powdered brazing filler metals is required.

7.2 The material for the preparation of test samples, the brazing and testing procedures to be employed, and the results required are specified in Clauses 9 through 13.

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Samples for retest may be taken from the original sample or from one or two new samples. For chemical analysis, retest need be only for the specific elements that failed to meet the requirement.

If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that during the preparation or after the completion of any test it is clearly determined that prescribed or proper procedures were not followed in preparing the test sample(s) or in conducting the test, the test shall be considered invalid without regard to whether the test was actually completed or whether test results met or failed to meet the requirement. That test shall be repeated following proper prescribed procedures. In this case, the requirement for doubling the number of test specimens does not apply.

9. Chemical Analysis

9.1 Brazing filler metals shall conform to the chemical composition requirements of Tables 1 through 7 for the specific brazing filler metal being tested.

⁹ See B4 (in Annex B) for further information concerning certification and the testing called for to meet this requirement.

Table 1^{a, b}
Chemical Composition Requirements for Silver Brazing Filler Metals

AWS Classification	UNS Number ^c	Chemical Composition, Weight Percent								Other Elements, Total ^d
		Ag	Cu	Zn	Cd	Ni	Sn	Li	Mn	
B _{Ag} -1	P07450	44.0–46.0	14.0–16.0	14.0–18.0	23.0–25.0	—	—	—	—	0.15
B _{Ag} -1a	P07500	49.0–51.0	14.5–16.5	14.5–18.5	17.0–19.0	—	—	—	—	0.15
B _{Ag} -2	P07350	34.0–36.0	25.0–27.0	19.0–23.0	17.0–19.0	—	—	—	—	0.15
B _{Ag} -2a	P07300	29.0–31.0	26.0–28.0	21.0–25.0	19.0–21.0	—	—	—	—	0.15
B _{Ag} -3	P07501	49.0–51.0	14.5–16.5	13.5–17.5	15.0–17.0	2.5–3.5	—	—	—	0.15
B _{Ag} -4	P07400	39.0–41.0	29.0–31.0	26.0–30.0	—	1.5–2.5	—	—	—	0.15
B _{Ag} -5	P07453	44.0–46.0	29.0–31.0	23.0–27.0	—	—	—	—	—	0.15
B _{Ag} -6	P07503	49.0–51.0	33.0–35.0	14.0–18.0	—	—	—	—	—	0.15
B _{Ag} -7	P07563	55.0–57.0	21.0–23.0	15.0–19.0	—	—	4.5–5.5	—	—	0.15
B _{Ag} -8	P07720	71.0–73.0	Remainder	—	—	—	—	—	—	0.15
B _{Ag} -8a	P07723	71.0–73.0	Remainder	—	—	—	—	0.25–0.50	—	0.15
B _{Ag} -9	P07650	64.0–66.0	19.0–21.0	13.0–17.0	—	—	—	—	—	0.15
B _{Ag} -10	P07700	69.0–71.0	19.0–21.0	8.0–12.0	—	—	—	—	—	0.15
B _{Ag} -13	P07540	53.0–55.0	Remainder	4.0–6.0	—	0.5–1.5	—	—	—	0.15
B _{Ag} -13a	P07560	55.0–57.0	Remainder	—	—	1.5–2.5	—	—	—	0.15
B _{Ag} -18	P07600	59.0–61.0	Remainder	—	—	—	9.5–10.5	—	—	0.15
B _{Ag} -19	P07925	92.0–93.0	Remainder	—	—	—	—	0.15–0.30	—	0.15
B _{Ag} -20	P07301	29.0–31.0	37.0–39.0	30.0–34.0	—	—	—	—	—	0.15
B _{Ag} -21	P07630	62.0–64.0	27.5–29.5	—	—	2.0–3.0	5.0–7.0	—	—	0.15
B _{Ag} -22	P07490	48.0–50.0	15.0–17.0	21.0–25.0	—	4.0–5.0	—	—	7.0–8.0	0.15
B _{Ag} -23	P07850	84.0–86.0	—	—	—	—	—	—	Remainder	0.15
B _{Ag} -24	P07505	49.0–51.0	19.0–21.0	26.0–30.0	—	1.5–2.5	—	—	—	0.15
B _{Ag} -26	P07250	24.0–26.0	37.0–39.0	31.0–35.0	—	1.5–2.5	—	—	1.5–2.5	0.15
B _{Ag} -27	P07251	24.0–26.0	34.0–36.0	24.5–28.5	12.5–14.5	—	—	—	—	0.15
B _{Ag} -28	P07401	39.0–41.0	29.0–31.0	26.0–30.0	—	—	1.5–2.5	—	—	0.15
B _{Ag} -33	P07252	24.0–26.0	29.0–31.0	26.5–28.5	16.5–18.5	—	—	—	—	0.15
B _{Ag} -34	P07380	37.0–39.0	31.0–33.0	26.0–30.0	—	—	1.5–2.5	—	—	0.15
B _{Ag} -35	P07351	34.0–36.0	31.0–33.0	31.0–35.0	—	—	—	—	—	0.15
B _{Ag} -36	P07454	44.0–46.0	26.0–28.0	23.0–27.0	—	—	2.5–3.5	—	—	0.15
B _{Ag} -37	P07253	24.0–26.0	39.0–41.0	31.0–35.0	—	—	1.5–2.5	—	—	0.15

^a See Table B.3 for discontinued brazing filler metal classifications.

^b See Table 7 for the following Ag classifications intended for vacuum service not included here: B_VAg-0, B_VAg-6b, B_VAg-8b, and B_VAg-29 to B_VAg-32.

^c SAE HS-1086, *Metals & Alloys in the Unified Numbering System*.

^d The brazing filler metal shall be analyzed for those specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified.

9.2 The sample shall be analyzed by accepted analytical methods.

9.3 In case of dispute, the referee methods for all elements except phosphorus shall be the appropriate analytical method in the latest edition of the *Annual Book of ASTM Standards, Section 03—Metals Test Methods and Analytical Procedures, Volume 5—Analytical Chemistry for Metals, Ores, and Related Materials*. For phosphorus, the referee method shall be that of ASTM E1371-05.

10. Sieve Analysis

10.1 Sieve analyses for standard sizes of powdered brazing filler metals shall be made in accordance with ASTM B214.

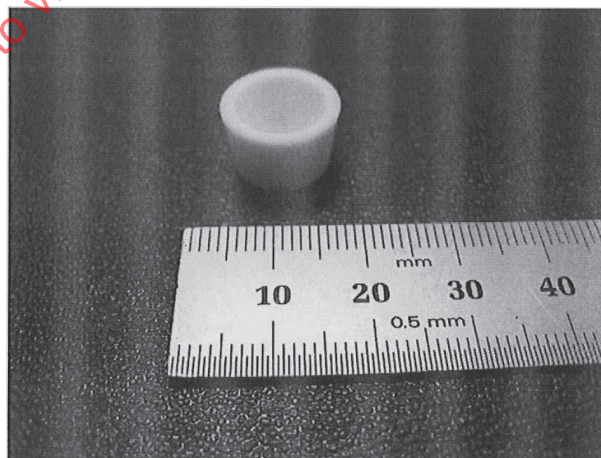
10.2 The results of the sieve analysis shall conform to the particle size distribution shown in Table 8. Sizes other than the standard sizes shall be as agreed upon between the purchaser and the supplier.

11. Melt Cleanliness Test

11.1 The melt cleanliness test shall be required for all BV class brazing filler metals produced for use in vacuum service applications only. The melt cleanliness test shall be performed on a sample of approximately 0.5 grams (g) [0.015 troy ounce (0.001 pound (lb))] of brazing filler metal. Clean, dry tools shall be used to extract the sample from the stock, and the sample shall be placed in a clean, dense polycrystalline (greater than 94%) high purity alumina crucible. As an alternative, a fused silica crucible or boat that has been precleaned by air firing at a temperature of at least 1100°C [2000°F] and stored in a dust-free container may be used. Figure 1 illustrates a representative test crucible.

11.2 The container with the sample shall be placed in a combustion tube muffle made of dense polycrystalline alumina, fused silica, or an equivalent. The muffle shall be purged with a minimum of 30% dry hydrogen to keep the nitrogen level balanced (−40°C [−40°F] dew point or lower), and the sample shall be heated to a minimum of 20°C [36°F] above the liquidus temperature established for the material (see Table B.2). It shall be held at that temperature for ten minutes and then allowed to cool in the muffle to a temperature no higher than 65°C [150°F]. At that time, the flow of hydrogen shall be stopped, and the sample shall be removed for examination.

11.3 The fused sample shall be examined at a magnification of 5×. If it has melted completely and does not exhibit excessive black specks on the surface, it meets the requirements of the cleanliness test. The acceptance standard for black specks shall be established by the supplier or as agreed upon between the supplier and purchaser. Evidence of proper melting of the specimen is shown by the alloy forming into a spherical shape in the alumina crucible.



Photograph courtesy of WESGO Ceramics

Figure 1—Illustration of an Acceptable Crucible

Table 2^{a,b}
Chemical Composition Requirements for Gold Brazing Filler Metals

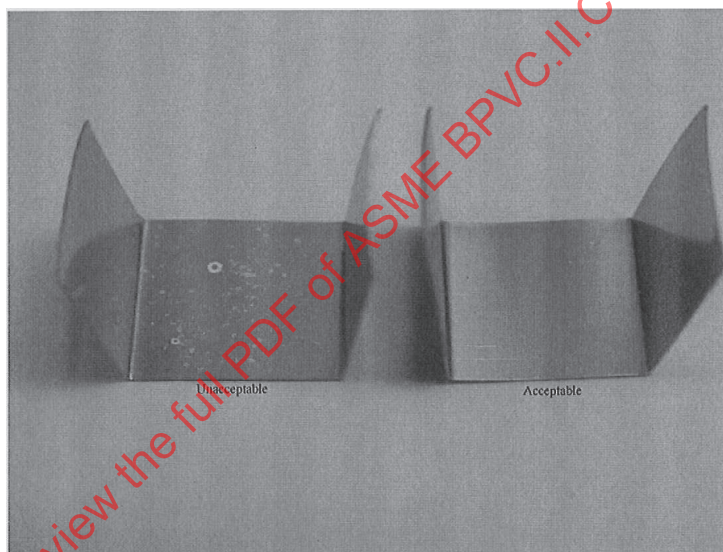
AWS Classification	UNS Number ^c	Chemical Composition, Weight Percent				Other Elements, Total ^d
		Au	Cu	Pd	Ni	
BAu-1	P00375	37.0–38.0	Remainder	—	—	0.15
BAu-2	P00800	79.5–80.5	Remainder	—	—	0.15
BAu-3	P00350	34.5–35.5	Remainder	—	2.5–3.5	0.15
BAu-4	P00820	81.5–82.5	—	—	Remainder	0.15
BAu-5	P00300	29.5–30.5	—	33.5–34.5	35.5–36.5	0.15
BAu-6	P00700	69.5–70.5	—	7.5–8.5	21.5–22.5	0.15

^a See Table B.3 for discontinued brazing filler metal classifications.

^b See Table 7 for the following Au classifications intended for vacuum service not included here: BVAu-2, BVAu-3, BVAu-4, BVAu-7, BVAu-8, BVAu-9, and BVAu-10.

^c SAE HS-1086, *Metals & Alloys in the Unified Numbering System*.

^d The brazing filler metal shall be analyzed for those specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified.



Photograph courtesy of Lucas-Milhaupt, Incorporated

Figure 2—Nickel Channel with Acceptable Test Results (right) and Unacceptable Spatter (left)

12. Spatter Test

12.1 The spatter test shall be required for all BV class brazing filler metals produced for use in vacuum service applications only. Brazing filler metal in the form of powder is exempt from the spatter test due to its high ratio of surface area to volume and the oxides usually present on these surfaces.

12.2 The spatter test shall be performed at the same time as the melt cleanliness test by bridging the crucible or boat with a nickel channel, the legs of which are designed to allow a small clearance, 1.5 mm [0.06 in] maximum, above the crucible. The bridge shall be no more than 10 mm [0.39 in] above the brazing filler metal. Figure 2 shows a suitable nickel channel and illustrates acceptable and unacceptable test results.

12.3 Upon completion of the test, the bottom side of the nickel channel shall be examined at a 5× magnification for evidence of any spatter. If there is no evidence of spatter, the sample meets the requirements.

Table 3^a
Chemical Composition Requirements for Aluminum and Magnesium Brazing Filler Metals

Chemical Composition, Weight Percent ^b														
AWS Classification	UNS Number ^c	Si	Cu	Mg	Bi	Fe	Zn	Mn	Cr	N	Ti	Be	Al	Other Elements ^d
														Each Total
BAISi-2	A94343	6.8–8.2	0.25	—	—	0.8	0.20	0.10	—	—	—	—	Remainder	0.05 0.15
BAISi-3	A94145	9.3–10.7	3.3–4.7	0.15	—	0.8	0.20	0.15	0.15	—	—	—	Remainder	0.05 0.15
BAISi-4	A94047	11.0–13.0	0.30	0.10	—	0.8	0.20	0.15	—	—	—	—	Remainder	0.05 0.15
BAISi-5	A94045	9.0–11.0	0.30	0.05	—	0.8	0.10	0.05	—	—	0.20	—	Remainder	0.05 0.15
BAISi-7	A94004	9.0–10.5	0.25	1.0–2.0	—	0.8	0.20	0.10	—	—	—	—	Remainder	0.05 0.15
BAISi-9	A94147	11.0–13.0	0.25	0.10–0.50	—	0.8	0.20	0.10	—	—	—	—	Remainder	0.05 0.15
BAISi-11	A94104	9.0–10.5	0.25	1.0–2.0	0.02–0.20	0.8	0.20	0.10	—	—	—	—	Remainder	0.05 0.15
BMg-1	M19001	0.05	0.05	Remainder	—	0.005	1.7–2.3	0.15–1.50	—	0.005	—	0.0002– 0.0008	8.3–9.7	— 0.30

^a See Table B.3 for discontinued brazing filler metal classifications.

^b Single values are maximum unless noted.

^c SAE HS-1086, *Metals & Alloys in the Unified Numbering System*.

^d The brazing filler metal shall be analyzed for those specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified.

Table 4
Chemical Composition Requirements for Copper, Copper–Zinc, and Copper–Phosphorus Brazing Filler Metals^{a, b}

Chemical Composition, Weight Percent ^c													
AWS Classification	UNS Number ^d	Cu	Ag	Zn	Sn	Fe	Mn	Ni	P	Pb	Al	Si	Other Elements, Total ^e
BCu-1	C14180	99.90 min.	—	—	—	—	—	—	0.075	0.02	0.01	—	0.10
BCu-1a	TBD	99.00 ^f min.	—	—	—	—	—	—	—	—	—	—	0.30
BCu-1b	C11000	99.90 min.	—	—	—	—	—	—	—	—	—	—	0.10
BCu-2 ^g	TBD	86.50 ^f min.	—	—	—	—	—	—	—	—	—	—	0.50
BCu-3 ^h	C10200	99.95 min.	—	—	—	—	—	—	—	—	—	—	0.05
RBCuZn-A	C47000	57.0–61.0	—	Remainder	0.25–1.00	*	*	—	—	0.05*	0.01*	*	0.50
RBCuZn-B	C68000	56.0–60.0 ⁱ	—	Remainder	0.80–1.10	0.25–1.20	0.01–0.50	0.20–0.80 ⁱ	—	0.05*	0.01*	0.04–0.20	0.50
RBCuZn-C	C68100	56.0–60.0 ⁱ	—	Remainder	0.80–1.10	0.25–1.20	0.01–0.50	—	—	0.05*	0.01*	0.04–0.15	0.50
RBCuZn-D	C77300	46.0–50.0 ⁱ	—	Remainder	—	—	—	9.0–11.0 ⁱ	0.25	0.05*	0.01*	0.04–0.25	0.50
BCuP-2	C55181	Remainder	—	—	—	—	—	—	7.0–7.5	—	—	—	0.15
BCuP-3	C55281	Remainder	4.8–5.2	—	—	—	—	—	5.8–6.2	—	—	—	0.15
BCuP-4	C55283	Remainder	5.8–6.2	—	—	—	—	—	7.0–7.5	—	—	—	0.15
BCuP-5	C55284	Remainder	14.5–15.5	—	—	—	—	—	4.8–5.2	—	—	—	0.15
BCuP-6	C55280	Remainder	1.8–2.2	—	—	—	—	—	6.8–7.2	—	—	—	0.15
BCuP-7	C55282	Remainder	4.8–5.2	—	—	—	—	—	6.5–7.0	—	—	—	0.15
BCuP-8	C55285	Remainder	17.2–18.0	—	—	—	—	—	6.0–6.7	—	—	—	0.15
BCuP-9	C55385	Remainder	—	—	6.0–7.0	—	—	—	6.0–7.0	—	—	0.01–0.40	0.15
BCuP-10	C55386	Remainder	—	—	5.5–6.5	—	—	3.0–5.0	6.8–7.2	—	—	—	0.15

^a See Table B.3 for discontinued brazing filler metal classifications.

^b See Table 7 for the following Cu classifications intended for vacuum service not included here: BVCu-1x.

^c Single values are maximum unless noted.

^d SAE HS-1086, *Metals & Alloys in the Unified Numbering System*. Classifications BCu-1a and BCu-2 have had UNS Numbers applied for.

^e The brazing filler metal shall be analyzed for those specific elements for which values or asterisks (*) are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified in “Other Elements, Total.”

^f The balance is oxygen, which is present as cuprous oxide. Oxygen is not to be included in “Other Elements.”

^g These chemical composition requirements pertain only to the cuprous oxide powder and do not include requirements for the organic vehicle in which the cuprous oxide is suspended, when supplied in paste form.

^h The maximum allowable percentage of oxygen for this alloy is 0.001%.

ⁱ Includes residual cobalt.

^j Includes residual silver.

Table 5^a
Chemical Composition Requirements for Nickel and Cobalt Brazing Filler Metals

Chemical Composition, Weight Percent ^b																				Other Elements, Total ^d
AWS Classification	UNS Number ^c	Ni	Cr	B	Si	Fe	C	P	S	Al	Ti	Mn	Cu	Zr	W	Co	Mo	Nb	Se	
BNi-1	N99600	Rem.	13.0–15.0	2.75–3.50	4.0–5.0	4.0–5.0	0.60–0.90	0.02	0.02	0.05	0.05	—	—	0.05	—	0.10	—	—	0.005	0.50
BNi-1a	N99610	Rem.	13.0–15.0	2.75–3.50	4.0–5.0	4.0–5.0	0.06	0.02	0.02	0.05	0.05	—	—	0.05	—	0.10	—	—	0.005	0.50
BNi-2	N99620	Rem.	6.0–8.0	2.75–3.50	4.0–5.0	2.5–3.5	0.06	0.02	0.02	0.05	0.05	—	—	0.05	—	0.10	—	—	0.005	0.50
BNi-3	N99630	Rem.	—	2.75–3.50	4.0–5.0	0.5	0.06	0.02	0.02	0.05	0.05	—	—	0.05	—	0.10	—	—	0.005	0.50
BNi-4	N99640	Rem.	—	1.50–2.20	3.0–4.0	1.5	0.06	0.02	0.02	0.05	0.05	—	—	0.05	—	0.10	—	—	0.005	0.50
BNi-5	N99650	Rem.	18.5–19.5	0.03	9.75–10.50	—	0.06	0.02	0.02	0.05	0.05	—	—	0.05	—	0.10	—	—	0.005	0.50
BNi-5a	N99651	Rem.	18.5–19.5	1.0–1.5	7.0–7.5	0.5	0.10	0.02	0.02	0.05	0.05	—	—	0.05	—	0.10	—	—	0.005	0.50
BNi-5b	N99652	Rem.	14.5–15.5	1.1–1.6	7.0–7.5	1.0	0.06	0.02	0.02	0.05	0.05	—	—	0.05	—	1.0	—	—	0.005	0.50
BNi-6	N99700	Rem.	—	—	—	—	0.06	10.0–12.0	0.02	0.05	0.05	—	—	0.05	—	0.10	—	—	0.005	0.50
BNi-7	N99710	Rem.	13.0–15.0	0.02	0.10	0.2	0.06	9.7–10.5	0.02	0.05	0.05	0.04	—	0.05	—	0.10	—	—	0.005	0.50
BNi-8	N99800	Rem.	—	—	6.0–8.0	—	0.06	0.02	0.02	0.05	0.05	21.5–24.5	4.0–5.0	0.05	—	0.10	—	—	0.005	0.50
BNi-9	N99612	Rem.	13.5–16.5	3.25–4.00	—	1.5	0.06	0.02	0.02	0.05	0.05	—	—	0.05	—	0.10	—	—	0.005	0.50
BNi-10	N99622	Rem.	10.0–13.0	2.0–3.0	3.0–4.0	2.5–4.5	0.40–0.55	0.02	0.02	0.05	0.05	—	—	0.05	15.0–17.0	0.10	—	—	0.005	0.50
BNi-11	N99624	Rem.	9.00–11.75	2.2–3.1	3.35–4.25	2.5–4.0	0.30–0.50	0.02	0.02	0.05	0.05	—	—	0.05	11.00–12.75	0.10	—	—	0.005	0.50
BNi-12	N99720	Rem.	24.0–26.0	0.02	0.1	0.2	0.06	9.0–11.0	0.02	0.05	0.05	—	—	0.05	—	0.10	—	—	0.005	0.50
BNi-13	N99810	Rem.	7.0–9.0	2.75–3.50	3.8–4.8	0.4	0.06	0.02	0.02	0.05	0.05	—	2.0–3.0	0.05	—	0.10	1.5–2.5	1.5–2.5	0.005	0.50
BNi-14	N99660	Rem.	21.0–23.0	0.1	6.0–7.0	0.5	0.16	3.5–4.5	0.02	0.05	0.05	—	—	0.05	—	0.10	—	—	0.005	0.50
BCo-1	R39001	16.0–18.0	18.0–20.0	0.70–0.90	7.5–8.5	1.0	0.35–0.45	0.02	0.02	0.05	0.05	—	—	0.05	3.5–4.5	Rem.	—	—	0.005	0.50

^a See Table B.3 for discontinued brazing filler metal classifications.

^b Single values are maximum.

^c SAE HS-1086, *Metals & Alloys in the Unified Numbering System*.

^d The brazing filler metal shall be analyzed for those specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified.

Table 6
Chemical Composition Requirements for Titanium and Titanium–Zirconium Brazing Filler Metals

Chemical Composition, Weight Percent^a

AWS Classification	UNS Number ^b	Ti	Zr	Cu	Ni	Mo	Hf	Fe	Al	Si	O	N	C	Other Elements, Total ^c
BTi-1	TBD	Remainder	—	14.0–16.0	14.0–16.0	—	—	0.1	0.05	0.02	0.15	0.02	0.04	0.30
BTi-2	TBD	Remainder	—	14.0–16.0	24.0–26.0	—	—	0.1	0.05	0.02	0.15	0.02	0.04	0.30
BTi-3	TBD	Remainder	37.0–38.0	14.0–16.0	9.5–10.5	0.1	0.1	0.08	0.05	0.02	0.20	0.03	0.04	0.50
BTi-4	TBD	Remainder	23.5–24.5	15.0–17.0	15.0–17.0	1.5	0.1	0.08	0.05	0.02	0.20	0.03	0.04	0.50
BTi-5	TBD	Remainder	19.0–21.0	19.0–21.0	19.0–21.0	0.1	0.1	0.08	0.05	0.02	0.20	0.03	0.04	0.50

^a Single values are maximum.

^b UNS number has been applied for.

^c The brazing filler metal shall be analyzed for those specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified.

Table 7
Chemical Composition Requirements for Brazing Filler Metals for Vacuum Service

AWS	UNS	Chemical Composition, Weight Percent ^{a,b}												
Classification	Number ^c	Ag	Au	Cu	Ni	Co	Sn	Pd	In	Zn	Cd	Pb	P	C
Grade 1														
BVAg-0	P07017	99.95 min.	—	0.05	—	—	—	—	—	0.001	0.001	0.002	0.002	0.005
BVAg-6b	P07507	49.0–51.0	—	Remainder	—	—	—	—	—	0.001	0.001	0.002	0.002	0.005
BVAg-8	P07727	71.0–73.0	—	Remainder	—	—	—	—	—	0.001	0.001	0.002	0.002	0.005
BVAg-8b	P07728	70.5–72.5	—	Remainder	0.3–0.7	—	—	—	—	0.001	0.001	0.002	0.002	0.005
BVAg-18	P07607	59.0–61.0	—	Remainder	—	—	9.5–10.5	—	—	0.001	0.001	0.002	0.002	0.005
BVAg-29	P07627	60.5–62.5	—	Remainder	—	—	—	—	14.0–15.0	0.001	0.001	0.002	0.002	0.005
BVAg-30	P07687	67.0–69.0	—	Remainder	—	—	—	4.5–5.5	—	0.001	0.001	0.002	0.002	0.005
BVAg-31	P07587	57.0–59.0	—	31.0–33.0	—	—	—	Remainder	—	0.001	0.001	0.002	0.002	0.005
BVAg-32	P07547	53.0–55.0	—	20.0–22.0	—	—	—	Remainder	—	0.001	0.001	0.002	0.002	0.005
BVAu-2	P00807	—	79.5–80.5	Remainder	—	—	—	—	—	0.001	0.001	0.002	0.002	0.005
BVAu-3	P00351	—	34.5–35.5	Remainder	2.5–3.5	—	—	—	—	0.001	0.001	0.002	0.002	0.005
BVAu-4	P00827	—	81.5–82.5	—	Remainder	—	—	—	—	0.001	0.001	0.002	0.002	0.005
BVAu-7	P00507	—	49.5–50.5	—	24.5–25.5	0.06	—	Remainder	—	0.001	0.001	0.002	0.002	0.005
BVAu-8	P00927	—	91.0–93.0	—	—	—	—	Remainder	—	0.001	0.001	0.002	0.002	0.005
BVAu-9	P00354	—	34.5–35.5	Remainder	—	—	—	—	—	0.001	0.001	0.002	0.002	0.005
BVAu-10	P00503	—	49.5–50.5	Remainder	—	—	—	—	—	0.001	0.001	0.002	0.002	0.005
BVPd-1	P03657	—	—	—	0.06	Remainder	—	64.0–66.0	—	0.001	0.001	0.002	0.002	0.005
Grade 2														
BVAg-0	P07017	99.95 min.	—	0.05	—	—	—	—	—	0.002	0.002	0.002	0.002	0.005
BVAg-6b	P07507	49.0–51.0	—	Remainder	—	—	—	—	—	0.002	0.002	0.002	0.020	0.005
BVAg-8	P07727	71.0–73.0	—	Remainder	—	—	—	—	—	0.002	0.002	0.002	0.020	0.005
BVAg-8b	P07728	70.5–72.5	—	Remainder	0.3–0.7	—	—	—	—	0.002	0.002	0.002	0.020	0.005
BVAg-18	P07607	59.0–61.0	—	Remainder	—	—	9.5–10.5	—	—	0.002	0.002	0.002	0.020	0.005
BVAg-29	P07627	60.5–62.5	—	Remainder	—	—	—	—	14.0–15.0	0.002	0.002	0.002	0.020	0.005
BVAg-30	P07687	67.0–69.0	—	Remainder	—	—	—	4.5–5.5	—	0.002	0.002	0.002	0.020	0.005
BVAg-31	P07587	57.0–59.0	—	31.0–33.0	—	—	—	Remainder	—	0.002	0.002	0.002	0.002	0.005
BVAg-32	P07547	53.0–55.0	—	20.0–22.0	—	—	—	Remainder	—	0.002	0.002	0.002	0.002	0.005
BVAu-2	P00807	—	79.5–80.5	Remainder	—	—	—	—	—	0.002	0.002	0.002	0.002	0.005
BVAu-3	P00351	—	34.5–35.5	Remainder	2.5–3.5	—	—	—	—	0.002	0.002	0.002	0.002	0.005
BVAu-4	P00827	—	81.5–82.5	—	Remainder	—	—	—	—	0.002	0.002	0.002	0.002	0.005
BVAu-7	P99507	—	49.5–50.5	—	24.5–25.5	0.06	—	Remainder	—	0.002	0.002	0.002	0.002	0.005
BVAu-8	P00927	—	91.0–93.0	—	—	—	—	Remainder	—	0.002	0.002	0.002	0.002	0.005
BVAu-9	P00354	—	34.5–35.5	Remainder	—	—	—	—	—	0.002	0.002	0.002	0.002	0.005
BVAu-10	P00503	—	49.5–50.5	Remainder	—	—	—	—	—	0.002	0.002	0.002	0.002	0.005
BVPd-1	P03657	—	—	—	0.06	Remainder	—	64.0–66.0	—	0.002	0.002	0.002	0.002	0.005
BVCu-1x	C14181	—	—	99.99 min.	—	—	—	—	—	0.002	0.002	0.002	0.002	—

^a The brazing filler metal shall be analyzed for those specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined. Elements detected that have a vapor pressure higher than 1.3×10^{-5} Pa [10^{-7} torr] at 500°C [932°F] are limited to 0.001% each for Grade 1 brazing filler metals and 0.002% each for Grade 2 brazing filler metals. The total of all high vapor pressure elements (including zinc, cadmium, and lead) is limited to 0.010%. The total of all other impurity elements is 0.01% maximum for Grade 1 and 0.05% maximum for Grade 2.

^b Single values are maximum unless noted.

^c SAE HS-1086, *Metals & Alloys in the Unified Numbering System*.

Table 8
Powder Mesh Designations and Particle Size Distribution^a

Powder Mesh ^b Designation		Particle Size Distribution		
		Sieve Size		Distribution
μm	U.S. Number	μm	U.S. Number	%
150	100 mesh	Through 250	Through 60	100
		Through 150	Through 100	95 min.
106 (C)	140 C ^c mesh	On 150	On 100	0.5 max.
		On 106	On 140	10 max.
		Through 45	Through 325	20 max.
106 (F)	140 F ^d mesh	On 150	On 100	0.5 max.
		On 106	On 140	10 max.
		Through 45	Through 325	55 max.
45	325 mesh	On 75	On 200	0.5 max.
		On 45	On 325	10 max.
		Through 45	Through 325	90 min.

^a All of the above sieve sizes are standard ASTM sizes selected from Table 1 of ASTM E11-01, *Standard Specification for Wire Cloth and Sieves for Testing Purposes*.

^b 106 μm F [140 F mesh] shall be supplied unless otherwise specified by the customer.

^c C = Coarse

^d F = Fine

13. Binder Content of Transfer Tape

13.1 The binder content of the transfer tape shall be determined by the following method:

13.1.1 A strip of Type 304 stainless steel approximately 0.8 mm × 13 mm × 50 mm [0.03 in × 0.5 in × 2 in] shall be weighed, and the weight shall be recorded as **Weight A**.

13.1.2 The transfer tape shall be shaped to the dimensions of the stainless steel strip, applied to the strip, the plastic carrier removed, and the composite weighed. This weight shall be recorded as **Weight B**.

13.1.3 The composite strip and transfer tape shall be heated in a vacuum or other protective atmosphere furnace to a temperature of 550°C to 650°C [1022°F to 1200°F], then cooled in the protective atmosphere, and reweighed. This weight shall be recorded as **Weight C**.

13.1.4 The percentage of binder shall be calculated as follows:

$$\text{Percentage of binder} = \frac{\text{Weight B} - \text{Weight C}}{\text{Weight B} - \text{Weight A}} \times 100$$

13.1.5 The binder content of the transfer tape may also be determined by the alternative method described in 13.1.6 through 13.1.9.

13.1.6 A ceramic crucible shall be used. The crucible should be a clean, dense polycrystalline alumina. As an alternative, a fused silica crucible or boat that has been precleaned by air firing at a temperature of at least 1100°C [2000°F] and stored in a dust-free container may be used. The crucible shall be weighed, and the weight shall be recorded as “Weight A.”

13.1.7 A section of transfer tape approximately 0.8 mm × 13 mm × 50 mm [0.03 in × 0.5 in × 2 in], with the plastic carrier removed, shall be placed in the ceramic crucible. The crucible and transfer tape shall be weighed. This weight shall be recorded as “Weight B.”

13.1.8 The crucible and transfer tape shall be heated in a protective atmosphere furnace (including vacuum) to a temperature of 550°C to 650°C [1022°F to 1200°F], then cooled in the protective atmosphere, and reweighed. This weight shall be recorded as “Weight C.”

13.1.9 The percentage of binder shall be calculated as specified in 13.1.4.

13.2 To meet the requirements, the binder content of transfer tape shall be 6% maximum binder for transfer tape above 0.25 mm [0.010 in] and 10% maximum binder for transfer tape for 0.25 mm [0.010 in] and below; titanium transfer tape binder content shall not exceed 15% maximum.

14. Method of Manufacture

The brazing filler metals classified according to this specification may be manufactured by any method that will produce brazing filler metals that meet the requirements of this specification.

15. Standard Forms, Sizes, and Tolerances

15.1 Standard forms and sizes of brazing filler metals shall be as shown in Table 9.

15.2 Dimensional tolerances of wrought wire, rod, sheet, and strip shall be in accordance with Tables 10 and 11, as applicable.

15.3 Size and tolerances of cast rod, transfer tape, bonded sheet, and bonded rope shall be as agreed upon between the purchaser and supplier.

16. Brazing Filler Metal Identification

16.1 Brazing filler metal identification is to be accomplished by tags, labels, or appropriate marking on the unit package. Unit packages include coils, spools, bundles, mandrels, and containers. Specific marking requirements are listed in Clause 18.

16.2 When required by the purchase order or contract, special identification of individual pieces of brazing filler metals shall be provided in addition to the identification of the unit package. When so prescribed, the use of pressure-sensitive labels or imprint marking shall become a requirement for conformance to this specification.

17. Packaging

Brazing filler metals shall be suitably packaged to ensure against damage during shipment or storage under normal conditions.

18. Marking of Packages

18.1 The following product information (as a minimum) shall be legibly marked on the outside of each unit package:

- (1) AWS specification and classification designations (year of issue may be excluded);
- (2) Supplier's name and trade designation;
- (3) Size and net weight;
- (4) Lot, control, or heat number; and
- (5) Date of manufacture for tape and paste.

Table 9
Standard Forms and Sizes of Brazing Filler Metals^{a, b, c}

AWS Classification	Standard Form	Dimensions Specified	Standard Sizes			
			Width, Length, or Powder Mesh Designation		Thickness or Diameter	
					mm	in
BAg All Classifications	Strip ^d (coiled or spooled)	Width and Thickness	6 mm to 150 mm in multiples of 1 mm		0.05	0.002
					0.08	0.003
					0.10	
					0.13	0.005
					0.15	
			or 0.25 in to 6.0 in in multiples of 2.25 in		0.20	
					0.25	0.010
					0.50	0.020
BVAg All Classifications	Round Wire (coiled or spooled); Rod (straight lengths)	Diameter for Wire and Rod	—		0.8	1/32 (0.031)
					1.0	
					1.2	3/64 (0.047)
					1.5	
					1.6	1/16 (0.062)
		Length for Rod	450 mm and 900 mm or 18 in and 36 in		2.0	
					2.4	3/32 (0.094)
					2.5	
					3.0	
					3.2	1/8 (0.125)
BAu, BVAu, BVPd, BCu All Classifications	Powder and Paste	Mesh Size (see Table 8)	150 µm [100 mesh] 106 µm C [140 C mesh] 106 µm F [140 F mesh] 45 µm [325 mesh]			
BAISi, BMg-1 All Classifications	Strip, Wire (coiled or spooled), and Powder	Thickness	Dimension shall be agreed by the purchaser and supplier			
BAISi-3 BAISi-4 BMg-1	Sheet (coiled) ^e	Length and Diameter for Rod	900 mm or 36 in		0.25	0.010
					0.38	0.015
					0.50	0.020
					1.6	1/16 (0.062)
					2.4	3/32 (0.094)
					3.2	1/8 (0.125)
					4.0	5/32 (0.156)
					4.8	3/16 (0.188)
BAISi-4 BCuP-5	Powder and Paste	Mesh Size (see Table 8)	150 µm [100 mesh]			
BCuP-5	Strip (coiled or spooled)	Width and Thickness	6.35 mm to 152.4 mm in multiples of 6.35 mm [0.25 in to 6.0 in in multiples of 0.25 in]		0.08	0.003
					0.13	0.005
					0.25	0.010
					0.6	0.025

Table 9 (Continued)
Standard Forms and Sizes of Brazing Filler Metals

			Standard Sizes		
AWS Classification	Standard Form	Dimensions Specified	Width, Length, or Powder Mesh Designation	Thickness or Diameter	
				mm	in
BCuP: All Classifications	Round Wire (coiled or spooled)	Diameter	—	1.3 1.6 2.0 2.4 2.8 3.2 4.0 6.4	0.050 0.062 0.094 0.109 0.125 0.250
	Round Rod (straight lengths)	Length and Diameter	450 mm and 900 mm or 18 in and 36 in		
	Rectangular Wire (coils or spools)	Width and Thicknesses	1.6 mm to 6.4 mm width in multiples of 0.8 mm or 1/16 in to 1/4 in width in multiples of 1/32 in		
	Rectangular Rod (straight lengths)	Width, Length, and Thickness	1.6 mm, 2.4 mm, and 3.2 mm or 1/16 in, 3/32 in, and 18 in width		
			450 mm and 900 mm lengths or 18 in and 36 in length		
	Powder and Paste	Mesh Size (see Table 8)	150 μm [100 mesh] 106 μm C [140 C mesh] 106 μm F [140 F mesh] 45 μm [325 mesh]		
	BCu-1, BCu-1b, BCu-3 RBCuZn-A	Strip (coiled or spooled)	Dimensions shall be agreed upon between the purchaser and supplier		
BCu-1, BCu-1b, BCu-3 RBCuZn-A RBCuZn-B RBCuZn-C RBCuZn-D	Round Wire (coiled)	Diameter	0.8 1.6 2.4 3.2 4.0 4.8 6.4 8.0 9.5	1/32 (0.031) 1/16 (0.062) 3/32 (0.094) 1/8 (0.125) 5/32 (0.156) 3/16 (0.188) 1/4 (0.250) 5/16 (0.312) 3/8 (0.375)	
	Rod (straight lengths)	Length and Diameter			450 mm and 900 mm or 18 in and 36 in
BCu-1a BCu-2	Powder and Paste	Mesh Size (see Table 8)	106 μm C [140 C mesh] 106 μm F [140 F mesh] 45 μm [325 mesh]		
BVCu-1x	Strip, Round Wire (coils or spools)	Dimensions shall be agreed upon between the purchaser and supplier			

Table 9 (Continued)
Standard Forms and Sizes of Brazing Filler Metals

AWS Classification	Standard Form	Dimensions Specified	Width, Length, or Powder Mesh Designation	Standard Sizes	
				Thickness or Diameter	
				mm	in
BNi: All Classifications except BNi-5a and BNi-5b	Cast Round (straight lengths) ^f Foil	Diameter		1.6	1/16 (0.0625)
				3.2	1/8 (0.125)
BCo-1	Cast and Wrought (borided) Foil	Width and Thickness	1/8 in to 4.0 in or 3.2 mm to 100 mm	0.025	0.001
				0.037 ^g	0.0015
				0.05	0.002
	Bonded Powder Rope, Sheet, and Transfer Tape ^h	Dimensions shall be agreed upon between the purchaser and supplier			
		Powder and Paste	Mesh Size (see Table 8)	106 μm C [140 C mesh] 106 μm F [140 F mesh] 45 μm [325 mesh]	
BNi-5a	Foil		1/8 in to 4.0 in or 3.2 mm to 100 mm	0.025	0.001
				0.037	0.015
				0.05	0.002
				0.06	0.0025
BNi-5b	Foil		1/8 in to 8.0 in or 3.2 mm to 200 mm	0.025	0.001
				0.037	0.0015
				0.05	0.002
				0.06	0.0025
	Powder and Paste	Mesh Size (see Table 8)	149 μm [100 mesh] 106 μm C [140 C mesh] 106 μm F [140 F mesh] 74 μm [200 mesh] 45 μm [325 mesh]		
BTi: All Classifications	Transfer Tape and Sheet	Thickness	As Specified		
	Amorphous or Partly Amorphous Foil	Thickness	As Specified		
	Clad Tape	Thickness	As Specified		

^a Dimensions, sizes, and package forms other than those shown shall be as agreed upon between the purchaser and supplier.

^b C = Coarse

^c F = Fine

^d BAg-2, BAg-3, BAg-4, BAg-22, BAg-24, and BAg-26 as filler metal clad or bonded to each side of a copper core is also a standard form. The standard thickness ratios of filler metal to copper core to filler metal cladding are 1:2:1 or 1:4:1.

^e BAlSi-2, BAlSi-5, BAlSi-7, BAlSi-9, BAlSi-11 filler metal clad or bonded to one or both sides of an aluminum alloy is also a standard form. The standard thickness of the filler metal cladding is 5% to 10% of the thickness of the aluminum alloy core.

^f Tolerances listed in Table 10 do not apply for cast rod forms.

^g Available in widths up to 50 mm [2 in].

^h Tolerances listed in Table 11 do not apply for these bonded powder forms.

18.2 Marking of any overpacking of unit packages only requires conformance with regulations of DOT or other shipping agencies. Items listed in 18.1 are not required in any overpacking.

18.3 The appropriate precautionary information¹⁰ as given in ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, (as a minimum) or its equivalent shall be prominently displayed in legible print on all packages of brazing filler metal, including individual unit packages enclosed within a larger package.

18.4 In addition to the precautionary information required in 18.3, all packages (including individual unit packages enclosed within a larger package and special containers such as spools and mandrels) of brazing filler metals BAg-1, BAg-1a, BAg-2, BAg-2a, BAg-3, BAg-27, and BAg-33 shall have the appropriate precautionary information for cadmium (as given in ANSI Z49.1) permanently affixed and prominently displayed in legible print.

¹⁰ Typical examples of “warning labels” from ANSI Z49.1 for some common or specific consumables used with certain processes are shown in Figure B.1 and Figure B.2.

Table 10
Tolerances for Wrought Wire and Rod^{a,b}

Form	Condition	Tolerances, $\pm$							
		Nominal Size ^c		Round		Rectangular			
				Thickness		Width			
		mm	in	mm	in	mm	in	mm	in
Wire	Cold-Drawn or Cold-Rolled	Over 0.25–0.51	Over 0.010–0.020	0.008	0.0003	0.020	0.0008	0.13	0.005
		Over 0.51–0.80	Over 0.020–0.031	0.013	0.0005	0.040	0.0016	0.13	0.005
		Over 0.80–1.00	Over 0.031–0.040	0.018	0.0007	0.045	0.0018	0.13	0.005
		Over 1.00–1.30	Over 0.040–0.051	0.020	0.0008	0.050	0.0020	0.13	0.005
		Over 1.30–1.50	Over 0.051–0.060	0.025	0.0010	0.064	0.0025	0.13	0.005
		Over 1.50–2.00	Over 0.060–0.080	0.038	0.0015	0.080	0.0031	0.13	0.005
		Over 2.00–6.40	Over 0.080–0.252	0.051	0.0020	0.100	0.0040	0.13	0.005
Rod	Cold-Drawn or Cold-Rolled	4.00 and under	5/32 and under	0.08	0.0031	0.23	0.0090	0.25	0.010
		4.80 and over	3/16 and over	0.10	0.0040	0.25	0.0100	0.25	0.010
Rod and Wire	Hot-Rolled or Extruded	Over 1.20–1.60	Over 3/64–1/16	0.13	0.0051	0.20	0.0080	0.25	0.010
		Over 1.60–3.20	Over 1/16–1/8	0.15	0.0060	0.23	0.0090	0.25	0.010
		Over 3.20–4.80	Over 1/8–3/16	0.18	0.0070	0.23	0.0090	0.25	0.010
		Over 4.80–6.40	Over 3/16–1/4	0.20	0.0080	0.25	0.0100	0.25	0.010

^a Tolerances for cast rod shall be as agreed upon between the purchaser and the supplier.

^b Length tolerance shall be $\pm 12\text{mm}$ [$\pm 1/2$ in] for rod.

^c Diameter for round; thickness or width for rectangular.

Table 11
Tolerances for Foil Strip and Sheet

Nominal Thickness		Thickness Tolerance, $\pm$			
		Width 200 mm [8 in] and Under		Width over 200 mm [8 in]	
mm	in	mm	in	mm	in
0.15 and under	0.006 and under	0.015	0.0006	0.020	0.0008
Over 0.15–0.33 incl.	Over 0.006–0.013 incl.	0.025	0.0010	0.025	0.0010
Over 0.33–0.53 incl.	Over 0.013–0.021 incl.	0.038	0.0015	0.038	0.0015
Over 0.53–0.66 incl.	Over 0.021–0.026 incl.	0.050	0.0020	0.051	0.0020
Nominal Width		Width Tolerance, $\pm$			
		Thickness of 1.59 mm [0.062 in] and Under		Thickness of 1.6 mm [0.063 in] to 3.18 mm [0.125 in] incl.	
mm	in	mm	in	mm	in
Over 1.6 to 25 incl.	Over 0.062–1.0.	0.13	0.005	0.007	0.18
Over 25–50 incl.	Over 1.0–2.0 incl.	0.13	0.005	0.009	0.23
Over 50–150 incl.	Over 2.0–6.0 incl.	0.13	0.005	0.012	0.30
Over 150–380 incl.	Over 6.0–15.0 incl.	0.18	0.007	0.43	0.017
Over 380–500 incl.	Over 15.0	0.18	0.007	0.43	0.017

Annex A (Informative)

Informative References

This annex is not part of AWS A5.8M/A5.8:2011, *Specification for Filler Metals for Brazing and Braze Welding*, but is included for informational purposes only.

AWS, 2007, *Brazing Handbook*, 5th ed., Miami: American Welding Society.

AWS A1.1, *Metric Practice Guide for the Welding Industry*, American Welding Society.

AWS A5.31M/A5.31, *Specification for Fluxes for Brazing and Braze Welding*, American Welding Society.

AWS B2.2/B2.2M, *Specification for Brazing Procedure and Performance Qualification*, American Welding Society.

AWS C3.2M/C3.2, *Standard Method for Evaluating the Strength of Brazed Joints*, American Welding Society.

AWS C3.3, *Recommended Practices for the Design, Manufacture, and Examination of Critical Brazed Components*, American Welding Society.

AWS C3.4M/C3.4, *Specification for Torch Brazing*, American Welding Society.

AWS C3.5M/C3.5, *Specification for Induction Brazing*, American Welding Society.

AWS C3.6M/C3.6, *Specification for Furnace Brazing*, American Welding Society.

AWS C3.7M/C3.7, *Specification for Aluminum Brazing*, American Welding Society.

AWS C3.8M/C3.8, *Specification for the Ultrasonic Pulse-Echo Examination of Brazed Joints*, American Welding Society.

AWS C3.9M/C3.9, *Specification for Resistance Brazing*, American Welding Society.

AWS D10.13, *Recommended Practice for the Brazing of Copper Pipe and Tubing for Medical Gas Systems*, American Welding Society.

Annex B (Informative)

Guide to AWS A5.8M/A5.8:2011, *Specification for Filler Metals for Brazing and Braze Welding*

This annex is not part of AWS A5.8M/A5.8:2011, *Specification for Filler Metals for Brazing and Braze Welding*, but is included for informational purposes only.

B1. Introduction

B1.1 Brazing is a group of joining processes that produces the coalescence of materials by heating them to the brazing temperature in the presence of a brazing filler metal having a liquidus above 450°C [840°F] and below the solidus of the base metal. The brazing filler metal is distributed into or held in the closely fitted faying surfaces of the joint by capillary action.

B1.2 The purpose of this guide is to correlate the brazing filler metal classifications with their intended applications so that the specification can be used effectively. The AWS *Brazing Handbook* should be consulted for detailed information. If the component has critical applications, AWS C3.3 should be followed.

B1.3 This specification is intended to provide both the supplier and the user of brazing filler metals with a guide for production control and a basis of acceptance through mutually acceptable standard requirements. This specification classifies only those brazing filler metals that were commercially significant at the time it was issued. As other brazing filler metals become commercially significant, they may be added to the specification. Those that lose their commercial significance may be discontinued.

B2. Method of Classification

B2.1 The classification of brazing filler metals is based on chemical composition rather than on mechanical property requirements. The mechanical properties of a brazed joint depend, among other things, on the base metal, the brazing filler metal, and the brazing conditions. Therefore, a classification method based on mechanical properties would be misleading as it would only apply if the brazing filler metal were used on a given base metal using specific brazing conditions. If the user of a brazing filler metal desires to determine the mechanical properties of a given base metal and brazing filler metal combination, tests should be conducted using the latest edition of AWS C3.2M/C3.2.

B2.2 Brazing filler metals are standardized into eight groups as follows: silver, gold, aluminum, copper, nickel, cobalt, magnesium, and titanium brazing filler metals. Many brazing filler metals in these classifications are used for joining assemblies for vacuum service applications, such as vacuum tubes and other electronic devices. For these critical applications, it is desirable to hold the high vapor pressure elements to a minimum, as they usually contaminate the vacuum with vaporized elements during the operation of the device. Filler metals for electronic devices have been incorporated as additional “vacuum grade” classifications within this specification.

B2.3 The basic classifications of brazing filler metal are identified by the principal element in their chemical composition, as shown in Tables 1 through 7 (see also Table B.2). For example, in the designation BCuP-2, the “B” denotes *brazing filler metal* (as the “E” denotes *electrodes* and the “R” denotes *welding rods* in other AWS specifications). The “RB” in RBCuZn-A, RBCuZn-B, RBCuZn-C, and RBCuZn-D indicates that the brazing filler metal is suitable as a braze welding rod and as a brazing filler metal. The term “CuP” denotes *copper-phosphorus*, the two principal elements in this particular brazing filler metal (similarly, in other brazing filler metals, “Si” denotes *silicon*, “Ag” denotes *silver*, and so forth, using standard chemical symbols). The designation following the chemical symbol indicates the chemical composition within a group.

The nomenclature for the vacuum grade brazing filler metals follows the examples above, with two exceptions. The first exception is the addition of the letter “V,” yielding the generic letters “BV,” denoting brazing filler metals for vacuum service. The second exception is the use of the grade suffix number; Grade 1 is used to indicate the more stringent requirements for high vapor pressure impurities, and Grade 2 is used to indicate less stringent requirements for high vapor pressure impurities. Vacuum grade brazing filler metals are considered to be spatter free. Therefore, this specification no longer lists spatter-free and nonspatter-free vacuum grades. An example of a brazing filler metal for vacuum service is BVAg-6b, Grade 1. Table 7 lists brazing filler metals for vacuum service.

B2.4 Request for Brazing Filler Metal Classification. When a brazing filler metal cannot be classified according to a classification given in this specification, the manufacturer may request that a classification be established for that brazing filler metal. The manufacturer can do this using the following procedure:

- (1) A request to establish a new brazing filler metal classification must be a written request, and it needs to provide sufficient detail to permit the AWS A5 Committee on Filler Metals and Allied Materials or the AWS A5H Subcommittee on Filler Metals and Fluxes for Brazing to determine whether the new classification or the modification of an existing classification is more appropriate, and whether either is necessary to satisfy the need.

In particular, the request needs to include:

- (a) All classification requirements as given for existing classifications, such as chemical composition ranges and usability test requirements;
- (b) Any conditions for conducting the tests used to demonstrate that the product meets the classification requirements (it would be sufficient, for example, to state that the brazing conditions are the same as for other classifications);
- (c) Information on Descriptions and Intended Use, paralleling that for existing classifications within that clause of the respective Annex; and
- (d) For all A5 specifications, other than A5.10/A5.10M: actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the filler metal specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.
- (e) Patent policy: If the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester shall disclose this in the request. Prior to adoption of a standard that requires the use of any patented classification, the owner of the patent shall provide written assurance to AWS that:
 - i. No patent rights will be enforced against anyone using the patent to comply with the standard;
 - or
 - ii. The owner will make a license available to anyone wishing to use the patent to comply with the standard, without compensation or for reasonable rates, with reasonable terms and conditions demonstrably free of any unfair competition.

The Secretary will return the request to the requestor for further information.

- (2) A request for a new classification without the above information will be considered incomplete. The Secretary will return the request to the requestor for further information. The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters. Upon receipt of the request, the Secretary will:
 - (a) Assign an identifying number to the request. This number will include the date the request was received;
 - (b) Confirm receipt of the request and give the identification number to the person who made the request;
 - (c) Send a copy of the request to the Chair of the Committee on Filler Metals and Allied Materials and the Chair of the Subcommittee on Filler Metals and Fluxes for Brazing;
 - (d) File the original request; and
 - (e) Add the request to the log of outstanding requests.
- (3) All necessary action on each request will be completed as soon as possible. If more than 12 months lapse, the Secretary shall inform the requestor of the status of the request, with copies to the chairs of the Committee and of the Subcommittee. Requests still outstanding after 18 months shall be considered not to have been answered in a “timely manner,” and the Secretary shall report these to the Chair of the AWS Committee on Filler Metals and Allied Materials for action.
- (4) The Secretary shall include a copy of the log of all requests pending and those completed during the preceding year with the agenda for each Committee on Filler Metals and Allied Materials meeting. Any other publication of requests that have been completed will be at the option of the American Welding Society, as deemed appropriate.

Table B.1
Comparison of Classifications with ISO/CD 17672

Aluminum (& Mg) Alloys		Silver (& Pd) Alloys		Copper Alloys		Nickel (& Co) Alloys		Gold Alloys	
A5.8M/A5.8	ISO 17672	A5.8M/A5.8	ISO 17672	A5.8M/A5.8	ISO 17672	A5.8M/A5.8	ISO 17672	A5.8M/A5.8	ISO 17672
BAISi-2	Al 107	BAG-1	Ag 345	BCu-1	Cu 141	BNi-1	Ni 600	BAu1*	Au 375
BAISi-3	Al 210	BAG-1a	Ag 350	BCu-1a	Cu 099	BNi-1a	Ni 610	BVAu-2	Au 800
BAISi-4	Al 112	BAG-2	Ag 335	BCu-1b	Cu 100	BNi-2	Ni 620	BVAu-3	Au 351
BAISi-5	Al 110	BAG-2a	Ag 330	BCu-2	Cu 087	BNi-3	Ni 630	BVAu-4	Au 827
BAISi-7	Al 310	BAG-3	Ag 351	BCu-3	Cu 103	BNi-4	Ni 631	BAu-5*	Au 300
BAISi-9	Al 317	BAG-4	Ag 440*	RBCuZn-A	Cu 470*	BNi-5	Ni 650	BAu-6*	Au 700
BAISi-11	Al 311	BAG-5	Ag 245	RBCuZn-B	Cu 680	BNi-5a	Ni 660	BVAu-7	Au 507
BMg-1	Mg 001	BAG-6	Ag 250	RBCuZn-C	Cu 681	BNi-5b	Ni 661	BVAu-8	Au 927
		BAG-7	Ag 156	RBCuZn-D	Cu 773	BNi-6	Ni 700	BVAu-9	Au 354
		BAG-8	Ag 272	BCuP-2	Cu 181	BNi-7	Ni 710	BVAu-10	Au 503
		BAG-8a		BCuP-3	CuP 281	BNi-8	Ni 800		
		BAG-9	Ag 265	BCuP-4	CuP 283	BNi-9	Ni 612		
		BAG-10	Ag 270	BCuP-5	CuP 284	BNi-10	Ni 670		
		BAG-13	Ag 454	BCuP-6	CuP 280	BNi-11	Ni 671		
		BAG-13a	Ag 456	BCuP-7	Cu 282	BNi-12	Ni 720		
		BAG-18	Ag 160	BCuP-8	CuP 285	BNi-13	Ni 810		
		BAG-19	—	BCuP-9	CuP 385	BNi-14	—		
		BAG-20	Ag 230	BCuP-10	—	BCo-1	Co 1		
		BAG-21	Ag 463						
		BAG-22	Ag 449						
		BAG-23	Ag 485						
		BAG-24	Ag 450						
		BAG-26	Ag 425						
		BAG-27	—						
		BAG-28	Ag 140						
		BVAg 29	—						
		BVAg 30	Pd 305						
		BVAg 31	Pd 309						
		BVAg 32	Pd 325						
		BAG-33 (Ag 326*)	—						
		BAG-34	Ag 138						
		BAG-35	Ag 235						
		BAG-36 (Ag 145*)	—						
		BAG-37	Ag 125						
		BVPd-1	Pd 365						
		* Nearest equivalent							

B2.5 An international system for designating welding filler metals developed by the International Institute of Welding (IIW) is being adopted in many ISO specifications. Table B.1 shows those used in the ISO/CD 17672 specification for comparison with comparable classifications in this specification.

B3. Acceptance

Acceptance of all brazing filler metals classified under this specification is in accordance with AWS A5.01M/A5.01 (ISO 14344 MOD) as this specification states. Any sampling and testing a purchaser requires of the supplier for brazing filler metal shipped in accordance with this specification should be clearly stated in the purchase order, according to the provisions of AWS A5.01M/A5.01 (ISO 14344 MOD).

In the absence of any such statement in the purchase order, the supplier may ship the brazing filler metal with whatever testing the supplier normally conducts on brazing filler metal of that classification, as specified in Schedule F, Table 1, of AWS A5.01M/A5.01 (ISO 14344 MOD). Testing in accordance with any other schedule in Table 1 should be specifically required by the purchase order. In such cases, the acceptance of the brazing filler metal shipped should be in accordance with those requirements.

B4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product or the classification on the product itself constitutes the supplier's or the manufacturer's certification that the product meets all of the requirements of the specification.

The only testing requirement implicit in this "certification" is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that the material has met the requirements of this specification. Representative material, in this case, is any production run of that classification from the same formulation. "Certification" is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the certification required by the specification is the classification test of "representative material" cited above, and the "Manufacturer's Quality Assurance Program" in AWS A5.01M/A5.01 (ISO 14344 MOD).

B5. Ventilation during Brazing

B5.1 Five major factors govern the quantity of fumes to which brazers and brazing operators can be exposed during brazing. They are:

- (1) Dimensions of the space in which brazing is performed;
- (2) Number of brazers and brazing operators working in that space;
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes used;
- (4) The proximity of the brazer or brazing operators to the fumes, as these fumes issue from the brazing zone, and to the gases and dusts in the space in which they are working; and
- (5) The ventilation provided to the space in which the brazing is performed.

B5.2 American National Standard ANSI Z49.1 discusses the ventilation that is required during brazing and braze welding and should be referred to for details. Particular attention should be drawn to the clause on ventilation in that document. Further information concerning ventilation during brazing can be found in AWS F3.2, *Ventilation Guide for Weld Fume*.

B6. Brazing Terminology and Considerations

B6.1 To avoid confusion, solidus and liquidus are specified instead of melting and flow points. The terms *solidus* and *liquidus* are defined as follows:

solidus. The highest temperature at which a metal or alloy is completely solid.¹¹

liquidus. The lowest temperature at which a metal or alloy is completely liquid.¹²

B6.2 Table B.2 lists the nominal solidus, liquidus, and the recommended brazing temperature range for the various brazing filler metals. When brazing with some brazing filler metals (particularly those with a wide temperature range between solidus and liquidus), the several constituents of the brazing filler metals tend to separate during the melting process. The lower melting constituent will flow, leaving behind an unmelted residue or skull of the high-melting constituent. This occurrence, termed *liquation*, is usually undesirable in that the unmelted skull does not readily flow into the joint. However, when wide joint clearance occurs, a brazing filler metal with a wide temperature range will usually fill the capillary joint more easily.

B6.3 Brazing requires an understanding of several elements of procedures that are beyond the scope of this annex. The *AWS Brazing Handbook* should be referred to for particulars on such items as cleaning, brazing fluxes, brazing atmospheres, brazing safety, joint clearances, etc. Also, AWS C3.3 should be consulted for information on procedures for critical components.

B7. Brazing Characteristics and Applications

B7.1 BAg-XX Group of Classifications (Silver). Brazing filler metals in the BAg-XX group of classifications are used to join most ferrous and nonferrous metals, except aluminum and magnesium. These brazing filler metals have good brazing properties and are suitable for preplacement in the joint or for manual feeding into the joint. Although lap joints are generally used, butt joints may be used if requirements are less stringent. Joint clearances of 0.025 mm to 0.13 mm [0.001 in to 0.005 in] are recommended for the proper capillary action. Flux is generally required on most metals.

When furnace brazing in a protective atmosphere, flux is generally not required. If brazing filler metals containing zinc or cadmium are used in a protective atmosphere furnace, the zinc or cadmium is vaporized, changing the chemical composition as well as the solidus and liquidus. Therefore, cadmium- and zinc-free brazing filler metals are recommended for furnace brazing in a protective atmosphere. Brazing filler metals containing cadmium and/or zinc should not be used in a vacuum furnace.

Brazing filler metals conforming to BAg-1, BAg-1a, BAg-2, BAg-2a, BAg-3, BAg-27, and BAg-33 contain cadmium. The special precautions in Figure B.2 shall be followed. The balance of the BAg classifications is cadmium free.¹³

B7.1.1 Brazing filler metal BAg-1 has the lowest brazing temperature range of the BAg brazing filler metals. It also flows most freely into narrow clearance capillary joints. Its narrow melting range is suitable for rapid or slow methods of heating. BAg-1 is more economical (less silver) than BAg-1a. **DANGER!** This brazing filler metal contains cadmium, and the fumes formed upon heating are toxic. Special precautions as shown in the required precautionary information, as specified in 18.4 of this specification, shall be followed.¹⁴

B7.1.2 Brazing filler metal BAg-1a has properties similar to those of BAg-1. BAg-1a has a narrower melting range than BAg-1, making it slightly more free flowing. It also has a higher silver-plus-copper to zinc-plus-cadmium ratio, resulting in a slight increase in its resistance to corrosion in chlorine, sulfur, and steam environments. Either composition may be used when low-temperature, free-flowing brazing filler metals are desired. **DANGER!** This brazing filler metal contains cadmium, and the fumes formed upon heating are toxic. Special precautions as shown in the required precautionary information, as specified in 18.4 of this specification, shall be followed.

B7.1.3 Brazing filler metal BAg-2, like BAg-1, is free flowing and suited for general-purpose work. Its broader melting range is helpful when clearances are wide or not uniform. Unless heating is rapid, care must be taken to prevent

¹¹ AWS A3.0M/A3.0:2010, *Standard Welding Terms and Definitions Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*, p. 39.

¹² AWS A3.0M/A3.0:2010, *Standard Welding Terms and Definitions Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*, p. 26.

¹³ Cadmium-free brazing filler metal contains no intentionally added cadmium and meets AWS specifications of 0.15% maximum for all other elements including cadmium.

¹⁴ See Footnote 13.

Table B.2
Solidus, Liquidus, and Recommended Brazing Temperature Ranges

AWS Classification	Solidus ^a		Liquidus ^a		Recommended Brazing Temperature Range	
	°C	°F	°C	°F	°C	°F
SILVER						
BAg-1	607	1125	618	1145	620–760	1145–1400
BAg-1a	627	1160	635	1175	635–760	1175–1400
BAg-2	607	1125	702	1295	700–840	1295–1550
BAg-2a	607	1125	710	1310	710–840	1310–1550
BAg-3	632	1170	688	1270	690–815	1270–1500
BAg-4	671	1240	779	1435	780–900	1435–1650
BAg-5	663	1225	743	1370	740–845	1370–1550
BAg-6	688	1270	774	1425	775–870	1425–1600
BAg-7	618	1145	652	1205	650–760	1205–1400
BAg-8	779	1435	779	1435	780–900	1435–1650
BAg-8a	766	1410	766	1410	765–870	1410–1600
BAg-9	671	1240	718	1325	720–840	1325–1550
BAg-10	691	1275	738	1360	740–845	1360–1550
BAg-13	718	1325	857	1575	860–970	1575–1775
BAg-13a	771	1420	893	1640	870–980	1600–1800
BAg-18	602	1115	718	1325	720–840	1325–1550
BAg-19	760	1400	891	1635	880–980	1610–1800
BAg-20	677	1250	766	1410	765–870	1410–1600
BAg-21	691	1275	802	1475	800–900	1475–1650
BAg-22	680	1260	699	1290	700–830	1290–1525
BAg-23	960	1760	970	1780	970–1040	1780–1900
BAg-24	660	1220	707	1305	705–845	1305–1550
BAg-26	707	1305	800	1475	800–870	1475–1600
BAg-27	605	1125	745	1375	745–860	1375–1575
BAg-28	649	1200	710	1310	710–840	1310–1550
BAg-33	607	1125	682	1260	680–760	1260–1400
BAg-34	649	1200	721	1330	720–845	1330–1550
BAg-35	685	1265	754	1390	755–840	1390–1545
BAg-36	646	1195	677	1251	680–815	1251–1495
BAg-37	688	1270	779	1435	780–885	1435–1625
BVAg-0	961	1761	961	1761	960–1035	1761–1900
BVAg-6b	779	1435	872	1602	870–980	1600–1800
BVAg-8	779	1435	779	1435	780–900	1435–1650
BVAg-8b	779	1435	795	1463	800–900	1470–1650
BVAg-18	602	1115	718	1325	715–840	1325–1550
BVAg-29	624	1155	707	1305	705–790	1305–1450
BVAg-30	806	1485	809	1490	810–900	1490–1650
BVAg-31	824	1515	852	1565	850–885	1565–1625
BVAg-32	900	1650	950	1740	950–980	1740–1800
GOLD						
BAu-1	991	1815	1016	1860	1015–1090	1860–2000
BAu-2	891	1635	891	1635	890–1010	1635–1850
BAu-3	990	1814	1010	1850	1010–1070	1850–1950
BAu-4	949	1740	949	1740	950–1005	1740–1840
BAu-5	1135	2075	1166	2130	1165–1230	2130–2250
BAu-6	1007	1845	1046	1915	1045–1120	1915–2050
BVAu-2	891	1635	891	1935	890–1010	1635–1850
BVAu-3	990	1814	1010	1850	1010–1070	1850–1950

Table B.2 (Continued)
Solidus, Liquidus, and Recommended Brazing Temperature Ranges

AWS Classification	Solidus ^a		Liquidus ^a		Recommended Brazing Temperature Range	
	°C	°F	°C	°F	°C	°F
BVAu-4	949	1740	949	1740	950–1005	1740–1840
BVAu-7	1102	2015	1121	2050	1120–1155	2050–2110
BVAu-8	1200	2190	1240	2265	1240–1275	2265–2325
BVAu-9	990	1814	1010	1850	1010–1060	1850–1940
BVAu-10	955	1751	970	1778	970–1020	1778–1868
PALLADIUM						
BVPd-1	1230	2245	1235	2255	1235–1250	2255–2285
ALUMINUM						
BAISi-2	577	1070	617	1142	600–620	1110–1150
BAISi-3	521	970	585	1085	570–605	1060–1120
BAISi-4	577	1070	582	1080	580–605	1080–1120
BAISi-5	577	1070	599	1110	580–605	1090–1120
BAISi-7	559	1038	596	1105	590–605	1090–1120
BAISi-9	562	1044	582	1080	580–605	1080–1120
BAISi-11	559	1038	596	1105	590–605	1090–1120
COPPER						
BCu-1	1083	1981	1083	1981	1095–1150	2000–2100
BCu-1a	1083	1981	1083	1981	1095–1150	2000–2100
BCu-1b	1083	1981	1083	1981	1095–1180	2000–2150
BVCu-1X	1083	1981	1083	1981	1095–1150	2000–2100
BCu-2	1083	1981	1083	1981	1095–1150	2000–2100
BCu-3	1083	1981	1083	1981	1095–1150	2000–2100
RBCuZn-A	888	1630	899	1650	910–955	1670–1750
RBCuZn-B	866	1590	882	1620	880–980	1620–1800
RBCuZn-C	866	1590	888	1630	910–955	1670–1750
RBCuZn-D	921	1690	935	1715	940–980	1720–1800
BCuP-2	710	1310	793	1460	730–845	1350–1550
BCuP-3	643	1190	813	1495	720–815	1325–1500
BCuP-4	643	1190	718	1325	690–790	1275–1450
BCuP-5	643	1190	802	1475	705–815	1300–1500
BCuP-6	643	1190	788	1450	730–815	1350–1500
BCuP-7	643	1190	771	1420	705–815	1300–1500
BCuP-8	643	1190	666	1230	665–685	1230–1270
BCuP-9	637	1178	675	1247	645–695	1190–1280
BCuP-10	597	1107	683	1262	630–710	1170–1310
NICKEL						
BNi-1	977	1790	1038	1900	1065–1205	1950–2200
BNi-1a	977	1790	1077	1970	1080–1205	1970–2200
BNi-2	971	1780	999	1830	1010–1180	1850–2150
BNi-3	982	1800	1038	1900	1010–1180	1850–2150
BNi-4	982	1800	1066	1950	1010–1180	1850–2150
BNi-5	1079	1975	1135	2075	1150–1205	2100–2200
BNi-5a	1065	1931	1150	2111	1150–1205	2100–2200
BNi-5b	1030	1886	1126	2053	1150–1205	2100–2200
BNi-6	877	1610	877	1610	930–1095	1700–2000
BNi-7	888	1630	888	1630	930–1095	1700–2000
BNi-8	982	1800	1010	1850	1010–1095	1850–2000
BNi-9	1055	1930	1055	1930	1065–1205	1950–2200

Table B.2 (Continued)
Solidus, Liquidus, and Recommended Brazing Temperature Ranges

AWS Classification	Solidus ^a		Liquidus ^a		Recommended Brazing Temperature Range	
	°C	°F	°C	°F	°C	°F
BNi-10	970	1780	1105	2020	1150–1205	2100–2200
BNi-11	970	1780	1095	2003	1150–1205	2100–2200
BNi-12	880	1620	950	1740	980–1095	1800–2000
BNi-13	970	1775	1080	1980	1095–1175	2000–2150
BNi-14	960	1760	1015	1860	1065–1175	1950–2150
COBALT						
BCo-1	1120	2050	1149	2100	1150–1230	2100–2250
MAGNESIUM						
BMg-1	443	830	599	1110	605–630	1120–1160
TITANIUM						
BTi-1 ^b	902	1655	950	1742	980–1050	1800–1920
BTi-2 ^b	901	1653	915	1679	930–960	1705–1760
BTi-3 ^b	825	1510	835	1535	850–880	1560–1620
BTi-4 ^b	835	1535	850	1560	890–920	1630–1690
BTi-5 ^b	848	1555	856	1572	870–900	1560–1620

^a The solidus and liquidus shown are for the nominal composition in each classification.

^b The brazing temperature ranges presented in this table relate to the brazing of titanium and titanium alloys. Brazing temperatures can be increased over these ranges for the brazing of titanium aluminide alloys, graphite, and ceramics.

the lower melting constituents from separating out due to liquation. **DANGER!** This brazing filler metal contains cadmium, and the fumes formed upon heating are toxic. Special precautions as shown in the required precautionary information, as specified in 18.4 of this specification, shall be followed.

B7.1.4 Brazing filler metal BAg-2a is similar to BAg-2, but it is more economical than BAg-2 because it contains 5% less silver. **DANGER!** This brazing filler metal contains cadmium, and the fumes formed upon heating are toxic. Special precautions as shown in the required precautionary information, as specified in 18.4 of this specification, shall be followed.

B7.1.5 Brazing filler metal BAg-3 is a modification of BAg-1a in that nickel is added. It has good corrosion resistance in marine environment and caustic media. When used on stainless steel, it inhibits crevice (interface) corrosion. Because its nickel content improves wettability on tungsten carbide tool tips, the largest use is in the brazing of carbide tool assemblies. Its melting range and low fluidity make BAg-3 suitable for forming larger fillets or filling wide joint clearances. **DANGER!** This brazing filler metal contains cadmium, and the fumes formed upon heating are toxic. Special precautions as shown in the required precautionary information, as specified in 18.4 of this specification, shall be followed.

B7.1.6 Brazing filler metal BAg-4, like BAg-3, is used extensively for the brazing of carbide tips, but it flows less freely than BAg-3. This brazing filler metal is cadmium free.

B7.1.7 Brazing filler metals BAg-5 and BAg-6 are cadmium-free brazing filler metals used especially for brazing in the electrical industry. They are used, along with BAg-7 and BAg-24, in the dairy and food industries, in which the use of cadmium-containing brazing filler metals is prohibited. BAg-5 is an excellent brazing filler metal for the brazing of brass components (e.g., ship piping, band instruments, lamps, and so forth). Since BAg-6 has a broad melting range and is not as free flowing as BAg-1 and BAg-2, it is a better brazing filler metal for filling wide joint clearances or forming large fillets.

B7.1.8 Brazing filler metal BAg-7, a cadmium-free substitute for BAg-1, is low-melting with good flow and wetting properties. BAg-7 is typically used for food equipment when cadmium must be avoided, when the white color will

improve the color match with the base metal, and to minimize the stress corrosion cracking of nickel or nickel-based alloys at low brazing temperatures.

B7.1.9 Brazing filler metal BAg-8 is suitable for furnace brazing in a protective atmosphere without the use of a flux, as well as for brazing procedures requiring a flux. It is usually used on copper or copper alloys. When molten, BAg-8 is very fluid and may flow out over the workpiece surfaces during some furnace brazing applications. It can also be used on stainless steel, nickel-based alloys, and carbon steel, although its wetting action on these metals is slow. Higher brazing temperatures improve flow and wetting. This brazing filler metal is cadmium free.

B7.1.10 Brazing filler metal BAg-8a is used for brazing in a protective atmosphere and is advantageous when brazing precipitation-hardening and other stainless steels in the 760°C to 870°C [1400°F to 1600°F] range. The lithium content serves to promote wetting and to increase the flow of the brazing filler metal on difficult-to-braze metals and alloys. Lithium is particularly helpful on base metals containing minor amounts of titanium or aluminum. This brazing filler metal is cadmium free.

B7.1.11 Brazing filler metals BAg-9 and BAg-10 are used particularly for joining sterling silver. These brazing filler metals have different brazing temperatures. Therefore, they can be used for the step brazing of successive joints. After brazing, the color of the brazing filler metal approximates the color of sterling silver. These brazing filler metals are cadmium free.

B7.1.12 Brazing filler metal BAg-13 is used for service temperatures up to 370°C [700°F]. Its low zinc content makes it suitable for furnace brazing when used at the low end of the temperature range and with flux. Without flux in a gaseous protective atmosphere or vacuum, the zinc vaporizes. This brazing filler metal is cadmium free.

B7.1.13 Brazing filler metal BAg-13a is similar to BAg-13, except that it contains no zinc, which is advantageous when volatilization is objectionable in furnace brazing. This brazing filler metal is cadmium free.

B7.1.14 Brazing filler metal BAg-18 is similar to BAg-8 in its applications. Its tin content helps promote wetting on stainless steel, nickel-base alloys, and carbon steel. BAg-18 has a lower liquidus than BAg-8 and is used in step brazing applications in which fluxless brazing is important. This brazing filler metal is cadmium free.

B7.1.15 Brazing filler metal BAg-19 is used for the same applications as BAg-8a. BAg-19 is often used in higher brazing temperature applications in which precipitation-hardening heat treatment and brazing are combined. This brazing filler metal is cadmium free.

B7.1.16 Brazing filler metal BAg-20 possesses good wetting and flow characteristics and has a brazing temperature range higher than the popular Ag-Cu-Zn-Cd compositions. Due to its good brazing properties and economical silver content, new uses for this brazing filler metal are being developed. This brazing filler metal is cadmium free.

B7.1.17 Brazing filler metal BAg-21 is used in brazing AISI 300- and 400-series stainless steels, as well as the precipitation-hardening nickel and steel alloys. BAg-21 is particularly suited to furnace brazing in a protective atmosphere because of the absence of zinc and cadmium. It does not require a flux for proper brazing when the temperature is 1010°C [1850°F] or above. It requires a high brazing temperature, and it flows in a sluggish manner. The nickel-rich layer (halo) formed along the fillet edges during melting and flow of the brazing filler metal prevents crevice (interface) corrosion of stainless steels. This is particularly important for the 400-series steels that do not contain nickel and are, therefore, more susceptible to crevice (interface) corrosion. BAg-21 has been used for brazing stainless steel vanes of aircraft gas turbine engines. This brazing filler metal is cadmium free.

B7.1.18 Brazing filler metal BAg-22 is a low-temperature brazing filler metal with improved wetting characteristics, particularly in the brazing of tungsten carbide tools. This brazing filler metal is cadmium free.

B7.1.19 Brazing filler metal BAg-23 is a high-temperature, free-flowing brazing filler metal usable for both torch brazing and furnace brazing in a protective atmosphere. This brazing filler metal is mainly used in the brazing of stainless steel, nickel-based, and cobalt-based alloys for high-temperature applications. If this brazing filler metal is used in a high-vacuum atmosphere, a loss of manganese will occur due to its high vapor pressure. Thus, a partial pressure produced by inert gas backfilling and a flow to provide a pressure of 67 Pa to 267 Pa [0.5 torr to 2 torr] is desirable when brazing with this brazing filler metal. This brazing filler metal is cadmium free.

B7.1.20 Brazing filler metal BAg-24 is a low-melting, free-flowing brazing filler metal suitable for use in joining 300-series stainless steels (particularly food-handling equipment and hospital utensils) and small tungsten carbide inserts in cutting tools. This brazing filler metal is cadmium free.

B7.1.21 Brazing filler metal BAg-26 is a low-silver brazing filler metal suitable for carbide and stainless steel brazing. The brazing filler metal is characterized by its low brazing temperature, good wetting and flow, and moderate-strength joints when used with these base metals. This brazing filler metal is cadmium free.

B7.1.22 Brazing filler metal BAg-27 is similar to BAg-2 but has a lower silver content and is somewhat more subject to liquation due to a wider melting range. **DANGER!** This brazing filler metal contains cadmium, and the fumes formed upon heating are toxic. Special precautions as shown in the required precautionary information, as specified in 18.4 of this specification, shall be followed.

B7.1.23 Brazing filler metal BAg-28 has a lower brazing temperature with a narrower melting range than other cadmium-free classifications with similar silver content. BAg-28 also has free-flowing characteristics. This brazing filler metal is cadmium free.

B7.1.24 Brazing filler metal BAg-33 was developed to minimize brazing temperature for a brazing filler metal containing 25% silver. It has a lower liquidus and therefore a narrower melting range than BAg-27. Its higher total zinc-plus-cadmium content may require more care during brazing. **DANGER!** This brazing filler metal contains cadmium, and the fumes formed upon heating are toxic. Special precautions as shown in the required precautionary information, as specified in 18.4 of this specification, shall be followed.

B7.1.25 Brazing filler metal BAg-34 is a brazing filler metal with free-flowing characteristics. Its brazing temperature range is similar to that of BAg-2 and BAg-2a, making it an ideal substitute for these brazing filler metals. This brazing filler metal is cadmium free.

B7.1.26 Brazing filler metal BAg-35 is a brazing filler metal used for brazing ferrous and nonferrous base metals. It is a moderate-temperature brazing filler metal frequently used for production brazing applications. This brazing filler metal is cadmium free.

B7.1.27 Brazing filler metal BAg-36 is a low-temperature brazing filler metal suitable for the brazing of ferrous and nonferrous base metals. Its lower brazing temperature makes it a useful replacement for several of the cadmium-bearing classifications. This brazing filler metal is cadmium free.

B7.1.28 Brazing filler metal BAg-37 is frequently used for the brazing of steel, copper, and brass. The low silver content makes it an economical brazing filler metal suitable for applications in which lower ductility is acceptable. This brazing filler metal is cadmium free.

B7.2 BAu-X Group of Classifications (Gold). Brazing filler metals in the BAu-X group of classifications are used for the brazing of iron, nickel, and cobalt base metals when better ductility or a greater resistance to oxidation and corrosion is required. Because of their low rate of interaction with the base metal, they are commonly used on thin base metals. These brazing filler metals are usually used with induction, furnace, or resistance brazing in a protective atmosphere. In these cases, no flux is used. Additional information is provided in AWS A5.31M/A5.31 or the AWS *Brazing Handbook* chapter on "Fluxes and Atmospheres."

B7.2.1 Brazing filler metals BAu-1, BAu-2, and BAu-3, when used for different joints in the same assembly, permit variation in brazing temperature so that step brazing can be used.

B7.2.2 Brazing filler metal BAu-4 is used to braze a wide range of high-temperature iron- and nickel-based alloys.

B7.2.3 Brazing filler metal BAu-5 is primarily used to join heat- and corrosion-resistant base metals when corrosion-resistant joints with good strength at high temperatures are required. This brazing filler metal is well suited for furnace brazing under protective atmospheres (including vacuum).

B7.2.4 Brazing filler metal BAu-6 is primarily used for the joining of iron and nickel-based superalloys for service at elevated temperature. This brazing filler metal is well suited for furnace brazing under protective atmospheres (including vacuum).

B7.3 BAISi-X Group of Classifications (Aluminum-Silicon). Brazing filler metals in the BAISi-X group of classifications are used for joining the following grades of aluminum and aluminum alloys: 1060, 1350, 1100, 3003, 3004, 3005, 3105, 5005, 5050, 6053, 6061, 6951, 7005, and cast alloys 710.0 and 711.0. Joint clearances of 0.05 mm to 0.20 mm [0.002 in to 0.008 in] are common for members that overlap less than 6.4 mm [0.25 in]. Joint clearances up to 0.20 mm to 0.25 mm [0.008 in to 0.010 in] are used for members that overlap more than 6.4 mm [0.25 in].

Fluxing is essential for all processes, except when brazing aluminum in a vacuum when clearances of 0.00 mm to 0.05 mm [0.000 in to 0.002 in] are recommended. After brazing with flux, the brazed parts should be cleaned thoroughly. Immersion in boiling water generally removes the residue. If this is not adequate, the parts are usually immersed in a concentrated commercial nitric acid or other suitable acid solution and then rinsed thoroughly.

B7.3.1 Brazing filler metal BAISi-2 is available as sheet and as a cladding on one or both sides of a brazing sheet having a core of either 3003 or 6951 aluminum alloy. It is used for furnace and dip brazing only.

B7.3.2 Brazing filler metal BAISi-3 is used with all brazing processes, some casting alloys, and when limited flow is desired; it is a general purpose brazing filler metal.

B7.3.3 Brazing filler metal BAISi-4 is used with all brazing processes requiring a free-flowing brazing filler metal and good corrosion resistance; it is a general purpose brazing filler metal.

B7.3.4 Brazing filler metal BAISi-5 is available as sheet and as a cladding on one side or both sides of a brazing sheet having a core of 6951 aluminum alloy. BAISi-5 is used for furnace and dip brazing at a lower temperature than BAISi-2 is. The core alloy employed in brazing sheet with this brazing filler metal cladding can be solution heat treated and aged.

B7.3.5 Brazing filler metal BAISi-7 is suitable for brazing in a vacuum. It is available as a cladding on one or both sides of a brazing sheet having a core of 3003 or 6951 aluminum alloy. The 6951 alloy core can be solution heat treated and aged after brazing. This brazing filler metal contains additional magnesium, which is used as an oxygen getter to improve brazing.

B7.3.6 Brazing filler metal BAISi-9 is suitable for brazing in a vacuum. It is available as a cladding on one side or both sides of a brazing sheet having a core of 3003 aluminum alloy and is typically used in heat-exchanger applications to join fins made from 5000- or 6000-series aluminum alloys. This brazing filler metal contains additional magnesium, which is used as an oxygen getter to improve brazing.

B7.3.7 Brazing filler metal BAISi-11 is a brazing sheet clad on one or two sides of alloy 3105 to form a composite sheet suitable for brazing in a vacuum. It is designed for brazing in a multi-zone furnace in which the vacuum level is interrupted one or more times during the brazing cycle. The composite can be used in batch-type vacuum furnaces; however, vacuum sheet suitable for brazing with a 3003 core is more resistant to erosion. The maximum brazing temperature for the BAISi-11/3105 composite is 595°C [1110°F]. BAISi-11 contains additional magnesium, which is used as an oxygen getter to improve brazing.

B7.4 BCuP-XX Group of Classifications (Copper-Phosphorus). Brazing filler metals in the BCuP-XX group of classifications are used primarily for joining copper and copper alloys, although they have some limited use on silver, tungsten, and molybdenum. These brazing filler metals should not be used on ferrous or nickel-based alloys or on copper-nickel alloys containing a nickel content in excess of 10%, as brittle intermetallic compounds are formed at the brazing filler metal-base metal interface. They are suitable for all brazing processes. These brazing filler metals have self-fluxing properties when used on copper; however, a flux is recommended when used on all other base metals, including alloys of copper. Corrosion resistance is satisfactory except when the joint is in contact with sulfurous atmospheres. It should be noted that the brazing temperature ranges begin below the liquidus (see Table B.2).

B7.4.1 Brazing filler metals BCuP-2 and BCuP-4 are very fluid at brazing temperatures and penetrate joints with small clearances. Best results are obtained with clearances of 0.03 mm to 0.08 mm [0.001 in to 0.003 in].

B7.4.2 Brazing filler metals BCuP-3 and BCuP-5 can be used when narrow joint clearances cannot be held. Joint clearances of 0.05 mm to 0.13 mm [0.002 in to 0.005 in] are recommended.

B7.4.3 Brazing filler metal BCuP-6 combines some of the properties of BCuP-2 and BCuP-3. It has the ability to fill wide joint clearances at the lower end of its brazing range. At the high end of the brazing range, it is more fluid. Joint clearances of 0.05 mm to 0.13 mm [0.002 in to 0.005 in] are recommended.

B7.4.4 Brazing filler metal BCuP-7 is slightly more fluid than BCuP-3 or BCuP-5 and has a lower liquidus temperature. It is used extensively in the form of preplaced rings in heat exchanger and tubing joints. Joint clearances of 0.05 mm to 0.13 mm [0.002 in to 0.005 in] are recommended.

B7.4.5 Brazing filler metal BCuP-8 is the most fluid and has the lowest brazing temperature of the BCuP series filler metals. It is used primarily for tight clearances, 0.03 mm to 0.08 mm [0.001 in to 0.003 in].

B7.4.6 Brazing filler metal BCuP-9 is used for the brazing of copper, brass, and bronze. The addition of silicon lowers the melting temperature and produces a silver-colored braze that resists oxidation darkening during cooling. It also provides the ability to produce a large shoulder or cap around the assembly. The phosphorous inclusion gives the brazing filler metal a self-fluxing property on copper. A flux is required when brazing brass or bronze. Joint clearances of 0.051 mm to 0.127 mm [0.002 in to 0.005 in] are recommended.

B7.4.7 *Brazing filler metal BCuP-10 is used for the brazing of copper, brass, and bronze. The addition of nickel improves corrosion resistance and produces a silver-colored braze that resists oxidation during cooling. The phosphorous inclusion gives the brazing filler metal a “self-fluxing” property on copper. A flux is required when brazing brass or bronze. Joint clearances of 0.05 mm to 0.13 mm [0.002 in to 0.005 in] are recommended.*

B7.5 BCu-X and RBCuZn-X Group of Classifications (Copper and Copper–Zinc). Brazing filler metals in the BCu-X and RBCuZn-X group of classifications are used for joining various ferrous and nonferrous metals. They can also be used with various brazing processes. However, with the RBCuZn filler metals, overheating should be avoided. Voids may be formed in the joint by entrapped zinc vapors.

B7.5.1 Brazing filler metal BCu-1 is used for the joining of ferrous metals, nickel-based alloys, and copper–nickel alloys. It is very free flowing and is often used in furnace brazing, with a protective atmosphere of partially combusted natural gas, hydrogen, dissociated ammonia, or a nitrogen-based atmosphere, generally without flux. On metals that have constituents with difficult-to-reduce oxides (chromium, manganese, silicon, titanium, vanadium, and aluminum), a flux may be required. However, pure dry hydrogen, argon, dissociated ammonia, and vacuum atmospheres are suitable for base metals containing chromium, manganese, or silicon. Flux may also be used with zinc-containing base metals to retard vaporization. Vacuum atmospheres, electrolytic nickel plating, or both, are used for base metals containing titanium and aluminum. Mineral fluxes should not be used in vacuum atmospheres.

B7.5.2 Brazing filler metal BCu-1a is a powder form similar to BCu-1. Its application and use are similar to those of BCu-1.

B7.5.3 Brazing filler metal BCu-1b is very free flowing. It is used most often in furnace brazing with a protective atmosphere of partially combusted natural gas, hydrogen, dissociated ammonia, or nitrogen-based atmosphere, usually without flux.

B7.5.4 Brazing filler metal BCu-2 is supplied as a copper-oxide suspension in an organic vehicle. Its applications are similar to those of BCu-1 and BCu-1a.

B7.5.5 Brazing filler metal BCu-3 is similar to BCu-1 and may be used for the joining of ferrous metals, nickel-based alloys, and copper–nickel alloys. It is very free flowing and is often used in furnace brazing, with a protective atmosphere of partially combusted natural gas, hydrogen, dissociated ammonia, or nitrogen-base atmosphere, generally without flux. On metals that have constituents with difficult-to-reduce oxides (chromium, manganese, silicon, titanium, vanadium, and aluminum), a flux may be required. However, pure dry hydrogen, argon, dissociated ammonia, and vacuum atmospheres are suitable for base metals containing chromium, manganese, or silicon. Flux may also be used with zinc-containing base metals to retard vaporization. Vacuum atmospheres, electrolytic nickel plating, or both, are used for base metals containing titanium and aluminum. Mineral fluxes should not be used in vacuum atmospheres.

B7.5.6 Brazing filler metal RBCuZn-A is used on steel, copper, copper alloys, nickel, nickel alloys, and stainless steel when corrosion resistance is not of importance. It is used with torch, furnace, and induction brazing processes. Fluxing is generally required, and a borax–boric acid type flux is commonly used.¹⁵ Joint clearances from 0.05 mm to 0.13 mm [0.002 in to 0.005 in] are suitable.

B7.5.7 Brazing filler metal RBCuZn-B is used for the brazing and braze welding of steel, cast iron, copper, copper alloys, nickel, nickel alloys, and stainless steel. It is also used for the surfacing of steel, as well as with torch, induction, and furnace processes. RBCuZn-B (low-fuming brass–nickel) braze welding rods are similar to RBCuZn-A rods but contain additions of iron and manganese that serve to increase the hardness and strength. In addition, a small amount of silicon (0.04% to 0.20%) serves to control the vaporization of the zinc, yielding the “low-fuming” property. The nickel addition (0.2% to 0.8%) assures uniform distribution of the iron in the deposit. Flux and joint clearances are the same as those specified for RBCuZn-A.¹⁶

¹⁵ For additional information, see AWS A5.31M/A5.31, or the AWS *Brazing Handbook* chapter entitled “Fluxes and Atmospheres.”

¹⁶ See Footnote 15.

B7.5.8 Brazing filler metal RBCuZn-C is used on steel, copper, copper alloys, nickel, nickel alloys, and stainless steel. It is used with the torch, furnace, and induction brazing processes. Fluxing is required, and a borax-boric acid flux is commonly used.¹⁷ Joint clearances from 0.05 mm to 0.13 mm [0.002 in to 0.005 in] are suitable.

B7.5.9 Brazing filler metal RBCuZn-D (referred to as *nickel silver*) is primarily used for brazing tungsten carbide. It is also used with steel, nickel, and nickel alloys. It can be used with all brazing processes. This brazing filler metal is unsuitable for furnace brazing in a protective atmosphere.¹⁸

B7.6 BNi-X Group of Classifications (Nickel). Brazing filler metals in the BNi-X group of classifications are generally used for their corrosion-resistant and heat-resistant properties. The BNi brazing filler metals have excellent properties at high service temperatures. They are also satisfactorily used for room-temperature applications and when the service temperatures are equal to the temperature of liquid oxygen, helium, or nitrogen. Best quality can be obtained by brazing in an atmosphere that is reducing to both the base metal and the brazing filler metal. Narrow joint clearances and postbrazing thermal diffusion cycles are often employed to minimize the presence of intermetallic compounds, increase joint ductility, and raise the remelt temperature. With complete diffusion, the remelt temperature can be increased to above 1370°C [2500°F].

When BNi brazing filler metals are used with the torch, air-atmosphere furnace, and induction brazing processes, a suitable flux must be used. BNi brazing filler metals are particularly suited to vacuum systems and vacuum tube applications because of their low vapor pressure. Chromium is the limiting element in metals to be used in vacuum applications. It should be noted that when phosphorus is combined with some other elements, these compounds have very low vapor pressures and can be readily used in a vacuum brazing atmosphere of 0.13 Pa [1×10^{-3} torr] at 1066°C [1950°F] without removal of the phosphorus. Greater strength and ductility in this group of brazing filler metals is obtainable by diffusion brazing.

B7.6.1 Brazing filler metal BNi-1 was the first of the nickel brazing filler metals to be developed. The nickel, chromium, and iron contents render it suitable for the brazing of nickel, chromium, or iron base metals. Since high carbon content in 300-series stainless steels is usually metallurgically undesirable from a corrosion standpoint, the high carbon in BNi-1 would appear to make it undesirable for brazing stainless steels. However, Strauss test results have not shown any adverse affects when used on base metals such as AISI 347 stainless steel since the carbon is already tied up with the chromium in the brazing filler metal.

B7.6.2 Brazing filler metal BNi-1a is a low-carbon grade of BNi-1 with an identical chemical composition, except that while the specified carbon content is 0.06% maximum, the carbon content is usually 0.03% or lower. While the carbon content is lower, corrosion testing results with the Strauss and Huey tests are no better than for joints made with BNi-1. This brazing filler metal produces stronger joints but is less fluid than brazing filler metal BNi-1.

B7.6.3 Brazing filler metal BNi-2 has a lower and narrower melting range and better flow characteristics than BNi-1. These characteristics have made this brazing filler metal the most widely used of the nickel brazing filler metals.

B7.6.4 Brazing filler metal BNi-3 is used for applications similar to BNi-1 and BNi-2 and is less sensitive to marginally protective atmospheres (includes vacuum). BNi-3 is a Ni-Si-B brazing filler metal that does not contain chromium.

B7.6.5 Brazing filler metal BNi-4 is similar to but more ductile than BNi-3. It is used to form large fillets or joints when large joint clearances are present.

B7.6.6 Brazing filler metal BNi-5 is used for applications similar to those for BNi-1, except that it can be used in certain nuclear applications in which boron cannot be tolerated.

B7.6.7 Brazing filler metal BNi-5a is a modified BNi-5 composition with reduced silicon content plus a small addition of boron. The presence of boron excludes this alloy from nuclear applications. Otherwise, the applications are similar to those of BNi-5. High-strength joints can be produced. BNi-5a material can be used in place of BNi-1 when a reduced level of boron is desired. The brazing of thin-gauge honeycomb to sheet metal base parts is a typical application.

B7.6.8 Brazing filler metal BNi-5b is a modified BNi-5 composition with reduced chromium. The presence of boron excludes this alloy from nuclear applications. Otherwise, the applications are similar to those of BNi-5. High-strength joints can be produced. BNi-5b material can be used in place of BNi-1 when a reduced level of boron is desired.

¹⁷ See Footnote 15.

¹⁸ See Footnote 15.

B7.6.9 Brazing filler metal BNi-6 is free flowing. It is used in marginally protective atmospheres and for the brazing of low-carbon steels in exothermic atmospheres.

B7.6.10 Brazing filler metal BNi-7 is used for the brazing of honeycomb structures, thin-walled tube assemblies, and other structures that are used at high temperatures. It is recommended for nuclear applications when boron cannot be used. The best results are obtained when it is used in the furnace brazing process. The microstructure and ductility of the joint are improved by increasing the time at the brazing temperature.

B7.6.11 Brazing filler metal BNi-8 is used in honeycomb brazements and on stainless steels and other corrosion-resistant base metals. Since this brazing filler metal contains a high percentage of manganese, special brazing procedures should be observed. As manganese oxidizes more readily than chromium, the hydrogen, argon, and helium brazing atmospheres must be pure and very dry, with a dew point of -57°C [-70°F] or below. The vacuum atmosphere must employ a partial pressure using dry argon or nitrogen, and the furnace must have a low leak rate to ensure a very low partial pressure of oxygen. It should be noted that the chemical composition and the melting characteristics of this brazing filler metal change when the manganese is oxidized or vaporized during brazing in gas or vacuum atmospheres. However, the effect of manganese is not a concern in an atmosphere of proper quality.

B7.6.12 Brazing filler metal BNi-9 is a eutectic nickel–chromium–boron brazing filler metal that is particularly well suited for diffusion brazing applications. As boron has a small molecular diameter, it diffuses rapidly out of the brazed joint, leaving the more ductile nickel–chromium alloy in the joint along with elements that diffuse from the base metal into the joint, such as aluminum, titanium, and so forth. Depending on the diffusion time and temperature, the joint remelt temperature can be above 1370°C [2500°F], and, depending on the base metal, the hardness can be as low as HRB70. With further diffusion time, the grains can grow across the joint, and it may appear as all base metal. The single solidus and liquidus temperature (eutectic) eliminates the possibility of liquation and thus helps in brazing thick sections that require slower heating.

B7.6.13 Brazing filler metal BNi-10 is a high-strength material for high-temperature applications. The tungsten is a matrix strengthener that makes it useful for brazing base metals containing cobalt, molybdenum, and tungsten. This brazing filler metal has a wide melting range. It has been used for brazing cracks in 0.5 mm [0.02 in] thick combustion chambers. It results in a layer of brazing filler metal across the joint that acts as a doubler, while the lower melting constituent is fluid enough to flow through the thin crack and produce a suitable brazement.

B7.6.14 Brazing filler metal BNi-11 is a strong material for high-temperature brazement applications. The tungsten matrix hardener makes it suitable for brazing base metals containing cobalt, molybdenum, and tungsten. With its wider melting range, it is suitable for slightly higher than normal brazing clearances.

B7.6.15 Brazing filler metal BNi-12 is formulated to improve the oxidation resistance and corrosion resistance of the brazed joint. It is recommended for nuclear applications in which boron-containing brazing filler metals cannot be used. This brazing filler metal is also used to coat base metals, such as copper to protect against oxidation at temperatures such as 816°C [1500°F]. Best results are obtained when using the furnace brazing process. The microstructure, strength, and ductility of the joint are improved by increasing the time and/or the temperature of brazing.

B7.6.16 Brazing filler metal BNi-13 is formulated to improve the corrosion resistance of the brazed joint. It is especially used for brazing 300-series stainless steels when interfacial corrosion has occurred under some conditions. For best results, the brazing cycle should be as short as possible with the brazing temperature as low as practical. Alternatively, the diffusion brazing process is used, and the brazement is held at the highest practical brazing temperature for up to two hours.

B7.6.17 *Brazing filler metal BNi-14 is formulated to provide a lower brazing temperature compared to BNi-5. It is recommended for applications where boron filler metals cannot be used. This filler metal is also used to braze assemblies made of thin sheet metal as the diffusion with the base metal is minimized. Microstructure, strength, and ductility of the brazed joint are improved by increasing the time and/or the temperature of brazing and reducing the joint clearance.*

B7.7 BCo Classification Group (Cobalt). Brazing filler metals in the BCo-1 classification group are generally used for their high-temperature properties and their compatibility with cobalt-alloy base metals.

B7.8 BMg Classification Group (Magnesium). Brazing filler metal BMg-1 is used for the joining of AZ10A, K1A, and M1A magnesium alloys.

B7.9 Brazing Filler Metals for Vacuum Service. The brazing filler metals listed in Table 7 are specially controlled to fabricate high-quality electronic devices when the service life and operating characteristics are of prime importance.

Brazing filler metals for vacuum service should be brazed in a high-purity protective atmosphere in order to maintain the purity of the brazing filler metal and to assure proper brazing and final brazement quality. In some applications, it is very important that the brazing filler metal not spatter onto areas near the joint area. For this reason, this specification includes the spatter test requirements described in Clause 12, "Spatter Test," for the vacuum grade classifications.

In addition to these brazing filler metals tested and classified for vacuum service, BCo-1 and all BNi-xx brazing filler metals except BNi-8 may also be suitable for vacuum service, although they are not required to be tested per Clause 12, "Spatter Test," and are not alternatively classified in this specification as BVxx-xx, Grade y.

B7.10 BTi-X Group of Classifications (Titanium). *Brazing filler metals of the BTi classification group are used primarily for the joining of titanium, titanium alloys, and titanium aluminide alloys, although they are successfully used for the joining of titanium matrix composites, ceramics, ceramic composites, graphite, and carbon-carbon composite materials.*

The brazing filler metals of the BTi group are considered the best choice for joining titanium-based materials, especially for brazed structures that should operate at high temperatures up to 550°C [1020°F] and in highly corrosive atmospheres such as marine environments. The hot strength of brazed joints at 500°C to 550°C [932°F to 1020°F] is about 40% to 50% of the strength of the same joints at room temperature. However, the strength of titanium brazed joints produced with BTi brazing filler metals is significantly higher than that of joints produced with Ag-Cu-based or Al-based brazing filler metals both at hot and room temperatures.

All BTi brazing filler metals provide the best joint formation and strength with a maximum joint clearance of <0.1 mm [<0.004 in]. It is preferable to use a joint clearance of <0.08 mm [<0.003 in].

Brazing filler metals in the clad strip form can be placed both at the brazing clearance edge and into the joint between the titanium parts to be brazed. Brazing filler metals in the form of amorphous foil should be placed only into the joint. It is recommended that brazing filler metals in the form of powder or paste be applied at the edge of the brazing clearance. In order to braze large surfaces such as honeycombs or fin-plate heat exchangers, the powdered BTi brazing filler metal can be applied by painting with a paste or seeding dry powders on the surface first covered with a liquid adhesive binder.

When setting up brazing technology using the BTi group, attention should be paid to the microstructure to prevent uncontrolled growth of a continuous intermetallic layer at the joint-base metal interface, which may cause low impact and fatigue resistance of the brazed joints.

B7.10.1 *Although brazing filler metal BTi-1 has a brazing temperature above 900°C [1652°F], it provides sufficiently high-strength brazed joints, usually above 50% of the strength of the base metals. Moreover, the increase of brazing temperature up to 1050°C [1920°F] for BTi-1 may result in increasing the tensile and shear strength of joints with titanium alloys.*

B7.10.2 *Although brazing filler metal BTi-2 has a brazing temperature above 900°C [1652°F], it provides sufficiently high-strength brazed joints, usually above 50% of the strength of the base metals. Moreover, the increase of brazing temperature up to 960°C [1760°F] for BTi-2 may result in increasing the tensile and shear strength of joints with titanium alloys.*

B7.10.3 *Brazing filler metal BTi-3 has a brazing temperature below 900°C [1652°F] and can be especially recommended for the joining of thin-wall structures. BTi-3 is suitable for brazing beta-titanium alloys with the proviso of a relatively short holding time at the brazing temperature.*

The particle size of -105 microns [-140 mesh] is optimal for powdered brazing filler metal BTi-3 used for the brazing of titanium alloys and titanium matrix composites. Coarse powder of -177 microns [-80 mesh] or -149 microns [-100 mesh] is recommended for brazing titanium aluminide alloys, graphite, or carbon-carbon composites.

B7.10.4 *Brazing filler metal BTi-4 has a brazing temperature above 920°C [1688°F] and can be especially recommended for the joining of thin-wall structures. The particle size of -105 microns [-140 mesh] is optimal for powdered brazing filler metal BTi-4 when used for the brazing of titanium alloys and titanium matrix composites. Coarse powders of -177 microns [-80 mesh] or -149 microns [-100 mesh] are recommended for brazing titanium aluminide alloys, graphite, or carbon-carbon composites.*

B7.10.5 *Brazing filler metal BTi-5 has a brazing temperature below 900°C [1652°F] and can be especially recommended for the joining of thin-wall structures. BTi-5 is suitable for brazing beta-titanium alloys with the proviso of a relatively short holding time at the brazing temperature.*

The particle size of –105 microns [–140 mesh] is optimal for powdered brazing filler metal BTi-5 used for the brazing of titanium alloys and titanium matrix composites. Coarse powder of –177 microns [–80 mesh] or –129 microns [–100 mesh] is recommended for brazing titanium aluminide alloys, graphite, or carbon–carbon composites.

B8. Discontinued Classifications

Some classifications have been discontinued, from one revision of this specification to another. This results either from changes in commercial practice or changes in the classification system used in the specification. The classifications that have been discontinued are listed in Table B.3, along with the year in which they were last included in the specification.

B9. Special Marking

Strip, wire, and rods may be identified by either indenting or imprinting on the surface of the brazing filler metal. Spooled wire that is too small to be marked with imprinting or indenting may be identified with fade-proof ink on the flange of the spools and on the interior and exterior of shipping containers. Preformed rings may be identified with fade-proof ink on metal surfaces or, when in individual envelopes, on the envelope itself. Powders may be identified on the interior container. Fade-proof ink shall be resistant to oils, solvents, all atmospheric conditions, and to the normal wear and tear encountered during shipping and handling. Marking by the use of a group of impressed dots is not permitted.

Table B.3
Discontinued Brazing
Filler Metal Classifications

AWS Classification	Last AWS A5.8 Publication Date
RBCuZn-1	1952
RBCuZn-2	1952
RBCuZn-3	1952
RBCuZn-4	1952
RBCuZn-5	1952
RBCuZn-6	1952
RBCuZn-7	1952
BAGMn	1956
BAISi-1	1956
BNiCr	1956
BCuAu-1	1956
BCuAu-2	1956
BAG-11	1962
BMg-2	1962
BMg-2a	1976
BAISi-6	1981
BAISi-8	1981
BAISi-10	1981
BAG-25	1981
RBCuZn-E	1981
RBCuZn-F	1981
RBCuZn-G	1981
RBCuZn-H	1981
BCuP-1	1992
BAG-12	The Committee has chosen not to use these numbers, as they were improperly placed in another publication.
BAG-14	
BAG-15	
BAG-16	
BAG-17	

B10. General Safety Considerations

B10.1 Safety and Health Fact Sheets. The Safety and Health Fact Sheets listed below are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>; revisions and additional sheets are periodically posted.

No.	Title
1	<i>Fumes and Gases</i>
2	<i>Radiation</i>
3	<i>Noise</i>
4	<i>Chromium and Nickel in Welding Fume</i>
5	<i>Electrical Hazards</i>
6	<i>Fire and Explosion Prevention</i>
7	<i>Burn Protection</i>
8	<i>Mechanical Hazards</i>
9	<i>Tripping and Falling</i>
10	<i>Falling Objects</i>
11	<i>Confined Spaces</i>
12	<i>Contact Lens Wear</i>
13	<i>Ergonomics in the Welding Environment</i>
14	<i>Graphic Symbols for Precautionary Labels</i>
15	<i>Style Guidelines for Safety and Health Documents</i>
16	<i>Pacemakers and Welding</i>
17	<i>Electric and Magnetic Fields (EMF)</i>
18	<i>Lockout/Tagout</i>
19	<i>Laser Welding and Cutting Safety</i>
20	<i>Thermal Spraying Safety</i>
21	<i>Resistance Spot Welding</i>
22	<i>Cadmium Exposure from Welding and Allied Processes</i>
23	<i>California Proposition 65</i>
24	<i>Fluxes for Arc Welding and Brazing: Safe Handling and Use</i>
25	<i>Metal Fume Fever</i>
26	<i>Under Development</i>
27	<i>Thoriated Tungsten Electrodes</i>
28	<i>Under Development</i>
29	<i>Grounding of Portable and Vehicle Mounted Welding Generators</i>
30	<i>Cylinders: Safe Storage, Handling, and Use</i>
31	<i>Eye and Face Protection for Welding and Cutting Operations</i>
33	<i>Personal Protective Equipment (PPE) for Welding & Cutting</i>
34	<i>Coated Steels: Welding and Cutting Safety Concerns</i>
36	<i>Ventilation for Welding & Cutting</i>
37	<i>Selecting Gloves for Welding & Cutting</i>

B11. General Label Information

B11.1 An example of the minimum appropriate precautionary information as given in ANSI Z49.1:2005 is shown in Figure B.1.

B11.2 An example of the precautionary information used for brazing filler metals containing cadmium (e.g., BAg-1, BAg-1a, BAg-2, BAg-2a, BAg-3, BAg-27, and BAg-33) is shown in Figure B.2.

WARNING:

PROTECT yourself and others. Read and understand this information.

FUMES AND GASES can be hazardous to your health.

HEAT RAYS (INFRARED RADIATION) from flame or hot metal can injure eyes.

- Before use, read and understand the manufacturer's instructions, Material Safety Data Sheets (MSDSs), and your employer's safety practices.
- Keep your head out of the fumes.
- Use enough ventilation, exhaust at the flame, or both, to keep fumes and gases from your breathing zone and the general area.
- Wear correct eye, ear, and body protection.
- See American National Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, published by the American Welding Society, 8669 Doral Blvd., Suite 130, Doral, Florida 33166. OSHA *Safety and Health Standards* are published by the U.S. Government Printing Office, 732 North Capitol Street NW, Washington DC 20401.

DO NOT REMOVE THIS INFORMATION

Source: Reproduced from ANSI Z49.1:2005, *Safety in Welding, Cutting, and Allied Processes*, American Welding Society, Figure 2.

Figure B.1—Precautionary Information for Brazing Processes and Equipment**DANGER: CONTAINS CADMIUM**

PROTECT yourself and others. Read and understand this information.

FUMES ARE POISONOUS AND CAN KILL.

- Before use, read and understand the manufacturer's instructions, Material Safety Data Sheets (MSDSs), and your employer's safety practices.
- Do not breathe fumes. Even brief exposure to high concentrations should be avoided.
- Use enough ventilation or exhaust, or both, to keep fumes and gases from your breathing zone and the general area. If this cannot be done, use air supplied respirators.
- Keep children away when using.
- See American National Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, published by the American Welding Society, 8669 Doral Blvd., Suite 130, Doral, Florida 33166. OSHA *Safety and Health Standards*, available from the U.S. Government Printing Office, Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7954.

First Aid: If chest pain, shortness of breath, cough, or fever develops after use, obtain medical help immediately.

DO NOT REMOVE THIS INFORMATION

Source: Adapted from ANSI Z49.1:2005, *Safety in Welding, Cutting, and Allied Processes*, American Welding Society, Figure 3.

Figure B.2—Precautionary Information for Brazing Filler Metals Containing Cadmium

Annex C (Informative)

Analytical Methods

This annex is not part of AWS A5.8M/A5.8:2011, *Specification for Filler Metals for Brazing and Braze Welding*, but is included for informational purposes only.

In case of dispute, the referee methods for all elements shall be the appropriate analytical method in *Annual Book of ASTM Standards, Section 03 — Metals Test Methods and Analytical Procedures, Volume 5 — Analytical Chemistry for Metals, Ores, and Related Materials*, or as indicated in this annex.

The following methods are suggested for the analysis of various elements in silver brazing filler metals:

C1. Phosphorous in Silver or Copper Brazing Filler Metals

Phosphorous range: Less than 0.030%, the Vanadate Colorimetric method in accordance with ASTM E378-97, *Standard Test Method for Spectrographic Analysis of Silver by the Powder Technique*.

Phosphorous range: 4.0% to 8.0%, gravimetric as magnesium pyrophosphate in accordance with ASTM E1371-05.

C2. Lithium in Silver Brazing Filler Metals

Lithium range: Less than 5%, atomic absorption in accordance with ASTM E663-86(1991)E01, *Practice for Flame Atomic Absorption Analysis*.

C3. Manganese in Silver or Copper Brazing Filler Metals

Manganese range: Less than 0.1%, optical emission spectroscopy in accordance with ASTM E378-97, *Standard Test Method for Spectrographic Analysis of Silver by the Powder Technique*.

Manganese range: Greater than 0.1%, atomic absorption in accordance with ASTM E663-86(1991)E01, *Practice for Flame Atomic Absorption Analysis*.

C4. Tin in Silver or Copper Brazing Filler Metals

Tin range: 1% or less, optical emission spectroscopy in accordance with ASTM E378-97, *Standard Test Method for Spectrographic Analysis of Silver by the Powder Technique*.

Tin range: Greater than 0.1%, gravimetric method in accordance with *Standard Methods of Chemical Analysis*, 5th edition.¹⁹

¹⁹ Scott, W. W., and N. H. Furman, eds., 1939, *Standard Methods of Chemical Analysis*, 5th ed., New York: D. Van Nostrand.

C5. Nickel in Silver or Palladium Brazing Filler Metals

Nickel range: 0% to 3.0%, atomic absorption in accordance with ASTM E663-86(1991)E01.

Nickel range: 3% to 20%, gravimetric method as Ni-dimethylglyoxime, ASTM E1473-03, *Standard Test Methods for Chemical Analysis of Nickel, Cobalt, and High-Temperature Alloys*.

C6. Palladium in Silver, Gold, or Palladium Brazing Filler Metals

Palladium range: Less than 0.1%, optical emission spectroscopy, ASTM E378-97.

Palladium range: 1% to 5%, atomic absorption in accordance with ASTM E663-86(1991)E01.

Palladium range: 5% to 90%, gravimetric method in accordance with *Standard Methods of Chemical Analysis*, 5th edition.²⁰

NOTE: Although several of the above-referenced specifications have been discontinued, the bases for analysis are still derived from these standards.

²⁰ Scott, W. W., and N. H. Furman, eds., 1939, *Standard Methods of Chemical Analysis*, 5th ed., New York: D. Van Nostrand.

INTENTIONALLY LEFT BLANK

SPECIFICATION FOR BARE STAINLESS STEEL WELDING ELECTRODES AND RODS



SFA-5.9/SFA-5.9M



(Identical with AWS Specification A5.9/A5.9M:2022 (ISO 14343:2017 MOD). In case of dispute, the original AWS text applies.)

Specification for Bare Stainless Steel Welding Electrodes and Rods

1. Scope

1.1 This specification prescribes requirements for the classification of bare stainless steel wire electrodes (including stranded wire in which all wires in the strand are from one heat), strip electrodes, wires, and rods for gas metal arc welding, gas tungsten arc welding, plasma arc welding, submerged arc welding, electrosag welding, and laser beam welding of stainless and heat resisting steels. The classification of the wire electrodes, strip electrodes, wires, and rods is based upon their chemical composition. The chromium content of these filler metals is not less than 10.5% and the iron content exceeds that of any other element. For purposes of classification, the iron content shall be derived as the balance element when all other elements are considered to be at their minimum specified values.

1.2 This standard makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way. The specification with the designation A5.9 uses U.S. Customary Units. The specification A5.9M uses SI Units. The latter are shown within brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing of electrodes, rods, and strips or packaging or both under A5.9 or A5.9M specifications. This specification's Annex A makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents. The specification designated A5.9 uses U.S. customary units in its Annex A and the specification designated A5.9M uses SI units in its Annex A. The latter units are shown within brackets [] or in appropriate columns in tables and figures.

1.3 Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in Annex Clauses A6 and A12.

Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. Unless otherwise defined in this document, welding terms are as defined in AWS A3.0M/A3.0. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to or revisions of any of these publications do not apply.

American Welding Society (AWS) documents:

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

AWS A5.01M/A5.01 (ISO 14344 MOD), *Welding Consumables—Procurement of Filler Metals and Fluxes*

AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*

AWS F3.2, *Ventilation Guide for Welding Fume*

American National Standards Institute (ANSI) document:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

ASTM International (ASTM) documents:

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

ASTM E353, *Standard Test Methods for Chemical Analysis of Stainless, Heat-Resisting, Maraging, and Other Similar Chromium-Nickel-Iron Alloys*

ASTM E1019, *Standard Test Methods for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel, Iron, Nickel, and Cobalt Alloys by Various Combustion and Inert Gas Fusion Techniques*

International Organization for Standardization (ISO) documents:

ISO 544, *Welding Consumables — Technical Delivery Conditions for Welding Filler Materials — Type of Product, Dimensions, Tolerances and Markings*

ISO 14344, *Welding and Allied Processes — Flux and Gas Shielded Electrical Welding Processes — Procurement Guidelines for Consumables*

ISO 80000-1, *Quantities and Units — Part 1: General*

3. Terms and Definitions

For the purposes of this specification, the following terms and definitions apply.

3.1 Rod. Form of welding filler metal, normally packaged in straight lengths, that does not conduct the welding current, generally used in gas tungsten arc and plasma arc welding.

3.2 Strip Electrode. Form of welding filler metal, normally packaged as coils, having a rectangular cross section of width much greater than thickness, that becomes part of the welding circuit through which current is conducted, and that terminates at the arc for submerged arc welding, or at the slag bath for electrosag welding.

3.3 Wire. Form of welding filler metal, normally packaged as coils, spools, or drums, that does not conduct the welding current, generally used for gas tungsten arc, plasma arc, and laser beam welding.

3.4 Wire Electrode. Form of welding filler metal, normally packaged as coils, spools, or drums, that becomes part of the welding circuit through which electrical current is conducted, and that terminates at the arc; generally used in gas metal arc and submerged arc welding.

4. Classification

4.1 The wire electrodes, strip electrodes, wires, or rods covered by this A5.9/A5.9M specification are classified using a system that is independent of U.S. Customary Units and the International System of Units (SI). Classification is according to the chemical composition of the filler metal as specified in Table 1 and product form. Cast, helix, and package size are given in U.S. Customary Units in AWS A5.9 and in the International System of Units (SI) in AWS A5.9M.

4.2 Materials may be classified under more than one classification provided they meet all the requirements of those classifications as specified in Table 1.

4.3 The materials classified under this specification are intended for gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), plasma arc welding (PAW), submerged arc welding (SAW) and electroslag welding (ESW), but that is not to prohibit their use with any other process for which they are found suitable.

5. Acceptance

Acceptance of the material shall be in accordance with the provisions of AWS A5.01M/A5.01 and the tests and requirements of this specification. See A3 (in Annex A) for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

6. Certification

By affixing the AWS specification and classification designations to the packaging or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification. See A4 (in Annex A) for further information concerning certification and the testing called for to meet this requirement.

7. Rounding Procedure

For the purpose of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest unit in the last right-hand place of figures used in expressing the limiting values. The rounded results shall fulfill the requirements for the classification under test.

8. Summary of Tests

Chemical analysis of the bare stainless steel wire electrodes, strip electrodes, wires, and rods, or of a fused sample of stranded wires or wire electrodes is the only test required for classification of a product under this specification.

9. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Material for retest may be taken from the original test sample or from a new sample. Retest need be only for those specific elements that failed to meet the test requirement.

If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that during preparation or after completion of any test it is clearly determined that prescribed or proper procedures were not followed in preparing the samples or in conducting the test, the test shall be considered invalid without regard to whether the test was actually completed or whether test results met or failed to meet the requirement. That test

shall be repeated, following proper specified procedures. In this case, the requirement for doubling of the number of test specimens does not apply.

10. Properties of All-Weld Metal

Properties of the all-weld metal are not part of the classification.

NOTE 1: The influence of the shielding gas or flux on the chemical composition of the all-weld metal has to be considered. Differences between the chemical composition of the all-weld metal and the wire electrode, wire, or rod can occur.

NOTE 2: Tensile strength and elongation of the weld metal deposited by a consumable listed in Table 1 is expected to approximate the expected values given in Annex A, Table A.2 obtained with SMAW electrodes. Actual measured properties of the weld metal can deviate from the expected values listed in Table A.2 as a result of variations in the welding procedure. In the case of weld metal deposited by the submerged arc process, guidance can be found in AWS A5.39/A5.39M.

11. Chemical Analysis

11.1 A sample of the filler metal or the stock from which it is made, provided there are no processes that alter the composition between stock and finished product, shall be prepared for chemical analysis. See Annex Clause A5, Preparation of Samples for Chemical Analysis, for several possible methods.

11.2 The sample shall be analyzed by acceptable analytical methods capable of determining whether the composition meets the requirements of this specification. In case of dispute, the referee method shall be from ASTM E353 or E1019, depending on the element under test.

11.3 The results of the analysis shall meet the requirements of Table 1 for the classification of the filler metal under test.

12. Method of Manufacture

The bare stainless steel wire electrodes, strip electrodes, wires, and rods classified according to this specification may be manufactured by any method that will produce materials that meet the requirements of this specification.

13. Standard Sizes and Shapes

Standard sizes for filler metal in the different package forms (straight lengths, coils with support, coils without support, spools, and drums) are as specified in AWS A5.02/A5.02M.

14. Finish and Uniformity

14.1 Finish and uniformity shall be as specified in AWS A5.02/A5.02M.

15. Standard Package Forms

15.1 Standard package dimensions and other requirements for each form shall be as specified in AWS A5.02/A5.02M. Other package forms and sizes not listed in A5.02/A5.02M shall be as agreed upon between purchaser and supplier.

16. Winding Requirements

16.1 Winding requirements shall be as specified in AWS A5.02/A5.02M. The outermost layer of electrode and rod on spools *shall be below the rim* (the OD) of the flanges of the spool.

16.2 The cast and helix of filler metal shall be as specified in AWS A5.02/A5.02M. *Additional requirements shall be as below in 16.3, 16.4, and 16.5.*

16.3 The cast and helix of filler metal on 4 in (100 mm) spools shall be such that a specimen long enough to produce a single loop, when cut from the spool and laid unrestrained on a flat surface, will:

- (1) Form a circle not less than 2-1/2 in [65 mm] nor more than 15 in [380 mm] in diameter, and
- (2) Rise above the flat surface no more than 1/2 in [13 mm] at any location.

16.4 The cast and helix of filler metal on 8 in [200 mm] spools shall be such that a specimen long enough to produce a single loop, when cut from the spool and laid unrestrained on a flat surface, will:

- (1) Form a circle not less than 8 in [200 mm] nor more than 50 in [1.3 m] in diameter, and
- (2) Rise above the flat surface no more than 1 in [25 mm] at any location.

16.5 The cast and helix of filler metal on 12 in [300 mm] and 14 in [350 mm] spools shall be such that a specimen long enough to produce a single loop, when cut from the spool and laid unrestrained on a flat surface, will:

- (1) Form a circle not less than 15 in [380 mm] nor more than 50 in [1.3 m] in diameter, and
- (2) Rise above the flat surface no more than 1 in [25 mm] at any location.

16.6 *Either edge of the strip electrode (camber) shall not deviate from a straight line by more than 0.5 in [12.5 mm] in any 8 ft [2.5 m] length.*

17. Filler Metal Identification

17.1 Filler metal identification, including marking of bare straight lengths of filler rod, product information, and precautionary information shall be as specified in AWS A5.02/A5.02M.

17.2 Coils without support shall have a tag containing this information securely attached to the filler metal at the inside end of the coil.

18. Packaging

Filler metal shall be suitably packaged to prevent damage during shipment and storage under normal conditions.

19. Marking of Packages

19.1 The product information (as a minimum) that shall be legibly marked so as to be visible from the outside of each unit package shall be as specified in AWS A5.02/A5.02M.

19.2 The appropriate precautionary information as given in ANSI Z49.1 (as a minimum) or its equivalent shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages enclosed within a larger package. Typical examples of "warning labels" and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

Table 1
Chemical Composition Requirements

Traditional AWS A5.9 Alloy Designation ^c	Nominal Composition Designation ^c	Composition, wt % ^{a,b}										Other Required Elements	
		C	Cr	Ni	Mo	Mn	Si	P	S	N	Cu	Element	Amount
209	—	0.05	20.5–24.0	9.5–12.0	1.5–3.0	4.0–7.0	0.90	0.03	0.03	0.10–0.30	0.75	V	0.10–0.30
218	—	0.10	16.0–18.0	8.0–9.0	0.75	7.0–9.0	3.5–4.5	0.03	0.03	0.08–0.18	0.75	—	—
219	—	0.05	19.0–21.5	5.5–7.0	0.75	8.0–10.0	1.00	0.03	0.03	0.10–0.30	0.75	—	—
240	—	0.05	17.0–19.0	4.0–6.0	0.75	10.5–13.5	1.00	0.03	0.03	0.10–0.30	0.75	—	—
307	—	0.04–0.14	19.5–22.0	8.0–10.7	0.5–1.5	3.30–4.75	0.30–0.65	0.03	0.03	—	0.75	—	—
—	18 8 Mn	0.20	17.0–20.0	7.0–10.0	0.5	5.0–8.0	1.2	0.03	0.03	—	0.5	—	—
308	—	0.08	19.5–22.0	9.0–11.0	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
308Si	—	0.08	19.5–22.0	9.0–11.0	0.75	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	—	—
308H	—	0.04–0.08	19.5–22.0	9.0–11.0	0.50	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
308L	—	0.03	19.5–22.0	9.0–11.0	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
—	19 9 L	0.03	19.0–21.0	9.0–11.0	0.5	1.0–2.5	0.65	0.03	0.02	—	0.5	—	—
308LSi	—	0.03	19.5–22.0	9.0–11.0	0.75	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	—	—
—	19 9 L Si	0.03	19.0–21.0	9.0–11.0	0.5	1.0–2.5	0.65–1.25	0.03	0.02	—	0.5	—	—
308Mo	—	0.08	18.0–21.0	9.0–12.0	2.0–3.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
—	20 10 3	0.12	18.0–21.0	8.0–12.0	1.5–3.5	1.0–2.5	1.0	0.03	0.02	—	0.5	—	—
308LMo	—	0.04	18.0–21.0	9.0–12.0	2.0–3.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
309	—	0.12	23.0–25.0	12.0–14.0	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
309Si	—	0.12	23.0–25.0	12.0–14.0	0.75	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	—	—
309L	—	0.03	23.0–25.0	12.0–14.0	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
—	23 12 L	0.03	22.0–25.0	11.0–14.0	0.5	1.0–2.5	0.65	0.03	0.02	—	0.5	—	—
309LSi	—	0.03	23.0–25.0	12.0–14.0	0.75	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	—	—
—	23 12 L Si	0.03	22.0–25.0	11.0–14.0	0.5	1.0–2.5	0.65–1.25	0.03	0.02	—	0.5	—	—
309Mo	—	0.12	23.0–25.0	12.0–14.0	2.0–3.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—

(Continued)

Table 1 (Continued)
Chemical Composition Requirements

Traditional AWS A5.9 Alloy Designation ^c	Nominal Composition Designation ^c	Composition, wt % ^{a,b}										Other Required Elements	
		C	Cr	Ni	Mo	Mn	Si	P	S	N	Cu	Element	Amount
309LMo	—	0.03	23.0–25.0	12.0–14.0	2.0–3.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
—	23 12 2 L	0.03	21.0–25.0	11.0–15.5	2.0–3.5	1.0–2.5	1.0	0.03	0.02	—	0.5	—	—
—	21 13 3 L ^f	0.03	19.0–22.0	12.0–14.0	2.8–3.3	1.0–2.5	0.65	0.03	0.03	—	0.75	—	—
309LNb	—	0.03	23.0–25.0	12.0–14.0	0.75	1.0–2.5	0.65	0.03	0.03	—	0.75	Nb ^g	10 × C to 1.0; 0.2 min.
310 ^d	—	0.08–0.15	25.0–28.0	20.0–22.5	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
312	—	0.15	28.0–32.0	8.0–10.5	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
316	—	0.08	18.0–20.0	11.0–14.0	2.0–3.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
316Si	—	0.08	18.0–20.0	11.0–14.0	2.0–3.0	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	—	—
316H	—	0.04–0.08	18.0–20.0	11.0–14.0	2.0–3.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
316L	—	0.03	18.0–20.0	11.0–14.0	2.0–3.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
—	19 12 3 L	0.03	18.0–20.0	11.0–14.0	2.5–3.0	1.0–2.5	0.65	0.03	0.02	—	0.5	—	—
316LSi	—	0.03	18.0–20.0	11.0–14.0	2.0–3.0	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	—	—
—	19 12 3 L Si	0.03	18.0–20.0	11.0–14.0	2.5–3.0	1.0–2.5	0.65–1.25	0.03	0.02	—	0.5	—	—
316LMn ^e	—	0.03	19.0–22.0	15.0–18.0	2.5–3.5	5.0–9.0	0.30–0.65	0.03	0.03	0.10–0.20	0.75	—	—
—	20 16 3 Mn N L ^e	0.03	19.0–22.0	15.0–18.0	2.5–4.5	5.0–9.0	1.0	0.03	0.02	0.10–0.20	0.5	—	—
317	—	0.08	18.5–20.5	13.0–15.0	3.0–4.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
317L	—	0.03	18.5–20.5	13.0–15.0	3.0–4.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
—	18 16 5 N L ^e	0.03	17.0–20.0	16.0–19.0	3.5–5.0	1.0–4.0	1.0	0.03	0.02	0.10–0.20	0.5	—	—
318	—	0.08	18.0–20.0	11.0–14.0	2.0–3.0	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	Nb ^g	8 × C to 1.0; 0.2 min.
—	19 12 3 Nb	0.08	18.0–20.0	11.0–14.0	2.5–3.0	1.0–2.5	0.65	0.03	0.02	—	0.5	Nb ^g	10 × C to 1.0
—	19 12 3 Nb Si	0.08	18.0–20.0	11.0–14.0	2.5–3.0	1.0–2.5	0.65–1.25	0.03	0.02	—	0.5	Nb ^g	10 × C to 1.0

(Continued)

Table 1 (Continued)
Chemical Composition Requirements

Traditional AWS A5.9 Alloy Designation ^c	Nominal Composition Designation ^c	Composition, wt % ^{a,b}										Other Required Elements	
		C	Cr	Ni	Mo	Mn	Si	P	S	N	Cu	Element	Amount
320 ^d	—	0.07	19.0–21.0	32.0–36.0	2.0–3.0	2.5	0.60	0.03	0.03	—	3.0–4.0	Nb ^g	8 × C to 1.0
320LR ^d	—	0.025	19.0–21.0	32.0–36.0	2.0–3.0	1.5–2.0	0.15	0.015	0.02	—	3.0–4.0	Nb ^g	8 × C to 0.40
321	—	0.08	18.5–20.5	9.0–10.5	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	Ti	9 × C to 1.0; 0.2 min.
330 ^d	—	0.18–0.25	15.0–17.0	34.0–37.0	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	—	—
347	—	0.08	19.0–21.5	9.0–11.0	0.75	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	Nb ^g	10 × C to 1.0; 0.2 min.
—	19 9 Nb	0.08	19.0–21.0	9.0–11.0	0.5	1.0–2.5	0.65	0.03	0.02	—	0.5	Nb ^g	10 × C to 1.0
347L	—	0.03	19.0–21.5	9.0–11.0	0.75	1.0–2.5	0.65	0.03	0.03	—	0.75	Nb ^g	10 × C to 1.0; 0.2 min.
347Si	—	0.08	19.0–21.5	9.0–11.0	0.75	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	Nb ^g	10 × C to 1.0; 0.2 min.
—	19 9 Nb Si	0.08	19.0–21.0	9.0–11.0	0.5	1.0–2.5	0.65–1.25	0.03	0.02	—	0.5	Nb ^g	10 × C to 1.0
383 ^d	—	0.025	26.5–28.5	30.0–33.0	3.2–4.2	1.0–2.5	0.50	0.02	0.03	—	0.70–1.50	—	—
385 ^d	—	0.025	19.5–21.5	24.0–26.0	4.2–5.2	1.0–2.5	0.50	0.02	0.03	—	1.2–2.0	—	—
—	20 25 5 Cu L ^e	0.03	19.0–22.0	24.0–27.0	4.0–6.0	1.0–4.0	1.0	0.03	0.02	—	1.0–2.0	—	—
409	—	0.08	10.5–13.5	0.6	0.50	0.8	0.8	0.03	0.03	—	0.75	Ti	10 × C to 1.5
409Nb	—	0.08	10.5–13.5	0.6	0.50	0.8	1.0	0.04	0.03	—	0.75	Nb ^g	10 × C to 0.75
410	—	0.12	11.5–13.5	0.6	0.75	0.6	0.5	0.03	0.03	—	0.75	—	—
410NiMo	—	0.06	11.0–12.5	4.0–5.0	0.4–0.7	0.6	0.5	0.03	0.03	—	0.75	—	—
420	—	0.25–0.40	12.0–14.0	0.6	0.75	0.6	0.5	0.03	0.03	—	0.75	—	—
430	—	0.10	15.5–17.0	0.6	0.75	0.6	0.5	0.03	0.03	—	0.75	—	—
439	—	0.04	17.0–19.0	0.6	0.5	0.8	0.8	0.03	0.03	—	0.75	Ti	10 × C to 1.1
446LMo	—	0.015	25.0–27.5	^h	0.75–1.50	0.4	0.4	0.02	0.02	0.015	^h	—	—

(Continued)

Table 1 (Continued)
Chemical Composition Requirements

Traditional AWS A5.9 Alloy Designation ^c	Nominal Composition Designation ^c	Composition, wt % ^{a, b}										Other <i>Required</i> Elements	
		C	Cr	Ni	Mo	Mn	Si	P	S	N	Cu	Element	Amount
630	—	0.05	16.00–16.75	4.5–5.0	0.75	0.25–0.75	0.75	0.03	0.03	—	3.25–4.00	Nb ^g	0.15–0.30
19-10H	—	0.04–0.08	18.5–20.0	9.0–11.0	0.25	1.0–2.0	0.30–0.65	0.03	0.03	—	0.75	Nb ^g Ti	0.05 0.05
16-8-2	—	0.10	14.5–16.5	7.5–9.5	1.0–2.0	1.0–2.0	0.30–0.65	0.03	0.03	—	0.75	—	—
2209	—	0.03	21.5–23.5	7.5–9.5	2.5–3.5	0.50–2.00	0.90	0.03	0.03	0.08–0.20	0.75	—	—
—	22 9 3 N L	0.03	21.0–24.0	7.0–10.0	2.5–4.0	2.5	1.0	0.03	0.02	0.10–0.20	0.5	—	—
2307	23 7 N L	0.03	22.5–25.5	6.5–9.5	0.8	2.5	1.0	0.03	0.02	0.10–0.20	0.5	—	—
2553	—	0.04	24.0–27.0	4.5–6.5	2.9–3.9	1.5	1.0	0.04	0.03	0.10–0.25	1.5–2.5	—	—
2594	25 9 4 N L	0.03	24.0–27.0	8.0–10.5	2.5–4.5	2.5	1.0	0.03	0.02	0.20–0.30	1.5	W	1.0
33-31 ^d	—	0.015	31.0–35.0	30.0–33.0	0.5–2.0	2.00	0.50	0.02	0.01	0.35–0.60	0.3–1.2	—	—
3556 ^d	—	0.05–0.15	21.0–23.0	19.0–22.5	2.5–4.0	0.50–2.00	0.20–0.80	0.04	0.015	0.10–0.30	—	Co	16.0–21.0
												W	2.0–3.5
												Nb ^g	0.30
												Ta	0.30–1.25
												Al	0.10–0.50
												Zr	0.001–0.100
G	—	—	—	—	—	—	—	—	—	—	—	La	0.005–0.100
												B	0.02
G	—	Not Specified—Any other agreed composition											

^a Analysis shall be made for the elements for which specific values are shown in this table. If the presence of *unspecified* elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total, excluding iron, does not exceed 0.50%.

^b Single values shown are maximum percentages.

^c The table is arranged so that similar compositions are on adjacent rows. However, “similar” shall not be taken to mean “identical.” A given product may, by having a more restricted chemical composition which fulfills both sets of designation requirements, be assigned both designations independently. In cases where designations appear in both columns of a given row (e.g., 2594 and 25 9 4 N L), either or both designations may be applied to the filler metal. See also Table A.1 in Annex A.

^d The all-weld metal is in most cases fully austenitic and therefore can be susceptible to microfissuring or hot cracking.

^e The all-weld metal is in most cases fully austenitic and therefore can be susceptible to microfissuring or hot cracking. The occurrence of fissuring/cracking is reduced by increasing the weld metal manganese level and in recognition of this the manganese range is extended for a number of grades.

^f These compositions are mainly used in low dilution overlay welding such as electroslag strip cladding.

^g Up to 20% of the amount of Nb can be replaced by Ta.

^h Nickel + copper equals 0.5% maximum.

Annex A (Informative)

Guide to AWS Specification for Bare Stainless Steel Welding Electrodes and Rods

This annex is not part of this standard but is included for informational purposes only.

A1. Introduction

A1.1 The purpose of this guide is to correlate the filler metal classifications with their intended applications so the specification can be used effectively. Appropriate base metal specifications and welding processes are referred to whenever that can be done and when it would be helpful. Such references are intended only as examples rather than complete listings of the materials or welding processes for which each filler metal is suitable.

A1.2 This guide has been prepared as an aid to prospective users of the bare stainless steel filler metals of the types covered by this specification in determining the classification best suited for a particular application, with due consideration to the requirements of that application.

A1.3 In some cases, the composition of filler metal classified in this specification may differ from that of core wire used for the corresponding classification of covered electrodes classified in AWS A5.4/A5.4M, *Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding*. Caution, therefore, should be exercised regarding the use of core wire from a covered electrode as bare solid filler metal.

A2. Classification System

A2.1 The chemical composition of the filler metal is identified by a series of numbers and, in some cases, chemical symbols, the letters L, H, or LR. Chemical symbols are used to designate modifications of basic alloy types, for example, ER308Mo. The letter “H” denotes carbon content restricted to the upper part of the range that is specified for the standard grade of the specific filler metal. The letter “L” denotes carbon content in the lower part of the range that is specified for the corresponding standard grade of filler metal. The letters “LR” denote low residuals (see A8.36).

A2.1.1 The first two or three designators may be “ER” for solid wires that may be used as electrodes or rods; or they may be “EQ” for strip electrodes; or they may be “ERS” for stranded wires in which all the wires are from the same heat that may be used as electrodes or rods.

A2.1.2 The three- or four-digit number, such as 308 in ER308, designates the chemical composition of the filler metal for products classified according to the traditional AWS A5.9 system (see Table 1). In the nominal composition system, the first pair of numbers indicates the Cr content, the second number or pair of numbers indicates the Ni content, the third number indicates the Mo content; these numbers are sometimes followed by additional symbols for additional alloying elements and carbon level (see Table 1).

A2.2 “G” Classifications

A2.2.1 This specification includes filler metals classified as ERG, EQG, and ERSG. The “G” indicates that the filler metal is of a general classification. It is general because not all of the particular requirements specified for each of the other classifications are specified for this classification. The intent in establishing this classification is to provide a means by which filler metal that differs in one respect or another (chemical composition, for example) from all other classifications (meaning that the composition of the filler metal—in the case of the example—does not meet the composition specified for any of the classifications in the specification) can still be classified according to the specification. The

purpose is to allow a useful filler metal—one that otherwise would have to await a revision of the specification—to be classified immediately, under the existing specification. This means that two filler metals—each bearing the same “G” classification—may be quite different in some certain respect (chemical composition, again, for example).

A2.2.2 The point of difference between filler metal of a “G” classification and filler metal of a similar classification without the “G” (or even with it, for that matter) may be further clarified from the use of the words “not required” and “not specified” in the specification. The use of these words is as follows.

Not Required is used in those areas of the specification that specify the tests that must be conducted in order to classify a filler metal. It indicates that that test is not required because the results for the particular test are not a requirement for that particular classification. When a test is “not required”, it is not necessary to conduct the corresponding test in order to classify a filler metal to that classification. When a purchaser wants the information provided by that test in order to consider a particular product of that classification for a certain application, the purchaser will have to arrange for that information with the supplier of the product. The purchaser will have to establish with that supplier just what the testing procedure and the acceptance requirements are to be for that test. The purchaser may want to incorporate that information (via AWS A5.01M/A5.01) in the purchase order.

Not Specified is used in those areas of the specification that refer to the results of some particular test. It indicates that the requirements for that test are not specified for that particular classification. If the required results from a specific test are listed as “not specified” but the test in question is shown as “required” then the test results must be reported.

A2.2.3 Request for Filler Metal Classification. When a filler metal cannot be classified other than as a “G” classification, a manufacturer may request that a new classification be established. The manufacturer shall do this using the following procedure.

(1) A request to establish a new filler metal classification must be submitted in writing. The request needs to provide sufficient detail to permit the Committee on Filler Metals and Allied Materials and the relevant Subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

- (a) A declaration that the new classification will be offered for sale commercially.
- (b) All classification requirements as given for existing classifications, such as chemical composition ranges.
- (c) Any conditions for conducting the tests used to demonstrate that the filler metal meets the classification requirements. (It would be sufficient, for example, to state that welding conditions are the same as for other classifications.)
- (d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the annex).
- (e) Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.
- (f) A request for a new classification without the above information will be considered incomplete. The Secretary will return the request to the requester for further information.

(2) In order to comply with the AWS Policy on Patented Items, Trademarks, and Restraint of Trade, if the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester shall disclose this. In these cases, the patent holder must allow the use of this technology, such as by license. The Secretary will provide examples of acceptable wording to the patent holder, as required.

(3) The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters for processing.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01M/A5.01. Any testing a purchaser requires of the supplier for material shipped in accordance with this specification shall be clearly

stated in the purchase order. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing the supplier normally conducts on material of that classification, as specified in Schedule F of AWS A5.01M/A5.01. Testing in accordance with any other Schedule must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product or of placing the classification on the product itself constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification.

The only testing requirement implicit in this certification is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that the material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation. *Certification* is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the certification required by the specification is the classification test of *representative material*, cited above, and the Manufacturer's Quality Assurance Program, in AWS A5.01M/A5.01.

A5. Preparation of Samples for Chemical Analysis

Preparation of a chemical analysis sample from solid, bare welding electrodes and rods presents no technical difficulties. Such filler metal may be subdivided for analysis by any convenient method with all samples representative of the lot of filler metal.

A5.1 Preparation of a chemical analysis sample for elements other than carbon and nitrogen, as described in A5.2, may be made by any process that melts a sample under vacuum or inert atmosphere, including preparation by welding.

A5.1.1 Melting into a mold is an acceptable method but must be utilized in such a manner that no dilution of the mold occurs to contaminate the fused sample.

A5.1.2 Preparation of a weld pad under inert gas shielding is an acceptable method, if assured that there is essentially no dilution of base metal in the portion of the weld pad being analyzed. This can be done by analyzing metal from successively lower layers of the pad. Layers that are undiluted will all have the same chemical composition. Therefore, the determination of identical compositions for two successive layers of deposited filler metal will provide evidence that the last layer is undiluted.

A5.1.3 Other methods of sample preparation may be used, as long as they have been shown to accurately and repeatably report the chemical composition of the wire or rod.

A5.2 Upon fusing a sample, it is common to observe a change in the nitrogen and carbon in the metal. Because these elements are generally introduced or removed as a gas, there is often no visual indication that the composition has changed. This change in carbon and nitrogen content is especially important in higher nitrogen classifications and lower carbon classifications.

A5.2.1 Specimens for nitrogen analysis are best taken directly from the wire, strip, or rod.

A5.2.2 Specimens for carbon analysis are best taken directly from the wire, strip, or rod.

A6. Ventilation During Welding

A6.1 Five major factors govern the quantity of fumes in the atmosphere to which welders and welding operators can be exposed during welding. They are:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling)
- (2) Number of welders and welding operators working in that space
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes involved
- (4) The proximity of the welders or welding operators to the fumes as they issue from the welding zone, and to the gases and dusts in the space in which they are working
- (5) The ventilation provided to the space in which the welding is done.

A6.2 American National Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the Clause on Ventilation in that document. See also AWS F3.2, *Ventilation Guide for Welding Fume* for more detailed descriptions of ventilation options.

A7. Ferrite in Weld Deposits

A7.1 Ferrite is known to be very beneficial in reducing the tendency for cracking or fissuring in weld metals; however, it is not essential. Millions of pounds of fully austenitic weld metal have been used for years and provided satisfactory service performance. Generally, ferrite is helpful when the welds are restrained, the joints are large, and when cracks or fissures adversely affect service performance. Ferrite increases the weld strength level. Ferrite may have a detrimental effect on corrosion resistance in some environments. It is also generally regarded as detrimental to toughness in cryogenic service, and in high-temperature service where it can transform into the brittle sigma phase.

A7.2 Ferrite can be measured on a relative scale by means of various magnetic instruments. However, work by the Subcommittee for Welding of Stainless Steel of the High Alloys Committee of the Welding Research Council (WRC) established that the lack of a standard calibration procedure resulted in a very wide spread of readings on a given specimen when measured by different laboratories. A specimen averaging 5.0% ferrite based on the data collected from all the laboratories was measured as low as 3.5% by some and as high as 8.0% by others. At an average of 10%, the spread was 7.0% to 16.0%. In order to substantially reduce this problem, the WRC Subcommittee published on July 1, 1972, *A Calibration Procedure for Instruments to Measure the Delta Ferrite Content of Austenitic Stainless Steel Weld Metal*. In 1974, the AWS adopted this procedure as AWS A4.2, *Standard Procedures for Calibrating Magnetic Instruments to Measure Delta Ferrite Content of Austenitic Stainless Steel Weld Metal*. In 1997, the AWS extended this procedure to higher ferrite contents and prepared AWS A4.2/A4.2M, *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal*. Subsequently, ISO also accepted this extended method as ISO 8249. In 2006, AWS adopted the ISO standard and prepared AWS A4.2M (ISO 8249:2006 MOD), *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal*. An error in ISO 8249:2006 that carried over into AWS A4.2M was corrected in ISO 8249:2018. AWS adopted the corrected version of ISO 8249:2018 as AWS A4.2M:2020. All instruments used to measure the ferrite content of AWS classified stainless electrode products were to be traceable to this AWS standard.

A7.3 The WRC Subcommittee also adopted the term *Ferrite Number* (FN) to be used in place of percent ferrite, to clearly indicate that the measuring instrument was calibrated to the WRC procedure. The Ferrite Number, up to 10 FN, is to be considered equal to the “percent ferrite” term previously used. It represents a good average of commercial U.S. and world practice on the “percent ferrite.” Through the use of standard calibration procedures, differences in readings due to instrument calibration are expected to be reduced to about $\pm 5\%$, or at the most $\pm 10\%$ of the measured ferrite value.

A7.4 In the opinion of the WRC Subcommittee, it has been impossible, to date, to accurately determine the true absolute ferrite content of weld metals.

A7.5 Even on undiluted pads, ferrite variations from pad to pad must be expected due to slight changes in welding and measuring variables. On a large group of pads from one heat or lot and using a standard pad welding and preparation procedure, plus or minus two sigma values indicate that 95 percent of the tests are expected to be within a range of

approximately ± 2.2 FN at about 8 FN. If different pad welding and preparation procedures are used, these variations will increase.

A7.6 Even larger variations may be encountered if the welding technique allows excessive nitrogen pickup, in which case the ferrite can be much lower than it should be. High-nitrogen pickup can cause a typical 8 FN deposit to drop to 0 FN. A nitrogen pickup of 0.10% will typically decrease the FN by about 8.

A7.7 Base materials tend to be balanced chemically *and thermo-mechanically processed* to have inherently lower ferrite content than matching weld metals. Weld metal diluted with base metal will usually be somewhat lower in ferrite than the undiluted weld metal, though this does vary depending on the amount of dilution and the composition of the base metal. An exception is duplex base metals where the ferrite content in most cases increases with increasing dilution.

A7.8 The welding process used and the welding conditions and technique have a significant influence on the chemical composition and the ferrite content of the weld deposit in many instances. These influences must be considered by the user if the weld deposit must meet specific chemical or Ferrite Number limits. The purpose of A7.9.1 through A7.9.3 is to present some general information on the effect of common arc welding processes on the chemical composition and the ferrite content of weld deposits made with filler metal classified in this specification.

A7.9 The chemical composition of a given weld deposit has the capability of providing an approximately predictable Ferrite Number for the undiluted deposit, as described in A7.13 with the limitations discussed here. However, important changes in the chemical compositions can occur from wire to deposit as described in A7.9.1 through A7.9.3.

A7.9.1 Gas Tungsten Arc Welding. This welding process usually involves the least change in the chemical composition from wire to deposit, and hence produces the smallest difference between the ferrite content calculated from the wire analysis and that measured on the undiluted deposit. However, there is some loss of carbon in gas tungsten arc welding—about half of the carbon content above 0.02%. Thus, a wire of 0.06% carbon will typically produce a deposit of 0.04% carbon. In low-nitrogen alloys, there is usually some nitrogen pickup—a gain of 0.02%. In higher nitrogen alloys (0.08% or more) a loss of nitrogen may be observed. The change in other elements is not significant in the undiluted weld metal. The loss of carbon and/or nitrogen will increase the ferrite content.

A7.9.2 Gas Metal Arc Welding. For this process, typical carbon losses are low, only about one quarter those of the gas tungsten arc welding process. However, the typical nitrogen pickup is much higher than in gas tungsten arc welding, and it should be estimated at about 0.04% (equivalent to about 3 FN or 4 FN loss) unless specific measurements on welds for a particular application establish other values. Nitrogen pickup in this process is very dependent upon the welding technique and may go as high as 0.15% or more. This may result in little or no ferrite in the weld deposits of filler metals such as ER308 and ER309. Some slight oxidation plus volatilization losses may occur in manganese, silicon, and chromium contents.

A7.9.3 Submerged Arc Welding. AWS A5.9/A5.9M is an integral part of AWS A5.39/A5.39M where stainless and heat resisting steel wires are used in combination with a flux. Details of the process including the effect of the flux on the weld are described in AWS A5.39/A5.39M Annex B.

A7.9.4 Electroslag Welding. Electroslag weld cladding is similar to submerged arc cladding, both using strip electrodes. It is capable of very low dilution. The fluxes used are usually distinct from fluxes used for submerged arc strip cladding. These fluxes also show variable gains or losses of alloying elements, or both depending upon the flux used.

A7.10 Bare solid filler metal, unlike covered electrodes and bare composite cored wires, cannot be adjusted for ferrite content by means of further alloy additions by the electrode producer, except through the use of flux in the submerged arc welding process. Thus, if specific FN ranges are desired, they must be obtained through wire chemical composition selection and welding procedure selection. It must be recognized that changes in the ferrite content from filler metal to deposit may be caused by the welding process and techniques, as previously discussed.

A7.11 In the 300 series filler metals, the compositions of the bare filler metal wires in general tend to cluster around the midpoints of the available chemical ranges. Thus, the potential ferrite for the 308, 308L, and 347 wires is approximately 10 FN, for the 309 wire approximately 12 FN, and for the 316 and 316L wires approximately 5 FN. Around these midpoints, the ferrite contents may be ± 7 FN or more, but the chemical compositions of these filler metals will still be within the chemical limits specified in this specification.

A7.12 In summary, the ferrite potential of a filler metal afforded by this chemical composition may be modified upward or downward in the deposit due to changes in the chemical composition that are caused by the welding process and the technique used.

A7.13 The ferrite content of welds may be predicted from the chemical composition of the weld deposit. This can best be done using the WRC-1992 Diagram (Figure A.1). Many earlier diagrams and other predictive methods have been proposed and found useful. These may be reviewed in handbooks and other references. *An in-depth discussion of predictive diagrams, effects of ferrite on weld properties, and guidance on specification and measurement of ferrite can be found in ISO TR 22824.*

A7.13.1 WRC-1992 Diagram (Figure A.1) predicts ferrite content in Ferrite Number (FN). This diagram is the newest of the diagrams mentioned. Studies within the WRC Subcommittee on Welding Stainless Steel and within Commission II of the International Institute of Welding show the closest agreement between measured and predicted ferrite using this diagram. It should be noted that predictions of the WRC-1992 Diagram are independent of silicon and manganese contents because these elements were not found to have statistically significant effects. The WRC 1992 Diagram is preferred for nominally austenitic stainless steels and for duplex stainless steels. It may not be applicable to compositions having greater than 1% Si or greater than 0.25% N.

A7.13.2 The differences between measured and predicted ferrite are somewhat dependent on the ferrite level of the deposit, increasing as the ferrite level increases. The agreement between the predicted and measured ferrite values is also strongly dependent on the quality of the chemical analysis. Variations in the results of the chemical analyses encountered from laboratory to laboratory can have significant effects on the calculated ferrite value, changing it as much as 4 FN to 8 FN. Cooling rate has a significant effect on the actual ferrite content and is one reason for the variations between predicted and measured ferrite of weld metal.

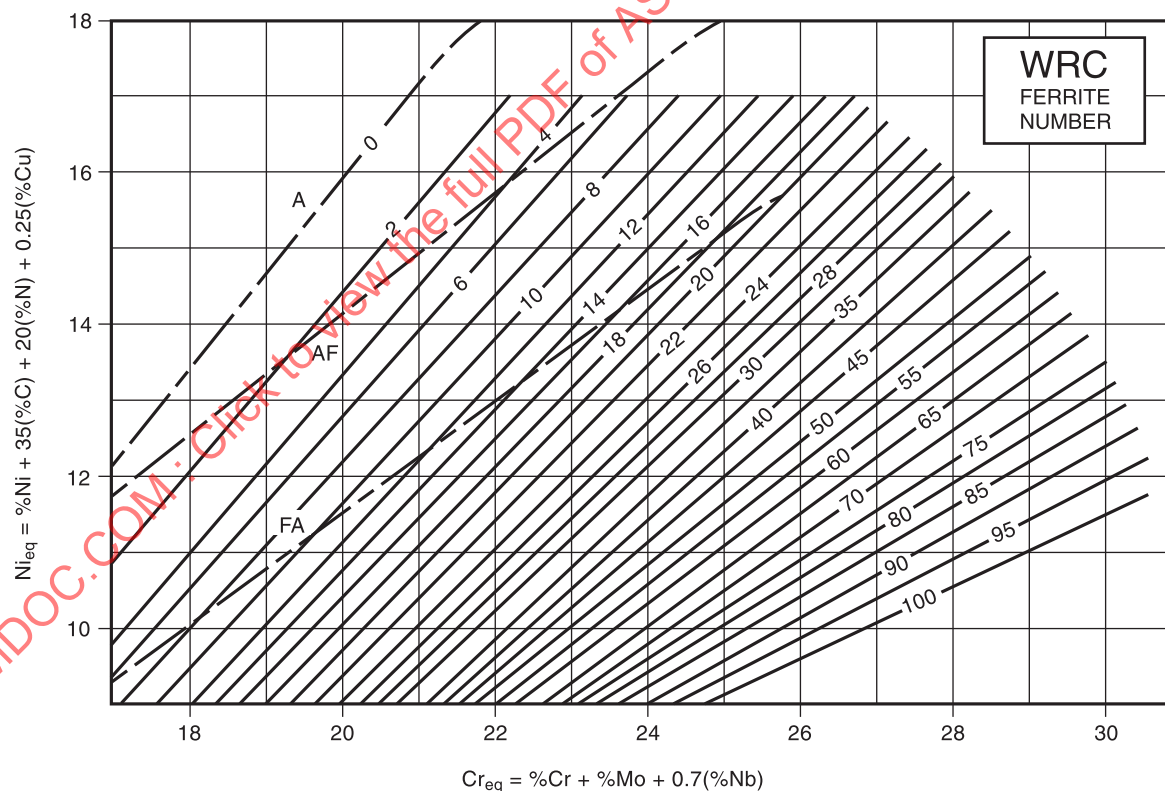


Figure A.1—WRC-1992 Diagram for Stainless Steel Weld Metal

A8. Description and Intended Use of Filler Metals

As indicated in Note c of Table 1, some compositions of filler metals bearing traditional designations are similar to compositions bearing nominal composition designations. The similar compositions are identified more clearly in Table A.1, which also includes UNS numbers where available. Specific products of these similar compositions may, or may not, fall within the composition limits of the similar traditional AWS classification and UNS number composition limits. The similar compositions are grouped together in the following paragraphs. See also Note a of Table A.1.

A8.1 ER209. The nominal composition (wt %) of this classification is 22 Cr, 11 Ni, 5.5 Mn, 2 Mo, and 0.20 N, and the all-weld metal microstructure is normally austenite with a small amount of ferrite. Filler metals of this classification are most often used to weld UNS S20910 base metal. This alloy exhibits high strength and good toughness over a wide range of temperature. Weldments in the as-welded condition made using this filler metal are not subject to carbide precipitation. Nitrogen alloying reduces the tendency for carbon diffusion and thereby increases resistance to intergranular corrosion. The ER209 filler metal has sufficient total alloy content for use in welding dissimilar alloys like mild steel and the stainless steels, and also for direct overlay on mild steel for corrosion applications when used with the gas metal arc welding process. The gas tungsten arc, plasma arc, and electron beam processes are not suggested for direct application of this filler metal on mild steel.

A8.2 ER218. The nominal composition (wt %) of this classification is 17 Cr, 8.5 Ni, 8 Mn, 4 Si, and 0.13 N, and the all-weld metal microstructure is normally austenite with a small amount of ferrite. Filler metals of this classification are most often used to weld UNS S21800 base metals. This alloy exhibits high strength and good toughness over a wide range of temperature. Nitrogen alloying in this base composition results in significant improvement in wear resistance in particle-to-metal and metal-to-metal (galling) applications when compared to the more conventional austenitic stainless steels such as Type 304. The ER218 filler metal has sufficient total alloy content for use in welding dissimilar alloys like mild steel and the stainless steels, and also for direct overlay on mild steel for corrosion and wear applications when used with the gas metal arc process. The gas tungsten arc, plasma arc, and electron beam processes are not suggested for direct application of this filler metal on mild steel.

A8.3 ER219. The nominal composition (wt %) of this classification is 20 Cr, 6 Ni, 9 Mn, and 0.20 N, and the all-weld metal microstructure is normally austenite with a small amount of ferrite. Filler metals of this classification are most often used to weld UNS S21900 base metals. This alloy exhibits high strength and good toughness over a wide range of temperatures. Welds made using this filler metal are not subject to carbide precipitation in the as-welded condition. Nitrogen alloying reduces the tendency for intergranular carbide precipitation in the weld area by inhibiting carbon diffusion and thereby increases resistance to intergranular corrosion. The ER219 filler metal has sufficient total alloy content for use in joining dissimilar alloys like mild steel and the stainless steels, and also for direct overlay on mild steel for corrosive applications when used with the gas metal arc welding process. The gas tungsten arc, plasma arc, and electron beam processes are not suggested for direct application of this filler metal on mild steel.

A8.4 ER240. The nominal composition (wt %) of this classification is 18 Cr, 5 Ni, 12 Mn, and 0.20 N, and the all-weld metal microstructure is normally austenite with a small amount of ferrite. Filler metal of this classification is most often used to weld UNS S24000 and UNS S24100 base metals. This alloy exhibits high strength and good toughness over a wide range of temperatures. Significant improvement of wear resistance in particle-to-metal and metal-to-metal (galling) applications is a valuable characteristic when compared to the more conventional austenitic stainless steels such as Type 304. Nitrogen alloying reduces the tendency toward intergranular carbide precipitation in the weld area by inhibiting carbon diffusion, thereby reducing the possibility for intergranular corrosion. Nitrogen alloying also improves resistance to pitting and crevice corrosion in aqueous chloride-containing media. In addition, weldments in Type 240 exhibit improved resistance to transgranular stress corrosion cracking in hot aqueous chloride-containing media. The ER240 filler metal has sufficient total alloy content for use in joining dissimilar alloys like mild steel and the stainless steels and also for direct overlay on mild steel for corrosion and wear applications when used with the gas metal arc process. The gas tungsten arc, plasma arc, and electron beam processes are not suggested for direct application of this filler metal on mild steel.

A8.5 ER307. The nominal composition (wt %) of this classification is 21 Cr, 9.5 Ni, 4 Mn, and 1 Mo, and the all-weld metal microstructure is normally austenite with a small amount of ferrite. Filler metals of this classification are used primarily for moderate-strength welds with good crack resistance between dissimilar steels such as austenitic manganese steel and carbon steel forgings or castings.

A8.6 ER 18 8 Mn. The nominal composition (wt %) of this classification is 18 Cr, 8 Ni, and 6 Mn, and the all-weld metal microstructure is normally austenite with a small amount of ferrite. Its applications are essentially the same as those of the 307 composition.

A8.7 ER308. The nominal composition (wt %) of this classification is 21 Cr and 10 Ni, and the all-weld metal microstructure is normally austenite with a small amount of ferrite. Commercial specifications for filler and base metals vary in the minimum alloy requirements; consequently, the names 18-8, 19-9, and 20-10 are often associated with filler metals of this classification. This classification is most often used to weld base metals of similar composition, in particular, Type 304.

A8.8 ER308Si. This classification is the same as ER308, except for the higher silicon content. Higher silicon improves the usability of the filler metal in the gas metal arc welding process (see A9.2). If the dilution by the base metal produces a low-ferrite or fully austenitic weld metal, the crack sensitivity of the weld is somewhat higher than that of lower silicon content weld metal.

A8.9 ER308H. This classification is the same as ER308, except that the allowable carbon content has been restricted to the higher portion of the 308 range. Carbon content in the range of 0.04%–0.08% provides higher strength at elevated temperatures. This filler metal is used for welding 304H base metal.

A8.10 ER308L and ER 19 9 L. These classifications are essentially the same as ER308, except for the carbon content. Low carbon (0.03% maximum) in this filler metal reduces the possibility of intergranular carbide precipitation. This increases the resistance to intergranular corrosion without the use of stabilizers such as niobium or titanium. Strength of this low-carbon alloy, however, is less than that of the niobium-stabilized alloys or Type 308H at elevated temperatures.

A8.11 ER308LSi and ER 19 9 L Si. These classifications are essentially the same as ER308L, except for the higher silicon content. Higher silicon improves the usability of the filler metal in the gas metal arc welding process (see A9.2). If the dilution by the base metal produces a low-ferrite or fully austenitic weld, the crack sensitivity of the weld is somewhat higher than that of lower silicon content weld metal.

A8.12 ER308Mo and ER 20 10 3. These classifications are essentially the same as ER308, except for the addition of molybdenum. The all-weld metal microstructure is normally austenite with a small amount of ferrite. They are used for welding ASTM CF8M stainless steel castings and match the base metal with regard to chromium, nickel, and molybdenum contents. They may be used for welding wrought materials such as Type 316 (UNS31600) stainless steel when a ferrite content in excess of that attainable with the ER316 classification is desired.

A8.13 ER308LMo. This classification is the same as ER308Mo except for lower carbon. It is used for welding ASTM CF3M stainless steel castings and matches the base metal with regard to chromium, nickel, and molybdenum contents. It may be used for welding wrought materials such as Type 316L stainless when a ferrite content in excess of that attainable with ER316L is desired.

A8.14 ER309. The nominal composition (wt %) of this classification is 24 Cr and 13 Ni, and the all-weld metal microstructure is normally austenite with a small amount of ferrite. Filler metals of this classification are commonly used for welding similar alloys in wrought or cast form. Occasionally, they are used to weld Type 304 and similar base metals where severe corrosion conditions exist requiring higher alloy weld metal. They are also used in dissimilar metal welds, such as joining Type 304 to carbon steel, welding the clad side of Type 304 clad steels, and applying stainless steel sheet linings to carbon steel shells.

A8.15 ER309Si. This classification is the same as ER309, except for higher silicon content. The higher silicon improves the usability of the filler metal in the gas metal arc welding process (see A9.2). If the dilution by the base metal produces a low-ferrite or fully austenitic weld metal deposit, the crack sensitivity of the weld is somewhat higher than that of a lower silicon content weld metal.

A8.16 ER309L and ER 23 12 L. These classifications are essentially the same as ER309, except for the carbon content. Low carbon (0.03% maximum) in these filler metals reduces the possibility of intergranular carbide precipitation. This increases the resistance to intergranular corrosion without the use of stabilizers such as niobium or titanium. Strength of this low-carbon alloy, however, may not be as great at elevated temperatures as that of the niobium-stabilized alloys or ER309.

A8.17 ER309LSi and ER 23 12 L Si. These classifications are essentially the same as ER309L, except for higher silicon content. The higher silicon improves the usability of the filler metal in the gas metal arc welding process (see A9.2). If

the dilution by the base metal produces a low-ferrite or fully austenitic weld, the crack sensitivity of the weld is somewhat higher than that of lower silicon content weld metal.

A8.18 ER309Mo. This classification is the same as ER309, except for the addition of 2.5% molybdenum to increase its pitting corrosion resistance in halide-containing environments, and the all-weld metal microstructure is normally austenite with a small amount of ferrite. The primary application for this filler metal is surfacing of base metals to improve their corrosion resistance. The ER309Mo is used to achieve a single-layer overlay with a chemical composition similar to that of a 316 stainless steel. It is also used for the first layer of multilayer overlays with filler metals such as ER316 or ER317 stainless steels. Without the first layer of 309Mo, elements such as chromium and molybdenum might be reduced to unacceptable levels in successive layers by dilution from the base metal. Other applications include the welding of molybdenum-containing stainless steel linings to carbon steel shells, the joining of carbon steel base metals that had been clad with a molybdenum-containing stainless steel, and the joining of dissimilar base metals such as carbon steel to Type 304 stainless steel.

A8.19 ER309LMo and ER 23 12 2 L. These classifications are essentially the same as an ER309Mo, except for the lower carbon content (0.03%). Low-carbon contents in stainless steels reduce the possibility of chromium carbide precipitation and thereby increase weld metal resistance to intergranular corrosion. These classifications are used in the same type of applications as the ER309Mo, but where excessive pickup of carbon from dilution by the base metal, where intergranular corrosion from carbide precipitation, or both are factors to be considered in the selection of the filler metal. In multilayer overlays, the low-carbon filler metal is usually needed for the first layer in order to achieve low-carbon contents in successive layers with filler metals such as ER316L or ER317L.

A8.20 EQ 21 13 3 L. The nominal composition (wt %) of this classification is 21 Cr, 13 Ni, and 3 Mo, it is low in carbon, and the all-weld metal microstructure is normally austenite with a small amount of ferrite. It is normally produced as strip electrodes for low dilution cladding by SAW or ESW to achieve a first layer on carbon steel similar in composition to undiluted 316L.

A8.21 ER309LNb. *The nominal composition (wt %) of this classification is 23 Cr, 12 Ni, and 0.5 Nb, and the all-weld metal microstructure is normally austenite with a small amount of ferrite. Its principle use is for cladding of carbon steel to achieve a first layer composition similar to that of undiluted 347 stainless steel.*

A8.22 ER310. The nominal composition (wt %) of this classification is 26.5 Cr and 21 Ni, and the all-weld metal microstructure is normally fully austenitic. Filler metal of this classification is most often used to weld base metals of similar composition.

A8.23 ER312. The nominal composition (wt %) of this classification is 30 Cr and 9 Ni, and the all-weld metal microstructure is normally duplex ferritic-austenitic. Filler metal of this classification was originally designed to weld cast alloys of similar composition. It also has been found to be valuable in welding dissimilar metals such as carbon steel to stainless steel, particularly those grades high in nickel. Even with considerable dilution by austenite-forming elements such as nickel, the microstructure remains two-phase and thus highly resistant to weld metal cracks and fissures. The undiluted weld metal can be brittle.

A8.24 ER316. The nominal composition (wt %) of this classification is 19 Cr, 12.5 Ni, and 2.5 Mo, and the all-weld metal microstructure is normally austenite with a small amount of ferrite. This filler metal is used for welding Type 316 and similar alloys. It has been used successfully in certain applications involving special base metals for high-temperature service. The presence of molybdenum provides creep resistance at elevated temperatures and pitting resistance in a halide atmosphere.

A8.25 ER316Si. This classification is the same as ER316, except for the higher silicon content. The higher silicon improves the usability of the filler metal in the gas metal arc welding process (see A9.2). If the dilution by the base metal produces a low-ferrite or fully austenitic weld, the crack sensitivity of the weld is somewhat higher than that of lower silicon content weld metal.

A8.26 ER316H. This filler metal is the same as ER316, except that the allowable carbon content has been restricted to the higher portion of the 316 range. Carbon content in the range of 0.04 wt % to 0.08 wt % provides higher strength at elevated temperatures. This filler metal is used for welding 316H base metal.

A8.27 ER316L and ER 19 12 3 L. These classifications are essentially the same as ER316, except for the carbon content. Low carbon (0.03%) in this filler metal reduces the possibility of intergranular chromium carbide precipitation

and thereby increases the resistance to intergranular corrosion without the use of stabilizers such as niobium or titanium. This filler metal is primarily used for welding low-carbon molybdenum-bearing austenitic alloys. This low-carbon alloy, however, is not as strong at elevated temperature as the niobium-stabilized alloys or Type ER316H.

A8.28 ER316LSi and ER 19 12 3 L Si. These classifications are essentially the same as ER316L, except for the higher silicon content. The higher silicon improves the usability of the filler metal in the gas metal arc welding process (see A9.2). If the dilution by the base metal produces a low-ferrite or fully austenitic weld, the crack sensitivity is somewhat higher than that of lower silicon content weld metal.

A8.29 ER316LMn and ER 20 16 3 Mn N L. The nominal composition (wt %) of these classifications is 19 Cr, 15 Ni, 7 Mn, 3 Mo, and 0.2 N, and the all-weld metal microstructure is nearly fully austenitic with a typical ferrite content of 0.5 FN maximum. One of the primary uses of this filler metal is for the joining of similar and dissimilar cryogenic steels for applications down to -452°F (-269°C). This filler metal also exhibits good corrosion resistance in acids and seawater, and is particularly suited for corrosion conditions found in urea synthesis plants. It is also nonmagnetic. The high-Mn content of the alloy helps to stabilize the austenitic microstructure and aids in hot cracking resistance.

A8.30 ER317. The nominal composition (wt %) of this classification is 19.5 Cr, 14 Ni, and 3.5 Mo, somewhat higher than ER316, and the all-weld metal microstructure is normally austenite with a small amount of ferrite. It is usually used for welding alloys of similar composition. ER317 filler metal is utilized in severely corrosive environments where crevice and pitting corrosion are of concern.

A8.31 ER317L. This classification is the same as ER317, except for the carbon content. The all-weld metal microstructure of ER317L is normally austenite with a small amount of ferrite. Low carbon (0.03% maximum) in this filler metal reduces the possibility of intergranular carbide precipitation. This increases the resistance to intergranular corrosion without the use of stabilizers such as niobium or titanium. This low-carbon alloy, however, may not be as strong at elevated temperature as the niobium-stabilized alloys or Type 317.

A8.32 ER 18 16 5 N L. The nominal composition (wt%) of this classification is 18 Cr, 16 Ni, 4 Mo, and 0.15 N, and the all-weld metal microstructure is nominally fully austenitic. It is used for welding 317LM (UNS S31725) and 317LMN (UNS S31726) stainless steels, commonly in the pulp and paper industry.

A8.33 ER318 and ER 19 12 3 Nb. These compositions are essentially identical to ER316, except for the addition of niobium. The all-weld metal microstructure is normally austenite with a small amount of ferrite. Niobium provides resistance to intergranular chromium carbide precipitation and thus increased resistance to intergranular corrosion. Filler metal of these classifications is used primarily for welding base metals of similar composition.

A8.34 ER 19 12 3 Nb Si. This composition is identical to ER318 except for the higher silicon content. This improves the usability of the filler metal in the gas metal arc welding process (see A9.2). If the dilution by the base metal produces a low-ferrite or fully austenitic weld, the crack sensitivity is somewhat higher than that of lower silicon content weld metal.

A8.35 ER320. The nominal composition (wt %) of this classification is 20 Cr, 34 Ni, 2.5 Mo, and 3.5 Cu, with Nb added to provide resistance to intergranular corrosion, and the all-weld metal microstructure is normally fully austenitic. Filler metal of this classification is primarily used to weld base metals of similar composition for applications where resistance to severe corrosion involving a wide range of chemicals, including sulfuric and sulfurous acids and their salts, is required. This filler metal can be used to weld both castings and wrought alloys of similar composition without postweld heat treatment. A modification of this classification without niobium is available for repairing castings that do not contain niobium, but with this modified composition, solution annealing is required after welding.

A8.36 ER320LR (Low Residuals). This classification has the same basic composition as ER320; however, the elements C, Si, P, and S are specified at lower maximum levels and the Nb and Mn are controlled at narrower ranges. These changes reduce the weld metal hot cracking and fissuring (while maintaining the corrosion resistance) frequently encountered in fully austenitic stainless steel weld metals. Consequently, welding practices typically used for austenitic stainless steel weld metals containing ferrite can be used in bare filler metal welding processes such as gas tungsten arc and gas metal arc at the sacrifice of some corrosion resistance. ER320LR filler metal has been used successfully in submerged arc overlay welding, but it may be prone to cracking when used for joining base metal by the submerged arc process. ER320LR weld metal has a lower minimum tensile strength than ER320 weld metal.

A8.37 ER321 The nominal composition (wt %) of this classification is 19.5 Cr and 9.5 Ni, with titanium added, and the all-weld metal microstructure is normally austenite with a small amount of ferrite. The titanium acts in the same way as niobium in Type 347 in reducing intergranular chromium carbide precipitation and thus increasing resistance to intergranular corrosion. The filler metal of this classification is used for welding chromium-nickel stainless steel base metals of similar composition, using an inert gas shielded process. It is not suitable for use with the submerged arc process because only a small portion of the titanium will be recovered in the weld metal.

A8.38 ER330. The nominal composition (wt %) of this classification is 16 Cr and 35.5 Ni, and the all-weld metal microstructure is normally fully austenitic. Filler metal of this type is commonly used where heat and scale resisting properties above 1800 °F [980 °C] are required, except in high-sulfur environments, as these environments may adversely affect elevated temperature performance. Repairs of defects in alloy castings and the welding of castings and wrought alloys of similar composition are the most common applications.

A8.39 ER347 and ER 19 9 Nb. The nominal composition (wt %) of these classifications is 20 Cr and 10 Ni, with Nb added as a stabilizer, and the all-weld metal microstructure is normally austenite with a small amount of ferrite. The addition of niobium reduces the possibility of intergranular chromium carbide precipitation and thus susceptibility to intergranular corrosion. The filler metal of these classifications is usually used for welding chromium-nickel stainless steel base metals of similar composition stabilized with either Nb or Ti. Although Nb is the stabilizing element usually specified in Type 347 alloys, it should be recognized that tantalum (Ta) is also present. Ta and Nb are almost equally effective in stabilizing carbon and in providing high-temperature strength. If dilution by the base metal produces a low-ferrite or fully austenitic weld metal, the crack sensitivity of the weld may increase substantially.

A8.40 ER347L. This classification is the same as ER347 except that the carbon content is limited to 0.03% maximum. *Heat-affected zones in the weld metal of multi-pass welds or intersecting weld metals are less susceptible to knifeline attack than those of ER347.* This low carbon alloy may not be as strong at elevated temperatures as the higher carbon ER347 weld metal. Lower Si may be specified for nuclear applications.

A8.41 ER347Si and ER 19 9 Nb Si. These classifications are essentially the same as ER347, except for the higher silicon content. The higher silicon improves the usability of the filler metal in the gas metal arc welding process (see A9.2). If the dilution by the base metal produces a low-ferrite or fully austenitic weld, the crack sensitivity of the weld is somewhat higher than that of lower silicon content weld metal.

A8.42 ER383. The nominal composition (wt %) of this classification is 27.5 Cr, 31.5 Ni, 3.7 Mo, and 1 Cu, and the all-weld metal microstructure is normally fully austenitic. Filler metal of this classification is used to weld UNS N08028 base metal to itself, or to other grades of stainless steel. ER383 filler metal is recommended for sulfuric and phosphoric acid environments. The elements C, Si, P, and S are specified at low maximum levels to minimize weld metal hot cracking and fissuring (while maintaining the corrosion resistance) frequently encountered in fully austenitic stainless steel weld metals.

A8.43 ER385 and ER 20 25 5 Cu L. The nominal composition (wt %) of these classifications is 20.5 Cr, 25 Ni, 4.7 Mo, and 1.5 Cu, and the all-weld metal microstructure is normally fully austenitic. These filler metals are used primarily for welding of ASTM B625, B673, B674, and B677 (UNS N08904) materials for the handling of sulfuric acid and many chloride containing media. These filler metals also may be used to join Type 317L material where improved corrosion resistance in specific media is needed. These filler metals may be used for joining UNS N08904 base metals to other grades of stainless steel. The elements C, S, P, and Si are specified at lower maximum levels to minimize weld metal hot cracking and fissuring (while maintaining corrosion resistance) frequently encountered in fully austenitic weld metals.

A8.44 ER409. The nominal composition (wt %) of this classification is 12 Cr and the all-weld metal microstructure is nearly fully ferritic. The titanium addition forms carbides to improve corrosion resistance, increase strength at high temperature, and promote the ferritic microstructure. ER409 filler metals may be used to join matching base metals. The greatest usage is for applications where thin stock is fabricated into automotive exhaust system components.

A8.45 ER409Nb. This classification is the same as ER409, except that niobium is used instead of titanium to achieve similar results. The all-weld metal microstructure is nearly fully ferritic. Oxidation losses across the arc generally are lower. Applications are the same as those of ER409 filler metals.

A8.46 ER410. The nominal composition (wt %) of this classification is 12 Cr, and the all-weld metal microstructure is nearly fully martensitic. The weld metal is an air-hardening steel. Preheat and postweld heat treatments are required to achieve welds of adequate ductility for many engineering purposes. The most common application of filler metal of this

type is for welding alloys of similar composition. It is also used for deposition of overlays on carbon steels to resist corrosion, erosion, or abrasion.

A8.47 ER410NiMo. The nominal composition (wt %) of this classification is 12 Cr, 4.5 Ni, and 0.55 Mo, and the all-weld metal microstructure is nearly fully martensitic. It is primarily designed for welding ASTM CA6NM castings or similar material, as well as light-gauge 410, 410S, and 405 base metals. Filler metal of this classification is modified to contain less chromium and more nickel to eliminate ferrite in the microstructure as ferrite has a deleterious effect on mechanical properties. Final postweld heat treatment should not exceed 1150 °F [620 °C], as higher temperatures may result in rehardening due to untempered martensite in the microstructure after cooling to room temperature.

A8.48 ER420. This classification is similar to ER410, except for slightly higher chromium and carbon contents. The all-weld metal microstructure is normally fully martensitic. ER420 is used for many surfacing operations requiring corrosion resistance provided by 12% chromium along with somewhat higher hardness than weld metal deposited by ER410 electrodes. This increases wear resistance.

A8.49 ER430. The nominal composition (wt %) is 16 Cr, and the all-weld metal microstructure is normally dual phase ferritic-martensitic, with ferrite more prevalent. The composition is balanced by providing sufficient chromium to give adequate corrosion resistance for the usual applications, and yet retain sufficient ductility in the heat-treated condition. (Excessive chromium will result in lower ductility.) Welding with filler metal of the ER430 classification usually requires preheating and postweld heat treatment.

Optimum mechanical properties and corrosion resistance are obtained only when the weldment is heat treated following the welding operation.

A8.50 ER439. The nominal composition (wt %) of this classification is 18 Cr, stabilized with titanium, and the all-weld metal microstructure is normally fully ferritic. ER439 provides improved oxidation and corrosion resistance over ER409 in similar applications. Applications are the same as those of ER409 filler metals, where thin stock is fabricated into exhaust system components.

A8.51 ER446LMo. The nominal composition (wt %) of this classification (formerly listed as ER26-1) is 26 Cr and 1 Mo, and the all-weld metal microstructure is normally fully ferritic. It is used for welding base metal of the same composition with inert gas shielded welding processes. Due to the high purity of both base metal and filler metal, cleaning of the parts before welding is most important. Complete coverage by shielding gas during welding is extremely important to prevent contamination by oxygen and nitrogen. Non-conventional gas shielding methods (leading, trailing, and back shielding) often are employed.

A8.52 ER630. The nominal composition (wt %) of this classification is 16.4 Cr, 4.7 Ni, and 3.6 Cu, and the all-weld metal is normally nearly fully martensitic with traces of ferrite. The composition is designed primarily for welding ASTM A564 Type 630 and some other precipitation-hardening stainless steels. The composition is modified to prevent the formation of ferrite networks in the martensitic microstructure which have a deleterious effect on mechanical properties. Dependent on the application and weld size, the weld metal may be used as-welded, welded and precipitation hardened, or welded, solution treated, and precipitation hardened.

A8.53 ER19-10H. The nominal composition (wt %) of this classification is 19 Cr and 10 Ni and the all-weld metal microstructure is austenitic with a small amount of ferrite. It is similar to ER308H except that the Cr content is lower and there are additional limits on Mo, Nb, and Ti. This lower limit of Cr and additional limits on other Cr equivalent elements allows a lower ferrite range to be attained. A lower ferrite level in the weld metal decreases the chance of sigma embrittlement after long-term exposure at temperatures in excess of 1000 °F [540 °C]. This filler metal should be used in conjunction with welding processes and other welding consumables that do not deplete or otherwise significantly change the amount of chromium in the weld metal. If used with submerged arc welding, a flux that neither removes nor adds chromium to the weld metal is highly recommended.

This filler metal also has the higher carbon level required for improved creep properties in high-temperature service. The user is cautioned that actual weld application qualification testing is recommended in order to be sure that an acceptable weld metal carbon level is obtained. If corrosion or scaling is a concern, special testing as outlined in Annex Clause A10, Special Tests, should be included in application testing.

A8.54 ER16-8-2. The nominal composition (wt %) of this classification is 15.5 Cr, 8.5 Ni, and 1.5 Mo, and the all-weld metal microstructure is austenitic with a trace of ferrite. Filler metal of this classification is used primarily for welding

stainless steel such as types 16-8-2, 316, and 347 for high-pressure, high-temperature piping systems. The weld deposit usually has a Ferrite Number no higher than 5 FN. The deposit also has good hot-ductility properties that offer greater freedom from weld or crater cracking even under restraint conditions. The weld metal is usable in either the as-welded condition or solution-treated condition. This filler metal depends on a very carefully balanced chemical composition to develop its fullest properties. Corrosion tests indicate that the 16-8-2 weld metal may have less corrosion resistance than 316 base metal, depending on the corrosive media. Where the weldment is exposed to severe corrosives, the surface layers should be deposited with a more corrosion-resistant filler metal.

A8.55 ER2209 and ER 22 9 3 N L. The nominal composition (wt %) of these classifications is 22.5 Cr, 8.5 Ni, 3 Mo, and 0.15 N, and the all-weld metal microstructure is normally duplex ferritic-austenitic. Filler metal of these classifications is used primarily to weld duplex stainless steels which contain approximately 22% chromium, such as UNS S31803 and S32205. They are also used for lean duplex stainless steel such as UNS S32101 and S32304. These stainless steels are characterized by high tensile strength, resistance to stress corrosion cracking, and improved resistance to pitting as compared to these properties in austenitic stainless steels such as 304L.

A8.56 ER2307 and ER 23 7 N L. The nominal composition (wt %) of these two identical classifications is 24 Cr, 8 Ni, and 0.15 N, and the all-weld metal microstructure is normally duplex ferritic-austenitic. Filler metals of these classifications are used primarily for welding lean duplex stainless steels such as UNS S32101 and S32304. Weld metal deposited with these filler metals combines increased tensile strength and improved resistance to stress corrosion cracking as compared to these properties in weld metal from ER308L.

A8.57 ER2553. The nominal composition (wt %) of this classification is 25.5 Cr, 5.5 Ni, 3.4 Mo, 2 Cu, and 0.2 N, and the all-weld metal microstructure is normally duplex ferritic-austenitic. Filler metal of this classification is used primarily to weld duplex stainless steels UNS S32550 that contain approximately 25% chromium. These stainless steels are characterized by high tensile strength, resistance to stress corrosion cracking, and improved resistance to pitting. This filler metal is especially useful for weldments to be given a postweld annealing heat treatment as the low-nickel content provides a higher ferrite content after the anneal.

A8.58 ER2594 and ER 25 9 4 N L. The nominal composition (wt %) of these two identical classifications is 25.5 Cr, 9.2 Ni, 3.5 Mo, and 0.25 N, and the all-weld metal microstructure is normally duplex ferritic-austenitic. The sum of the $Cr + 3.3(Mo + 0.5 W) + 16N$, known as the Pitting Resistance Equivalent Number (PREN), is at least 40, thereby allowing the weld metal to be called a “super duplex stainless steel.” This number is a semi-quantitative indicator of resistance to pitting in aqueous chloride-containing environments. It is designed for the welding of super duplex stainless steels UNS S32750 and 32760 (wrought), and UNS J93380, and J93404 (cast). It can also be used for the welding of UNS S32550, J93370, and J93372 when not subject to sulfurous or sulfuric acids in service. In the latter case, the presence of Cu and W in the weld metal can overcome the problem. It can also be used for the welding of carbon and low-alloy steels to duplex stainless steels as well as to weld “standard” duplex stainless steel such as UNS S32205 and J92205 especially for root runs in pipe.

A8.59 ER33-31. The nominal composition (wt %) of this classification is 33 Cr, 31Ni, and 1.6 Mo, and the all-weld metal microstructure is normally fully austenitic. The filler metal is used for welding nickel-chromium-iron alloy (UNS R20033) to itself and to carbon steel, and for weld overlay on boiler tubes. The weld metal is resistant to high-temperature corrosive environments of coal fired power plant boilers.

A8.60 ER3556. The nominal composition (wt %) of this classification is 31 Fe, 20 Ni, 22 Cr, 18 Co, 3 Mo, and 2.5 W, and the all-weld metal microstructure is normally fully austenitic. Filler metal of this classification is used for welding 31 Fe, 20 Ni, 22 Cr, 18 Co, 3 Mo, 2.5 W (UNS R30556) base metal to itself, for joining steel to other nickel alloys, and for surfacing steel by the gas tungsten arc, gas metal arc, and plasma arc welding processes. The filler metal is resistant to high-temperature corrosive environments containing sulfur. Typical specifications for 31 Fe, 20 Ni, 22 Cr, 18 Co, 3 Mo, 2.5 W base metal are ASTM B435, B572, B619, B622, and B626, UNS number R30556.

A9. Usability

A9.1 When welding stainless steels with the gas tungsten arc process, direct current electrode negative (dcen) is preferred. For base metal up to 1/16 in [1.5 mm] thick, argon is the preferred shielding gas because there is less tendency to melt through these lighter thicknesses. For greater thicknesses or for automatic welding, mixtures of helium and argon

are recommended because of the greater penetration and better surface appearance. Argon gas for shielding may also be used and will give satisfactory results in most cases, but a somewhat higher amperage will be required. For information on the effects of higher silicon, see A9.2 and the classification of interest.

A9.2 When using the gas metal arc welding process in which the filler metal is employed as an electrode, direct current electrode positive (dcep) is most commonly used. The shielding gas for spray transfer is usually argon, with or without minor additions of oxygen. For short circuiting transfer, shielding gases composed of helium plus additions of argon, oxygen, and/or carbon dioxide often are used. The minimum thickness that can be welded by spray transfer is approximately 1/8 in to 3/16 in [3 mm to 5 mm]. Short circuiting transfer can be used to weld material as thin as 1/16 in [1.5 mm]. However, thinner sections can be joined if a backing is used. The higher silicon levels improve the washing and wetting behavior of the weld metal. For instance, for increases from 0.30% to 0.65% silicon, the improvement is pronounced; for increases from 0.65% to 1.0% silicon, further improvement is experienced but is less pronounced. Pulsed welding can also be used for welding thin material and sometimes for out of position welding.

A9.3 Each submerged arc welding flux can increase or decrease the percentage of alloying elements from the electrode to the deposit. Neither the direction nor the magnitude of change can be predicted solely by the flux classification or description, e.g., neutral, active, basic. Each flux and electrode combination must be evaluated on its own, especially when properties like Ferrite Number or impact toughness are important. See also AWS A5.39/A5.39M Annex B.

A9.4 The strip cladding process closely resembles conventional submerged arc welding, except that a thin, consumable strip electrode is substituted for the conventional wire. Thus, the equipment consists of conventional submerged arc units with modified contact tips and feed rolls. Normal power sources with a minimum output of 750 amperes are used. If submerged arc equipment is available, then the same feeding motor, gear box, flux-handling system, wire spool, and controls used to feed wire electrodes can be used for strip surfacing. The only difference in most cases is a strip welding head and "bolt-on" adaptor plate.

Strip surfacing is generally carried out using direct current supplied either from a generator or from a rectifier. Power sources with either constant voltage or drooping characteristics are used routinely.

A constant-voltage power source is preferable; however, generator or rectifier type can be connected in parallel to produce higher current for specific applications. The use of direct current electrode positive (dcep) yields somewhat better edge shape and a more regular deposit surface.

Strip cladding is conducted with either the submerged arc or electroslog welding process. Although electroslog welding does not involve an arc, except for initiation, it uses identical strip feeding equipment, controls, and power sources. Voltage and flux composition control are generally necessary whether the process is submerged arc or electroslog. The electroslog process is widely used because of its ability to deposit weld metal with low dilution and allow single layer cladding in some cases.

A10. Special Tests

A10.1 Corrosion or Scaling Tests. Tests of joint specimens have the advantage that the joint design and welding procedure can be made identical to that being used in fabrication. They have the disadvantage of testing the combined properties of the weld metal, the heat-affected zone (HAZ) of the base metal, and the unaffected base metal. Furthermore, it is difficult to obtain reproducible data if a difference exists between the corrosion or oxidation rates of the various metal structures (weld metal, heat-affected zone, and unaffected base metal). Test samples cannot be readily standardized if welding procedure and joint design are to be considered variables. Joint specimens for corrosion tests should not be used for qualifying the filler metal, but may be used for qualifying welding procedures using approved materials. Special corrosion or scale resisting tests that are pertinent to the intended application may be conducted as agreed upon between the purchaser and supplier. This section is included for the guidance of those who desire to specify such special tests.

A10.1.1 The heat treatments, surface finish, and marking of the specimens prior to testing should be in accordance with standard practices for tests of similar alloys in the wrought or cast forms. The testing procedure should correspond to ASTM G4, *Standard Method for Conducting Corrosion Tests in Plant Equipment*, ASTM A262, *Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels*, or ASTM G48, *Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution*.

A10.2 Tests for Mechanical Properties. The tensile properties, bend ductility, and soundness of welds produced using filler metal that conforms with this specification are frequently determined during welding procedure qualification. For cryogenic applications, impact properties of welds are required. It should be realized that the variables in the process, such as current, voltage, and welding speed, variables in the shielding medium, such as the gas mixture or flux, variables in the manual dexterity of the welder, and variables in the composition of the base metal influence the results that may be obtained. When properly controlled, however, these filler metals will give sound welds under widely varying conditions with tensile strength and ductility similar to that obtained by the covered arc welding electrodes. For submerged arc welding see AWS A5.39/A5.39M.

Tensile and elongation requirements for weld metal deposited by shielded metal arc welding (covered) electrodes specified in AWS A5.4/A5.4M, *Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding*, and/or ISO 3581, *Welding consumables — Covered electrodes for manual metal arc welding of stainless and heat-resisting steels — Classification*, are shown in Table A.2. For a discussion of impact properties for cryogenic applications, see A9.3 of AWS A5.4/A5.4M:2012. Note that the impact properties of welds made with bare filler metals in the GTAW or GMAW processes are usually superior to those produced with the SMAW or SAW processes. When supplementary tests for mechanical properties are specified, the procedures should be in accordance with the latest edition of AWS B4.0, *Standard Methods for Mechanical Testing of Welds*. Welding procedure and test assembly will be as agreed upon between purchaser and supplier.

A11. Discontinued Classifications

Some classifications have been discontinued from one revision of this specification to another. This results from either changes in commercial practice or changes in the classification system used in the specification. The classifications that have been discontinued are listed in Table A.3, along with the year in which they were last included in the specification.

A12. General Safety Considerations

A12.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Annex Clause A6. Safety and health information is available from other sources, including, but not limited to Safety and Health Fact Sheets referenced in A12.2, ANSI Z49.1 *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations.

A12.2 Safety and Health Fact Sheets. Safety and Health Fact Sheets are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

Table A.1
Traditional AWS A5.9 Alloy Designations with Corresponding
UNS Numbers and Nearest Nominal Composition Designations

Traditional AWS A5.9 Alloy Designation		Nearest Nominal Composition Alloy Designation	
Alloy Designation	UNS Number	Nominal Composition Alloy Designation ^a	Deviation from Traditional AWS and UNS Number Composition Limits ^a
209	S20980	—	—
218	S21880	—	—
219	S21980	—	—
240	S24080	—	—
307	S30780	—	—
—	—	18 8 Mn	—
308	S30880	—	—
308Si	S30881	—	—
308H	S30880	—	—
308L	S30883	19 9 L	Lower Cr limits, no Si minimum
308LSi	S30888	19 9 L Si	Lower Cr limits, higher Si maximum
308Mo	S30882	20 10 3	Higher C limit, lower Ni limit, wider Mo and Si ranges
308LMo	S30886	—	—
309	S30980	—	—
309Si	S30981	—	—
309L	S30983	23 12 L	Lower Cr and Ni limits, no Si minimum
309LSi	S30981	23 12 L Si	Lower Cr and Ni limits, higher Si maximum
309Mo	S30982	—	—
309LMo	S30986	23 12 2 L	Lower Cr limit, wider Ni range, higher Mo maximum, wider Si range
—	—	21 13 3 L	—
310	S31080	—	—
312	S31380	—	—
316	S31680	—	—
316Si	S31681	—	—
316H	S31680	—	—
316L	S31683	19 12 3 L	Higher Mo minimum, no Si minimum
316LSi	S31688	19 12 3 L Si	Higher Mo minimum, higher Si maximum
316LMn	S31682	20 16 3 Mn N L	Higher Mo maximum, wider Si range
317	S31780	—	—
317L	S31783	—	—
—	—	18 16 5 N L	—

(Continued)

Table A.1 (Continued)
Traditional AWS A5.9 Alloy Designations with Corresponding
UNS Numbers and Nearest Nominal Composition Designations

Traditional AWS A5.9 Alloy Designation		Nearest Nominal Composition Alloy Designation	
Alloy Designation	UNS Number	Nominal Composition Alloy Designation ^a	Deviation from Traditional AWS and UNS Number Composition Limits ^a
318	S31980	19 12 3 Nb	Higher Mo minimum, no Si minimum or Nb minimum
—	—	19 12 3 Nb Si	—
320	N08021	—	—
320LR	N08022	—	—
321	S32180	—	—
330	N08331	—	—
347	S34780	19 9 Nb	Lower Cr maximum, no Si minimum, no Nb minimum
347Si	S34788	19 9 Nb Si	Lower Cr maximum, higher Si maximum, no Nb minimum
383	N08028	—	—
385	N08904	20 25 5 Cu L	Higher C maximum, wider Cr range, higher Ni maximum, wider Mo range, higher Mn and Si maxima, lower Cu minimum
409	S40900	—	—
409Nb	S40940	—	—
410	S41080	—	—
410NiMo	S41086	—	—
420	S42080	—	—
430	S43080	—	—
439	S43035	—	—
446LMo	S44687	—	—
630	S17480	—	—
19-10H	S30480	—	—
16-8-2	S16880	—	—
2209	S39209	22 9 3 N L	Wider Cr and Ni ranges, higher Mo maximum, wider Mn range, higher Si maximum, higher N minimum
2307	S82371	23 7 N L	Identical
2553	S39553	—	—
2594	S32750	25 9 4 N L	Identical
33-31	R20033	—	—
3356	R30556	—	—

^a Specific products classified with nearest nominal composition designations may, or may not, fall within the traditional AWS A5.9 and UNS number composition limits in the same row of this table. In general, alloys with nominal composition designations have lower S, Mo, and Cu maxima when these elements are residuals.

Table A.2
Expected (Typical) Minimum All-Weld Metal Mechanical Properties
from AWS A5.4/A5.4M:2012 and/or ISO 3581:2016^a

AWS and/or ISO Classification ^b	Tensile Strength, Minimum		Elongation ^a , min. percent	Heat Treatment
	ksi	MPa		
E209-XX	100	690	15	none
E219-XX	90	620	15	none
E240-XX	100	690	15	none
E307-XX	85	590	30	none
E 18 8 Mn X	—	500	25 (5:1)	none
E308-XX	80	550	30	none
E308H-XX	80	550	30	none
E308L-XX, E 19 9 L X	75	520	30	none
E308Mo-XX, E 20 10 3 X	80	550	30	none
E308LMo-XX	75	520	30	none
E309-XX	80	550	30	none
E309L-XX, E 23 12 L X	75	520	30	none
E309Mo-XX	80	550	30	none
E309LMo-XX, E 23 12 2 L X	75	520	30	none
E310-XX	80	550	30	none
E312-XX	95	660	22	none
E316-XX	75	520	30	none
E316H-XX	75	520	30	none
E316L-XX, E 19 12 3 L X	70	490	30	none
E316LMn-XX, E 20 16 3 Mn N L X	80	550	20	none
E317-XX	80	550	30	none
E317L-XX	75	520	30	none
E318-XX, E 19 12 3 Nb X	80	550	25	none
E320-XX	80	550	30	none
E320LR-XX	75	520	30	none
E330-XX	75	520	25	none
E347-XX, E 19 9 Nb X	75	520	30	none
E383-XX	75	520	30	none
E385-XX	75	520	30	none
E409Nb-XX	65	450	20	c

(Continued)

Table A.2 (Continued)
Expected (Typical) Minimum All-Weld Metal Mechanical Properties
from AWS A5.4/A5.4M:2012 and/or ISO 3581:2016^a

AWS and/or ISO Classification ^b	Tensile Strength, Minimum		Elongation ^a , min. percent	Heat Treatment
	ksi	MPa		
E410-XX	75	520	20	d
E410NiMo-XX	110	760	15	e
E430-XX	65	450	20	c
E630-XX	135	930	7	f
E16-8-2-XX	80	550	35	none
E2209-XX, E 22 9 3 N L X	100	690	20	none
E2307-XX	100	690	20	none
E2553-XX	110	760	15	none
E2594-XX, E 25 9 4 N L X	110	760	15	none
E33-31-XX	105	720	25	none

^a In cases where AWS A5.4/A5.4M and ISO 3581 have somewhat different requirements for essentially the same composition, the AWS A5.4/A5.4M requirements are included. It should be noted that ISO 3581 elongation requirements are based on a 5:1 gage length:diameter ratio while AWS A5.4/A5.4M requirements are based on a 4:1 ratio. Typically the 5:1 ratio produces about 91% of the 4:1 ratio. Elongations based on 5:1 ratio are so marked.

^b Not all AWS A5.9/A5.9M (ISO 14343 MOD) compositions are present in AWS A5.4/A5.4M or ISO 3581. For example, 321 and 409 compositions cannot be made as covered electrodes. In these cases, no requirement is shown.

^c Heat to 1400 °F to 1450 °F [760 °C to 790 °C], hold for two hours (–0, +15 minutes), furnace cool at a rate not exceeding 100 °F [55 °C] per hour to 1100 °F [595 °C] and air cool to ambient.

^d Heat to 1350 °F to 1400 °F [730 °C to 760 °C], hold for one hour (–0, +15 minutes), furnace cool at a rate not exceeding 200 °F [110 °C] per hour to 600 °F [315 °C] and air cool to ambient.

^e Heat to 1100 °F to 1150 °F [595 °C to 620 °C], hold for one hour (–0, +15 minutes), and air cool to ambient.

^f Heat to 1875 °F to 1925 °F [1025 °C to 1050 °C], hold for one hour (–0, +15 min), and air cool to ambient, and then precipitation harden at 1135 °F to 1165 °F [610 °C to 630 °C], hold for four hours (–0, +15 min), and air cool to ambient.

Table A.3
Discontinued Classifications

Discontinued Classification	Last Published	Discontinued Classification	Last Published
ER26-1 ^a	1981	316LCu	2017
ER349	1981	20 16 3 Mn L	2017
ER502 ^b	1993	18 15 3 L	2017
ER505 ^c	1993	19 13 4 L	2017
ER409Cb ^d	1993	19 13 4 N L	2017
ECXXX ^e	2012	318L	2017
19 9 H	2017	18 36 H	2017
21 10 N	2017	28 35 N	2017
22 12 H	2017	27 31 4 Cu L	2017
309LD	2017	20 25 5 Cu N L	2017
309LMoD	2017	13	2017
23 12 Nb	2017	13L	2017
309LNbD	2017	13 4	2017
22 12 L Nb	2017	16 5 1	2017
25 20	2017	17	2017
25 20 Mn	2017	430Nb	2017
25 20 H	2017	439LNb	2017
310L	2017	18 L Nb	2017
310S	2017	25 4	2017
25 22 2 N L	2017	16 8 2	2017
26 23 5 N	2017	25 7 2 L	2017
29 9	2017	25 9 3 Cu N L	2017
19 12 3 H	2017		

^a This classification was not really discontinued, but was changed to ER446LMo.

^b This electrode classification was transferred to the AWS A5.28/A5.28M specification where it is classified as ER80S-B6, and to the AWS A5.23/A5.23 specification where it is classified as EB6.

^c This electrode classification was transferred to the AWS A5.28/A5.28M specification where it is classified as ER80S-B8, and to the AWS A5.23/A5.23M specification where it is classified as EB8.

^d This classification was not really discontinued, but was changed to ER409Nb to reflect the adoption of Nb for niobium instead of Cb for columbium.

^e The classifications with the two initial designators "EC" were transferred to the AWS A5.22/A5.22M specification without change.

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the Welding Journal, and post it on the AWS website.

B6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The AWS Board Policy Manual requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

Annex C (Informative)

List of Deviations from ISO 14343:2017

This annex is not part of this standard but included for informational purposes only.

Technical Changes

Standard AWS clauses for Acceptance, Certification, Summary of Tests, and Method of Manufacture were added.

ISO classifications for which evidence of approval by a major agency such as TÜV could not be found were removed.

ISO Z classification was removed.

Editorial Changes

Traditional “ER” has replaced ISO “SS” and traditional “EQ” has replaced ISO “BS” as the leading portion of the classification designation.

ISO process designations W, G, P, S, B, and L were eliminated.

Table 1 and Table A.1 were sorted to put them in sequence of information used in AWS A5.9/A5.9M:2017.

Changed ISO decimal commas to decimal periods.

Added Annexes A, B, and C.

INTENTIONALLY LEFT BLANK

SPECIFICATION FOR BARE ALUMINUM AND ALUMINUM-ALLOY WELDING ELECTRODES AND RODS



SFA-5.10/SFA-5.10M



(25)

(Identical with AWS Specification A5.10/A5.10M:2023 (ISO 18273:2015 MOD). In case of dispute, the original AWS text applies.)

Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods

1. Scope

1.1 This specification prescribes requirements for classification of solid electrodes and rods for fusion welding of aluminum and aluminum alloys. The classification of the solid electrodes and rods is based on their chemical composition, operability testing and mechanical testing, when required.

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to weld metal properties. The specification A5.10 uses U.S. Customary Units. The specification with the designation A5.10M uses SI units. The latter are shown within brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for the sizing of electrodes or packaging or both under specification A5.10 or A5.10M.

1.3 Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in Annex A Clauses A5 and A11.

Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments or revisions of the publications may not apply since the relevant requirements may have changed.

American Welding Society (AWS) documents:

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

AWS A5.01M/A5.01, *Welding Consumables—Procurement of Filler Metals and Fluxes*

AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*

AWS B4.0, *Standard Methods for Mechanical Testing of Welds*

American National Standards Institute (ANSI) documents:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

ASTM International (ASTM) documents:

ASTM B108, *Standard Specification for Aluminum-Alloy Permanent Mold Castings*

ASTM B209, *Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate*

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

ASTM E34, *Standard Test Methods for Chemical Analysis of Aluminum and Aluminum-Base Alloys*

ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*

ASTM E2033, *Standard Practice for Computed Radiology (Photostimulable Luminescence Method)*

ASTM E2698, *Standard Practice for Radiological Examination Using Digital Detector Arrays*

International Organization for Standardization (ISO) documents.

ISO 80000-1:2022, *Quantities and units — Part 1: General*

3. Classifications

3.1 The classification designation system is as shown in Figure 1, and the symbols and chemical compositions are as shown in Table 1.

3.1.1 Any filler metal tested and classified as an electrode shall also be considered classified as a welding rod. Filler metal tested and classified only as a welding rod shall not be considered classified as an electrode.

3.1.2 The electrodes and rods classified under this specification are intended for gas metal arc, gas tungsten arc, oxyfuel gas, and plasma arc welding, but that is not to prohibit their use with any other process for which they are found suitable.

3.2 Electrodes and rods classified under one classification shall not be classified under any other classification in this specification.

4. Acceptance

Acceptance of the welding electrodes and rods shall be in accordance with the provisions of AWS A5.01M/A5.01. See Clause A3 in Annex A for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

5. Certification

By affixing the AWS specification and classification designations to the packaging or the classification designation to the product, the manufacturer certifies that the product meets the requirements of this specification. See Clause A4 in Annex A for further information concerning certification and the testing called for to meet this requirement.

6. Rounding Procedure

The Aluminum Association International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys (commonly known as Teal Sheets) has a rule (Footnote 1 in its table of Chemical Composition Limits) for setting chemical composition as follows:

Composition in weight percent maximum unless shown as a range or a minimum. Standard limits for alloying elements and impurities are expressed to the following places:

Less than 0.001 percent..... 0.000X

0.001 but less than 0.01 percent..... 0.00X

0.01 but less than 0.10 percent

Unalloyed aluminum made by a refining process 0.0XX

Alloys and unalloyed aluminum not made by a refining process 0.0X

0.10 through 0.55 percent 0.XX

(It is customary to express limits of 0.30 percent through 0.55 percent as 0.X0 or 0.X5).

Over 0.55 percent 0.X, X.X, etc.

(except that combined Si + Fe limits for 1xxx designations must be expressed as 0.XX or 1.XX).

The following rounding rules apply to all other areas of this specification:

For the purpose of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest 1000 psi (1 ksi) for tensile and yield strength for A5.10 [to the nearest 5 MPa for tensile and yield strength for A5.10M] and to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfill the requirements for the classification under test.

7. Summary of Tests

The tests required for each classification are specified in Table 2. The purpose of these tests is to determine the chemical composition of the filler metal, the soundness of the weld metal produced by gas metal arc welding electrodes, the deposition characteristics of welding rods, and the strength of the weld metal, when required. The base metal for the weld test assemblies, the welding and testing procedures to be employed, and the results required are given in Clauses 9 through 13.

8. Retest

If the result of any test fails to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Specimens for the retest may be taken from the original weld test assembly or test sample or from a new weld test assembly or from a new test sample. For chemical analysis, retest need be only for those specific elements that failed to meet the test requirement. If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that, during preparation or after completion of any test, it is clearly determined that prescribed or proper procedures were not followed in preparing the weld test sample or test specimen(s), or in conducting the test, the test shall be considered invalid, without regard to whether the test was actually completed, or whether the test results met or failed to meet the requirement. That test shall be repeated, following proper prescribed procedures. In this case, the requirement for doubling the number of test specimens does not apply.

9. Weld Test Assemblies

9.1 One or two weld test assemblies are required:

- (a) The groove weld test assembly for the usability of electrodes and the soundness of the weld metal (see 9.3 and Figure 2).
- (b) The groove weld test assembly for mechanical properties (see 9.4 and Figure 3).
- (c) The bead-on-plate weld test assembly for the usability of rods (see 9.5).

9.2 Usability tests shall be made using electrodes and welding rods of each diameter. A filler metal that satisfactorily meets the requirements of the radiographic soundness test, when tested as an electrode, shall also be classified as a welding rod without being subjected to the bead-on-plate test required for a welding rod. A filler metal that satisfactorily meets the bead-on-plate test requirements may be classified as a rod. In order to be classified as an electrode, the filler metal shall also be tested as an electrode, and meet the testing requirements.

9.3 Groove Weld for Soundness and Usability of Electrodes

9.3.1 A test assembly shall be prepared and welded as specified in Figure 2 and Clause 9.3.2 through 9.3.4 using base metal of the appropriate type specified in Table 3. The welding position shall be as specified in Figure 2 for each electrode diameter. Testing of the assembly shall be as specified in Clause 11, Radiographic Test.

9.3.2 Welding of the test assembly shall be conducted using the gas metal arc welding process with techniques and procedures specified by the manufacturer for the factors not covered herein.

9.3.3 Dimensions of the groove weld joint and the position of welding shall be as specified in Figure 2 for the electrode diameter being tested. The backing material shall be of the same type as the test plate base metal.

9.3.4 The test assembly shall be at a temperature of not less than 60 °F [16 °C] when commencing the initial or subsequent weld passes. The preheat and interpass temperatures shall not exceed 250 °F [120 °C].

9.4 Groove Weld Test for Mechanical Properties

9.4.1 When required in Table 2, a groove weld test assembly shall be prepared and welded as specified in Figure 3 and Table 4.

9.4.2 The electrode diameter shall be 0.047 in or 0.062 in [1.2 mm or 1.6 mm], or the nearest size manufactured. The welding parameters shall be as specified in Table 4. Base plate and backing strip materials shall be used as specified in Table 3. Alternately, 1xxx or 6xxx series base plate and backing strip materials may be used for all classifications. The test assembly shall be at a temperature of not less than 60 °F [16 °C] when commencing the initial or subsequent weld passes. The preheat and interpass temperatures shall not exceed 250 °F [120 °C].

9.4.3 Welding shall be in the flat position. The assembly may be pre-set or restrained during welding to prevent excess warpage. Testing of the assemblies shall be as required in Clause 12, Tension Test.

9.5 Bead-on-Plate Weld Test for Usability of Welding Rods

9.5.1 The test assembly shall consist of sheet, plate, or extrusion approximately 12 in [300 mm] in length upon which a weld shall be made as specified in 9.5.2, using base metal of the appropriate type specified in Table 3. Examination of the assembly shall be as specified in Clause 13, Bead-on-Plate Test.

9.5.2 The assembly shall be welded in the flat position with the gas tungsten arc welding process employing alternating current and argon gas shielding. The test plate thickness and the welding current shall be compatible with the rod size being tested.

9.5.3 The completed bead-on-plate welds shall be examined with the unaided eye (corrected to normal vision) and shall meet the requirements specified in Clause 13, Bead-on-Plate Test.

10. Chemical Analysis

10.1 A sample of the filler metal, or the stock from which it is made, shall be prepared for chemical analysis by any method that will not affect the chemical composition.

10.2 The sample shall be analyzed by accepted analytical methods. The referee method shall be ASTM E34.

10.3 The results of the analysis shall meet the requirements of Table 1 for the classification of electrode or rod under test.

11. Radiographic Test

11.1 The groove weld described in 9.3 and shown in Figure 2 shall be radiographed to evaluate the soundness of the weld metal. In preparation for radiography, the backing shall be removed and both surfaces of the weld shall be machined or ground smooth and flush with the original surfaces of the base metal or with a uniform reinforcement not exceeding $3/32$ in [2.5 mm]. It is permitted on both sides of the test assembly to remove base metal to a depth of $1/16$ in [1.5 mm] nominal below the original base metal surface in order to facilitate backing and/or buildup removal. The thickness of the weld metal shall not be reduced by more than $1/16$ in [1.5 mm] so that the thickness of the prepared radiographic test specimen equals at least the thickness of the base metal minus $1/16$ in [1.5 mm]. Both surfaces of the test assembly, in the area of the weld, shall be smooth enough to avoid difficulty in interpreting the radiograph.

11.2 The weld shall be radiographed in accordance with one of the following. The quality level of inspection shall be 2-2T.

(1) Film Radiology: ASTM E1032.

(2) Computed Radiology (CR): ASTM E2033 and the requirements of ASTM E1032 except where CR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2033, refers to phosphor imaging plate.

(3) Digital Radiology (DR): ASTM E2698 and the requirements of ASTM E1032 except where DR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2698, refers to digital detector array (DDA).

11.3 The soundness of the weld metal and the usability of the electrode meet the requirements of this specification if the radiograph shows no cracks, no incomplete fusion, and no rounded indications in excess of those permitted by the radiographic standards in Figure 4 for test assemblies welded in the overhead position for electrode sizes up to and including $1/16$ in [1.6 mm], and in Figure 5 for test assemblies welded in the flat position for electrode sizes larger than $1/16$ in [1.6 mm]. In evaluating the radiograph, the center 6 in [150 mm] of the test specimen shall be considered, and all extra weld shall be disregarded.

A rounded indication is an indication on the radiograph whose length is no more than three times its width. Rounded indications may be circular, elliptical, conical, or irregular in shape and they may have tails. The size of the rounded indication is the largest dimension of the indication including any tail that may be present. Indications whose largest dimension does not exceed $1/64$ in [0.4 mm] shall be disregarded. Test assemblies with indications larger than the large indications permitted in the radiographic standards in Figure 4 and Figure 5 do not meet the requirements of this specification.

11.4 The alternative method of evaluation of radiographic conformance involves calculation of the total area of the rounded indications as they appear on the radiograph. This total area shall not exceed 1.5% of the thickness of the test assembly multiplied by the length of the weld used in evaluation for overhead weld assemblies, or 1% of the thickness of the test assembly multiplied by the length of the weld used in evaluation for flat weld assemblies. The values given in Note 3 to each Figure (4A, 4B, and 5) have been calculated for 6 in [150 mm] of weld. The maximum size permitted still applies.

11.5 An electrode that produces a groove weld which satisfactorily meets these radiographic requirements may also be classified as a welding rod under this specification without conducting the test specified in 9.5.

12. Tension Test

12.1 One all-weld-metal tension test specimen, as specified in the Tension Test Clause of AWS B4.0, shall be machined from the welded test assembly described in 9.4 and shown in Figure 3. The tensile specimen shall have a nominal diameter of 0.500 in [12.5 mm], and a nominal gage length to diameter ratio of 4:1. The specimen shall be tested in the

manner described in the Tension Test Clause of AWS B4.0. The results of the all-weld-metal tension test shall meet the requirements specified in Table 5 for that classification.

12.2 An electrode that produces a groove weld which satisfactorily meets the tension test requirements of Table 5 and the other requirements for classification as an electrode may also be classified as a welding rod under this specification.

13. Bead-on-Plate Test

13.1 Welding rod tested in accordance with 9.5 shall produce weld metal that flows freely and uniformly without sputtering or other irregularities. The resultant weld metal shall be smooth and uniform with no visible evidence of cracks or porosity.

13.2 If a filler metal satisfactorily meets the weld bead-on-plate test requirements when tested as a welding rod, it also shall be tested as an electrode if it is to be classified as an electrode.

14. Method of Manufacture

The electrodes and rods classified according to this specification may be manufactured by any method that will produce material that meets the requirements of this specification.

15. Standard Sizes

15.1 Standard sizes for round filler metal in the different package forms of straight lengths, coils without support, and spools are as shown in AWS A5.02/A5.02M. Diameters of cast rods in straight lengths are approximate with no specified tolerance.

15.2 Typical sizes for flattened shapes of straight length welding rod are shown in Table 6. The cross-sectional area of such shapes shall be equivalent to that of corresponding round rods of the same nominal diameter as listed in AWS A5.02/A5.02M.

16. Finish and Uniformity

Finish and uniformity shall be as specified as in AWS A5.02/A5.02M.

17. Standard Package Forms

Standard package dimensions and weights and other requirements for each form shall be as specified in AWS A5.02/A5.02M.

18. Winding Requirements

18.1 Winding requirements shall be as specified in AWS A5.02/A5.02M.

18.2 The cast and helix of the filler metal shall be as specified in AWS A5.02/A5.02M.

19. Filler Metal Identification

Filler metal identification, product information, and precautionary information shall be as specified in AWS A5.02/A5.02M.

20.1 Filler metal in all product forms, except welding rods in straight lengths, shall be packaged in accordance with AWS A5.02/A5.02M.

20.2 Packaging of straight lengths of bare welding rods shall be as agreed upon between the purchaser and supplier.

The product information (as a minimum) that shall be legibly marked and visible from the outside of each unit package shall be as specified in AWS A5.02/A5.02M.

Table 1
Symbols and Chemical Composition Requirements for Electrodes and Rods

Alloy Symbol			Chemical Composition in Weight Percent ^a													
AWS Classification	ISO 18273 Chemical Composition Symbols		Si	Fe	Cu	Mn	Mg	Cr	Zn	Ga, V	Ti	Zr	Al (minimum)	Be ^b	Other Unspecified Elements each	Other Unspecified Elements total
ALUMINUM-LOW ALLOYED																
ER1070, R1070	Al 1070	Al99,7	0.20	0.25	0.04	0.03	0.03	—	0.04	V 0.05	0.03	—	99.70	0.0003	0.03	—
ER1080A, R1080A	Al 1080A	Al99,8(A)	0.15	0.15	0.03	0.02	0.02	—	0.06	Ga 0.03	0.02	—	99.80	0.0003	0.02	—
ER1100, R1100	Al 1100	Al99, 0Cu	Si + Fe 0.95		0.05–0.20	0.05	—	—	0.10	—	—	—	99.00	0.0003	0.05	0.15
ER1188 R1188	Al 1188	Al99,88	0.06	0.06	0.005	0.01	0.01	—	0.03	Ga 0.03 V 0.05	0.01	—	99.88	0.0003	0.01	—
ER1200, R1200	Al 1200	Al99,0	Si + Fe 1.00		0.05	0.05	—	—	0.10	—	0.05	—	99.00	0.0003	0.05	0.15
ER1450, R1450	Al 1450	Al99,5Ti	0.25	0.40	0.05	0.05	0.05	—	0.07	—	0.10–0.20	—	99.50	0.0003	0.03	—
ALUMINUM-COPPER																
R-206.0 ^c	—	—	0.10	0.15	4.2–5.0	0.20–0.50	0.15–0.35	—	0.10	—	0.15–0.30	—	Rem	—	0.05	0.15
ER2319, R2319	Al 2319	AlCu6MnZrTi	0.20	0.30	5.8–6.8	0.20–0.40	0.02	—	0.10	V 0.05–0.15	0.10–0.20	0.10–0.25	Rem	0.0003	0.05	0.15
ALUMINUM-MANGANESE																
ER3103, R3103	Al 3103	AlMn1	0.50	0.7	0.10	0.9–1.5	0.30	0.10	0.20	—	Ti + Zr 0.10		Rem	0.0003	0.05	0.15
ALUMINUM-SILICON																
R-C355.0	—	—	4.5–5.5	0.20	1.0–1.5	0.10	0.40–0.6	—	0.10	—	0.20	—	Rem	—	0.05	0.15
R-A356.0	—	—	6.5–7.5	0.20	0.20	0.10	0.25–0.45	—	0.10	—	0.20	—	Rem	—	0.05	0.15
R-357.0	—	—	6.5–7.5	0.15	0.05	0.03	0.45–0.6	—	0.05	—	0.20	—	Rem	—	0.05	0.15
R-A357.0	—	—	6.5–7.5	0.20	0.20	0.10	0.40–0.7	—	0.10	—	0.04–0.20	—	Rem	0.04–0.07	0.05	0.15
ER4009, R4009	Al 4009	AlSi5Cu1Mg	4.5–5.5	0.20	1.0–1.5	0.10	0.45–0.6	—	0.10	—	0.20	—	Rem	0.0003	0.05	0.15
ER4010, R4010	Al 4010	AlSi7Mg	6.5–7.5	0.20	0.20	0.10	0.30–0.45	—	0.10	—	0.20	—	Rem	0.0003	0.05	0.15
R4011	Al 4011	AlSi7Mg0,5Ti	6.5–7.5	0.20	0.20	0.10	0.45–0.7	—	0.10	—	0.04–0.20	—	Rem	0.04–0.07	0.05	0.15
ER4018, R4018	Al 4018	AlSi7Mg	6.5–7.5	0.20	0.05	0.10	0.50–0.8	—	0.10	—	0.20	—	Rem	0.0003	0.05	0.15
ER4043, R4043	Al 4043	AlSi5	4.5–6.0	0.8	0.30	0.05	0.05	—	0.10	—	0.20	—	Rem	0.0003	0.05	0.15

(Continued)

Table 1 (Continued)
Symbols and Chemical Composition Requirements for Electrodes and Rods

Alloy Symbol			Chemical Composition in Weight Percent ^a													
AWS Classification	ISO 18273 Chemical Composition Symbols		Si	Fe	Cu	Mn	Mg	Cr	Zn	Ga, V	Ti	Zr	Al (minimum)	Be ^b	Other Unspecified Elements each	Other Unspecified Elements total
ER4043A, R4043A	Al 4043A	AlSi5(A)	4.5–6.0	0.6	0.30	0.15	0.20	—	0.10	—	0.15	—	Rem	0.0003	0.05	0.15
ER4046, R4046	Al 4046	AlSi10Mg	9.0–11.0	0.50	0.03	0.40	0.20–0.50	—	0.10	—	0.15	—	Rem	0.0003	0.05	0.15
ALUMINUM-MAGNESIUM																
ER5087, R5087	Al 5087	AlMg4,5MnZr(A)	0.25	0.40	0.05	0.7–1.1	4.5–5.2	0.05–0.25	0.25	—	0.15	0.10–0.20	Rem	0.0003	0.05	0.15
ER5183, R5183	Al 5183	AlMg4,5Mn0,7(A)	0.40	0.40	0.10	0.50–1.0	4.3–5.2	0.05–0.25	0.25	—	0.15	—	Rem	0.0003	0.05	0.15
ER5183A, R5183A	Al 5183A	AlMg4,5Mn0,7	0.40	0.40	0.10	0.50–1.0	4.3–5.2	0.05–0.25	0.25	—	0.15	—	Rem	0.0005	0.05	0.15
ER5187, R5187	Al 5187	AlMg4,5MnZr	0.25	0.40	0.05	0.7–1.1	4.5–5.2	0.05–0.25	0.25	—	0.15	0.10–0.20	Rem	0.0005	0.05	0.15
ER5249, R5249	Al 5249	AlMg2Mn0,8Zr	0.25	0.40	0.05	0.50–1.1	1.6–2.5	0.30	0.20	—	0.15	0.10–0.20	Rem	0.0003	0.05	0.15
ER5356, R5356	Al 5356	AlMg5Cr(A)	0.25	0.40	0.10	0.05–0.20	4.5–5.5	0.05–0.20	0.10	—	0.06–0.20	—	Rem	0.0003	0.05	0.15
ER5356A, R5356A	Al 5356A	AlMg5Cr	0.25	0.40	0.10	0.05–0.20	4.5–5.5	0.05–0.20	0.10	—	0.06–0.20	—	Rem	0.0005	0.05	0.15
ER5554, R5554	Al 5554	AlMg2,7Mn	0.25	0.40	0.10	0.50–1.0	2.4–3.0	0.05–0.20	0.25	—	0.05–0.20	—	Rem	0.0003	0.05	0.15
ER5556, R5556	Al 5556	AlMg5Mn1Ti(A)	0.25	0.40	0.10	0.50–1.0	4.7–5.5	0.05–0.20	0.25	—	0.05–0.20	—	Rem	0.0003	0.05	0.15
ER5556A, R5556A	Al 5556A	AlMg5Mn(A)	0.25	0.40	0.10	0.6–1.0	5.0–5.5	0.05–0.20	0.20	—	0.05–0.20	—	Rem	0.0003	0.05	0.15
ER5556B, R5556B	Al 5556B	AlMg5Mn1	0.25	0.40	0.10	0.6–1.0	5.0–5.5	0.05–0.20	0.20	—	0.05–0.20	—	Rem	0.0005	0.05	0.15

(Continued)

Table 1 (Continued)
Symbols and Chemical Composition Requirements for Electrodes and Rods

Alloy Symbol			Chemical Composition in Weight Percent ^a													
AWS Classification	ISO 18273 Chemical Composition Symbols		Si	Fe	Cu	Mn	Mg	Cr	Zn	Ga, V	Ti	Zr	Al (minimum)	Be ^b	Other Unspecified Elements each	Other Unspecified Elements total
ER5556C, R5556C	Al 5556C	AlMg5Mn1Ti	0.25	0.40	0.10	0.50–1.0	4.7–5.5	0.05–0.20	0.25	—	0.05–0.20	—	Rem	0.0005	0.05	0.15
ER5654, R5654	Al 5654	AlMg3,5Ti(A)	Si + Fe 0.45		0.05	0.01	3.1–3.9	0.15–0.35	0.20	—	0.05–0.15	—	Rem	0.0003	0.05	0.15
ER5654A, R5654A	Al 5654A	AlMg3,5Ti	Si + Fe 0.45		0.05	0.01	3.1–3.9	0.15–0.35	0.20	—	0.05–0.15	—	Rem	0.0005	0.05	0.15
ER5754, R5754	Al 5754 ^d	AlMg3	0.40	0.40	0.10	0.50	2.6–3.6	0.30	0.20	—	0.15	—	Rem	0.0003	0.05	0.15
GENERAL																
ERG, RG	—	—	Chemical composition as agreed upon between supplier and user													

^a Single values shown in the table are maximum values, except for Al, which is a minimum. The results shall be rounded as specified in Clause 6.

^b Metal containing greater than 0.0003% Be is typically not used as an electrode.

^c For R-206.0, Ni = 0.05 max. and Sn = 0.05 max.

^d Alloy Al 5754 also limits the sum (Mn + Cr): 0.10 to 0.6.

Table 2
Required Tests^a

AWS Classification	Chemical Analysis	Soundness and Usability Test (Electrode) See 9.3 and Figure 2	Weld Metal Tension Test and Soundness Test (Electrode) See 9.4 and Figure 3	Bead-on-Plate Test (Rod) See 9.5
ER1070	X	X	X	—
R1070	X	—	—	X
ER1080A	X	X	X	—
R1080A	X	—	—	X
ER1100	X	X	X	—
R1100	X	—	—	X
ER1188	X	X	X	—
R1188	X	—	—	X
ER1200	X	X	X	—
R1200	X	—	—	X
ER1450	X	X	X	—
R1450	X	—	—	X
ER2319	X	X	X	—
R2319	X	—	—	X
ER3103	X	X	—	—
R3103	X	—	—	X
ER4009	X	X	X	—
R4009	X	—	—	X
ER4010	X	X	X	—
R4010	X	—	—	X
R4011	X	—	—	X
ER4018	X	X	X	—
R4018	X	—	—	X
ER4043	X	X	X	—
R4043	X	—	—	X
ER4043A	X	X	X	—
R4043A	X	—	—	X
ER4046	X	X	X	—
R4046	X	—	—	X
ER4047	X	X	X	—
R4047	X	—	—	X
ER4145	X	X	X	—
R4145	X	—	—	X
ER4643	X	X	X	—
R4643	X	—	—	X
ER4943	X	X	X	—
R4943	X	—	—	X
ER5087	X	X	X	—
R5087	X	—	—	X
ER5183	X	X	X	—
R5183	X	—	—	X
ER5183A	X	X	X	—
R5183A	X	—	—	X
ER5187	X	X	X	—
R5187	X	—	—	X
ER5249	X	X	X	—
R5249	X	—	—	X
ER5356	X	X	X	—
R5356	X	—	—	X
ER5356A	X	X	X	—
R5356A	X	—	—	X
ER5554	X	X	X	—
R5554	X	—	—	X
ER5556	X	X	X	—

(Continued)

**Table 2 (Continued)
Required Tests^a**

AWS Classification	Chemical Analysis	Soundness and Usability Test (Electrode) See 9.3 and Figure 2	Weld Metal Tension Test and Soundness Test (Electrode) See 9.4 and Figure 3	Bead-on-Plate Test (Rod) See 9.5
R5556	X	—	—	X
ER5556A	X	X	X	—
R5556A	X	—	—	X
ER5556B	X	X	X	—
R5556B	X	—	—	X
ER5556C	X	X	X	—
R5556C	X	—	—	X
ER5654	X	X	X	—
R5654	X	—	—	X
ER5654A	X	X	X	—
R5654A	X	—	—	X
ER5754	X	X	X	—
R5754	X	—	—	X
R-206.0	X	—	—	X
R-C355.0	X	—	—	X
R-A356.0	X	—	—	X
R-357.0	X	—	—	X
R-A357.0	X	—	—	X
ERG	X	X	X	—
RG	X	—	—	X

^a Filler metal meeting the classification requirements when tested as an electrode is not required to be tested as a rod, as specified in 9.2.

Table 3
Base Metal for Soundness, Usability, and Mechanical Testing

Electrode and Rod (AWS Classification)	Base Metal
ER1070, R1070, ER1080A, R1080A, ER1100, R1100, ER1188, R1188, ER1200, R1200, ER1450, R1450	1060, 1100, 1350, or 3003
ER2319, R2319, ER4145, R4145	2014, 2219, 3003, 6005 or 6061
ER4009, R4009, ER4010, R4010, R4011, ER4018, R4018, ER4043, R4043, ER4043A, R4043A, ER4046, R4046, ER4047, R4047, ER4047A, R4047A, ER4643, R4643, ER4943, R4943, ER3103, R3103	3003, 6005 or 6061
ER5087, R5087, ER5183, R5183, ER5183A, R5183A, ER5187, R5187, ER5249, R5249, ER5356, R5356, ER5356A, R5356A, ER5554, R5554, ER5556, R5556, ER5556A, R5556A, ER5556B, R5556B, ER5556C, R5556C, ER5654, R5654, ER5654A, R5654A, ER5754, R5754	3004, 5052, 5083, 5086, 5154, 5454, 5456, 6005 or 6061
R-206.0	206.0, 2014, 2219, 3003, 6005 or 6061
R-C355.0	355.0, C355.0, 3003, 6005 or 6061
R-A356.0, R357.0, R-A357.0	356.0, A356.0, 357.0, A357.0, 3003, 6005 or 6061
<i>ERG and RG</i>	<i>Not Specified</i>

All wrought base alloys 1060, 1100, 2014, 2219, 3003, 3004, 5052, 5083, 5086, 5154, 5454, 6005, and 6061 are included in ASTM B 209. Cast base alloys 355.0, C355.0, 356.0, A356.0, 357.0, and A357.0 are included in ASTM B 108.

Table 4
Welding Parameters for Groove Weld Mechanical Testing

Standard Size ^a	0.047 in [1.2 mm]	0.062 in [1.6 mm]
Shielding Gas	100% Ar	100% Ar
Wire Feed Speed	300 in/min to 650 in/min [125 mm/sec to 275 mm/sec]	150 in/min to 350 in/min [65 mm/sec to 150 mm/sec]
Arc Voltage	23 V to 28 V	23 V to 29 V
Resulting Current, DCEP (DCEP = Electrode Positive)	200 A to 300 A	200 A to 350 A
Contact tip-to-work distance	5/8 in to 7/8 in [16 mm to 22 mm]	3/4 in to 1 in [19 mm to 25 mm]
Travel Speed	20 in/min to 35 in/min [8.5 mm/sec to 15 mm/sec]	20 in/min to 35 in/min [8.5 mm/sec to 15 mm/sec]

^a If sizes other than 0.047 in and 0.062 in [1.2 mm and 1.6 mm] are tested, wire feed speed (and resulting current), arc voltage, and tip-to-work distance shall be changed to follow the manufacturer's recommended settings.

Table 5
Mechanical Testing Requirements^a

AWS Classification	Tensile Strength, minimum (ksi) [MPa] ^c	Yield Strength (ksi) [MPa] ^b	Percent Elongation ^b
ER1100	11 [75]	Not specified	Not specified
R1100	11 [75]	Not specified	Not specified
ER2319	35 [240]	Not specified	Not specified
R2319	35 [240]	Not specified	Not specified
ER4043	24 [165]	Not specified	Not specified
R4043	24 [165]	Not specified	Not specified
ER4047	25 [170]	Not specified	Not specified
R4047	25 [170]	Not specified	Not specified
ER4145	40 [275]	Not specified	Not specified
R4145	40 [275]	Not specified	Not specified
ER4943	30 [205]	Not specified	Not specified
R4943	30 [205]	Not specified	Not specified
ER5183	40 [275]	Not specified	Not specified
R5183	40 [275]	Not specified	Not specified
ER5356	35 [240]	Not specified	Not specified
R5356	35 [240]	Not specified	Not specified
ER5554	31 [215]	Not specified	Not specified
R5554	31 [215]	Not specified	Not specified
ER5556	42 [290]	Not specified	Not specified
R5556	42 [290]	Not specified	Not specified
ER5654	30 [205]	Not specified	Not specified
R5654	30 [205]	Not specified	Not specified
ERG and RG	Not Specified	Not Specified	Not Specified

^a Listed classification must meet the minimum tensile strength shown. For all other classifications, tensile testing is required to be reported, but minimum requirements have not yet been established for those classifications. As additional data is made available, alloys will be added to this table. Inclusion in this table may be necessary for use in some design codes.

^b The yield strength and percent elongation shall be tested and reported on the test certificate.

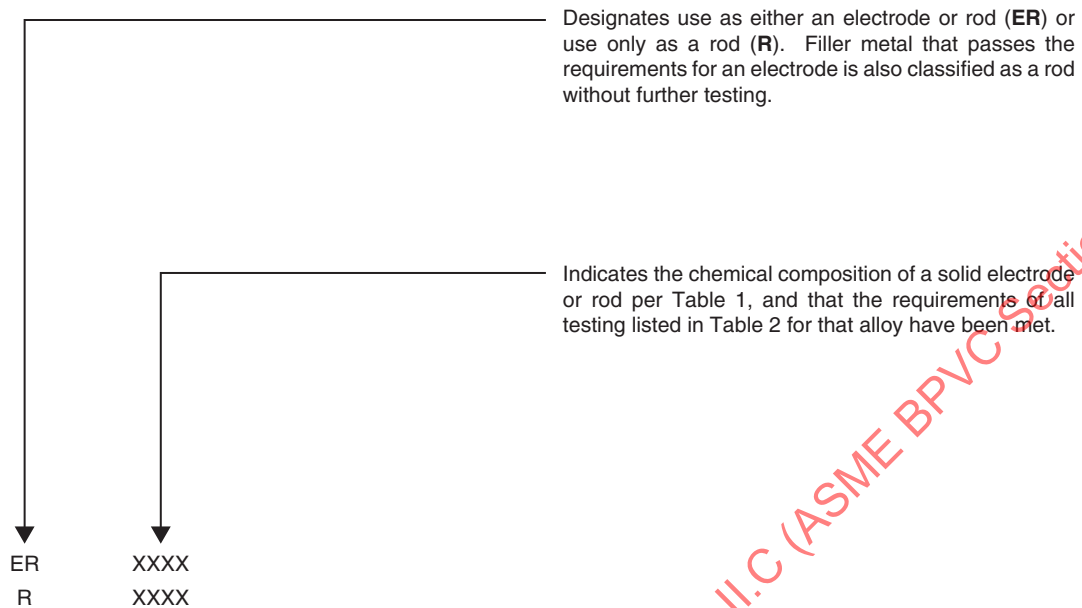
^c The minimum tensile strength of R classifications is addressed by the testing requirements of the same ER classification as prescribed in Table 2.

Table 6
Typical Sizes of Flattened Rods

Equivalent Round Diameter		Thickness		Width	
in	mm	in	mm	in	mm
1/16	1.6	0.047	1.2	0.072	1.8
—	2.0	—	1.5	—	2.1
3/32	2.4	0.070	1.8	0.105	2.7
—	2.5	—	1.9	—	2.6
1/8	3.2	0.095	2.4	0.142	3.6
5/32	4.0	0.115	2.9	0.175	4.4
3/16	4.8	0.140	3.6	0.210	5.0
—	5.0	—	3.8	—	5.2
1/4	6.4	0.187	4.8	0.280	7.1

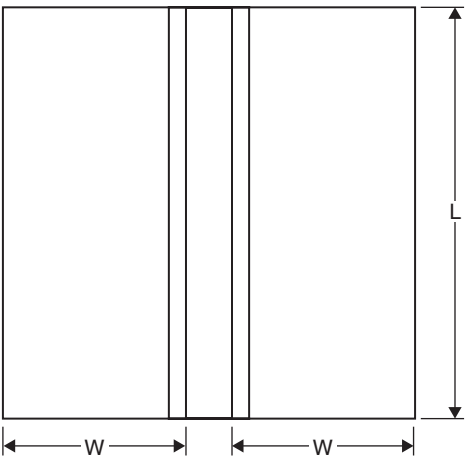
Note:

1. Standard length is 36 in, +0, -1/2 in [914 mm +0, -13 mm]. Custom lengths and applicable tolerances shall be as agreed by purchaser and supplier.

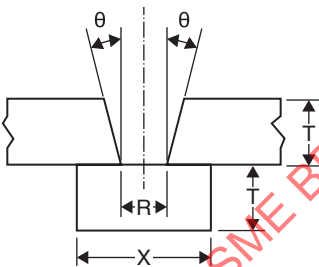
Mandatory Classification Designators^a

^aThe combination of these designators constitutes the electrode (or rod) classification.

Figure 1—A5.10/A5.10M Classification System



(A) TOP VIEW



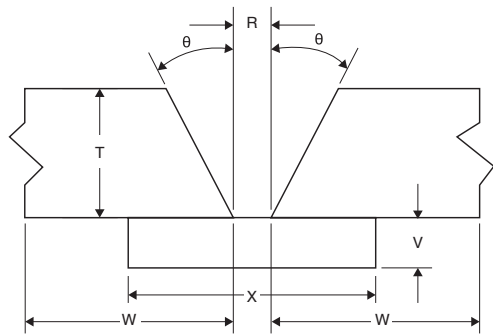
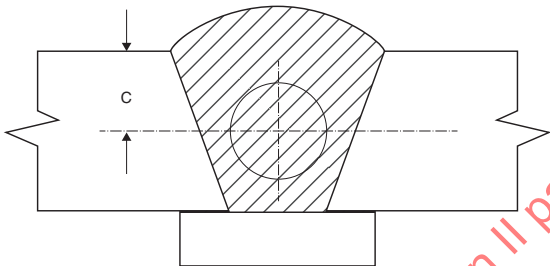
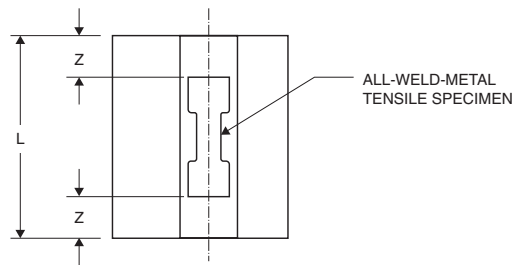
(B) SIDE VIEW

Electrode Diameter		Welding Position	Plate Thickness (T) ^a		Nominal Root Opening (R)	Length (L), min.	Width (W), typical	Bevel Angle (θ)	Backing Width (X), min.
in	mm		in	mm	in [mm]	in [mm]	in [mm]	degrees	in [mm]
0.030	—	Overhead	3/16 or 1/4	5 or 6	1/4 [6]	10 [250]	5 [125]	30–35	1 [25]
—	0.8								
0.035	—								
—	0.9	Overhead	1/4	6	1/4 [6]	10 [250]	5 [125]	30–35	1 [25]
—	1.0								
3/64	1.2								
1/16	1.6	Overhead	3/8	10	3/8 [10]	10 [250]	5 [125]	30–35	1 [25]
—	2.0								
3/32	2.4								
—	2.5	Flat	3/8	10	3/8 [10]	10 [250]	5 [125]	30–35	1 [25]
1/8	3.2								

^a A variation of ±5 percent in the specified plate thickness is acceptable

- Notes: 1) Assembly shall be welded employing the gas metal arc welding process.
2) Assembly may be machined or extruded as a single piece if the minimum dimensions shown are maintained for the specific electrode diameter being tested.

Figure 2—Groove Weld Test Assembly for Radiographic Test



Dimension	Description	A5.10, in	A5.10, mm
L	Length (min.)	6	150
T	Thickness (min.)	3/4	20
W	Width (min.)	5	125
V	Backing Strip Thickness (min.)	1/4	6
C	Specimen Center	3/8 ± 1/32	10 ± 1
X	Backing Strip Width (min.)	2 × R	
R	Root Opening (min.)	1/2	12
Z	Discard (min.)	1	25
θ	Bevel Angle (min.)	22.5°	

Figure 3—Groove Weld Test Assembly for Weld Metal Tension Properties



ASSORTED ROUNDED INDICATIONS

SIZE PERMITTED is 0.050 in [1.3 mm] maximum
NUMBER PERMITTED in any 6 in [150 mm] of weld is 29 with the following restrictions:
LARGE (up to 0.050 in [1.3 mm])—6 permitted
MEDIUM (up to 0.030 in [0.8 mm])—5 permitted
SMALL (up to 0.020 in [0.5 mm])—18 permitted



LARGE ROUNDED INDICATIONS

SIZE PERMITTED is 0.050 in [1.3 mm] maximum
NUMBER PERMITTED in any 6 in [150 mm] of weld is 8



MEDIUM ROUNDED INDICATIONS

SIZE PERMITTED is 0.030 in [0.8 mm] maximum
NUMBER PERMITTED in any 6 in [150 mm] of weld is 39



SMALL ROUNDED INDICATIONS

SIZE PERMITTED is 0.020 in [0.5 mm] maximum
NUMBER PERMITTED in any 6 in [150 mm] of weld is 72

Notes:

1. In using these standards, the chart that is most representative of the size of the rounded indications present in the test specimen radiograph shall be used for determining conformance to these radiographic standards.
2. Indications which do not exceed 1/64 in [0.4 mm] diameter or length, or both, shall be disregarded.
3. When using the alternative method of evaluation described in 11.4, total area of porosity in a 6 in [150 mm] length of weld is 0.0225 sq in [14.52 sq mm] based on 1.5% T per in [25 mm] where T is the base metal thickness.

Figure 4A—Radiographic Acceptance Standards for 3/16 in [5 mm] and 1/4 in [6 mm] Thick Test Assemblies—Overhead Welding Position

**ASSORTED ROUNDED INDICATIONS**

SIZE PERMITTED is 0.075 in [1.9 mm] maximum

NUMBER PERMITTED in any 6 in [150 mm] of weld is 26 with the following restrictions:

- LARGE (up to 0.075 in [1.9 mm])—4 permitted
- MEDIUM (up to 0.050 in [1.3 mm])—5 permitted
- SMALL (up to 0.020 in [0.5 mm])—17 permitted

**LARGE ROUNDED INDICATIONS**

SIZE PERMITTED is 0.075 in [1.9 mm] maximum

NUMBER PERMITTED in any 6 in [150 mm] of weld is 6

**MEDIUM ROUNDED INDICATIONS**

SIZE PERMITTED is 0.050 in [1.3 mm] maximum

NUMBER PERMITTED in any 6 in [150 mm] of weld is 17

**SMALL ROUNDED INDICATIONS**

SIZE PERMITTED is 0.020 in [0.5 mm] maximum

NUMBER PERMITTED in any 6 in [150 mm] of weld is 108

Notes:

1. In using these standards, the chart that is most representative of the size of the rounded indications present in the test specimen radiograph shall be used for determining conformance to these radiographic standards.
2. Indications which do not exceed 1/64 in [0.4 mm] diameter or length, or both, shall be disregarded.
3. When using the alternative method of evaluation described in 11.4, total area of porosity in a 6 in [150 mm] length of weld is 0.0337 sq in [21.7 sq mm] based on 1.5 percent T per in [25 mm] where T is the base metal thickness.

Figure 4B—Radiographic Acceptance Standards for 3/8 in [10 mm] Thick Test Assemblies—Overhead Welding Position



ASSORTED ROUNDED INDICATIONS

SIZE PERMITTED IS 0.075 in [1.9 mm] MAXIMUM
NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 17 WITH THE FOLLOWING RESTRICTIONS:
LARGE: UP TO 0.075 in [1.9 mm]—3 PERMITTED
MEDIUM: UP TO 0.049 in [1.3 mm]—3 PERMITTED
SMALL: UP TO 0.020 in [0.5 mm]—11 PERMITTED



LARGE ROUNDED INDICATIONS

SIZE PERMITTED IS 0.075 in [1.9 mm] MAXIMUM
NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 5



MEDIUM ROUNDED INDICATIONS

SIZE PERMITTED IS 0.049 in [1.3 mm] MAXIMUM
NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 11



SMALL ROUNDED INDICATIONS

SIZE PERMITTED IS 0.020 in [0.5 mm] MAXIMUM
NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 72

- Notes:
1. In using these standards, the chart that is most representative of the size of the rounded indications present in the test specimen radiograph shall be used for determining conformance to these radiographic standards.
 2. Indications which do not exceed 1/64 in [0.4 mm] diameter or length, or both, shall be disregarded.
 3. When using the alternative method of evaluation described in 11.4, total area of porosity in a 6 in [150 mm] length of weld is 0.0225 sq in [14.52 sq mm] based upon 1.0% T per in [25 mm] where T is the base metal thickness.

This radiographic acceptance standard is identical to that previously incorporated in MIL-E-16053L (Amendment 2, 20 October 1980) and as Class 1 in NAVSEA 0900-LP-003-9000. (See Annex Clause A5.)

Figure 5—Radiographic Acceptance Standard for Test Assemblies—Flat Welding Position

Annex A (Informative)

Guide to Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods

This annex is not part of this standard but is included for informational purposes only.

A1. Introduction

The purpose of this guide is to correlate the filler metal classifications with their intended applications so the specification can be used more effectively. Reference to appropriate base metal alloys is made whenever that can be done and when it would be helpful. Such references are intended only as examples rather than complete listings of the materials for which each filler metal is suitable.

A2. Classification System

A2.1 Both welding electrodes and rods are classified based on the chemical composition of the aluminum filler metal, a usability test, and when required a test of weld metal strength. The AWS classifications used in this specification are based as follows:

A2.1.1 The Aluminum Association alloy designation nomenclature is used for the numerical portion to identify the alloy based on chemical composition.

A2.1.2 A letter prefix designates usability of the filler metal. The letter system for identifying the filler metal classifications in this specification follows the standard pattern used in other AWS filler metal specifications. The prefix “E” indicates the filler metal is suitable for use as an electrode and the prefix “R” indicates suitability as welding rod. Since some of these filler metals are used as electrodes in gas metal arc welding, and as welding rods in oxyfuel gas, gas tungsten arc, and plasma arc welding, both letters, “ER,” are used to indicate suitability as an electrode or a rod. In all cases, a product which meets the test requirements for an electrode in this specification also meets the requirements for a welding rod. A product that meets the test requirements for a welding rod must also pass the test for an electrode before being classified as an electrode.

A2.1.3 “G” Classification

A2.1.3.1 This specification includes filler metals classified as ERG and RG. The “G” indicates that the filler metal is of a “general” classification. It is general because not all of the particular requirements specified for each of the other classifications are specified for this classification. The intent in establishing this classification is to provide a means by which filler metal that differs in one respect or another (chemical composition, for example) from all other classifications (meaning that the composition of the filler metal—in the case of the example—does not meet the composition specified for any of the classifications in the specification) can still be classified according to the specification. The purpose is to allow a useful filler metal—one that otherwise would have to await a revision of the specification—to be classified immediately under the existing specification. This means that two filler metals—each bearing the same “G” classification—may be quite different in some certain respect (chemical composition, again, for example).

A2.1.3.2 The point of difference between filler metal of a “G” classification and filler metal of a similar classification without the “G” (or even with it, for that matter) may be further clarified from the use of the words “not required” and “not specified” in the specification. The use of these words is as follows:

Not Required is used in those areas of the specification that specify the tests that must be conducted in order to classify an electrode or rod. It indicates that that test is not required because the results for the particular test are not a requirement for that particular classification. When a test is “not required”, it is not necessary to conduct the corresponding test in order to classify an electrode or rod to that classification. When a purchaser wants the information provided by that test in order to consider a particular product of that classification for a certain application, the purchaser will have to arrange for that information with the supplier of the product. The purchaser will have to establish with that supplier just what the testing procedure and the acceptance requirements are to be for that test. The purchaser may want to incorporate that information (via AWS A5.01M/A5.01) in the purchase order.

Not Specified is used in those areas of the specification that refer to the results of some particular test. It indicates that the requirements for that test are not specified for that particular classification. If the required results from a specific test are listed as “not specified” but the test in question is shown as “required” then the test results must be reported.

A2.2 Description of ISO Classification Designations

A2.2.1 The ISO classifications are divided into two parts:

- a) the first part indicates the product form being solid wires or rods, see A2.2.2;
- b) the second part gives a numerical symbol and optional chemical symbol indicating the chemical composition of the solid wire or rod, see Table 1.

A2.2.2 ISO Symbols for the Product Form. The ISO symbol for the solid wire and rod shall be S.

Note: One product form may be used for more than one welding process.

A2.2.3 ISO Designation Examples. The ISO designation of solid wires and rods shall follow the principle given in the example below.

EXAMPLE 1 A solid wire (S) for gas metal arc welding (GMAW), having a chemical composition within the limits for the alloy symbol Al 4043 (AlSi5) of Table 1, is designated:

Solid wire ISO 18273 – S Al 4043

or alternatively

Solid wire ISO 18273 – S Al 4043 (AlSi5)

EXAMPLE 2 A solid rod (S) for gas tungsten arc welding is designated

Solid rod ISO 18273 – S Al 4043

or alternatively

Solid rod ISO 18273 – S Al 4043 (AlSi5)

where:

ISO 18273 is the standard number;

S is the product form (see A2.2.2);

Al 4043 is the numerical symbol for the chemical composition of the welding consumable (see Table 1);

AlSi5 is the optional chemical symbol of welding consumable (see Table 1).

A2.3 Request for Filler Metal Classification. When a filler metal cannot be classified other than as a “G” classification, a manufacturer may request that a new classification be established. The manufacturer shall do this using the following procedure:

(1) A request to establish a new filler metal classification must be submitted in writing. The request needs to provide sufficient detail to permit the Committee on Filler Metals and Allied Materials and the relevant Subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

- (a) A declaration that the new classification will be offered for sale commercially.

(b) All classification requirements as given for existing classifications, such as, chemical composition ranges, mechanical property requirements, and usability test requirements.

(c) Any conditions for conducting the tests used to demonstrate that the filler metal meets the classification requirements. (It would be sufficient, for example, to state that welding conditions are the same as for other classifications.)

(d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the Annex).

(e) Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.

(f) A request for a new classification without the above information will be considered incomplete. The Secretary will return the request to the requester for further information.

(2) In order to comply with the AWS Policy on Patented Items, Trademarks, and Restraint of Trade, if the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester shall disclose this. In these cases, the patent holder must allow the use of this technology, such as by license. The Secretary will provide examples of acceptable wording to the patent holder, as required.

(3) The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters for processing.

A2.4 Minor changes in procedures used in the manufacture of aluminum filler metals can affect their surface quality and significantly affect the resultant weld soundness. Usability testing of the electrode is desirable on a periodic basis to assure that the product classified in this specification continues to meet the soundness requirement. The supplier should perform the usability tests of this specification on an annual basis, as a minimum, to assure that the specified soundness and operating characteristics criteria are maintained. AWS A5.01M/A5.01, *Welding Consumables – Procurement of Filler Metals and Fluxes*, should be used by a purchaser for definition of lot and frequency of testing references when purchasing aluminum filler metals.

A2.5 Application of Military and Federal Specifications. At the time of cancellation (June 7, 1982) of Military Specification MIL-E-16053L, Amendment 2 (October 20, 1980), *Electrodes, Welding, Bare, Aluminum Alloys*, the technical requirements were identical to those of AWS A5.10-80. They both covered the same aluminum alloys, compositions, welding tests, and radiographic standards. The MIL-E-16053L cancellation notice canceled the Qualified Products List QPL-16053 as well as the specification and stated, “Future acquisition of replacement electrodes should be made under ANSI/AWS A5.10-80, *Aluminum and Aluminum-Alloy Bare Welding Rods and Electrodes*.”

Federal Specification QQ-R-566B, *Rods and Electrodes, Welding, Aluminum, and Aluminum Alloys*, was technically the same as AWS A5.10 when it was issued July 5, 1973 and was in the process of being updated at the time of the MIL-E-16053L cancellation. On November 29, 1982, Federal Specification QQ-R-566B was also canceled with the recommendation, “The AWS Standard A5.10, latest issue in effect, concerning Aluminum Alloy Bare Welding Rods and Electrodes should be used.” Straight length, coiled, and spooled rod and wire for oxyfuel gas and gas tungsten arc welding were included in QQ-R-566B, as well as the spooled electrode for gas metal arc welding. Thus, the total coverage was the same as AWS A5.10.

AWS A5.10/A5.10M is a classification document, which defines tests and acceptance criteria to determine that the product meets the requirements for that classification. These tests need to be repeated only if a significant change is made in the manufacturing process. These tests become a part of the specific procurement only when used in combination with AWS A5.01M/A5.01, which identifies lot classifications, level of testing, and the frequency of tests.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01M/A5.01, as the specification states. Any additional testing required by the purchaser, for material shipped in accordance with this specification, shall be clearly stated in the purchase order, according to the provisions of A5.01M/A5.01. In the absence of any

such statement in the purchase order, the supplier may ship the material with whatever testing the supplier normally conducts on material of that classification, as specified in Schedule F, Table 1, of A5.01M/A5.01. Testing in accordance with any other Schedule in that Table must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product or the classification on the product itself, constitutes the supplier's (manufacturer's) certification that the product meets all the requirements of the specification. The only testing requirement implicit in this certification is that the manufacturer has conducted the tests required by the specification on material that is representative of that being shipped and that the material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation. "Certification" is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been made. The basis for the certification required by the specification is the classification test of representative material cited above and the "Manufacturer's Quality Assurance Program" in AWS A5.01M/A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes in the atmosphere to which welders and welding operators are exposed during welding:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling)
- (2) Number of welders and welding operators working in that space
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes involved
- (4) The proximity of the welder or welding operator to the fumes as they issue from the welding zone, and to the gases and dusts in the space in which the welder or welding operator is working
- (5) The ventilation provided to the space in which the welding is done.

A5.2 ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, published by the American Welding Society, discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the sections of that document covering ventilation and confined spaces. See also AWS F3.2M/F3.2, *Ventilation Guide for Weld Fume*, for more detailed description of ventilation options.

A6. Welding Considerations

The electrodes and rods described in this specification are primarily for use with the inert gas arc welding processes; however, they may be used with other welding processes such as electron beam or oxyfuel gas welding.

A6.1 The gas metal arc welding process permits the successful welding of aluminum alloys that are crack-sensitive when welded by oxyfuel gas or other manual welding processes. The reasons for this might be described briefly as follows:

Distortion is reduced to a minimum because the increase in temperature of the parts being welded is confined to a narrow zone. Because aluminum alloys have high thermal conductivity, the reduction of distortion is greater than would be the case with ferrous base metals. Cracking of welds in the aluminum alloys is reduced if the cooling rate is high. The GMAW process permits the welding of alloys that have a wide melting range, which may be difficult to weld with higher heat input processes.

A6.2 The high melting and solidification rate of the weld metal from the gas metal arc welding process can result in hydrogen gas being entrapped in the welds. Control of this factor should be understood to obtain good results. Hydrogen gas entrapment within the weld metal results from the presence of hydrogen containing substances on the base metal, filler metal, or in the atmosphere immediately adjacent to the weld zone. Hydrocarbons such as grease or oil, hydrocarbon-

based cleaning agents, and moisture, whether on a surface or within the stream of shielding gas itself, are all common contributors of hydrogen in the weld. The introduction of hydrogen gas in the weld metal from any of these causes will result in porosity, because the solidification rate is high, and the gas may not have time to escape before the molten metal solidifies. Precautions such as degreasing with acetone should be employed to mitigate the effects of these and other contaminants.

A6.3 Welds can be made in all positions with the gas metal arc welding process. Edge preparation similar to that used for gas tungsten arc welding is satisfactory. Either pure argon or argon/helium mixtures may be used as shielding gas. Semiautomatic welding, in which the welding gun is moved by a welder, may be difficult to control on metal thicknesses below 0.08 in [2 mm]. The use of a pulsed power source permits the welding of base metal as thin as 0.03 in [0.8 mm]. No upper limit on metal thickness has been established for the gas metal arc welding process. Welds in plate up to 8 in [200 mm] in thickness have been made.

A6.4 Gas metal arc welding is typically performed with direct current electrode positive (DCEP). Stabilization of the arc with high frequency current is not required. U-groove drive rolls and polymer gun liners are preferred in both manual and mechanized equipment in order to limit distortion, shaving, and contamination of the filler wire.

A6.5 Gas tungsten arc welds can be made in all positions. Welding travel speed is reduced compared to gas metal arc welding (GMAW), however, this reduction is beneficial in several aspects. The gas tungsten arc welding process is more maneuverable than GMAW for manually welding small tubes or piping; entrapment of gases is minimized to permit production of sound welds; short repair welds can be made more easily; and the reduced concentration of heat allows welding aluminum base metal thicknesses as thin as 0.02 in [0.5 mm] or less. Corner and edge joints in sheet gauges can be made more satisfactorily than with GMAW due to the better control of the filler metal additions.

A6.6 Gas tungsten arc welds are most commonly made with alternating current power and pure argon [AWS A5.32M (ISO 14175) – I1] gas shielding. Helium [AWS A5.32M (ISO 14175) – I2] additions to the extent of 25 percent of the mixture with argon are used to increase the rate of initial melting and the amount of melting in thick base metal. Helium additions of up to 75% can be very effective with square wave AC power sources and with AC frequencies up to 400 Hz. Pure tungsten (AWS A5.12M/A5.12 Class EWP) or zirconiated tungsten (AWS A5.12M/A5.12 Class EWZr-1) electrodes are preferred for AC-GTAW when using transformer or magnetic amplification power sources while ceriated (AWS A5.12M/A5.12 Class EWCe) and lanthanated (AWS A5.12M/A5.12 Class EWLs) tungsten electrodes with sharpened and truncated tips are preferred when using modern inverter power sources. The positive electrode polarity of the AC power provides an arc etching action to remove the surface oxide; however, thick aluminum oxides caused by weathering, thermal treatments, or anodic treatments need to be reduced by chemical or mechanical means prior to welding to obtain uniform results and proper fusion. As stated in A6.2, sources of hydrogen, such as moisture on the base or filler metals or in the gas shielding and residual hydrocarbons on the base or filler metals, must be removed to avoid porosity in the welds.

A6.7 Direct current power can also be used to gas tungsten arc weld aluminum. DCEP power can technically be used to weld sheet gauges; however, a 1/4 in [6.4 mm] diameter tungsten electrode is required to carry the 125 amperes needed to weld 1/8 in [3 mm] thickness, so this polarity is seldom used. DCEN power is used with helium (AWS A5.32 (ISO 14175) – I2) gas shielding and a thoriated, ceriated, or lanthanated tungsten electrode for welding aluminum-base alloys. This electrode negative polarity provides a deep, narrow melting pattern, which is advantageous for repair of thick weldments or castings and for increased welding speeds in all thicknesses. Higher as-welded strength is obtained with DCEN-GTAW welds in the heat treatable aluminum alloys due to the reduced heat input compared to AC-GTAW. Since no arc cleaning action occurs in the DCEN arc, special attention must be given to minimizing the oxide thickness immediately before welding, such as by mechanical scraping or arc cleaning all base metal surfaces within the fusion zone.

Additional information may be found in the aluminum chapter of the AWS Welding Handbook, Volume 5, Ninth Edition.

A7. Filler Metal Selection, Typical Usage, Cleanliness, Storage, and Handling of Aluminum Filler Metal.

A7.1 Filler Metal Selection. There are many aluminum base metals that can be welded successfully with any number of different filler metals. The base metal 6061-T6 for instance, is commonly welded with at least four different filler metals and can be welded successfully with even more. It is not possible to select, with any certainty, the most appropriate

filler metal for a specific base metal without an understanding of the welded component application and expected performance in service. When choosing an aluminum filler metal, it is important to determine which of the criteria associated with weld performance are of most importance. The selection of a filler metal that is not recommended for a specific application may result in inadequate service performance and possibly premature failure of the welded joint. Filler metals for arc welding aluminum are often evaluated against the following criteria:

Strength of welded joint – Consideration of the tensile strength of groove welds and shear strength of fillet welds, when welded with different filler metals, can prove to be extremely important during welding design. Different filler metals, which may both exceed the as-welded tensile strength of the base material, can be significantly different in shear strength performance.

Crack Sensitivity – This is the relative freedom from weld cracking. By use of hot cracking sensitivity curves for the various aluminum alloys, and through the consideration of dilution between filler metal and base metal, a filler metal / base metal crack sensitivity rating can be established.

Ductility – This may be a consideration if forming operations are to be used during fabrication. Also, testing procedures for guided bend testing may vary based upon filler metal ductility.

Corrosion Resistance – A consideration for some environmental conditions is typically based on exposure to fresh and salt water.

Sustained Temperature Services – Some filler metals at sustained elevated temperature (above 150 °F [65 °C]) may promote premature component failure due to stress corrosion cracking.

Color Match – Base metal and filler metal color match after anodizing can be of major concern in some cosmetic applications.

As an example of the extent and complexity of this situation, we can take one of the many aluminum base metals and three of the many applications in which this base material may be used. If we consider the base metal 6061-T6, and its use in the following different applications, we can appreciate that the filler metal that we select for welding can seriously affect the welded component's performance.

Application 1. Using 6061-T6 extruded angle bar as a welded attachment bracket for a heating component that will be operating consistently at 250 °F [120 °C].

In this application we would investigate those filler alloys that are suitable for elevated temperature service. We may consider 5554, 4043, 4943, or 4047 filler alloys, which are all suitable for elevated temperature service applications. If we were to use the 5356, 5183, or 5556 filler alloys, which are often shown as being suitable for this base material, we would introduce the possibility of sensitization of the magnesium in these alloys and run the risk of stress corrosion cracking and premature failure of the welded component.

Application 2. Using 6061-T6 base metal to fabricate a large safety-critical lifting device that is required to undergo extensive welding during fabrication, followed by postweld solution heat treatment and artificial aging to restore strength and return the structure to the -T6 temper.

In this application our concerns may be the strength of our weld after it has been exposed to postweld heat treatment. Most filler metals commonly used for welding this base material will not respond favorably to this type of heat treatment. The 5356, 5183, and 5556 filler alloys are non-heat treatable alloys which can undergo undesirable changes if subjected to this form of heat treatment. 4043 filler metal, on its own, is non-heat treatable and would be dependent on dilution with the base material to achieve any significant response to the heat treatment. In this application we should seriously consider the use of filler metals 4943, or 4643, which are both heat treatable filler metals and will, therefore, respond to the heat treatment after welding and provide a weld of comparable strength to that of the base material in the -T6 temper.

Application 3. Using 6061-T6 tubing for hand railing that is to be clear coat anodized after welding. In this application we must select the filler metal that is going to provide us with the best color match after anodizing. With color match as our prime consideration, the most appropriate filler for this application is 5356. If we were to select filler metal 4043, 4943, or 4047, which are often shown as being suitable for this base material, we would find that after anodizing, our weld would become dark gray in color and would not provide a suitable match to the bright silver appearance of the hand rail tubing.

A7.2 Using the Filler Metal Selection Chart (Table A.1 and Table A.2). By using Table A.1 Weld Metal Properties, and Table A.2 Aluminum Filler Metal Selection Chart, each of the weld metal attributes specific to an application can be

evaluated to establish the most suitable filler metal. These charts have been developed through consideration of the most commonly required attributes and provide a relative rating system for each attribute to help with the selection process. In the absence of specific information, consultation with the material supplier is recommended.

Filler metal property ratings A, B, C, D and E are relative values for an attribute when welding the base metals that intersect in a specific box. For example, in the strength column an “A” rating designates the highest strength and an “E” rating the lowest strength that matches or exceeds that of the lower strength base metal listed. While an E rating may be suitable for a specific attribute, an A, B, or C, rating may be a better choice if that factor being evaluated is of prime importance. A “blank” rating indicates that the filler metal is not recommended for that specific weldment application property. All ratings listed are in the as welded condition. Ratings have comparative meaning within a single box only. For example, an “A” rating in one box does not have any comparative value to an “A” rating in another box.

A7.3 Typical Usage. Filler metal in the form of straight lengths and coils without support is used as welding rod with several welding processes. These processes include oxyfuel gas welding, plasma arc welding, gas tungsten arc welding, and laser welding. The filler metal may be fed by hand, although mechanized welding in these processes may involve either manual feeding of the welding rod or use of a feeding mechanism for wire. Spooled filler metal is used most commonly as electrode for the gas metal arc welding process. It also is used as filler wire when mechanized feeding systems are employed for gas tungsten arc welding, plasma-arc welding and other processes. Finite lengths of filler metal can be removed from the spools for use as a high-quality, handfed filler rod with manual gas tungsten arc welding, plasma-arc welding, or oxyfuel gas welding processes.

A7.4 Cleanliness, Storage, and Handling of Aluminum Filler Metal. The cleanliness and minimal surface oxidation of the filler metal are important with all welding processes. Oil, or other organic materials, as well as a heavy oxide film on the rod, will interfere with coalescence of the weld and are sources of porosity. Because of this, it is necessary to clean the welding rod and electrode before packaging.

Proper storage of welding rods and electrodes is essential to avoid contamination that may affect their performance. Packages of filler metal should not be left outdoors or in unheated buildings, because the greater variations in temperature and humidity increase the possibility of condensation to create hydrated surface oxides. Experience has demonstrated that undesirable storage conditions may adversely affect filler metal performance. Investigation of the effect of storage time on electrode performance indicates that packaged electrodes stored under good conditions (dry places in heated buildings) are satisfactory after extended storage.

A8. Special Tests

It is recognized that supplementary tests may be required for certain applications of aluminum and aluminum-alloy filler metals. In such cases, tests to determine specific properties such as corrosion resistance, mechanical properties at high and low temperature, wear resistance and suitability for welding combinations of dissimilar metals may be required. AWS A5.01M/A5.01 contains provisions for ordering such tests. This clause is included for the guidance of those who desire to specify such special tests. Those tests may be conducted as agreed upon between the purchaser and supplier.

A9. Chemical Analysis

The most widely used method for chemical analysis has been ASTM E227, Optical Emission Spectrometric Analysis of Aluminum and Aluminum Alloy by the Point-to-Plane Technique (now withdrawn). Other established analytical methods are acceptable. The ASTM E227 method analyzes a bulk sample and all elements simultaneously. The ASTM E34 standard method prescribes individual test methods for which each element is tested. The ASTM E34 tests methods are used as a referee method if a dispute arises concerning a specific element analysis.

A10. Discontinued and Replaced Alloys

Classifications of bare aluminum and aluminum-alloy welding electrodes and rods have been discontinued and/or replaced as new editions of A5.10/A5.10M have been issued. These classifications are listed in Table A.3.

A11. General Safety Considerations

A11.1 Safety issues and concerns are addressed in this standard, although health issues and concerns are beyond the scope of this standard. Some safety and health information can be found in Clause A5. Safety and health information is available from other sources including, but not limited to, Safety and Health Fact Sheets, ANSI Z49.1, and applicable federal and state regulations.

A11.2 Safety and Health Fact Sheets. Safety and Health Fact Sheets are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

ASMENORMDOC.COM : Click to view the full PDF of ASME BPVC.II.C (ASME BPVC Section II part C) 2025

Table A.1
Weld Metal Properties—(To Be Used in Conjunction with Table A.2)

STRENGTH

Strength ratings are for fillet weld and groove weld strength in the as welded condition.

Groove welds – Any specified filler metal with a rating can provide minimum transverse tensile strength in groove welds that will meet the as-welded strength of the base material. Any filler metal with no rating (blank rating) will typically not meet the minimum tensile strength.

Fillet welds – Ratings provided are for fillet weld shear strength.

See note under Table A.2 for additional information for 5XXX series strength ratings.

CRACK SENSITIVITY – The probability of hot cracking.

This rating is established through use of crack sensitivity curves and the consideration of filler metal and base metal chemical composition combinations. There are levels of various alloying elements within aluminum that have been identified as seriously affecting hot cracking susceptibility during weld solidification. This rating is primarily based on the probability of producing a cracked weld. An “A” rating will provide the lowest probability of solidification cracking.

DUCTILITY

This rating may be of consideration if forming operations are to be used on a completed weldment during fabrication.

Note: Testing procedure requirements for guided bend tests may need to be adjusted to accommodate the varying ductility of filler metals (guidelines for this are given in the welding code).

CORROSION RESISTANCE

This rating may be a consideration for some environmental conditions. The rating is based on exposure to fresh and salt water environments and is not associated with a specific chemical exposure. It gives an indication as to the possibility of galvanic corrosion due to the difference in the electrode potential between the base metal and the filler metal.

ELEVATED TEMPERATURE SERVICE

This rating is based on the reaction of some filler metals when exposed to sustained elevated temperature: 150°F to 350°F (66°C to 180°C). If 5xxx series base metal or filler metal with more than 3% magnesium content are subjected to prolonged exposure to these temperatures, precipitate can form within them that is highly anodic to the aluminum-magnesium matrix. It is this continuous grain boundary network of precipitate that produces susceptibility to stress corrosion cracking (SCC) and the potential for premature component failure.

COLOR MATCH AFTER ANODIZING

Base metal and filler metal color match after postweld anodizing can be of major concern in some cosmetic applications. Some filler metals closely match the base metal color after anodizing and others will react to the anodizing process by changing to a color very different to that of the base metal.

Table A.2

[illegible]

(Continued)

Table A.2 (Continued)
Aluminum Filler Metal Selection Chart

Table A.2 (Continued)																																
Aluminum Filler Metal Selection Chart																																
BASE METAL ↓	Al – Mg						Al – Mg2Si						Al – Zn						Aluminum Castings												FILLER METAL ↓	
	5454						6061, 6005, 6063, 6070, 6151, 6201, 6351, 6951, 6082						7005, 7021, 7039, 7046, 7146, 710.0, 711.0						413.0, 443.0, 444.0, 356.0, A356.0, 357.0, 359.0						319.0, 333.0, 354.0, 355.0, C355.0, 380.0							
	STRENGTH	CRACKING	DUCTILITY	CORROSION	TEMPERATURE	COLOR	STRENGTH	CRACKING	DUCTILITY	CORROSION	TEMPERATURE	COLOR	STRENGTH	CRACKING	DUCTILITY	CORROSION	TEMPERATURE	COLOR	STRENGTH	CRACKING	DUCTILITY	CORROSION	TEMPERATURE	COLOR	STRENGTH	CRACKING	DUCTILITY	CORROSION	TEMPERATURE	COLOR		
319.0, 333.0, 354.0, 355.0, C355.0, 380.0							C	B	A	A	A	A	C	B	A	A	A	A	C	B	A	A	A	A	A	B	A	A	A	A	2319	
							A	A	B	A	A	A	A	A	B	A	A	A	A	A	B	A	A	A	A	B	A	B	B	A	A	4043
							B	B	A	A	A	A	B	B	A	A	A	A	B	B	A	A	A	A	A							4145
																																4943
413.0, 443.0, 444.0, 356.0, A356.0, 357.0, 359.0							C	A	A	A	A	A	D	A	B	A	A	A	D	A	A	A	A	A	A							4043
							A	A	B	B	A	A	B	A	B	B	A		B	A	B	B	A	B								4145
							B	A	A	A	A	A	C	A	B	A	A	A	C	A	A	A	A	A	A							4943
																		A	A	A	A	A	A	A								A356.0
																		A	A	A	A	A	A	A								A357.0
														A	A	A	A	B														5356
7005, 7021, 7039, 7046, 7146, 710.0, 711.0							E	A	C	B	A		E	B	C	B	A															4043
																																4145
							D	A	C	B	A		D	B	C	B	A															4943
	A	A	B	A		A	A	A	B	A		A	A	A	B	A	A	A														5183
	B	A	A	A		A	B	A	A	A		A	B	A	A	A	A															5356
	C	B	A	A	A	A	C	B	A	A	A	A	C	B	A	A	A	A														5554
	A	A	B	A		A	A	A	B	A		A	A	A	B	A	A	A														5556
	C	B	A	A		A	C	B	A	A		A	C	B	A	A																5654
6061, 6005, 6063, 6070, 6151, 6201, 6351, 6951, 6082							D	A	B	A	A																					4043
																																4145
							C	A	B	A	A																					4943
	A	B	B	C		A	A	B	A	C		A																				5183
	B	B	A	C		A	B	B	A	C		A																				5356
	C	C	A	A	A	A	C	C	A	B	B	A																				5554
	A	B	B	C		A	A	B	A	C		A																				5556
	C	C	A	B		B	C	C	A	B		B																				5654
5454	A	A	B	B		A																										5183
	B	A	A	B		A																										5356
	C	B	A	A	A	A																										5554
	A	A	B	B		A																										5556
	C	B	A	B		B																										5654

To use this chart: Find the base metals to be joined in the left and top of the chart and determine which weld metal properties are most important for your application. Follow the intersection of the row and column to the right to find the filler metal. An A indicates a very good choice for that attribute, with B, C, D and E following as still suitable. A blank indicates that the filler metal is not suitable for that attribute in that base metal combination. This chart is a tool designed to help select the most appropriate filler metal, taking into consideration base metal, and the desired weld metal properties for a given application.

Table A.3
Discontinued Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods

Discontinued		Replacement	
AWS A5.10		AWS A5. 10/A5.10M	
Classification	Issue	Classification	Issue
ER1060	1961	—	—
ER1260	1980	ER1188	1988
ER2014	1961	—	—
ER3004	1961	—	—
ER5039	1980	—	—
ER5052	1967	—	—
ER5154	1969	ER5654	1969
ER5254	1969	ER5654	1969
ER5652	1969	ER5654	1969
R242.0	1988	—	—
R295.0	1988	—	—
R355.0	1988	R-C355.0	1988
R356.0	1988	R-A356.0	1988
R-990A	1957	ERH00	1992
E-990A	1957	ER1100	1992
R-996A	1957	ER1060	1957
E-996A	1957	ER1060	1957
R-C4A	1980	R295.0	1980
R-CN42A	1980	R242.0	1980
R-C541A	1957	ER2014	1957
E-C541A	1957	ER2014	1957
R-G1A	1961	—	—
E-G1A	1961	—	—
R-GM50A	1957	ER5356	1957
E-GM50A	1957	ER5356	1957
R-GR20A	1957	ER5052	1957
E-GR20A	1957	ER5052	1957
R-GR40A	1957	ER5154	1957
E-GR40A	1957	ER5154	1957
R-MG11A	1957	ER3004	1957
E-MG11A	1957	ER3004	1957
R-SG70A	1980	R356.0	1980

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1-2006) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

B6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

Annex C (Informative)

List of Deviations from ISO 18273:2015

This annex is not part of this standard, but is included for informational purposes only

This document has significant differences from the original ISO document. ISO 18273 contains requirements for chemical composition of the filler material. This document adds requirements for soundness and strength testing of weld metal, conformance and acceptance requirements, product form, identification and manufacturing details. Clauses, tables and figures have been added to this end.

Editorial rewording and numbering of clauses, tables and figures in this document were updated to comply with AWS standards.

The title of the specification has changed to correspond to the historical title.

Decimal commas have been changed to decimal periods.

Replaced Al Z for a non-listed classification with RG and ERG, as is the norm in AWS standards.

AWS Filler Metal Specifications by Material and Welding Process

	OFW	SMAW	GTAW GMAW PAW	FCAW	SAW	ESW	EGW	Brazing
Carbon Steel	A5.2	A5.1, A5.35	A5.18	A5.20	A5.17	A5.25	A5.26	A5.8, A5.31
Low-Alloy Steel	A5.2	A5.5	A5.28	A5.29	A5.23	A5.25	A5.26	A5.8, A5.31
Stainless Steel		A5.4, A5.35	A5.9, A5.22	A5.22	A5.9, A5.22, A5.39	A5.9, A5.22, A5.39	A5.9	A5.8, A5.31
Cast Iron	A5.15	A5.15	A5.15	A5.15				A5.8, A5.31
Nickel Alloys		A5.11, A5.35	A5.14, A5.34	A5.34	A5.14 A5.34, A5.39	A5.14 A5.34, A5.39		A5.8, A5.31
Aluminum Alloys		A5.3	A5.10					A5.8, A5.31
Copper Alloys		A5.6	A5.7					A5.8, A5.31
Titanium Alloys			A5.16					A5.8, A5.31
Zirconium Alloys			A5.24					A5.8, A5.31
Magnesium Alloys			A5.19					A5.8, A5.31
Tungsten Electrodes			A5.12					
Brazing Alloys and Fluxes								A5.8, A5.31
Surfacing Alloys	A5.21	A5.13	A5.21	A5.21	A5.21			
Consumable Inserts			A5.30					
Shielding Gases			A5.32	A5.32			A5.32	

AWS Filler Metal Specifications and Related Documents

Designation	Title
A4.2M (ISO 8249 MOD)	<i>Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal</i>
A4.3	<i>Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding</i>
A4.4M	<i>Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings</i>
A4.5M/A4.5 (ISO 15792-3 MOD)	<i>Standard Methods for Classification Testing of Positional Capacity and Root Penetration of Welding Consumables in a Fillet Weld</i>
A5.01M/A5.01 (ISO 14344 MOD)	<i>Welding Consumables—Procurement of Filler Metals and Fluxes</i>
A5.02/A5.02M	<i>Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes</i>
A5.1/A5.1M	<i>Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding</i>
A5.2/A5.2M	<i>Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding</i>
A5.3/A5.3M	<i>Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.4/A5.4M	<i>Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding</i>
A5.5/A5.5M	<i>Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding</i>
A5.6/A5.6M	<i>Specification for Copper and Copper-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.7/A5.7M	<i>Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes</i>
A5.8M/A5.8	<i>Specification for Filler Metals for Brazing and Braze Welding</i>
A5.9/A5.9M (ISO 14343 MOD)	<i>Specification for Bare Stainless Steel Welding Electrodes and Rods</i>
A5.10/A5.10M (ISO 18273 MOD)	<i>Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods</i>
A5.11/A5.11M	<i>Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding</i>
A5.12M/A5.12 (ISO 6848 MOD)	<i>Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting</i>
A5.13/A5.13M	<i>Specification for Surfacing Electrodes for Shielded Metal Arc Welding</i>
A5.14/A5.14M	<i>Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods</i>
A5.15	<i>Specification for Welding Electrodes and Rods for Cast Iron</i>
A5.16/A5.16M (ISO 24034 MOD)	<i>Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods</i>
A5.17/A5.17M	<i>Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.18/A5.18M	<i>Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.19	<i>Specification for Magnesium-Alloy Welding Electrodes and Rods</i>
A5.20/A5.20M	<i>Specification for Carbon Steel Electrodes for Flux Cored Arc Welding</i>
A5.21/A5.21M	<i>Specification for Bare Electrodes and Rods for Surfacing</i>
A5.22/A5.22M	<i>Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods</i>

A5.23/A5.23M	<i>Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.24/A5.24M	<i>Specification for Zirconium and Zirconium-Alloy Welding Electrodes and Rods</i>
A5.25/A5.25M	<i>Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding</i>
A5.26/A5.26M	<i>Specification for Carbon and Low-Alloy Steel Electrodes for Electrogas Welding</i>
A5.28/A5.28M	<i>Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.29/A5.29M	<i>Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding</i>
A5.30/A5.30M	<i>Specification for Consumable Inserts</i>
A5.31M/A5.31	<i>Specification for Fluxes for Brazing and Braze Welding</i>
A5.32M/A5.32 (ISO 14175 MOD)	<i>Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes</i>
A5.34/A5.34M	<i>Specification for Nickel-Alloy Flux Cored and Metal Cored Welding Electrodes</i>
A4.35/A5.35M-AMD1	<i>Specification for Covered Electrodes for Underwater Wet Shielded Metal Arc Welding</i>
A5.39/A5.39M	<i>Specification for Flux and Electrode Combinations for Submerged Arc and Electroslag Joining and Surfacing of Stainless Steel and Nickel Alloys</i>

INTENTIONALLY LEFT BLANK

SPECIFICATION FOR NICKEL AND NICKEL-ALLOY WELDING ELECTRODES FOR SHIELDED METAL ARC WELDING



SFA-5.11/SFA-5.11M



(Identical with AWS Specification A5.11/A5.11M:2018. In case of dispute, the original AWS text applies.)

Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding

1. Scope

1.1 This specification prescribes requirements for the classification of nickel and nickel-alloy covered electrodes for shielded metal arc welding. It includes those compositions in which the nickel content generally exceeds that of any other element.¹

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to material properties. The specification with the designation A5.11 uses U.S. Customary Units. The specification A5.11M uses SI Units. The latter are shown within brackets ([]) or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing of filler metal or packaging or both under A5.11 or A5.11M specifications.

1.3 Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in Annex Clauses A5 and A10.

Safety and Health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers
- (3) Applicable federal and state regulations

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

2.1 The following standards contain provisions which, through reference in this text, constitute provisions of this AWS standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreement based on this AWS standard are encouraged to investigate the possibility of applying the most recent edition of the documents shown below. For undated references, the latest edition of the standard referred to applies.

¹Nickel-base covered electrodes for welding cast iron are treated separately in AWS A5.15, *Specification for Welding Electrodes and Rods for Cast Iron*.

2.2 The following AWS standards are referenced in the mandatory clauses of this document:

- (1) AWS A1.1, *Metric Practice Guide for the Welding Industry*
- (2) AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*
- (3) AWS A5.01M/A5.01 (ISO 14344 MOD), *Welding Consumables—Procurement of Filler Metals and Fluxes*
- (4) AWS A5.02/A5.02M:2007, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*
- (5) AWS B4.0, *Standard Methods for Mechanical Testing of Welds*
- (6) AWS B4.0M, *Standard Methods for Mechanical Testing of Welds*

2.3 The following ANSI standard is referenced in the mandatory clauses of this document:

- (1) ANSI Z49.1 *Safety in Welding, Cutting, and Allied Processes*

2.4 The following ASTM standards are referenced in the mandatory clauses of this document:

- (1) ASTM A131/A131M, *Standard Specification for Structural Steel for Ships*
- (2) ASTM A240/A240M, *Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications*
- (3) ASTM A285/A285M, *Standard Specification for Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength*
- (4) ASTM A515/A515M, *Standard Specification for Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service*
- (5) ASTM A560/A560M, *Standard Specification for Castings, Chromium-Nickel Alloy*
- (6) ASTM B127, *Standard Specification for Nickel-Copper Alloy (UNS N04400) Plate, Sheet, and Strip*
- (7) ASTM B160, *Standard Specification for Nickel Rod and Bar*
- (8) ASTM B162, *Standard Specification for Nickel Plate, Sheet, and Strip*
- (9) ASTM B164, *Standard Specification for Nickel-Copper Alloy Rod, Bar, and Wire*
- (10) ASTM B166, *Standard Specification for Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06025, N06045, and N06696) Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617) and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Rod, Bar, and Wire*
- (11) ASTM B167, *Standard Specification for Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696) Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617) and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Seamless Pipe and Tube*
- (12) ASTM B168, *Standard Specification for Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696) Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617) and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Plate, Sheet, and Strip*
- (13) ASTM B333, *Standard Specification for Nickel-Molybdenum Alloy Plate, Sheet, and Strip*
- (14) ASTM B435, *Standard Specification for UNS N06002, UNS N06230, UNS N12160, and UNS R30556 Plate, Sheet, and Strip*
- (15) ASTM B443, *Standard Specification for Nickel-Chromium-Molybdenum-Columbium Alloy (UNS N06625), and Nickel-Chromium-Molybdenum-Silicon Alloy (UNS N06219) Plate, Sheet, and Strip*
- (16) ASTM B446, *Standard Specification for Nickel-Chromium-Molybdenum-Columbium Alloy (UNS N06625), Nickel-Chromium-Molybdenum-Silicon Alloy (UNS N06219), and Nickel-Chromium-Molybdenum-Tungsten Alloy (UNS N06650), Rod and Bar*

(17) ASTM B575, *Standard Specification for Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Chromium-Molybdenum-Copper, Low-Carbon Nickel-Chromium-Molybdenum-Tantalum, Low-Carbon Nickel-Chromium-Molybdenum-Tungsten, and Low-Carbon Nickel-Molybdenum-Chromium Alloy Plate, Sheet, and Strip*

(18) ASTM B582, *Standard Specification for Nickel-Chromium-Iron-Molybdenum-Copper Alloy Plate, Sheet, and Strip*

(19) ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

(20) ASTM E76, *Standard Methods for Chemical Analysis of Nickel-Copper Alloys*

(21) ASTM E354, *Standard Test Methods for Chemical Analysis of High-Temperature, Electrical, Magnetic and Other Similar Iron, Nickel, and Cobalt Alloys*

(22) ASTM E1019, *Standard Test Methods for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel, Iron, Nickel and Cobalt Alloys by Various Combustion and Fusion Techniques*

(23) ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*

(24) ASTM E1473, *Standard Test Methods for Chemical Analysis of Nickel, Cobalt, and High Temperature Alloys*

2.5 The following ISO standards are referenced in the mandatory clauses of this document:

(1) ISO 544, *Welding consumables — Technical delivery conditions for welding filler materials and fluxes — Type of product, dimensions, tolerances and markings*

(2) ISO 14172, *Welding consumables — Covered electrodes for manual metal arc welding of nickel and nickel alloys — Classification*

(3) ISO 80000-1, *Quantities and units — Part 1: General*

3. Classification

3.1 The welding electrodes covered by the A5.11/A5.11M specification are classified using a system that is independent of U.S. Customary Units and the International System of Units (SI). Classification is according to the chemical composition of their undiluted weld metal, as specified in Table 1.

3.2 Electrodes classified under one classification shall not be classified under any other classification in this specification. However, material may be classified under both A5.11 and A5.11M specifications.

4. Acceptance

Acceptance² of the electrodes shall be in accordance with the provisions of AWS A5.01M/A5.01 (ISO 14344 MOD).

5. Certification

By affixing the AWS specification and classification designation to the packaging, or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification.³

² See Annex Clause A3 for further information concerning acceptance and testing of the material shipped, as well as AWS A5.01M/A5.01 (ISO 14344 MOD).

³ See Annex Clause A4 for further information concerning certification and the testing called for to meet this requirement.

Table 1
Chemical Composition Requirements for Undiluted Weld Metal

Weight-Percent ^{a, b}																		
AWS Classification	UNS Number ^c	C	Mn	Fe	P	S	Si	Cu	Ni ^d	Co	Al	Ti	Cr	Nb plus Ta	Mo	V	W	Other Elements Total
ENi-1	W82141	0.10	0.75	0.75	0.03	0.02	1.25	0.25	92.0 min.	—	1.0	1.0 to 4.0	—	—	—	—	—	0.50
ENiCr-4	W86172	0.10	1.5	1.0	0.02	0.02	1.0	0.25	Rem	—	—	—	48.0 to 52.0	1.0 to 2.5	—	—	—	0.50
ENiCu-7	W84190	0.15	4.0	2.5	0.02	0.015	1.5	Rem	62.0 to 69.0	—	0.75	1.0	—	—	—	—	—	0.50
ENiCrFe-1	W86132	0.08	3.5	11.0	0.03	0.015	0.75	0.50	62.0 min.	—	—	—	13.0 to 17.0	1.5 to 4.0 ^f	—	—	—	0.50
ENiCrFe-2	W86133	0.10	1.0 to 3.5	12.0	0.03	0.02	0.75	0.50	62.0 min.	(e)	—	—	13.0 to 17.0	0.5 to 3.0 ^f	0.5 to 2.5	—	—	0.50
ENiCrFe-3	W86182	0.10	5.0 to 9.5	10.0	0.03	0.015	1.0	0.50	59.0 min.	(e)	—	1.0	13.0 to 17.0	1.0 to 2.5 ^f	—	—	—	0.50
ENiCrFe-4	W86134	0.20	1.0 to 3.5	12.0	0.03	0.02	1.0	0.50	60.0 min.	—	—	—	13.0 to 17.0	1.0 to 3.5	1.0 to 3.5	—	—	0.50
ENiCrFe-7 ^g	W86152	0.05	5.0	7.0 to 12.0	0.03	0.015	0.75	0.50	Rem	(e)	0.50	0.50	28.0 to 31.5	1.0 to 2.5	0.5	—	—	0.50
ENiCrFe-9	W86094	0.15	1.0 to 4.5	12.0	0.02	0.015	0.75	0.50	55.0 min.	—	—	—	12.0 to 17.0	0.5 to 3.0	2.5 to 5.5	—	1.5	0.50

(Continued)

Table 1 (Continued)
Chemical Composition Requirements for Undiluted Weld Metal

Weight-Percent ^{a, b}																		
AWS Classification	UNS Number ^c	C	Mn	Fe	P	S	Si	Cu	Ni ^d	Co	Al	Ti	Cr	Nb plus Ta	Mo	V	W	Other Elements Total
ENiCrFe-10	W86095	0.20	1.0 to 3.5	12.0 to 15.0	0.02	0.015	0.75	0.50	55.0 min.	—	—	—	13.0 to 17.0	1.0 to 3.5	1.0 to 3.5	—	1.5 to 3.5	0.50
ENiCrFe-12	W86025	0.10 to 0.25	1.0	8.0 to 11.0	0.04	0.02	1.0	0.20	Rem	1.0	1.5 to 2.2	0.10 to 0.40	24.0 to 26.0	—	—	—	—	0.50
ENiCrFe-13 ^h	W86155	0.05	1.0	Rem	0.020	0.015	0.75	0.30	52.0 to 62.0	0.10	0.50	0.50	28.5 to 31.0	2.1 to 4.0	3.0 to 5.0	—	—	0.50
ENiCrFe-15	W86056	0.05	2.5 to 4.5	2.0 to 3.0	0.02	0.015	0.50	0.3	Rem	0.10	0.6	0.40	26.0 to 28.0	2.0 to 3.6	—	—	—	0.50
ENiCrFeSi-1	W86045	0.05 to 0.20	2.5	21.0 to 25.0	0.04	0.03	2.5 to 3.0	0.30	Rem	1.0	0.30	—	26.0 to 29.0	—	—	—	—	0.50
ENiMo-1	W80001	0.07	1.0	4.0 to 7.0	0.04	0.03	1.0	0.50	Rem	2.5	—	—	1.0	—	26.0 to 30.0	0.60	1.0	0.50
ENiMo-3	W80004	0.12	1.0	4.0 to 7.0	0.04	0.03	1.0	0.50	Rem	2.5	—	—	2.5 to 5.5	—	23.0 to 27.0	0.60	1.0	0.50
ENiMo-7	W80665	0.02	1.75	2.25	0.04	0.03	0.2	0.50	Rem	1.0	—	—	1.0	—	26.0 to 30.0	—	1.0	0.50
ENiMo-8	W80008	0.10	1.5	10.0	0.02	0.015	0.75	0.50	60.0 min.	—	—	—	0.5 to 3.5	—	17.0 to 20.0	—	2.0 to 4.0	0.50

(Continued)

Table 1 (Continued)
Chemical Composition Requirements for Undiluted Weld Metal

Weight-Percent ^{a, b}																		
AWS Classification	UNS Number ^c	C	Mn	Fe	P	S	Si	Cu	Ni ^d	Co	Al	Ti	Cr	Nb plus Ta	Mo	V	W	Other Elements Total
ENiMo-9	W80009	0.10	1.5	7.0	0.02	0.015	0.75	0.3 to 1.3	62.0 min.	—	—	—	—	—	18.0 to 22.0	—	2.0 to 4.0	0.50
ENiMo-10	W80675	0.02	2.0	1.0 to 3.0	0.04	0.03	0.2	0.50	Rem	3.0	—	—	1.0 to 3.0	—	27.0 to 32.0	—	3.0	0.50
ENiMo-11	W80629	0.02	2.5	2.0 to 5.0	0.04	0.03	0.2	0.5	Rem	1.0	0.1 to 0.5	0.3	0.5 to 1.5	0.5	26.0 to 30.0	—	—	0.50
ENiMoCr-1	N10362	0.02	0.60	1.25	0.030	0.015	0.20	—	Rem	—	0.50	—	13.8 to 15.6	—	21.5 to 23.0	—	—	0.50
ENiCrMo-1	W86007	0.05	1.0 to 2.0	18.0 to 21.0	0.04	0.03	1.0	1.5 to 2.5	Rem	2.5	—	—	21.0 to 23.5	1.75 to 2.50	5.5 to 7.5	—	1.0	0.50
ENiCrMo-2	W86002	0.05 to 0.15	1.0	17.0 to 20.0	0.04	0.03	1.0	0.50	Rem	0.50 to 2.50	—	—	20.5 to 23.0	—	8.0 to 10.0	—	0.2 to 1.0	0.50
ENiCrMo-3	W86112	0.10	1.0	7.0	0.03	0.02	0.75	0.50	55.0 min.	(e)	—	—	20.0 to 23.0	3.15 to 4.15	8.0 to 10.0	—	—	0.50
ENiCrMo-4	W80276	0.02	1.0	4.0 to 7.0	0.04	0.03	0.2	0.50	Rem	2.5	—	—	14.5 to 16.5	—	15.0 to 17.0	0.35	3.0 to 4.5	0.50
ENiCrMo-5	W80002	0.10	1.0	4.0 to 7.0	0.04	0.03	1.0	0.50	Rem	2.5	—	—	14.5 to 16.5	—	15.0 to 17.0	0.35	3.0 to 4.5	0.50

(Continued)

Table 1 (Continued)
Chemical Composition Requirements for Undiluted Weld Metal

Weight-Percent ^{a, b}																		
AWS Classification	UNS Number ^c	C	Mn	Fe	P	S	Si	Cu	Ni ^d	Co	Al	Ti	Cr	Nb plus Ta	Mo	V	W	Other Elements Total
ENiCrMo-6	W86620	0.10	2.0 to 4.0	10.0	0.03	0.02	1.0	0.50	55.0 min.	—	—	—	12.0 to 17.0	0.5 to 2.0	5.0 to 9.0	—	1.0 to 2.0	0.50
ENiCrMo-7	W86455	0.015	1.5	3.0	0.04	0.03	0.2	0.50	Rem	2.0	—	0.70	14.0 to 18.0	—	14.0 to 17.0	—	0.5	0.50
ENiCrMo-9	W86985	0.02	1.0	18.0 to 21.0	0.04	0.03	1.0	1.5 to 2.5	Rem	5.0	—	—	21.0 to 23.5	0.5	6.0 to 8.0	—	1.5	0.50
ENiCrMo-10	W86022	0.02	1.0	2.0 to 6.0	0.03	0.015	0.2	0.50	Rem	2.5	—	—	20.0 to 22.5	—	12.5 to 14.5	0.35	2.5 to 3.5	0.50
ENiCrMo-11	W86030	0.03	1.5	13.0 to 17.0	0.04	0.02	1.0	1.0 to 2.4	Rem	5.0	—	—	28.0 to 31.5	0.3 to 1.5	4.0 to 6.0	—	1.5 to 4.0	0.50
ENiCrMo-12	W86032 ⁱ	0.03	2.2	5.0	0.03	0.02	0.7	0.50	Rem	—	—	—	20.5 to 22.5	1.0 to 2.8	8.8 to 10.0	—	—	0.50
ENiCrMo-13	W86059	0.02	1.0	1.5	0.015	0.01	0.2	0.50	Rem	—	—	—	22.0 to 24.0	—	15.0 to 16.5	—	—	0.50
ENiCrMo-14	W86686	0.02	1.0	5.0	0.02	0.02	0.25	0.50	Rem	—	—	0.25	19.0 to 23.0	—	15.0 to 17.0	—	3.0 to 4.4	0.50
ENiCrMo-17	W86200	0.020	0.5	3.0	0.030	0.015	0.2	1.3 to 1.9	Rem	2.0	—	—	22.0 to 24.0	—	15.0 to 17.0	—	—	0.50

(Continued)

Table 1 (Continued)
Chemical Composition Requirements for Undiluted Weld Metal

Weight-Percent ^{a, b}																		
AWS Classification	UNS Number ^c	C	Mn	Fe	P	S	Si	Cu	Ni ^d	Co	Al	Ti	Cr	Nb plus Ta	Mo	V	W	Other Elements Total
ENiCrMo-18	W86650	0.03	0.7	12.0 to 15.0	0.03	0.02	0.6	0.3	Rem	1.0	0.5	—	19.0 to 22.0	0.3	10.0 to 13.0	0.15	1.0 to 2.0	0.50
ENiCrMo-19 ^{j, k}	W86058	0.02	1.5	1.5	0.03	0.02	0.2	0.5	Rem	0.3	0.4	—	20.0 to 23.0	—	18.5 to 21.0	—	0.3	0.50
ENiCrMo-22	W86035	0.05	0.50	2.00	0.030	0.015	0.60	0.30	Rem	1.00	0.40	0.20	32.25 to 34.25	0.50	7.6 to 9.0	0.20	0.60	0.50
ENiCrCoMo-1	W86117	0.05 to 0.15	0.3 to 2.5	5.0	0.03	0.015	0.75	0.50	Rem	9.0 to 15.0	—	—	21.0 to 26.0	1.0	8.0 to 10.0	—	—	0.50
ENiCrWMo-1	W86231	0.05 to 0.10	0.3 to 1.0	3.0	0.02	0.015	0.25 to 0.75	0.50	Rem	5.0	0.50	0.10	20.0 to 24.0	—	1.0 to 3.0	—	13.0 to 15.0	0.50

^a The weld metal shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of the work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for "Other Elements, Total" in the last column of the table.

^b Single values are maximum, except where otherwise specified. Rem = remainder.

^c ASTM DS-56/SAE HS-1086, *Metals & Alloys in the Unified Numbering System*.

^d Includes incidental cobalt.

^e Cobalt—0.12 maximum when specified by the purchaser.

^f Tantalum—0.30 maximum, when specified by the purchaser.

^g B is 0.005% maximum and Zr is 0.020% maximum when specified by purchaser.

^h B is 0.003% max. and Zr is 0.020% max.

ⁱ UNS number formerly was W86040.

^j N = 0.02 to 0.15.

^k VDM Metals, the requester of change in chemical composition of ENiCrMo-19 stated that this alloy is not patented in USA, but patent has been granted to "Outokumpu VDM" in Germany (patent DE 59801333), France (patent FR 991788), and the UK (patent GB 991788). All of these were generated out of European patent EP991788 which will expire on May 27, 2018.

6. Rounding Procedure

For purposes of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest 1000 psi (1 ksi) for tensile and yield strength for A5.11 or to the nearest 10 MPa for tensile and yield strength for A5.11M; and to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfill the requirements for the classification under test.

7. Summary of Tests

The tests required for classification are specified in Table 2. The purpose of these tests is to determine the chemical composition, the mechanical properties and soundness of the weld metal, and the usability of the electrode. The base metal for the weld test assemblies, the welding and testing procedures to be employed, and the results required are given in Clause 9, Weld Test Assemblies, through Clause 13, Bend Test.

8. Retest

8.1 If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Specimens for retest may be taken from the original test assembly, or from one or two new test assemblies. For chemical analysis, retest need be only for those specific elements that failed to meet the test requirement.

8.2 If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

8.3 In the event that, during preparation or after completion of any test, it is clearly determined that prescribed or proper procedures were not followed in preparing the weld test assembly or test specimen(s) or in conducting the test, the test shall be considered invalid, without regard to whether the test was actually completed, or whether test results met, or failed to meet, the requirement. That test shall be repeated, following proper prescribed procedures. In this case, the requirement for doubling of the number of test specimens does not apply.

9. Weld Test Assemblies

9.1 To perform all required tests as specified in Table 2, a minimum of one weld test assembly is required. Two, or even three, may be necessary (according to the classification, size, and manner in which the testing is conducted, i.e., with respect to alternative options).

The weld test assemblies are identified as follows:

- (1) The weld pad in Figure 1 for chemical analysis of the undiluted weld metal
- (2) The groove weld in Figure 2 for mechanical properties and soundness
- (3) The groove weld in Figure 3 for radiographic soundness

The sample for chemical analysis may be taken from a low dilution area in the groove weld in Figure 2, or from the reduced section of the fractured tension test specimen, thereby avoiding the need to make the weld pad. In case of dispute, the weld pad shall be the referee method.

9.2 Preparation of each weld test assembly shall be as prescribed in 9.3, 9.4.1, and 9.4.2. The base metal for each assembly shall meet the requirements of the appropriate ASTM specification shown in Table 3 or an equivalent specification. Testing of assemblies shall be as prescribed in Clauses 10 through 13.

Table 2
Required Tests and Positions^a

AWS Classification	Required Test						Position Radiographic Test ^d
	Electrode in	Diameter mm	Chemical Analysis	Tension Test	Bend Test ^b	Radiographic Test ^c	
ENi-1	5/64 3/32 — 1/8	2.0 2.4 ^e 2.5 3.2	Required	Required	Required	Required	V
ENiCr-4 ^g							
ENiCu-7							
ENiCrFe-1							
ENiCrFe-2							
ENiCrFe-3							
ENiCrFe-4							
ENiCrFe-7							
ENiCrFe-9							
ENiCrFe-10							
ENiCrFe-13							
ENiCrFe-15							
ENiMo-11	5/32 3/16 — 1/4 ^f	4.0 4.8 ^e 5.0 6.4 ^{e,f}	Required	Required	Required	Required	F
ENiCrMo-3							
ENiCrMo-6							
ENiCrMo-10							
ENiCrMo-12							
ENiCrMo-14							
ENiCrMo-17							
ENiCrCoMo-1	5/64 3/32 — 1/8 5/32 3/16 —	2.0 2.4 ^e 2.5 3.2 4.0 4.8 ^e 5.0	Required	Required	Required	Required	F
ENiCrFe-12							
ENiCrFeSi-1							
ENiMo-1							
ENiMo-3							
ENiMo-7							
ENiMo-8							
ENiMo-9							
ENiMo-10							
ENiMoCr-1							
ENiCrMo-1							
ENiCrMo-2							
ENiCrMo-4							
ENiCrMo-5							
ENiCrMo-7							
ENiCrMo-9							
ENiCrMo-11							
ENiCrMo-13							
ENiCrMo-18							
ENiCrMo-19							
ENiCrMo-22							
ENiCrWMo-1							

^a See Table 3 for base metals to be used in these tests.

^b Three transverse side-bend test specimens are required except for 5/64 in [2.0 mm] electrodes. For that size, two transverse face-bend specimens are required.

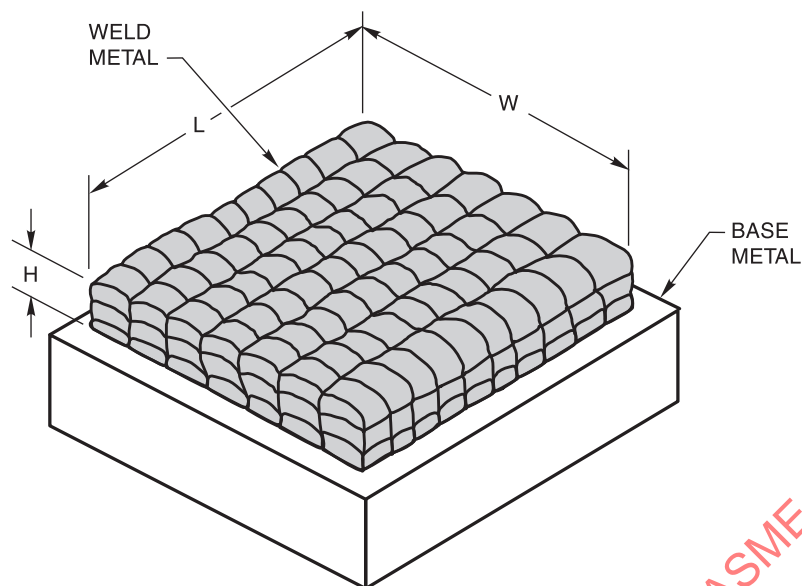
^c The groove weld for mechanical properties (Figure 2) may also be used for the radiographic soundness test conducted in the flat position. In that case, the test assembly is radiographed before the coupons for the tensile and bend test specimens are removed.

^d The position of welding shown in this column is only for the radiographic soundness test (V = vertical with uphill progression, F = flat). All other test assemblies are welded in the flat position.

^e Metric sizes not shown in ISO 544.

^f Applies only to ENiCu-7 classification.

^g No bend test required for this classification.



Electrode Size		Weld Pad Size	
in	mm	in, min.	mm, min.
5/64	2.0	$\left\{ \begin{array}{l} L = 1\text{-}1/2 \\ W = 1\text{-}1/2 \\ H = 1/2 \end{array} \right.$	38
3/32	2.4 ^a		38
—	2.5		13
1/8	3.2		
5/32	4.0	$\left\{ \begin{array}{l} L = 2 \\ W = 2 \\ H = 7/8 \end{array} \right.$	50
3/16	4.8 ^a		50
—	5.0		22
1/4	6.4 ^a		

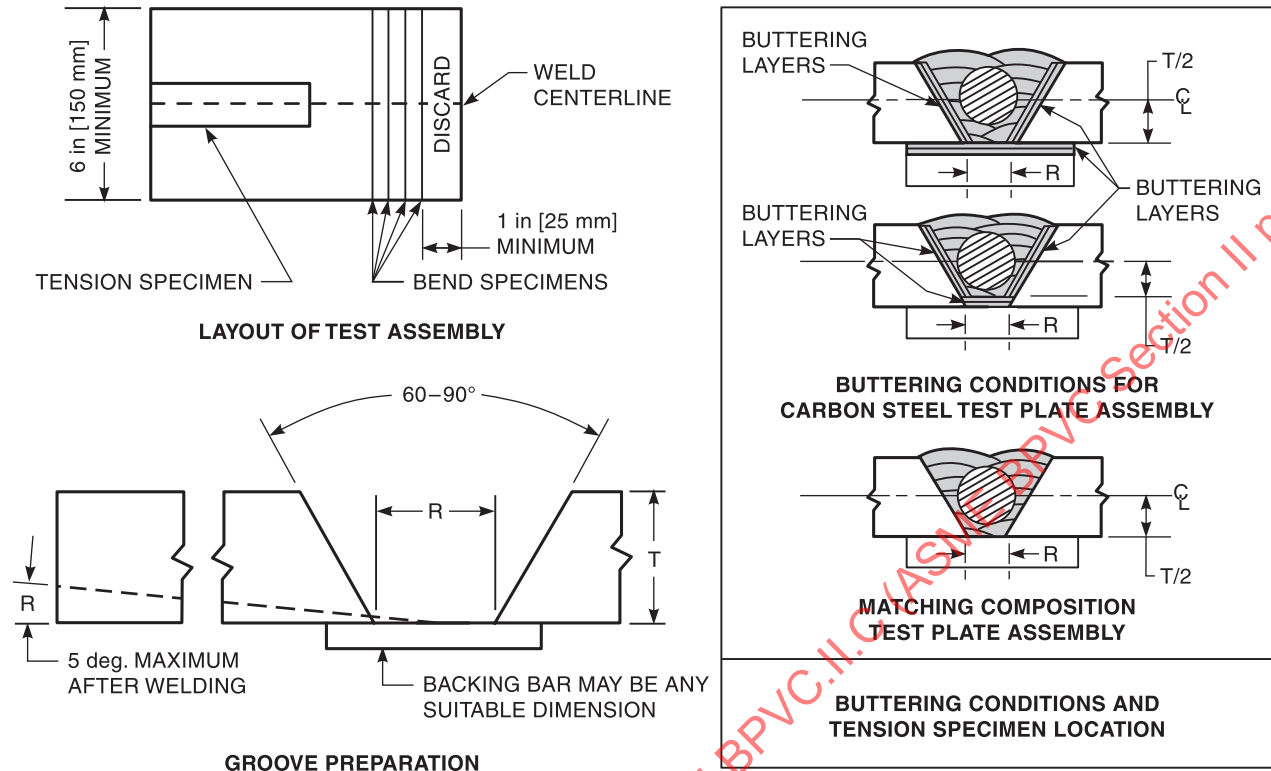
^a Metric sizes not shown in ISO 544.

Notes:

1. The number and size of the beads will vary according to the size of the electrode and the width of the weave, as well as the amperage employed.
2. If carbon steel base metal is used for the chemical analysis pad, the height of the pad (dimension H) shall be increased as required in Note a of Table 3.

Source: Figure 1 of AWS A5.11/A5.11M:2010.

Figure 1—Pad for Chemical Analysis of Undiluted Weld Metal



Electrode Size		T (Thickness), min.		R (Root Opening) ^a		Number of Layers
in	mm	in	mm	in	mm	min.
5/64	2.0	3/8	10	3/16	5	(b)
3/32	2.4 ^c	1/2	12	1/4	6	(b)
—	2.5	1/2	12	1/4	6	(b)
1/8	3.2	1/2	12	1/4	6	(b)
5/32	4.0	3/4	20	1/2	13	6
3/16	4.8 ^c	3/4	20	1/2	13	6
—	5.0	3/4	20	1/2	13	6
1/4	6.4 ^c	3/4	20	1/2	13	6

^a Tolerance: $\pm 1/16$ in [2 mm].

^b Number of layers not specified, but pass and layer sequence shall be recorded and reported.

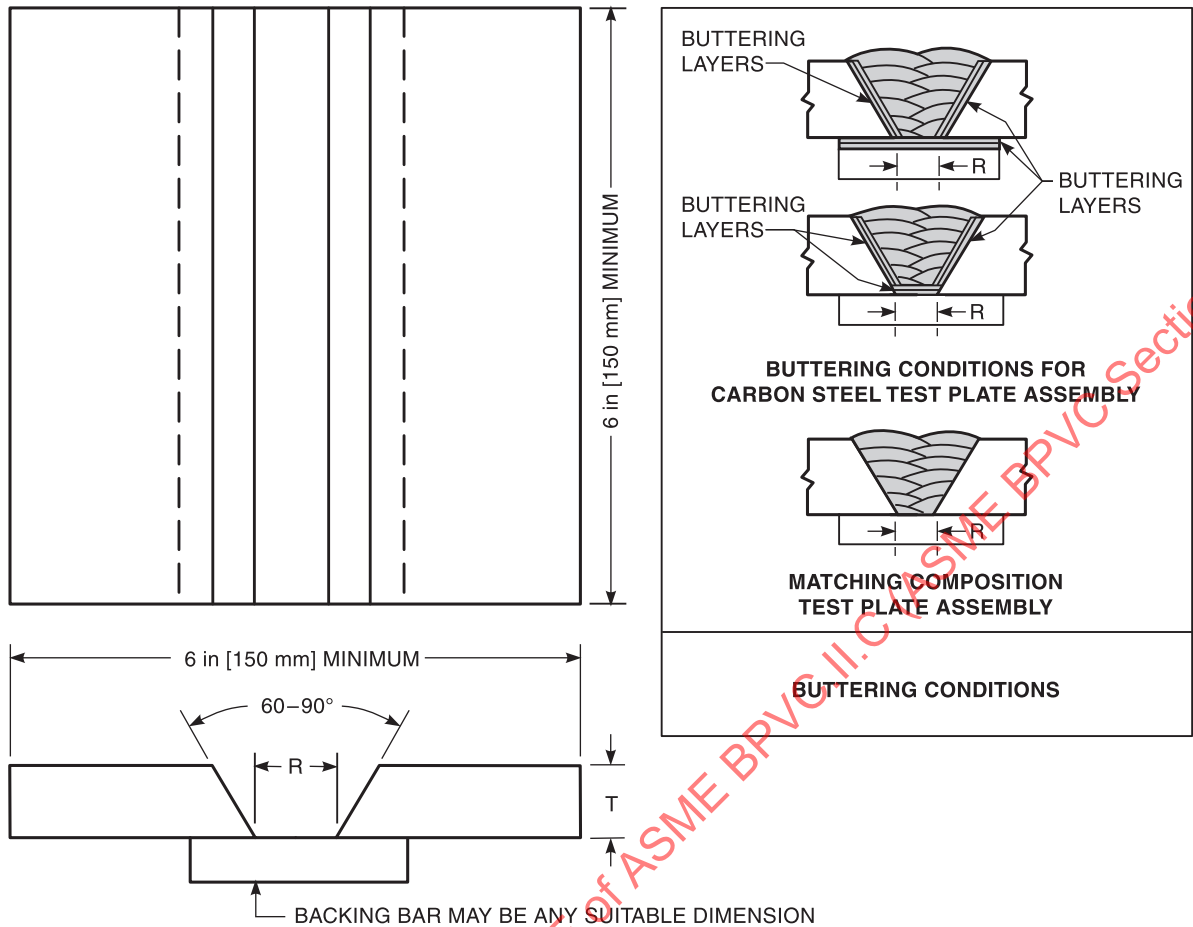
^c Metric sizes not shown in ISO 544.

Notes:

1. Base metal shall be as specified in Table 3.
2. The surfaces to be welded shall be clean.
3. The minimum length of the test assembly is 6 in [150 mm], but the assembly shall be as long as necessary to provide the specimens for the number and type of tests required. Minimum width is 6 in [150 mm].
4. Prior to welding, the assembly may be preset so that the welded joint will be within 5° of plane after welding. As an alternate, restraint or a combination of restraint and presetting may be used. A test assembly that is more than 5° out of plane shall be discarded. Straightening of the test assembly is prohibited.
5. Welding shall be performed in the flat position, using the type and range of current and welding technique recommended by the electrode manufacturer.
6. The minimum preheat temperature shall be 60°F [16°C]. The interpass temperature shall not exceed 300°F [150°C].
7. The welds shall be made with stringer beads or weave beads no wider than four times the diameter of the core wire. The completed weld shall be at least flush with the surface of the test plate. For electrodes larger than 1/8 in [3.2 mm], the root beads may be deposited with 3/32 in or 1/8 in [2.4 mm, 2.5 mm, or 3.2 mm] electrodes.
8. The tests shall be conducted without a postweld heat treatment.

Source: Figure 2 of AWS A5.11/A5.11M:2010.

Figure 2—Groove Weld Test Assembly for Mechanical Properties and Soundness



Electrode Size		T (Thickness), min.		R (Root Opening) ^a	
in	mm	in	mm	in	mm
5/64	2.0	1/8	3	1/8	3
3/32	2.4 ^b	1/4	6	1/4	6
—	2.5	1/4	6	1/4	6
1/8	3.2	3/8	10	5/16	8
5/32	4.0	3/8	10	3/8	10
3/16	4.8 ^b	1/2	12	1/2	13
—	5.0	1/2	12	1/2	13
1/4	6.4 ^b	1/2	12	1/2	13

^a Tolerance: $\pm 1/16$ in [2 mm].

^b Metric sizes not shown in ISO 544.

Notes:

1. Base metal shall be as specified in Table 3.
2. The surfaces to be welded shall be clean.
3. Welding shall be conducted in the vertical-up or flat position, as required in Table 2 (also see Note c in Table 2) using the type and range of current, and technique recommended by the electrode manufacturer.
4. The minimum preheat temperature shall be 60°F [16°C]. The interpass temperature shall not exceed 300°F [150°C].
5. The welds shall be made with a stringer bead technique or a weave to produce a bead no wider than four times the diameter of the core wire. The root layer in tests of electrodes larger than 1/8 in [3.2 mm] diameter may be deposited with 3/32 in or 1/8 in [2.4 mm, 2.5 mm, or 3.2 mm] electrodes of that same classification. In addition to the start and stop at the ends of the weld, each bead shall also contain a start and a stop somewhere in between.
6. A small amount of grinding between beads is permissible for welds in the vertical position, but an inordinate amount should not be required to produce a satisfactory weld.
7. The completed weld shall be at least flush with the surface of the test plate.
8. The backing strip shall be removed, and the weld on both sides of the assembly shall be machined or ground smooth and flush with the original surfaces of the base plate (see 11.1).
9. The assembly shall be radiographed as specified in Clause 11, Radiographic Test.

Source: Figure 3 of AWS A5.11/A5.11M:2010.

Figure 3—Groove Weld Test Assembly for Radiographic Soundness Test

Table 3
Base Metals for Test Assemblies

AWS Classification	Materials ^{a, b}	ASTM Specifications ^c	UNS Number
ENi-1	Nickel	B160, B162	N02200, N02201
ENiCr-4	Nickel-Chromium	A560	R20500
ENiCu-7	Nickel-Copper Alloy	B127, B164	N04400
ENiCrFe-1, 2, 3, 4, 9, 10	Nickel-Chromium-Iron Alloy	B166, B168	N06600
ENiCrFe-7, 13, 15	Nickel-Chromium-Iron Alloy	B166, B167, B168	N06690
ENiCrFe-12	Nickel-Chromium-Iron Alloy	B168	N06025
ENiCrFeSi-1	Nickel-Chromium-Iron-Silicon Alloy	B168	N06045
ENiMo-1, 3, 7, 8, 9, 10	Nickel-Molybdenum Alloy	B333	N10001, N10665, N10675
ENiMo-11	Nickel-Molybdenum Alloy	B333	N10629
ENiMoCr-1	Low Carbon Nickel-Molybdenum-Chromium Alloy	B575	N10362
ENiCrMo-1, 9, 11	Nickel-Chromium-Molybdenum Alloy	B582	N06007, N06985, N06030
ENiCrMo-2	Nickel-Chromium-Molybdenum Alloy	B435	N06002
ENiCrMo-3	Nickel-Chromium-Molybdenum Alloy	B443, B446	N06625
ENiCrMo-4, 5, 7, 10, 13, 14, 19, 22	Low Carbon Nickel-Chromium-Molybdenum Alloy	B575	N10276, N06455, N06022, N06059, N06686, N06058, N06035
ENiCrMo-6	Nickel-Chromium-Molybdenum Alloy	B166, B168	N06600
ENiCrMo-12	Chromium-Nickel-Molybdenum Alloy (Austenitic Stainless Steel)	A240	S31254
ENiCrMo-17	Low Carbon Nickel-Chromium-Molybdenum Alloy	B575	N06200
ENiCrMo-18	Nickel-Chromium-Iron-Molybdenum-Tungsten Alloy	B446	N06650
ENiCrCoMo-1	Nickel-Chromium-Cobalt-Molybdenum Alloy	B166, B168	N06617
ENiCrWMo-1	Nickel-Chromium-Tungsten-Molybdenum Alloy	B435	N06230

^a Either the base metals specified or carbon steel (ASTM A131, A285, A515) may be used. If carbon steel is used, two layers of buttering shall be applied to the surface and the backing strip if appropriate. For chemical analysis, base metals other than those specified may be used as the base for the undiluted weld pad provided that, for electrodes of the 1/8 in [3.2 mm] size and smaller, the minimum height shown in Figure 1 is 3/4 in [19 mm] and the sample for analysis is taken at least 5/8 in [16 mm] from the nearest surface of the base metal. For electrode of the 5/32 in [4.0 mm] size and larger, the minimum height shown in Figure 1 is 1 in [25 mm] and the sample for analysis is taken at least 7/8 in [22 mm] from the nearest surface of the base metal.

^b All specified base metals shall be in the annealed condition prior to welding.

^c Equivalent material specifications may be used.

9.3 Weld Pad. A weld pad shall be prepared as specified in Table 2 and shown in Figure 1, except when one of the alternatives in 9.1 (taking the sample from the weld metal in the groove or from the tension test specimen) is selected. Base metal of any convenient size, of the type specified in Table 3, shall be used as the base for the weld pad. The surface of the base metal on which the filler metal is deposited shall be clean. The pad shall be welded in the flat position with multiple beads and layers to obtain undiluted weld metal. The type of current and range of amperage used for welding shall be as recommended by the manufacturer. The preheat temperature shall be not less than 60°F [16°C] and the interpass temperature shall not exceed 300°F [150°C]. The slag shall be removed after each pass. The pad may be quenched in water (temperature above 60°F [16°C]) between passes. The dimensions of the completed pad shall be as shown in Figure 1 for each size of electrode. Testing of this assembly shall be as specified in Clause 10, Chemical Analysis.

9.4 Groove Weld

9.4.1 Mechanical Properties and Soundness. A test assembly shall be prepared and welded as specified in Table 2 and shown in Figure 2, using base metal of an appropriate type specified in Table 3. Testing of this assembly shall be as specified in Clause 12, Tension Test, and Clause 13, Bend Test. Additionally, this assembly may be used to satisfy the requirements of the flat position radiographic test (Note c to Table 2). In that case, the assembly shall be radiographed as required in Clause 11, Radiographic Test. The assembly shall be tested in the as-welded condition.

9.4.2 Radiographic Soundness. A test assembly shall be prepared for electrodes of all classifications and welded as shown in Figure 3, using base metal of the appropriate type specified in Table 3. The welding position shall be as specified in Table 2 for the different electrode sizes and classifications. Testing of the assembly shall be as specified in Clause 11, Radiographic Test. The groove weld in Figure 2 may be radiographed (for those classifications for which the radiographic test is welded in the flat position), thus eliminating the need to make the groove weld in Figure 3, in those cases.

10. Chemical Analysis

10.1 The sample for analysis shall be taken from weld metal obtained from the weld pad, the reduced section of the fractured tension test specimen, or a low-dilution area of the groove weld in Figure 2. The top surface of the pad described in 9.3 and shown in Figure 1 (when the pad is used), shall be removed and discarded. A sample for analysis shall be obtained from the underlying metal by any appropriate mechanical means. The sample shall be free of slag.

For electrodes smaller than 5/32 in [4.0 mm], the sample shall be taken at least 3/8 in [10 mm] from the nearest surface of the base metal. For electrodes 5/32 in [4.0 mm] and larger, the sample shall be taken at least 3/4 in [19 mm] from that surface. If carbon-steel base metal is used in the chemical analysis test pad, see Note a in Table 3. The sample from the reduced section of the fractured tension test specimen and the sample from a low-dilution area of the groove weld shall be prepared for analysis by any suitable mechanical means.

10.2 The sample shall be analyzed by accepted analytical methods. The referee method shall be ASTM E1473, supplemented by ASTM E1019 and ASTM E354 for nickel base alloys, and ASTM E76 for nickel copper alloys, as appropriate.

10.3 The results of the analysis shall meet the requirements of Table 1 for the classification of electrode under test.

11. Radiographic Test

11.1 The radiographic soundness test weld described in 9.4.2 and shown in Figure 3 (or the groove weld described in 9.4.1 and shown in Figure 2, when that is desired and is permitted by Note c of Table 2), shall be radiographed to evaluate the usability of the electrode. In preparation for radiography, the backing shall be removed and both surfaces of the weld shall be machined or ground smooth and flush with the original surfaces (except as noted) of the base metal or with a uniform reinforcement not exceeding 3/32 in [2.5 mm]. It is permitted on both sides of the test assembly to remove base metal to a depth of 1/16 in [1.5 mm] nominal below the original base metal surface in order to facilitate backing

and/or buildup removal. Thickness of the weld metal shall not be reduced by more than 1/16 in [1.5 mm] less than the nominal base metal thickness. Both surfaces of the test assembly, in the area of the weld, shall be smooth enough to avoid difficulty in interpreting the radiograph.

11.2 The weld shall be radiographed in accordance with ASTM E1032. The quality level of inspection shall be 2-2T.

11.3 The electrode meets the requirements of this specification if the radiograph shows the following:

- (1) No cracks, no incomplete fusion, and no incomplete penetration
- (2) No slag inclusions in excess of those permitted by Note 4 to the radiographic standards in Figures 4 through 8, according to the size of the electrode
- (3) No rounded indications in excess of those permitted by the radiographic standards in Figures 4 through 8, according to the thickness of the test assembly, or the alternative method of evaluation in 11.3.1

In evaluating the radiograph, 1 in [25 mm] of the weld on each end of the test assembly shall be disregarded.

11.3.1 The alternative method of evaluation involves calculation of the total area of the rounded indications as they appear on the radiograph. This total area shall not exceed 1% of the thickness of the test assembly multiplied by the length of the weld used in the evaluation (length of the weld in the test assembly minus 1 in [25 mm] on each end). The value given in Note 3 to each of the Figures (4 through 8) has been calculated for 6 in [150 mm] of weld (an 8 in [200 mm] long test assembly). The value for weld lengths other than this will differ on a linearly proportional basis.



(A) MEDIUM ROUNDED INDICATIONS

SIZE PERMITTED IS 0.025 in [0.6 mm] MAXIMUM.
NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 14.



(B) SMALL ROUNDED INDICATIONS

SIZE PERMITTED IS 0.020 in [0.5 mm] MAXIMUM.
NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 23.

Notes:

1. The chart that is most representative of the size of the rounded indications in the radiograph of the test assembly shall be used to determine conformance with this specification. Rounded indications 1/64 in [0.4 mm] and smaller shall be disregarded. The largest dimension of the indication (including any tail) is the size of the indication.
2. These radiographic requirements are for test welds made in the laboratory specifically for classification purposes. They are more restrictive than those normally encountered in general fabrication.
3. When using the alternative method of evaluation described in 11.3.1, the total cross-sectional area of the rounded indications (calculated from measurements taken from the radiograph) shall not exceed 0.008 in² [5.2 mm²] in any 6 in [150 mm] of weld.
4. The acceptance standard for slag inclusions in this assembly is the following:
 - (a) Length of each individual slag indication: 1/16 in [1.6 mm] maximum.
 - (b) Total length of all slag indications: 1/8 in [3.2 mm] maximum.

Source: Figure 4 of AWS A5.11/A5.11M:2010.

Figure 4—Radiographic Standards for 1/8 in [3 mm] Test Assembly

**(A) ASSORTED ROUNDED INDICATIONS**

SIZE PERMITTED IS 0.050 in [1.3 mm] MAXIMUM.

NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 21, WITH THE FOLLOWING RESTRICTIONS:

LARGE: UP TO 0.050 in [1.3 mm] – 4 PERMITTED

MEDIUM: UP TO 0.031 in [0.8 mm] – 5 PERMITTED

SMALL: UP TO 0.020 in [0.5 mm] – 12 PERMITTED

**(B) LARGE ROUNDED INDICATIONS**

SIZE PERMITTED IS 0.050 in [1.3 mm] MAXIMUM.

NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 8.

**(C) MEDIUM ROUNDED INDICATIONS**

SIZE PERMITTED IS 0.031 in [0.8 mm] MAXIMUM.

NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 19.

**(D) SMALL ROUNDED INDICATIONS**

SIZE PERMITTED IS 0.020 in [0.5 mm] MAXIMUM.

NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 48.

Notes:

1. The chart that is most representative of the size of the rounded indications in the radiograph of the test assembly shall be used to determine conformance with this specification. Rounded indications 1/64 in [0.4 mm] and smaller shall be disregarded. The largest dimension of the indication (including any tail) is the size of the indication.
2. These radiographic requirements are for test welds made in the laboratory specifically for classification purposes. They are more restrictive than those normally encountered in general fabrication.
3. When using the alternative method of evaluation described in 11.3.1, the total cross-sectional area of the rounded indications (calculated from measurements taken from the radiograph) shall not exceed 0.015 in² [9.7 mm²] in any 6 in [150 mm] of weld.
4. The acceptance standard for slag inclusions in this assembly is the following:
 - (a) Length of each individual slag indication: 5/32 in [4.0 mm] maximum.
 - (b) Total length of all slag indications: 1/4 in [6.4 mm] maximum.

Source: Figure 5 of AWS A5.11/A5.11M:2010.

Figure 5—Radiographic Standards for 1/4 in [6 mm] Test Assembly

**(A) ASSORTED ROUNDED INDICATIONS**

SIZE PERMITTED IS 0.075 in [1.9 mm] MAXIMUM.

NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 17, WITH THE FOLLOWING RESTRICTIONS:

LARGE: UP TO 0.075 in [1.9 mm] – 3 PERMITTED

MEDIUM: UP TO 0.049 in [1.3 mm] – 3 PERMITTED

SMALL: UP TO 0.020 in [0.5 mm] – 11 PERMITTED

**(B) LARGE ROUNDED INDICATIONS**

SIZE PERMITTED IS 0.075 in [1.9 mm] MAXIMUM.

NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 5.

**(C) MEDIUM ROUNDED INDICATIONS**

SIZE PERMITTED IS 0.049 in [1.3 mm] MAXIMUM.

NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 11.

**(D) SMALL ROUNDED INDICATIONS**

SIZE PERMITTED IS 0.020 in [0.5 mm] MAXIMUM.

NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 72.

Notes:

1. The chart that is most representative of the size of the rounded indications in the radiograph of the test assembly shall be used to determine conformance with this specification. Rounded indications 1/64 in [0.4 mm] and smaller shall be disregarded. The largest dimension of the indication (including any tail) is the size of the indication.
2. These radiographic requirements are for test welds made in the laboratory specifically for classification purposes. They are more restrictive than those normally encountered in general fabrication.
3. When using the alternative method of evaluation described in 11.3.1, the total cross-sectional area of the rounded indications (calculated from measurements taken from the radiograph) shall not exceed 0.023 in² [14.8 mm²] in any 6 in [150 mm] of weld.
4. The acceptance standard for slag inclusions in this assembly is the following:
 - (a) Length of each individual slag indication: 7/32 in [5.6 mm] maximum.
 - (b) Total length of all slag indications: 3/8 in [9.5 mm] maximum.

Source: Figure 6 of AWS A5.11/A5.11M:2010.

Figure 6—Radiographic Standards for 3/8 in [10 mm] Test Assembly

**(A) ASSORTED ROUNDED INDICATIONS**

SIZE PERMITTED IS 0.10 in [2.5 mm] MAXIMUM.

NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 45, WITH THE FOLLOWING RESTRICTIONS:

LARGE: UP TO 0.10 in [2.5 mm] – 1 PERMITTED

MEDIUM: UP TO 0.031 in [0.8 mm] – 9 PERMITTED

SMALL: UP TO 0.019 in [0.5 mm] – 35 PERMITTED

**(B) LARGE ROUNDED INDICATIONS**

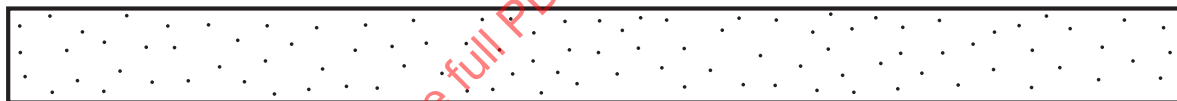
SIZE PERMITTED IS 0.10 in [2.5 mm] MAXIMUM.

NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 4.

**(C) MEDIUM ROUNDED INDICATIONS**

SIZE PERMITTED IS 0.031 in [0.8 mm] MAXIMUM.

NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 40.

**(D) SMALL ROUNDED INDICATIONS**

SIZE PERMITTED IS 0.019 in [0.5 mm] MAXIMUM.

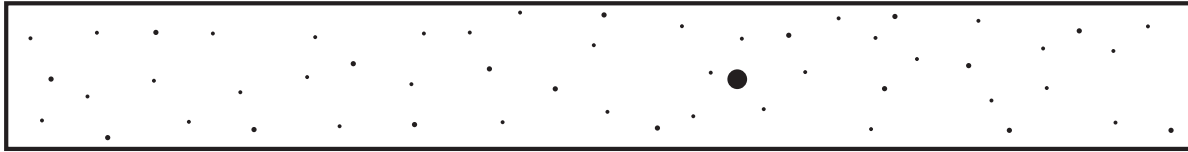
NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 101.

Notes:

1. The chart that is most representative of the size of the rounded indications in the radiograph of the test assembly shall be used to determine conformance with this specification. Rounded indications 1/64 in [0.4 mm] and smaller shall be disregarded. The largest dimension of the indication (including any tail) is the size of the indication.
2. These radiographic requirements are for test welds made in the laboratory specifically for classification purposes. They are more restrictive than those normally encountered in general fabrication.
3. When using the alternative method of evaluation described in 11.3.1, the total cross-sectional area of the rounded indications (calculated from measurements taken from the radiograph) shall not exceed 0.030 in² [19.4 mm²] in any 6 in [150 mm] of weld.
4. The acceptance standard for slag inclusions in this assembly is the following:
 - (a) Length of each individual slag indication: 7/32 in [5.6 mm] maximum.
 - (b) Total length of all slag indications: 7/16 in [11 mm] maximum.

Source: Figure 7 of AWS A5.11/A5.11M:2010.

Figure 7—Radiographic Standards for 1/2 in [12 mm] Test Assembly

**(A) ASSORTED ROUNDED INDICATIONS**

SIZE PERMITTED IS 0.125 in [3.2 mm] MAXIMUM.

NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 53, WITH THE FOLLOWING RESTRICTIONS:

LARGE: UP TO 0.125 in [3.2 mm] – 1 PERMITTED

MEDIUM: UP TO 0.034 in [0.9 mm] – 17 PERMITTED

SMALL: UP TO 0.024 in [0.6 mm] – 35 PERMITTED

**(B) LARGE ROUNDED INDICATIONS**

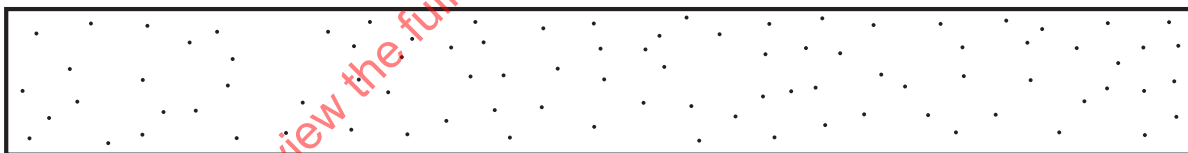
SIZE PERMITTED IS 0.125 in [3.2 mm] MAXIMUM.

NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 4.

**(C) MEDIUM ROUNDED INDICATIONS**

SIZE PERMITTED IS 0.034 in [0.9 mm] MAXIMUM.

NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 50.

**(D) SMALL ROUNDED INDICATIONS**

SIZE PERMITTED IS 0.024 in [0.6 mm] MAXIMUM.

NUMBER PERMITTED IN ANY 6 in [150 mm] OF WELD IS 90.

Notes:

1. The chart that is most representative of the size of the rounded indications in the radiograph of the test assembly shall be used to determine conformance with this specification. Rounded indications 1/64 in [0.4 mm] and smaller shall be disregarded. The largest dimension of the indication (including any tail) is the size of the indication.
2. These radiographic requirements are for test welds made in the laboratory specifically for classification purposes. They are more restrictive than those normally encountered in general fabrication.
3. When using the alternative method of evaluation described in 11.3.1, the total cross-sectional area of the rounded indications (calculated from measurements taken from the radiograph) shall not exceed 0.045 in² [29.0 mm²] in any 6 in [150 mm] of weld.
4. The acceptance standard for slag inclusions in this assembly is the following:
 - (a) Length of each individual slag indication: 5/16 in [7.9 mm] maximum.
 - (b) Total length of all slag indications: 15/32 in [11.9 mm] maximum.

Source: Figure 8 of AWS A5.11/A5.11M:2010.

Figure 8—Radiographic Standards for 3/4 in [20 mm] Test Assembly

11.3.2 A rounded indication is an indication (on the radiograph) whose length is no more than three times its width. Rounded indications may be circular, elliptical, conical, or irregular in shape, and they may have tails. The size of a rounded indication is the largest dimension of the indication including any tail that may be present. The indications may be of porosity or slag. The total area of the rounded indications for the alternative method shall not exceed the values given in Note 3 to the radiographic standards (Figures 4 through 8). Indications whose largest dimension does not exceed 1/64 in [0.4 mm] shall be disregarded. Test assemblies with rounded indications larger than the largest indications permitted in the radiographic standards do not meet the requirements of this specification.

12. Tension Test

12.1 One all-weld-metal tension test specimen, as specified in the Tension Test section of AWS B4.0 or AWS B4.0M, shall be machined as described and shown in Figure 2. The tensile specimen shall have a nominal diameter of 0.500 in [12.5 mm] for test assemblies 3/4 in [20 mm] thickness, a nominal diameter of 0.250 in [6.5 mm] for test assemblies 1/2 in [12 mm] thickness, and a nominal diameter of 0.160 in [4.0 mm] for test assemblies of 3/8 in [10 mm] thickness.

12.2 The specimen shall be tested in the manner described in the tension test section of the latest edition of AWS B4.0 or AWS B4.0M.

12.3 The results of the tension test shall meet the requirements specified in Table 4.

13. Bend Test

13.1 Three transverse side bend specimens (for electrodes larger than 5/64 in [2.0 mm]) or two transverse face bend specimens (for 5/64 in [2.0 mm] electrodes), as required in Table 2, shall be taken from the assembly described in 9.4.1 and shown in Figure 2. The dimensions of the specimens shall be as shown in Table 5.

13.2 The specimens shall be tested in the manner described in the Bend Test section of AWS B4.0 or B4.0M, by bending them uniformly through 180° over a 3/4 in [19 mm] radius. Any suitable jig, as specified in the Bend Test section of AWS B4.0 or B4.0M may be used. Positioning of the side bend specimens shall be such that the side of the specimen with the greater discontinuities, if any, is in tension. Positioning of the face bend specimens shall be such that the face of the weld is in tension. For both types of transverse bend specimen, the weld shall be at the center of the bend.

13.3 Each specimen, after bending, shall conform to the 3/4 in [19 mm] radius, with an appropriate allowance for spring-back, and the weld metal shall not contain fissures in excess of those permitted in Table 6 when examined with the unaided eye.

14. Method of Manufacture

The welding electrodes classified according to this specification may be manufactured by any method that will produce electrodes that meet the requirements of this specification.

15. Standard Sizes and Lengths

Standard sizes (diameter of the core wire) and lengths of electrodes and their respective tolerances are specified in 3.1 and Table 1 of AWS A5.02/A5.02M:2007

16. Core Wire and Covering

Requirements for the core wire and covering, including concentricity requirements, are specified in 3.2 of AWS A5.02/A5.02M:2007.

Table 4
All-Weld-Metal Tension Test Requirements

AWS Classification	Tensile Strength, min.		Elongation ^a Percent, min.
	ksi	MPa	
Ni			
ENi-1	60	410	20
NiCr			
ENiCr-4	110	760	—
NiCu			
ENiCu-7	70	480	30
NiCrFe			
ENiCrFe-1 ENiCrFe-2 ENiCrFe-3 ENiCrFe-7 ENiCrFe-13	80	550	30
ENiCrFe-15	90	620	30
ENiCrFe-4 ENiCrFe-12	95	650	20
ENiCrFe-9 ENiCrFe-10	95	650	25
NiCrFeSi			
ENiCrFeSi-1	90	620	20
NiMo			
ENiMo-8 ENiMo-9	95	650	25
ENiMo-1 ENiMo-3 ENiMo-7 ENiMo-10 ENiMo-11	100	690	25
NiMoCr			
ENiMoCr-1	105	720	25
NiCrMo			
ENiCrMo-11 ENiCrMo-22	85	590	25

(Continued)

Table 4 (Continued)
All-Weld-Metal Tension Test Requirements

AWS Classification	Tensile Strength, min.		Elongation ^a Percent, min.
	ksi	MPa	
NiCrMo (Continued)			
ENiCrMo-1	90	620	20
ENiCrMo-9	90	620	25
ENiCrMo-6	90	620	35
ENiCrMo-2	95	650	20
ENiCrMo-18	95	650	30
ENiCrMo-12	95	650	35
ENiCrMo-4 ENiCrMo-5 ENiCrMo-7 ENiCrMo-10 ENiCrMo-13 ENiCrMo-17	100	690	25
ENiCrMo-14	100	690	30
ENiCrMo-3	110	760	30
ENiCrMo-19	120	830	20
NiCrCoMo			
ENiCrCoMo-1	90	620	25
NiCrWMo			
ENiCrWMo-1	90	620	20

^a The elongation shall be determined from the gage length equal to four times the gage diameter.

Table 5
Dimensions of Bend Test Specimens

	Length, min.		Width, min.		Thickness, min.	
	in	mm	in	mm	in	mm
Side ^a	6	150	(b)	(b)	3/8	9.5
Face ^a	6	150	1-1/2	38	3/8	9.5

^aThe radius of the corners of the specimen shall be 1/8 in [3.2 mm] maximum.

^bThe width of the specimen is the thickness of the test assembly from which the specimen is taken (see Figure 2).

Table 6
Bend Test Requirements^a

AWS Classification	Fissures Permitted				
	Electrode Size		Maximum Number ^b	Maximum Length ^c	
	in	mm		in	mm
ENi-1	5/64	2.0	3	1/8	3
	3/32	2.4 ^d			
	—	2.5			
	1/8	3.2			
	5/32	4.0	4	1/8	3
	3/16	4.8 ^d			
	—	5.0			
ENiCu-7	5/64	2.0	3	3/32	2.5
	3/32	2.4 ^d			
	—	2.5			
	1/8	3.2			
	5/32	4.0	4	3/32	2.5
	3/16	4.8 ^d			
	—	5.0			
	1/4	6.4 ^d			
ENiCrFe-1	ENiCrFe-2	$\left\{ \begin{array}{l} 5/64 \\ 3/32 \\ — \\ 1/8 \\ 5/32 \\ 3/16 \\ — \end{array} \right\}$	3	3/32	2.5
ENiCrFe-4	ENiCrFe-7				
ENiCrFe-9	ENiCrFe-10				
ENiCrFe-12	ENiCrFe-13				
ENiCrFe-15	ENiCrFeSi-1				
ENiMo-1	ENiMo-3				
ENiMo-7	ENiMo-8				
ENiMo-9	ENiMo-10				
ENiMo-11	ENiMoCr-1				
ENiCrMo-1	ENiCrMo-2				
ENiCrMo-3	ENiCrMo-4				
ENiCrMo-5	ENiCrMo-6				
ENiCrMo-7	ENiCrMo-9				
ENiCrMo-10	ENiCrMo-11				
ENiCrMo-12	ENiCrMo-13				
ENiCrMo-14	ENiCrMo-17				
ENiCrMo-18	ENiCrMo-19				
ENiCrMo-22	ENiCrCoMo-1				
ENiCrWMo-1					
ENiCrFe-3		$\left\{ \begin{array}{l} 5/64 \\ 3/32 \\ — \\ 1/8 \\ 5/32 \\ 3/16 \\ — \end{array} \right\}$	2	3/32	2.5

^a These requirements apply to both side and face-bend specimens.

^b The value shown is the maximum number of fissures permitted in the weld metal on the tension side of each bend specimen. The sizes of the fissures are defined in Note c.

^c The number of fissures referred to in Note b is for fissures between 1/64 in [0.4 mm] and the length shown in the last column of the table. Those less than 1/64 in [0.4 mm] in length and those on the corners of the specimens shall be disregarded. Bend specimens with fissures longer than the length shown do not meet the requirements of this specification.

^d Metric sizes not shown in ISO 544.

17. Exposed Core

17.1 Requirements for the grip end of each electrode are specified in 3.3.1 of AWS A5.02/A5.02M:2007.

17.2 Requirements for the arc end of each electrode are specified in 3.3.2 of AWS A5.02/A5.02M:2007.

18. Electrode Identification

All electrodes shall be identified as follows:

18.1 At least one legible imprint of the AWS electrode classification shall be applied to the electrode covering starting within 2-1/2 in [65 mm] of the grip end of the electrode. Additionally, the numerical classification number from ISO 14172 may be applied as a reference designation, provided the requirements of ISO 14172 are satisfied (see A2.4 and Table A.1).

18.2 The numbers and letters of the imprint shall be per 3.4.2 of AWS A5.02/A5.02M:2007.

18.3 The ink used for imprinting shall be per 3.4.3 of AWS A5.02/A5.02M:2007.

18.4 The prefix letter "E" in the electrode classification may be omitted from the imprint.

19. Packaging

19.1 Electrodes shall be packaged per 3.5.1 of AWS A5.02/A5.02M:2007.

19.2 Package weights shall be per 3.5.2 of AWS A5.02/A5.02M:2007.

20. Marking of Packages

20.1 The product information specified in 3.6 of AWS A5.02/A5.02M:2007 (as a minimum) shall be legibly marked on the outside of each unit package.

20.2 The appropriate precautionary information shall be per 3.6.2 of AWS A5.02/A5.02M:2007.

Annex A (Informative)

Guide to AWS Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding

This annex is not part of this standard but is included for informational purposes only.

A1. Introduction

The purpose of this guide is to correlate the electrode classifications with their intended applications so the specification can be used effectively. Reference to appropriate base metal specifications is made whenever that can be done and when it would be helpful. Such references are intended only as examples rather than complete listings of the base metals for which each filler metal is suitable.

A2. Classification System

A2.1 The system for identifying the electrode classifications in this specification follows the standard pattern used in other AWS filler metal specifications. The letter “E” at the beginning of each classification designation stands for electrode.

A2.2 Since the electrodes are classified according to the chemical composition of the weld metal they deposit, the chemical symbol “Ni” appears immediately after the “E” as a means of identifying the electrodes as nickel-base alloys. The other symbols (Cr, Cu, Fe, Mo, Si, W, and Co) in the designations are intended to group the electrodes according to their principal alloying elements. The individual designations are made up of these symbols and a number at the end of the designation (ENiMo-1 and ENiMo-3, for example). These numbers separate one composition from another, within a group, and are not repeated within that group.

A2.3 Request for Filler Metal Classification

(1) When a filler metal cannot be classified other than as a “G” classification, a manufacturer may request that a new classification be established. The manufacturer shall do this using the following procedure:

If a manufacturer elects to use a “G” classification, the AWS A5 Committee on Filler Metals and Allied Materials recommends that the manufacturer still request that a new classification be established, as long as the filler metal is commercially available.

(2) A request to establish a new filler metal classification must be submitted in writing. The request needs to provide sufficient detail to permit the AWS A5 Committee on Filler Metals and Allied Materials and the relevant subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

- (a) A declaration that the new classification will be offered for sale commercially.
- (b) All classification requirements as given for existing classifications, such as, chemical composition ranges, mechanical property requirements, and usability test requirements.
- (c) Any conditions for conducting the tests used to demonstrate that the filler metal meets the classification requirements. (It would be sufficient, for example, to state that welding conditions are the same as for other classifications.)
- (d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the Annex).

(e) Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.

(f) A request for a new classification without the above information will be considered incomplete. The Secretary will return the request to the requester for further information.

(3) In order to comply with the AWS Policy on Patented Items, Trademarks, and Restraint of Trade, if the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester shall disclose this. The affected classification shall be identified in all drafts and eventually the published standard identifying the patent owner. The requester shall also provide written assurance to AWS that:

(a) No patent rights will be enforced against anyone using the patent to comply with the standard, or

(b) The owner will make licenses available to anyone wishing to use the patent to comply with the standard, without compensation or for reasonable rates, with reasonable terms and conditions demonstrably free of any unfair competition.

The status for the patent shall be checked before publication of the document and the patent information included in the document will be updated as appropriate.

Neither AWS, the Committee on Filler Metals and Allied Materials, nor the relevant Subcommittee is required to consider the validity of any patent or patent application.

The published standard shall include a note as follows:

“NOTE: The user’s attention is called to the possibility that compliance with this standard may require use of an invention covered by patent rights. By publication of this standard, no position is taken with respect to the validity of any such claim(s) or of any patent rights in connection therewith. If a patent holder has filed a statement of willingness to grant a license under these rights on reasonable and nondiscriminatory terms and conditions to applicants desiring to obtain such a license, then details may be obtained from the standards developer.”

(4) The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters. Upon receipt of the request, the Secretary will:

(a) Assign an identifying number to the request. This number will include the date the request was received.

(b) Confirm receipt of the request and give the identification number to the person who made the request.

(c) Send a copy of the request to the Chair of the Committee on Filler Metals and Allied Materials and the Chair of the particular Subcommittee involved.

(d) File the original request.

(e) Add the request to the log of outstanding requests.

(5) All necessary action on each request will be completed as soon as possible. If more than 12 months lapse, the Secretary shall inform the requestor of the status of the request, with copies to the Chairs of the Committee and of the Subcommittee. Requests still outstanding after 18 months shall be considered not to have been answered in a “timely manner” and the Secretary shall report these to the Chair of the Committee on Filler Metals and Allied Materials, for action.

(6) The Secretary shall include a copy of the log of all requests pending and those completed during the preceding year with the agenda for each AWS A5 Committee on Filler Metals and Allied Materials meeting. Any other publication of requests that have been completed will be at the option of the American Welding Society as deemed appropriate.

A2.4 From an application point of view, the electrode classifications in this specification have corresponding classifications in AWS A5.14/A5.14M, *Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods*, for those cases in which there is a corresponding application for a bare electrode or rod (ER). Table A.1 correlates the covered electrode classifications in this edition with the corresponding ER classification in AWS A5.14/A5.14M. It also lists the current designation for each classification as it is given in a prominent and pertinent military specification, when such a designation exists.

Table A.1
Comparison of Classifications^a

Present AWS Classification	UNS Number	Military Designation ^b	Corresponding A5.14/A5.14M ^c	ISO 14172 Designation
ENi-1	W82141	4N11	ERNi-1	E Ni 2061
ENiCr-4	W86172	—	ERNiCr-4	E Ni 6172
ENiCu-7	W84190	9N10	ERNiCu-7	E Ni 4060
ENiCrFe-1	W86132	3N12	ERNiCrFe-5	E Ni 6062
ENiCrFe-2	W86133	4N1A	ERNiCrFe-6	E Ni 6133
ENiCrFe-3	W86182	8N12	ERNiCr-3	E Ni 6182
ENiCrFe-4	W86134	—	—	E Ni 6093
ENiCrFe-7	W86152	—	ERNiCrFe-7	E Ni 6152
ENiCrFe-9	W86094	—	—	E Ni 6094
ENiCrFe-10	W86095	—	—	E Ni 6095
ENiCrFe-12	W86025	—	ERNiCrFe-12	E Ni 6025
ENiCrFe-13	W86155	—	ERNiCrFe-13	—
ENiCrFe-15	N06056	—	—	—
ENiCrFeSi-1	W86045	—	ERNiCrFeSi-1	E Ni 6045
ENiMo-1	W80001	3N1B	ERNiMo-1	E Ni 1001
ENiMo-3	W80004	4N1W	ERNiMo-3	E Ni 1004
ENiMo-7	W80665	—	ERNiMo-7	E Ni 1066
ENiMo-8	W80008	—	ERNiMo-8	E Ni 1008
ENiMo-9	W80009	—	ERNiMo-9	E Ni 1009
ENiMo-10	W80675	—	ERNiMo-10	E Ni 1067
ENiMo-11	W80629	—	ERNiMo-11	E Ni 1069
ENiMoCr-1	N10362	—	—	—
ENiCrMo-1	W86007	—	ERNiCrMo-1	E Ni 6007
ENiCrMo-2	W86002	—	ERNiCrMo-2	E Ni 6002
ENiCrMo-3	W86112	1N12	ERNiCrMo-3	E Ni 6625
ENiCrMo-4	W80276	—	ERNiCrMo-4	E Ni 6276
ENiCrMo-5	W80002	3N1C	—	E Ni 6275
ENiCrMo-6	W86620	—	—	E Ni 6620
ENiCrMo-7	W86455	—	ERNiCrMo-7	E Ni 6455
ENiCrMo-9	W86985	—	ERNiCrMo-9	E Ni 6985
ENiCrMo-10	W86022	—	ERNiCrMo-10	E Ni 6022
ENiCrMo-11	W86030	—	ERNiCrMo-11	E Ni 6030
ENiCrMo-12	W86032	—	—	E Ni 6627
ENiCrMo-13	W86059	—	ERNiCrMo-13	E Ni 6059
ENiCrMo-14	W86026	—	ERNiCrMo-14	E Ni 6686
ENiCrMo-17	W86200	—	ERNiCrMo-17	E Ni 6200
ENiCrMo-18	W86650	—	ERNiCrMo-18	E Ni 6650
ENiCrMo-19	W86058	—	ERNiCrMo-19	E Ni 6058
ENiCrMo-22	W86035	—	ERNiCrMo-22	—
ENiCrCoMo-1	W86117	—	ERNiCrCoMo-1	E Ni 6117
ENiCrWMo-1	W86231	—	ERNiCrWMo-1	E Ni 6231

^a The requirements for equivalent classifications are not necessarily identical in every respect.

^b Designations are from MIL-E-22200/3, *Electrodes, Welding, Covered: Nickel Base Alloy; and Cobalt Base Alloy*.

^c AWS A5.14/A5.14M:2018, *Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods*.

A2.5 An international system for designating welding filler metals developed by the International Institute of Welding (IIW) has been adopted in many ISO specifications. Table A.1 also shows those used in ISO 14172 specification for comparison with comparable classifications in this specification.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01M/A5.01 (ISO 14344 MOD), *Welding Consumables—Procurement of Filler Metals and Fluxes*, as the specification states. Any testing a purchaser requires of the supplier, for material shipped in accordance with this specification, needs to be clearly stated in the purchase order, according to the provisions of AWS A5.01M/A5.01 (ISO 14344 MOD). In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing the supplier normally conducts on material of that classification, as specified in Schedule F, Table 1, of AWS A5.01M/A5.01 (ISO 14344 MOD). Testing in accordance with any other schedule in that table must be specifically required in the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product, or the classification on the product itself, constitutes the supplier's (manufacturer's) *certification* that the product meets all of the requirements of the specification. The only testing requirement implicit in this *certification* is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that the material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation. *Certification* is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the certification required by the specification is the classification test of "representative material" cited above, and the "Manufacturer's Quality Assurance System" in AWS A5.01M/A5.01 (ISO 14344 MOD).

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes in the atmosphere to which welders and welding operators are exposed during welding:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling);
- (2) Number of welders and welding operators working in that space;
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes involved;
- (4) The proximity of the welders or welding operators to the fumes as they issue from the welding zone, and to the gases and dust in the space in which they are working; and
- (5) The ventilation provided to the space in which the welding is done.

A5.2 American National Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the section of that document dealing with ventilation. Further details about ventilation can be found in AWS F3.2.

A6. Welding Considerations

A6.1 Before welding or heating any nickel-base alloy, the material must be clean. Oil, grease, paint, lubricants, marking pencils, temperature-indicating materials, threading compounds, and other such materials frequently contain sulfur, lead, or silver, which may cause cracking (embrittlement) of the base metal or the weld metal if present during welding or heating.

A6.2 Electrodes of some of the classifications are used for dissimilar metal welds. When making such welds, it is important to obtain as little dilution as possible from the dissimilar metal member (steel, for example). This can be done by traveling slowly to deposit a thicker bead and to dissipate the energy of the arc against the molten weld metal or the nickel base metal, rather than the dissimilar metal member.

A6.3 Most of the electrodes in this specification are intended to be used with DCEP (Direct Current, Electrode Positive) polarity. Some electrodes may be designed to also operate on alternating current which makes them desirable for minimizing arc blow. The electrode manufacturer should be consulted to determine if a particular product is designed to be used with alternating current.

A7. Description and Intended Use of Electrodes

A7.1 ENi-1 Classification. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 95 Ni and 2.5 Ti. Electrodes of this classification are used for welding wrought and cast forms of commercially pure nickel to themselves and to steel (i.e., joining nickel to steel and surfacing steel with nickel). Typical specifications for this nickel base metal are ASTM B160, B161, B162, and B163, all of which have UNS Number N02200 or N02201. Electrodes through the 1/8 in [3.2 mm] size can be used in all positions. Electrodes larger than that are used only in the horizontal and flat positions.

A7.2 ENiCr-4 Classification. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 49.5 Ni, 49 Cr and 1.5 Nb plus Ta. These are primarily used to weld cast grade ASTM A560. ENiCr-4 is resistant to carburizing furnace atmospheres and fuel ash corrosion which occurs when burning low grade heavy fuels. ENiCr-4 is scale resistant up to 2100°F [1150°C].

A7.3 ENiCu-7 Classification. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 66 Ni, 30 Cu, 3 Mn, and 1 Fe. Electrodes of this classification are used for welding nickel-copper alloys to themselves and to steel, for welding the clad side of joints in steel clad with a nickel-copper alloy, and for surfacing steel with nickel-copper alloy weld metal. Typical specifications for the nickel-copper base metal are ASTM B127, B163, B164, and B165, all of which have UNS Number N04400. Electrodes through the 1/8 in [3.2 mm] size can be used for welding in all positions. Electrodes larger than that are used only in the flat and horizontal positions. The weld metal is suitable for service both in the as-welded condition and after an appropriate postweld heat treatment. Qualification tests should be conducted beforehand to make certain the necessary properties can be obtained after the particular heat treatment is employed.

A7.4 ENiCrFe-X Classifications

A7.4.1 ENiCrFe-1. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 70 Ni, 15 Cr, 8 Fe, 3.5 Mn, and 2.5 Nb plus Ta. Electrodes of this classification are used for welding nickel-chromium-iron alloys, for the clad side of joints in steel clad with nickel-chromium-iron alloy, and for surfacing steel with nickel-chromium-iron weld metal. The electrodes may be used for applications at temperatures ranging from cryogenic to around 1800°F [980°C]. However, for temperatures above 1500°F [820°C], weld metal produced by these electrodes does not exhibit optimum oxidation resistance and strength. These electrodes are also suitable for joining steel to nickel-base alloys. Typical specifications for the nickel-chromium-iron base metal are ASTM B163, B166, B167, and B168, all of which have UNS Number N06600. Electrodes through the 1/8 in [3.2 mm] size can be used for welding in all positions. Electrodes larger than that are used only in the horizontal and flat positions.

A7.4.2 ENiCrFe-2. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 70 Ni, 15 Cr, 8 Fe, 2 Mn, 2 Nb plus Ta, and 1.5 Mo. Electrodes of this classification are used for welding nickel-chromium-iron alloys, 9% nickel steel, and a variety of dissimilar metal joints (involving carbon steel, stainless steel, nickel, and nickel-base alloys). The base metals can be wrought or cast (welding grade), or both. The electrodes may be used for applications at temperatures ranging from cryogenic to around 1800°F [980°C]. However, for temperatures above 1500°F [820°C], weld metal produced by ENiCrFe-2 does not exhibit optimum oxidation resistance and strength. Typical specifications for the nickel-chromium-iron base metal are ASTM B163, B166, B167, and B168, all of which have UNS Number N06600. Electrodes through the 1/8 in [3.2 mm] size can be used for welding in all positions. Electrodes larger than that are used only in the horizontal and flat positions.

A7.4.3 ENiCrFe-3. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 65 Ni, 15 Cr, 8 Fe, 7.5 Mn, and 2 Nb plus Ta. Electrodes of this classification are used for welding nickel-chromium-iron alloys, for welding the clad side of joints on steel clad with nickel-chromium-iron alloy, and for surfacing steel with nickel-chromium-iron weld metal, when comparatively high manganese contents are not detrimental. The electrode may be used for applications at temperatures ranging from cryogenic to about 900°F [480°C]. Typical specifications for the nickel-chromium-iron base metal are ASTM B163, B166, B167, and B168, all of which have UNS Number N06600.

These electrodes can also be used for welding steel to other nickel-base alloys. Fewer fissures are permitted on the bend test for this weld metal than for weld metal of the ENiCrFe-1 and ENiCrFe-2 classifications. Electrodes through the 1/8 in [3.2 mm] size can be used for welding in all positions. Electrodes larger than that are used only in the horizontal and flat positions.

A7.4.4 ENiCrFe-4. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 70 Ni, 15 Cr, 8 Fe, 2.5 Mn, 2.5 Nb plus Ta, and 2.5 Mo. Electrodes of this classification are used for welding 9% nickel steel. Typical specifications for the 9% nickel steel base metal are ASTM A333, A334, A353, A522, and A553, all of which have UNS Number K81340. The strength of the weld metal is higher than that of the ENiCrFe-2 classification.

A7.4.5 ENiCrFe-7. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 55 Ni, 29 Cr, 9.5 Fe, 3 Mn, and 1.5 Nb plus Ta. Electrodes of this classification are used for welding the nickel-chromium-iron alloy with UNS Number N06690. Typical specifications for the nickel-chromium-iron base metal are ASTM B166, B167, and B168. The electrodes may also be used for the welding of nickel-chromium-iron alloys to steels and stainless steels, and for corrosion-resistant overlays on steels. Specification of values for boron and zirconium are helpful in reducing the tendency for ductility dip cracking. Electrodes through the 1/8 in [3.2 mm] size can be used for welding in all positions. Electrodes larger than that are used only in the flat and horizontal positions.

A7.4.6 ENiCrFe-9. The nominal composition (wt %) of electrodes of this classification is 70 Ni, 14 Cr, 9 Fe, 1.5 Nb plus Ta, and 4 Mo. Electrodes of this classification are used for welding 9% nickel steel. Typical specifications for the 9% nickel steel base metal are ASTM A333, A334, A353, A522, and A553, all of which have UNS Number K81340. Electrodes through the 5/32 in [4.0 mm] size can be used for welding in all positions. Electrodes larger than that are used only in the flat and horizontal positions.

A7.4.7 ENiCrFe-10. The nominal composition (wt %) of electrodes of this classification is 65 Ni, 15 Cr, 10 Fe, 1.5 Nb plus Ta, 3 Mo, and 2 W. Electrodes of this classification are used for welding 9% nickel steel. Typical specifications for the 9% nickel steel base metal are ASTM A333, A334, A353, A522, and A553, all of which have UNS Number K81340. Electrodes through the 5/32 in [4.0 mm] size can be used for welding in all positions. Electrodes larger than that are used only in the flat and horizontal positions.

A7.4.8 ENiCrFe-12. The nominal chemical composition (wt %) of weld metal produced by electrodes of this classification is 63 Ni, 25 Cr, 9.5 Fe, and 2.1 Al. Electrodes of this classification are used for welding UNS Number N06025, welding nickel-chromium-iron to steel and to other nickel base alloys. Typical specifications for the base metal are ASTM B163, B166, B167, B168, B366, B516, B517, B546, and B564, all of which have UNS Number N06025.

A7.4.9 ENiCrFe-13. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 55.5 Ni, 29 Cr, 8.5 Fe, 3.5 Mo, and 2.5 Nb plus Ta. Electrodes of this composition are used for welding nickel-chromium-iron alloy to themselves, to steels, and to weld clad steels with the nickel-chromium-iron alloy using the SMAW process. This classification provides improved resistance to ductility dip cracking under conditions of high restraint when compared to products offered under ENiCrFe-7. Electrodes through the 1/8 in [3.2 mm] size can be used for welding in all positions. Electrodes larger than that are used only in the flat and horizontal positions. Typical specifications for nickel-chromium-iron base metals are ASTM B163, B166, B167, and B168, all of which have UNS number N06690.

A7.4.10 ENiCrFe-15. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 63 Ni, 27 Cr, 3 Mn, 2.5 Nb, and 2.5 Fe. Electrodes of this classification are used for welding nickel-chromium-iron alloy 690 (ASTM B163, B166, B167, B168, and B564 having UNS number N06690) to itself, to steels, and weld overlay steels in nuclear pressure vessel applications. Weld metal of this composition is resistant to both ductility dip cracking and solidification cracking. It also shows resistance to primary water stress corrosion cracking (PWSCC) in intended service conditions. Electrodes through the 1/8 in [3.2 mm] size can be used for welding in all positions. Electrodes larger than that are used only in the flat and horizontal positions.

A7.5 ENiCrFeSi-1 Classification. The nominal chemical composition (wt %) of weld metal produced by electrodes of this classification is 46 Ni, 28 Cr, 23 Fe, and 2.75 Si. Electrodes of this classification are used for welding UNS Number N06045 and welding nickel-chromium-iron to steel and to other nickel base alloys. Typical specifications for the base metal are ASTM B163, B166, B167, B168, B366, B516, B517, B546, and B564, all of which have UNS Number N06045.

A7.6 ENiMo-X Classifications

A7.6.1 ENiMo-1. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 67 Ni, 28 Mo, and 5 Fe. Electrodes of the ENiMo-1 classification are used for welding nickel-molybdenum alloys as well as the clad side of joints in steel clad with a nickel-molybdenum alloy, and for welding nickel-molybdenum alloys to steel and to other nickel-base alloys. Typical specifications for the nickel-molybdenum base metal are ASTM B333, B335, B619, B622, and B626, all of which have UNS Number N10001. ENiMo-1 electrodes are normally used only in the flat position.

A7.6.2 ENiMo-3. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 63 Ni, 25 Mo, 5.5 Fe, and 4 Cr. Electrodes of the ENiMo-3 classification are used for welding dissimilar metal combinations of nickel-, cobalt-, and iron-base alloys. These electrodes are normally used only in the flat position.

A7.6.3 ENiMo-7. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 69 Ni, 28 Mo, 1.5 Fe, and 1.5 Mn. Electrodes of the ENiMo-7 classification have controlled low levels of carbon, iron, and cobalt and are used for welding nickel-molybdenum alloys, for welding the clad side of joints in steel clad with a nickel-molybdenum alloy, and for welding nickel-molybdenum alloys to steel and to other nickel-base alloys. Typical specifications for the nickel-molybdenum base metals are ASTM B333, B335, B619, B622, and B626, all of which have UNS Number N10665. These electrodes are normally used only in the flat position.

A7.6.4 ENiMo-8. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 70 Ni, 18 Mo, 7 Fe, 3 W, and 2 Cr. Electrodes of this classification are used for welding 9% nickel steel, but they can be used in other applications as well. Typical specifications for the 9% nickel steel base metal are ASTM A333, A334, A353, A522, and A553, all of which have UNS Number K81340. Electrodes through the 5/32 in [4.0 mm] size can be used for welding in all positions. Electrodes larger than that are used only in the flat and horizontal positions.

A7.6.5 ENiMo-9. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 70 Ni, 19 Mo, 3 Fe, 3 W, and 1 Cu. Electrodes of this classification are used for welding 9% nickel steel, but they can be used in other applications as well. Typical specifications for the 9% nickel steel base metal are ASTM A333, A334, A353, A522, and A553, all of which have UNS Number K81340. Electrodes through the 5/32 in [4.0 mm] size can be used for welding in all positions. Electrodes larger than that are used only in the flat and horizontal positions.

A7.6.6 ENiMo-10. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 69 Ni, 28 Mo, 1.5 Cr, 1.5 Fe, and low levels of carbon. These filler materials are used for welding nickel-molybdenum alloys (UNS numbers N10665 and N10675), for welding the clad side of joints in steel clad with a nickel-molybdenum alloy, and for welding nickel-molybdenum alloys to steel and to other nickel-base alloys. Typical specifications for the nickel-molybdenum base metals are ASTM B333, B335, B366, B564, B619, B622, and B626. These coated electrodes are normally used in the flat position.

A7.6.7 ENiMo-11. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 67 Ni, 28 Mo, 3 Fe, 1.3 Cr, and low C. The filler materials are used for welding nickel-molybdenum alloys (UNS Numbers N10665 and N10629), for welding the clad side of joints in steel clad with nickel-molybdenum alloy, and for welding nickel-molybdenum alloys to steel and to other nickel-base alloys. The ASTM specifications for the nickel-molybdenum alloy base metals are B333, B335, B366, B564, B619, B622, and B629. These electrodes are generally used in the flat position.

A7.7 ENiMoCr-1. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 62 Ni, 22 Mo, and 15 Cr. Electrodes of this classification are used for welding nickel-molybdenum-chromium alloys, for welding the clad side of joints in steel clad with nickel-molybdenum-chromium alloy, and for welding nickel-molybdenum-chromium alloys to steel and to other nickel base alloys. Typical specifications for this nickel-molybdenum-chromium alloy are ASTM B574, B575, B619, B622, and B626, all of which have UNS number N10362. These electrodes are normally used only in the flat position.

A7.8 ENiCrMo-X Classifications

A7.8.1 ENiCrMo-1. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 43 Ni, 22 Cr, 19.5 Fe, 6.5 Mo, 2 Nb plus Ta, 2 Cu, and 1.5 Mn. Electrodes of this classification are used for welding nickel-chromium-molybdenum alloys, for welding the clad side of joints in steel clad with nickel-chromium-molybdenum alloy, and for welding nickel-chromium-molybdenum alloy to steel and to other nickel-base alloys. Typical specifications for the nickel-chromium-molybdenum base metals are ASTM B581, B582, B619, and B622, all of which have UNS Number N06007. These electrodes are normally used only in the flat position.

A7.8.2 ENiCrMo-2. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 47 Ni, 22 Cr, 18 Fe, 9 Mo, and 1.5 Co. Electrodes of this classification are used for welding nickel-chromium-molybdenum alloys, for welding the clad side of joints in steel clad with nickel-chromium-molybdenum alloy, and for welding nickel-chromium-molybdenum alloys to steel and to other nickel-base alloys. Typical specifications for the nickel-chromium-molybdenum base metals are ASTM B435, B572, B619, B622, and B626, all of which have UNS Number N06002. These electrodes are normally used only in the flat position.

A7.8.3 ENiCrMo-3. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 60 Ni, 22 Cr, 9 Mo, 5 Fe, and 3.5 Nb plus Ta. Electrodes of this classification are used for welding nickel-chromium-molybdenum alloys to themselves and to steel, and for surfacing steel with nickel-chromium-molybdenum weld metal. These electrodes also can be used for welding nickel-base alloys to steel. The electrodes are used in applications where the temperature ranges from cryogenic to 1000°F [540°C]. Typical specifications for the nickel-chromium-molybdenum base metals are ASTM B443, B444, and B446, all of which have UNS Number N06625. Electrodes through the 1/8 in [3.2 mm] size can be used for welding in all positions. Electrodes larger than that are used only in the flat and horizontal positions.

A7.8.4 ENiCrMo-4. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 57 Ni, 16 Mo, 15.5 Cr, 5.5 Fe, 4 W, and low C. Electrodes of this classification are used for welding low-carbon nickel-chromium-molybdenum alloy, for welding the clad side of joints in steel clad with low-carbon nickel-chromium-molybdenum alloy, and for welding low-carbon nickel-chromium-molybdenum alloy to steel and to other nickel-base alloys. Typical specifications for the nickel-chromium-molybdenum base metals are ASTM B574, B575, B619, B622, and B626, all of which have UNS Number N10276. These electrodes are normally used only in the flat position.

A7.8.5 ENiCrMo-5. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 53 Ni, 16 Mo, 15.5 Cr, 5.5 Fe, and 4 W. Electrodes of this classification are used for surfacing steel clad with a nickel-chromium-molybdenum alloy. These electrodes are normally used only in the flat position.

A7.8.6 ENiCrMo-6. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 65 Ni, 14.5 Cr, 7 Fe, 7 Mo, 3 Mn, 1.5 W, and 1.5 Nb plus Ta. Electrodes of this classification are used for welding 9% nickel steel, but they can be used in other applications as well. Typical specifications for the 9% nickel steel base metal are ASTM A333, A334, A353, A522, and A553, all of which have UNS Number K81340. Electrodes through the 1/8 in [3.2 mm] size can be used for welding in all positions. Electrodes larger than that are used only in the flat and horizontal positions.

A7.8.7 ENiCrMo-7. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 65 Ni, 16 Cr, 15.5 Mo, and 1.5 Fe. Electrodes of this classification are used for welding nickel-chromium-molybdenum alloy, for the welding of the clad side of joints in steel clad with nickel-chromium-molybdenum alloy, and for joining nickel-chromium-molybdenum alloys to steel and to other nickel-base alloys. Typical specifications for the nickel-chromium-molybdenum base metals are ASTM B574, B575, B619, B622, and B626, all of which have UNS Number N06455. These electrodes normally are used only in the flat position.

A7.8.8 ENiCrMo-9. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 44 Ni, 22 Cr, 19.5 Fe, 7 Mo, 2 Co, and 2 Cu. Electrodes of this classification are used for welding nickel-chromium-molybdenum alloys, for the welding of the clad side of joints in steel clad with nickel-chromium-molybdenum alloys, and for joining nickel-chromium-molybdenum alloys to steel and to other nickel-base alloys. Typical specifications for the nickel-chromium-molybdenum base metal are ASTM B581, B582, B619, B622, and B626, all of which have UNS Number N06985. These electrodes are normally used only in the flat position.

A7.8.9 ENiCrMo-10. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 56 Ni, 22 Cr, 13 Mo, 4 Fe, and 3 W. Electrodes of this classification are used for welding nickel-chromium-molybdenum

alloys, for the welding of the clad side of joints in steel clad with nickel-chromium-molybdenum alloy, and for joining nickel-chromium-molybdenum alloys to steel and to other nickel-base alloys. Typical specifications for the nickel-chromium-molybdenum base metals are ASTM B574, B575, B619, B622, and B626, all of which have UNS Number N06022. Electrodes through the 1/8 in [3.2 mm] size can be used for welding in all positions. Electrodes larger than that are used only in the flat position.

A7.8.10 ENiCrMo-11. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 43 Ni, 30 Cr, 15 Fe, 5 Mo, 2 Co, 3 W, and 2 Cu. Electrodes of this classification are used for welding nickel-chromium-molybdenum alloys, for the welding of the clad side of joints in steel clad with nickel-chromium-molybdenum alloys, and for joining nickel-chromium-molybdenum alloys to steel and to other nickel-base alloys. Typical specifications for the nickel-chromium-molybdenum base metal are ASTM B581, B582, B619, B622, and B626, all of which have UNS Number N06030. These electrodes are normally used only in the flat position.

A7.8.11 ENiCrMo-12. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 58 Ni, 21.5 Cr, 9.5 Mo, 3 Fe, and 2 Nb plus Ta. Electrodes of this classification are used for welding chromium-nickel-molybdenum austenitic stainless steels to themselves, to duplex ferritic-austenitic stainless steels, to nickel-chromium-molybdenum alloys, and to steel. The ENiCrMo-12 composition is balanced to provide corrosion-resistant welds for use at temperatures below the creep range of highly alloyed austenitic stainless steels. Typical specifications for the chromium-nickel-molybdenum stainless steel base metals are ASTM A240, A167, A182, A249, A276, A312, A358, A473, and A479, most particularly the grade UNS S31254 contained in those specifications. Electrodes through the 1/8 in [3.2 mm] size can be used for welding in all positions. Electrodes larger than that can be used only for welding in the flat and horizontal positions.

A7.8.12 ENiCrMo-13. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 59 Ni, 23 Cr, 16 Mo, 1 Fe, and low C. Electrodes of this classification are used to weld low-carbon nickel-chromium-molybdenum alloys, for welding the clad side of joints in steel clad with low-carbon nickel-chromium-molybdenum alloys, and for welding low carbon nickel-chromium-molybdenum alloy to steel and to other nickel-base alloys. Typical specifications for the nickel-chromium-molybdenum base metals are ASTM B574, B575, B619, B622, and B626, all of which have UNS Number N06059.

A7.8.13 ENiCrMo-14. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 57 Ni, 21 Cr, 16 Mo, and 4 W. Electrodes of this classification are used to weld nickel-chromium-molybdenum alloys (UNS Numbers N06686, N06625, N10276, and N06022) that are used in severe corrosion applications where resistance to reducing, oxidizing, crevice and pitting conditions is required. It is recommended for corrosion-resistant overlay cladding of iron-base metals for the same environments.

A7.8.14 ENiCrMo-17. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 59 Ni, 23 Cr, 16 Mo, and 1.6 Cu. Electrodes of this classification are used for welding and joining nickel-chromium-molybdenum alloys, and for welding the clad side of joints in steel clad with nickel-chromium-molybdenum alloy to steel and to other nickel-base alloys. Electrodes through the 1/8 in [3.2mm] size can be used for welding in all positions. Electrodes larger than that are used only in the flat position.

A7.8.15 ENiCrMo-18. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 50 Ni, 20 Cr, 13.5 Fe, 11.5 Mo, and 1.5 W. Electrodes of this classification are used for welding nickel-chromium-molybdenum alloys like UNS Number N06625; for welding the clad side of joints in steel clad with nickel-chromium-molybdenum alloy; for joining nickel-chromium-molybdenum alloys to steel and to other nickel-base alloys; and for joining some other nickel-chromium-molybdenum alloys, such as UNS Numbers N06625, N08825, N06985, N08020, N08926, and N08031. Electrodes through the 1/8 in [3.2 mm] size can be used for welding in all positions. Electrodes larger than that are used only in the flat position.

A7.8.16 ENiCrMo-19. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 58 Ni, 21 Cr, 20 Mo, and 1 Fe. Electrodes of this classification are used for welding nickel-chromium-molybdenum alloys, for welding of the clad side of joints in steel clad with nickel-chromium-molybdenum alloy, and for joining nickel-chromium-molybdenum alloys to steel and to other nickel-base alloys. Typical specifications for the nickel-chromium-molybdenum base metals are B574, B575, B366, B564, B619, B622, and B626 all of which are UNS Number N06058. Electrodes through the 1/8 in [3.2mm] size can be used for welding in all positions. Electrodes larger than that are used only in the flat position.

A7.8.17 ENiCrMo-22. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 58 Ni, 33 Cr, and 8 Mo. Electrodes of this classification are used for welding nickel-chromium-molybdenum alloys, for welding the clad side of joints in steel clad with nickel-chromium-molybdenum alloy, and for welding nickel-chromium-molybdenum alloys to steel and other nickel-base alloys. Typical specifications for these nickel-chromium-molybdenum base metals are ASTM B574, B575, B619, B622, and B626, all of which have UNS Number N06035. These electrodes are normally used only in the flat position.

A7.9 ENiCrCoMo-1 Classification. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 52 Ni, 23 Cr, 12 Co, 9 Mo, 2 Fe, and 1.5 Mn. Electrodes of this classification are used for welding nickel-chromium-cobalt-molybdenum alloys (UNS Number N06617) to themselves and to steel, and for surfacing steel with nickel-chromium-cobalt-molybdenum weld metal. The electrodes are also used for applications where optimum strength and oxidation resistance are required above 1500°F [820°C] up to 2100°F [1150°C], especially when welding on base metals of nickel-iron-chromium alloys. Electrodes through the 1/8 in [3.2 mm] size can be used for welding in all positions. Larger electrodes are used for welding in the flat or horizontal positions.

A7.10 ENiCrWMo-1 Classification. The nominal composition (wt %) of weld metal produced by electrodes of this classification is 57 Ni, 22 Cr, 14 W, <5 Co, <3 Fe, and 2 Mo. Electrodes of this classification are used for welding nickel-chromium-tungsten-molybdenum-lanthanum alloy ASTM B366, B435, B564, and B572 having UNS Number N06230. Electrodes of this classification are generally used only in the flat position.

A8. Special Tests

It is recognized that supplementary tests may be required for certain applications. In such cases, tests to determine specific properties such as corrosion resistance, scaling resistance or strength at elevated or cryogenic temperatures may be required.

AWS A5.01M/A5.01 (ISO 14344 MOD) contains provisions for ordering such tests. This section is included for the guidance of those who desire to specify such special tests. Those tests may be conducted as agreed upon between the purchaser and supplier.

A8.1 Corrosion or Scaling Tests

A8.1.1 Although welds produced with electrodes in this specification are commonly used in corrosion and heat-resisting applications, tests for those properties are not included in the specification. When required for a particular application, tests can be conducted on specimens taken from either a weld pad or a welded joint. Specimens from a joint are suitable for qualifying the welding procedure (for a specific application involving corrosion or oxidation resistance), but not for qualifying the electrode.

Tests on specimens from a joint have the disadvantage of being a combined test of the properties of the weld metal, the heat-affected zone (HAZ), and the unaffected base metal. With them, it is more difficult to obtain reproducible data (when a difference exists in the properties of the metal in the various parts of the specimen). Specimens taken from a joint have the advantage of being able to duplicate the joint design and the welding sequence planned for fabrication.

A8.1.2 Specimens for testing the corrosion or oxidation resistance of the weld metal alone are prepared by following the procedure outlined in 9.3 and Figure 1 of the specification. The pad size should be at least 3/4 in [19 mm] in height, 2-1/2 in [65 mm] in width, and $1 + (5/8 \times n)$ in [$25 + (16 \times n)$ mm] in length, where n represents the number of specimens required from the pad. Specimens measuring $1/2 \times 2 \times 1/4$ in [$13 \times 50 \times 6.4$ mm] are machined from the top of the pad in a manner such that the 2 in [50 mm] dimension of the specimen is parallel with the 2-1/2 in [65 mm] dimension of the pad and the 1/2 in [13 mm] dimension is parallel with the length of the pad.

A8.1.3 The heat treatment, surface finish, and marking of the specimens prior to testing should be in accordance with standard practices for tests of similar alloys in the wrought or cast forms. The testing procedures should correspond to ASTM G4, *Standard Guide for Conducting Corrosion Tests in Field Applications*.

Table A.2
Discontinued Classifications

Discontinued Classification	Last Year Published
ENiCu-1	1969
ENiCu-2	1969
ENiCu-3	1964
ENiCu-4	1969
ENiCr-1	1969
ENiMo-2 ^a	1964
ENiMoCr-1 ^b	1969
ENiCuAl-1	1969

^a Reclassified as ENiMoCr-1 in 1969.

^b Reclassified as ENiCrMo-5 in 1976.

A9. Discontinued Classifications

Some classifications have been discontinued from one revision of this specification to another. This results either from changes in commercial practice or changes in the classification system used in the specification. The classifications that have been discontinued are listed in Table A.2, along with the year in which they were last included in the specification.

A10. General Safety Considerations

A10.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Annex Clause A5. Safety and health information is available from other sources, including, but not limited to Safety and Health Fact Sheets listed in A10.2, ANSI Z49.1, and applicable federal and state regulations.

A10.2 Safety and Health Fact Sheets. The Safety and Health Fact Sheets listed below are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

A10.3 AWS Safety and Health Fact Sheets Index (SHF)

No.	Title
1	<i>Fumes and Gases</i>
2	<i>Radiation</i>
3	<i>Noise</i>
4	<i>Chromium and Nickel in Welding Fume</i>
5	<i>Electrical Hazards</i>
6	<i>Fire and Explosion Prevention</i>
7	<i>Burn Protection</i>
8	<i>Mechanical Hazards</i>
9	<i>Tripping and Falling</i>
10	<i>Falling Objects</i>
11	<i>Confined Spaces</i>
12	<i>Contact Lens Wear</i>
13	<i>Ergonomics in the Welding Environment</i>
14	<i>Graphic Symbols for Precautionary Labels</i>
15	<i>Style Guidelines for Safety and Health Documents</i>
16	<i>Pacemakers and Welding</i>

No.	Title
17	<i>Electric and Magnetic Fields (EMF)</i>
18	<i>Lockout/Tagout</i>
19	<i>Laser Welding and Cutting Safety</i>
20	<i>Thermal Spraying Safety</i>
21	<i>Resistance Spot Welding</i>
22	<i>Cadmium Exposure from Welding & Allied Processes</i>
23	<i>California Proposition 65</i>
24	<i>Fluxes for Arc Welding and Brazing: Safe Handling and Use</i>
25	<i>Metal Fume Fever</i>
26	<i>Arc Viewing Distance</i>
27	<i>Thoriated Tungsten Electrodes</i>
28	<i>Oxyfuel Safety: Check Valves and Flashback Arrestors</i>
29	<i>Grounding of Portable and Vehicle Mounted Welding Generators</i>
30	<i>Cylinders: Safe Storage, Handling, and Use</i>
31	<i>Eye and Face Protection for Welding and Cutting Operations</i>
33	<i>Personal Protective Equipment (PPE) for Welding and Cutting</i>
34	<i>Coated Steels: Welding and Cutting Safety Concerns</i>
35	<i>Welding Safety in Education and Schools</i>
36	<i>Ventilation for Welding and Cutting</i>
37	<i>Selecting Gloves for Welding and Cutting</i>
38	<i>Respiratory Protection Basics for Welding Operations</i>
40	<i>Asbestos Hazards Encountered in the Welding and Cutting Environment</i>
41	<i>Combustible Dust Hazards in the Welding and Cutting Environment</i>

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

B6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

SPECIFICATION FOR TUNGSTEN AND OXIDE DISPERSED TUNGSTEN ELECTRODES FOR ARC WELDING AND CUTTING



SFA-5.12/SFA-5.12M



(25)

(Identical with AWS Specification A5.12/A5.12M:2024 (ISO 6848:2015 MOD). In case of dispute, the original AWS text applies.)

Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting

1. Scope

1.1 This standard prescribes requirements for the classification of nonconsumable tungsten electrodes for inert gas shielded arc welding, and for plasma welding, cutting, and thermal spraying.

1.2 This specification makes use of both the International System of Units (SI) and U.S. Customary Units. The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to material properties. The specification designated A5.12M uses SI Units; and the specification designated A5.12 uses U.S. Customary Units. The latter units are shown within brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing of tungsten electrodes or packaging or both under A5.12M or A5.12 specification.

1.3 Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in Annex Clauses B5 and B10.

Safety and Health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies.

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, the publications may not apply since the relevant requirements may have changed.

American Welding Society (AWS) documents:

AWS A5.01M/A5.01, *Procurement Guidelines for Consumables—Welding and Allied Processes—Flux and Gas Shielded Electrical Welding Processes*

American National Standards Institute (ANSI) document(s)

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

ASTM International (ASTM) document(s)

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

ASTM F288, *Standard Specification for Tungsten Wire for Electron Devices and Lamps*

International Organization for Standardization (ISO) document(s)

ISO 80000-1:2022, *Quantities and Units—Part 1: General*

3. Classification

3.1 The tungsten and oxide dispersed tungsten electrodes covered by this specification are classified using a system that is independent of the U.S. Customary Units and the International System of Units (SI). Classification is according to the chemical composition of the electrode as specified in Table 1. See Clause B7 for classification descriptions.

3.2 Electrodes classified under one classification shall not be classified under any other classification in this specification.

3.3 No electrode meeting the requirements of any other classification shall be classified under EWG.

3.4 The electrodes classified under this specification are intended for gas tungsten arc welding (GTAW), plasma arc welding (PAW), or plasma arc cutting (PAC), but that is not to prohibit their use with any other process for which they are found suitable.

See Clause B.2 for an explanation of the classification system.

4. Acceptance

Acceptance of the electrodes shall be in accordance with the provisions of AWS A5.01M/A5.01. See Annex B3 for further information concerning acceptance and testing of material shipped.

5. Certification

By affixing the AWS specification and classification designations to the packaging, or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification. See B4 (in Annex B) for further information concerning certification and the testing called for to meet this requirement.

6. Rounding Procedure

For the purpose of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfill the requirements for the classification under test.

7. Chemical Analysis

Chemical analysis shall be performed on specimens of the electrode being classified. Any analytical technique may be used but, in cases of dispute, reference shall be made to established published methods. The referee method shall be ASTM F288. The results of the analysis shall meet the requirements of Table 1 for the classification of electrode under test.

8. Retests

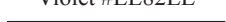
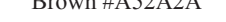
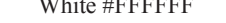
If any test fails to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Specimens for retest may be taken from the original test sample or from a new test sample. For chemical analysis, retests need only be for those specific elements that failed to meet their test requirement. If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that, during preparation or after completion of any test, it is clearly determined that prescribed or proper procedures were not followed in preparing the test specimen, or in conducting the tests, the test shall be considered invalid, without regard to whether the test was actually completed, or whether the test results met, or failed to meet, the requirement. That test shall be repeated, following proper prescribed procedures. In this case, the requirement for doubling the number of test specimens does not apply.

9. Marking

In accordance with Table 1, tungsten electrodes shall be marked on the basis of their chemical composition, with one color ring near one end of the electrode. The width of the color ring shall be at least 3 mm [1/8 in]. Such color coding shall have no adverse effect on the operation or use of the electrode. Alternatively, tungsten electrodes may have their classification symbols marked on the surface of the electrode near at least one end of the electrode.

Table 1
Chemical Composition Requirements for Tungsten Electrodes

Classification symbol (<i>ISO 6848</i> Classification)	Chemical Composition Requirements				Color code, RGB color value and color sample ^a
	Oxide addition		Impurities, mass percent	Tungsten, mass percent	
	Principal oxide	Mass percent			
EWP (WP)	None	N.A. ^b	0.1 max.	Balance	Green #008000 
EWCe-2 (<i>WCe20</i>)	CeO ₂	1.8 to 2.2	0.1 max.	Balance	Grey (formerly orange) #808080 
EWLa-1 (<i>WLa10</i>)	La ₂ O ₃	0.8 to 1.2	0.1 max.	Balance	Black #000000 
EWLa-1.5 (<i>WLa15</i>)	La ₂ O ₃	1.3 to 1.7	0.1 max.	Balance	Gold #FFD700 
EWLa-2 (<i>WLa20</i>)	La ₂ O ₃	1.8 to 2.2	0.1 max.	Balance	Blue #0000FF 
EWTh-1 (<i>WTh10</i>)	ThO ₂	0.8 to 1.2	0.1 max.	Balance	Yellow #FFFF00 
EWTh-2 (<i>WTh20</i>)	ThO ₂	1.7 to 2.2	0.1 max.	Balance	Red #FF0000 
(WTh30)	ThO ₂	2.8 to 3.2	0.1 max.	Balance	Violet #EE82EE 
EWZr-1 (<i>WZr3</i>)	ZrO ₂	0.15 to 0.50	0.1 max.	Balance	Brown #A52A2A 
EWZr-8 (WZr8)	ZrO ₂	0.7 to 0.9	0.1 max.	Balance	White #FFFFFF 
EWG	The manufacturer must identify all additions.	The manufacturer must state the <i>minimum & maximum mass percent</i> of each addition.	0.1 max.	Balance	The manufacturer may select any color not already in use.

^a RGB color values and color samples can be found at the following website: <https://www.color-hex.com>

^b N.A. = Not applicable.

Note:

¹ Intentional addition of “doping oxides” other than indicated for a particular electrode classification is prohibited.

10. Standard Sizes and Tolerances

10.1 Electrode Diameters, Lengths and Tolerances. Standard electrode diameters, lengths, and tolerances are given in Table 2. Other diameters, lengths, and tolerances may be as agreed upon between the purchaser and supplier. *Electrodes sold as a standard size must also meet the dimensional, surface finish, and identification requirements established in this specification.*

Table 2
Standard Diameters and Lengths

Size				Length			
Diameter mm	Tolerance ± mm	Diameter in	Tolerance ± in	Length mm	Tolerance mm	Length in	Tolerance ± in
0.25 ^b	0.02	0.010	0.001	50 ^b	±1.5		
0.30 ^b	0.02			75 ^b	−1.0, +2.5	3	1/16
0.50 ^b	0.05	0.020	0.002	150 ^b	−1.0, +4.0	6	1/16
1.00 ^b	0.05	0.040	0.002	175 ^b	−1.0, +6.0	7	1/8
1.50 ^b	0.05	0.060 ^a	0.002	300 ^b	−1.0, +8.0	12	1/8
1.60 ^b	0.05			450 ^b	−1.0, +8.0	18	1/8
2.00 ^b	0.05			600 ^b	−1.0, +13.0	24	1/8
2.40 ^b	0.08	0.093 (3/32)	0.003				
2.50 ^b	0.08						
3.00 ^b	0.08						
3.20 ^b	0.08	0.125 (1/8)	0.003				
4.00 ^b	0.08	0.156 (5/32)	0.003				
4.80 ^b	0.08	0.187 (3/16)	0.003				
5.00 ^b	0.08						
6.30 ^b	0.08						
6.40 ^b	0.08	0.250 (1/4)	0.003				
8.00 ^b	0.10						
10.00 ^b	0.10						

^a Although the metric size 1.6 mm [0.063 in] is closer to 1/16 in [0.0625 in], it has been common industry practice to refer to the U.S. customary size 0.060 in as 1/16 in.

^b Standard sizes and lengths in ISO 6848, though tolerances may be tighter in some cases.

10.2 Finish. Electrodes shall be supplied with a ground finish. The ground finish designates that the electrode has been cleaned of impurities after it has been centerless ground to a uniform size. It shall be supplied with a bright, polished surface. The maximum surface roughness shall be 0.8 μm [32 μin] Ra (AARH).

10.3 Electrode Straightness. The electrodes shall be straight such that any element of its surface, over a specified length, must lie between two parallel lines of a specified spacing where the two lines and the nominal axis of the electrode share a common plane, as shown in Figure 1. The specified spacing is 0.5 mm [0.020 in] over a length of 100 mm [4 in]. *For shorter electrodes, the electrode straightness shall not vary by more than 0.13 mm [0.005 in] over a length of 50 mm [2 in].*

10.4 Electrode Roundness. Electrodes shall fit through ring gages sized for their maximum allowable diameter according to Table 2.

11. Electrode Quality

The electrode surface shall be free of impurities, undesirable films, foreign inclusions, slivers, cracks, scale and other defects. Electrodes shall be internally free of foreign inclusions or anything else that would adversely affect the operation of the electrode. Oxide additions shall be sufficiently uniformly distributed throughout the electrode so that the operation of the electrode is not adversely affected.

12. Packaging

12.1 Marking of Packages. The following information, as a minimum, shall be legibly marked so as to be visible from the outside of each package:

- the number of this Standard, i.e., AWS A5.12M/A5.12 (ISO 6848:2015 MOD);
- electrode classification symbol in accordance with Table 1;

- c) electrode diameter;
- d) electrode length;
- e) net quantity of electrodes;
- f) supplier's name and trade designation;
- g) lot, control, or heat number;
- h) *for G classification electrodes, the minimum and maximum weight percent of each oxide addition.*

12.2 Packing. Tungsten electrodes shall be packed so that their surfaces are protected from all damage or staining when they are properly transported and stored.

12.3 Marking of Overpacking. Marking of any, or all, overpacking of unit packages with items listed in 12.1 shall be optional with the manufacturer.

12.4 Warning Label. The appropriate precautionary information as given in ANSI Z49.1 or its equivalent, shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages enclosed within a larger package. *Typical examples of "warning labels" and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.*

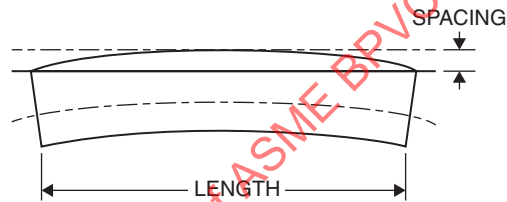


Figure 1—Measurement Procedure for Straightness

Annex A (Informative)

Conditions of Use

This annex is not part of this standard but is included for informational purposes only.

A1. Influence of the Type of Current

A1.1 General. The electric arc may be supplied with either direct current or alternating current. Table A.1 indicates which type of current is generally more suitable to the type of metal or alloy to be welded.

A1.2 Direct Current Source. The arc behavior is different depending on whether the electrode is connected to the positive or negative terminal of the power source. With direct current electrode positive (DCEP) polarity, there is greater output of heat at the electrode and less penetration of the work than with direct current electrode negative (DCEN) polarity. The current-carrying capacity of an electrode of a given size will therefore be lower with positive polarity than with negative polarity.

A1.3 Alternating Current Source. With alternating current (ac) supply, the current changes direction each half-cycle. The arc alternates between electrode positive polarity and electrode negative polarity. The current-carrying capacity of an electrode is then less than when it is used with electrode negative polarity, but greater than when it is used with electrode positive polarity.

Table A.1
Suitability of Current Supply Type^a

Type of metal or alloy to be welded	Direct current		Alternating current
	Electrode negative (–)	Electrode positive (+)	
Aluminum and its alloys, thickness ≤ 2.5 mm [0.10 in]	Acceptable	Acceptable	Best
Aluminum and its alloys, thickness > 2.5 mm [0.10 in]	Acceptable	N.R.	Best
Magnesium and its alloys	N.R.	Acceptable	Best
Non-alloy (<i>carbon</i>) steels and low alloy steels	Best	N.R.	N.R.
Stainless steels	Best	N.R.	N.R.
Copper	Best	N.R.	N.R.
Bronze	Best	N.R.	Acceptable
Aluminum bronze	Acceptable	N.R.	Best
Silicon bronze	Best	N.R.	N.R.
Nickel and its alloys	Best	N.R.	Acceptable
Titanium and its alloys	Best	N.R.	Acceptable

^a N.R. = Not recommended.

A2. Arc Current

The electrode size should be selected so that the current value is high enough for the arc to cover the whole area of the electrode tip, which is then heated up to a temperature approaching its melting temperature.

If the current is too low for the electrode size selected, the arc may be erratic.

If, however, the current is too high, it will cause the electrode to overheat and its tip to melt. Drops of molten tungsten may fall into the weld, and the arc will become erratic and unstable. Table A.2 provides recommended current ranges depending on the type of power source and electrode diameter. A high current value provides, in addition to a more stable arc, a higher concentration of heat, but this is limited depending on the conditions of use. An adequate degree of taper of the electrode tip with dc- (DCEN) polarity permits improvement of these conditions; e.g., the degree of taper of the electrode tip should be chosen according to the current used. A more obtuse angle is recommended at higher currents for a given electrode diameter.

Tungsten electrodes when used with alternating current or with direct current positive polarity will form a molten ball on the arcing end of the electrode. A pure tungsten electrode may produce tungsten inclusions in the weld when used on ac or dc+ (DCEP) without having accurate control of amperage and arc length. The use of zirconiated tungsten will alleviate this problem.

Many modern ac welding power sources allow the balance between the dc+ (DCEP) and dc- (DCEN) portions of the current cycle to be varied. When the dc+ (DCEP) portion of the cycle is increased relative to the dc- (DCEN) portion, the recommended average current is decreased somewhat from the ranges given in Table A.2. Conversely, when the dc- (DCEN) portion is increased relative to the dc+ (DCEP) portion, the recommended average ac current is increased somewhat from the ranges given in Table A.2.

A3. Further Remarks

The choice of an electrode type and size and of the welding current is influenced by the type and thickness of the parent metal to be welded or cut. The capacity of tungsten electrodes to carry current is dependent upon a number of other factors, in particular, the type of equipment used (gas- or water-cooled), the extension of the electrode beyond the nozzle and the welding position used.

An electrode of a given size will have its greatest current-carrying capacity with direct current, electrode negative; less with alternating current, and still less with direct current, electrode positive.

Table A.2 lists some typical current values that may be used with argon shielding. However, the other factors mentioned above should be carefully considered before selecting an electrode for a specific application.

Table A.2
Approximate Current Ranges Depending upon the Electrode Diameter^a

Electrode diameter		Direct current A				Alternating current A	
		Electrode negative (–)		Electrode positive (+)		Pure tungsten	Tungsten with oxide additives
mm	in	Pure tungsten	Tungsten with oxide additives	Pure tungsten	Tungsten with oxide additives		
0.25	0.010	up to 15	up to 15	not applicable	not applicable	up to 15	up to 15
0.30		up to 15	up to 15	not applicable	not applicable	up to 15	up to 15
0.50	0.020	2 to 20	2 to 20	not applicable	not applicable	2 to 15	2 to 15
1.0	0.040	10 to 75	10 to 75	not applicable	not applicable	15 to 55	15 to 70
1.5	0.060	60 to 150	60 to 150	10 to 20	10 to 20	45 to 90	60 to 125
1.6		60 to 150	60 to 150	10 to 20	10 to 20	45 to 90	60 to 125
2.0		75 to 180	100 to 200	15 to 25	15 to 25	65 to 125	85 to 160
2.4	0.093 (3/32)	120 to 220	150 to 250	15 to 30	15 to 30	80 to 140	120 to 210
2.5		130 to 230	170 to 250	17 to 30	17 to 30	80 to 140	120 to 210
3.0		150 to 300	210 to 310	20 to 35	20 to 35	140 to 180	140 to 230
3.2	0.125 (1/8)	160 to 310	225 to 330	20 to 35	20 to 35	150 to 190	150 to 250
4.0	0.156 (5/32)	275 to 450	350 to 480	35 to 50	35 to 50	180 to 260	240 to 350
4.8	0.187 (3/16)	380 to 600	480 to 650	50 to 70	50 to 70	240 to 350	330 to 450
5.0		400 to 625	500 to 675	50 to 70	50 to 70	240 to 350	330 to 460
6.3		550 to 875	650 to 950	65 to 100	65 to 100	300 to 450	430 to 575
6.4	0.250 (1/4)	575 to 900	750 to 1 000	70 to 125	70 to 125	325 to 450	450 to 600
8.0							650 to 830
10.0							

NOTE If no value is given, no recommendation is available.

a. The current values are based on the use of argon gas, and these values may vary depending on the type of shielding gas, type of equipment, and application.

Annex B (Informative)

Guide to AWS Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

B1.1 The purpose of this guide is to correlate the electrode classifications with their intended applications so the specification can be used effectively.

B1.2 Tungsten electrodes are nonconsumable in that they do not intentionally become part of the weld metal as do electrodes used as filler metals. The function of a tungsten electrode is to serve as one of the terminals of an arc which supplies the heat required for welding or cutting.

B2. Classification System

B2.1 The system for identifying the electrode classifications in this specification follows the standard pattern used in other AWS filler metal specifications. The letter “E” at the beginning of the classification designation stands for electrode. The “W” indicates that the electrode is primarily tungsten. The “P” indicates that the electrode is essentially pure tungsten and contains no intentionally added emission enhancing elements. The “Ce”, “La”, “Th”, and “Zr” indicate that the electrode is doped with oxides of cerium, lanthanum, thorium, or zirconium, respectively. The numeral at the end of some of the classifications indicates a different chemical composition level or product within a specific group.

B2.2 “G” Classification

B2.2.1 This specification includes electrodes classified as EWG. The “G” indicates that the electrode is of a general classification. It is “general” because the electrode may not meet all requirements for any other classification. The purpose is to allow a useful electrode to receive a classification before the specification is revised.

One electrode of a “G” classification is not interchangeable with another electrode of the same classification.

B2.2.2 Request for Electrode Classification. When an electrode cannot be classified according to some classification other than a “G” classification, a manufacturer may request that a classification be established. The manufacturer shall do this using the following procedure:

(1) A request to establish a new electrode classification must be submitted in writing. The request needs to provide sufficient detail to permit the Committee on Filler Metals and Allied Materials or the relevant Subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

- (a) A declaration that the new classification will be offered for sale commercially.
- (b) All classification requirements as given for existing classifications, such as chemical composition ranges, mechanical property requirements, and usability test requirements.

- (c) Any conditions for conducting the tests used to demonstrate that the product meets the classification requirements. (It would be sufficient, for example, to state that welding conditions are the same as for other classifications.)
- (d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the Annex).
- (e) A request for a new classification without the above information will be considered incomplete. The Secretary will return the request to the requester for further information.

(2) In order to comply with the AWS Policy on Patented Items, Trademarks, and Restraint of Trade, if the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester shall disclose this. In these cases, the patent holder must allow the use of this technology, such as by license. The Secretary will provide examples of acceptable wording to the patent holder, as required.

(3) The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters for processing.

B3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01M/A5.01. Any testing a purchaser requires of the supplier for material shipped in accordance with this specification shall be clearly stated in the purchase order. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing is normally conducted on material of that classification, as specified in Schedule F of AWS A5.01M/A5.01. Testing in accordance with any other Schedule must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

B4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product, or the classification identification on the product itself, constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification. The only testing requirement implicit in this certification is that the manufacturer has actually conducted the test required by the specification on material that is representative of that being shipped, and that that material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation.

"Certification" is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the "certification" required by the specification is the classification test of "representative material" cited above and the "Manufacturer's Quality Assurance Program" in AWS A5.01M/A5.01.

Electrodes sold as a standard size must also meet the dimensional, surface finish, and identification requirements established in this specification.

B5. Ventilation During Welding

B5.1 Five major factors govern the quantity of fumes in the atmosphere to which welders and welding operators are exposed during welding. They are:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling)
- (2) Number of welders and welding operators working in that space
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes used
- (4) The proximity of the welders or welding operators to the fumes, as the fumes issue from the welding zone, and to the gases and dusts in the space in which they are working.
- (5) The ventilation provided to the space in which the welding is done

B5.2 American National Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the clause on Ventilation in that document. See also AWS F3.2, *Ventilation Guide for Weld Fume* for more detailed descriptions of ventilation options.

B6. Operation Characteristics

B6.1 The choice of an electrode classification, size, and welding current is influenced by the type and thickness of the base metals being welded. The capacity of tungsten electrodes to carry current is dependent upon numerous factors in addition to the classification and size, including type and polarity of the current, the shielding gas used, the type of equipment (air or water cooled), the extension of the electrode beyond the collet (sleeve or tube that holds the electrode), and the welding position. An electrode of a given size will have its greatest current-carrying capacity with direct current, electrode negative (straight polarity), less with alternating current, and still less with direct current, electrode positive (reverse polarity). Table A.2 lists some typical current values that may be used with argon shielding gas. However, the other factors mentioned above should be carefully considered before selecting an electrode for a specific application.

B6.2 Tungsten has an electrical conductivity that is about 30 % that of copper and a thermal conductivity that is 40 % that of copper. Therefore, there will be more heating as current is passed through the tungsten electrode. When welding with tungsten electrodes, the arc tip should be the only hot part of the electrode; the remainder should be kept as cool as possible.

B6.3 One method of preventing electrode overheating is to keep the extension of the electrode from the collet short. If the extension is too long, even a relatively low current can cause the electrode to overheat and melt above the terminus of the arc. Conversely, if the current density is too low, the arc will be erratic and unstable.

B6.4 Many electrode classifications contain emissive oxide additions. These additions lower the temperature at which the electrode emits electrons, to a temperature below the melting point of tungsten. Such an electrode operates cooler, or it can operate at higher currents, as can be noted from Table A.2. Benefits of these additions include easier starting, particularly when using superimposed high frequency, more stable operation, and reduced contamination. These benefits are noted in the description listed for the various classifications containing oxide additives.

B6.5 All tungsten electrodes may be used in a similar manner. However, electrodes of each classification have distinct advantages with respect to other classifications. The following section discusses the specific electrode classifications with regard to their operating characteristics and usability.

B7. Description and Intended Use of Electrodes (*ISO Designations Are Given in Parentheses.*)

B7.1 EWP (WP) Electrode Classification (Green). The EWP electrodes are commercially pure tungsten electrodes (99.9 percent tungsten minimum). Their current-carrying capacity is lower than that of other electrodes. They provide good stability when used with alternating current, either balanced wave or continuously high frequency stabilized. They may be used with direct current and also with either argon or helium, or a combination of both, as a shielding gas. They maintain a clean, balled end, which is preferred for aluminum and magnesium welding. These electrodes have reasonably good resistance to contamination of the weld metal by the electrode, although the oxide containing electrodes are superior in this respect. EWP electrodes are generally used on less critical applications, except for welding aluminum and magnesium. The lower cost EWP electrodes can be used for less critical applications where some tungsten contamination of welds is acceptable.

B7.2 EWCe-2 (WCe20) Electrode Classification (Grey). The EWCe-2 electrodes are tungsten electrodes containing about two percent cerium oxide (CeO_2), referred to as ceria. The EWCe-2 electrodes were first introduced into the United States market in 1987. Several other grades of this type electrode are commercially practical, including electrodes containing one percent CeO_2 , but only one grade, EWCe-2, has been incorporated in this specification as having commercial significance.

The advantages of tungsten electrodes containing ceria, compared to pure tungsten, include increased ease of starting, improved arc stability, and reduced rate of vaporization or burn-off. Unlike thorium, ceria is not a radioactive material. These advantages increase with increased ceria content. These electrodes operate successfully with alternating current or direct current, either polarity.

B7.3 EWLa-X Electrode Classifications. The EWLa-X electrodes are tungsten electrodes containing lanthanum oxide, referred to as lanthana. The advantages and operating characteristics of these electrodes are similar to that of the EWCe-2 electrodes. Unlike thorium, lanthana is not a radioactive material.

B7.3.1 EWLa-1 (WLa10) Electrode Classification (Black). The EWLa-1 electrodes are tungsten electrodes which contain nominally 0.8-1.2 weight-percent (wt %) lanthanum oxide, referred to as lanthana. The advantages and operating characteristics of this electrode type are very similar to those of EWCe-2 electrodes.

B7.3.2 EWLa-1.5 (WLa15) Electrode Classification (Gold). EWLa-1.5 designates a tungsten electrode containing 1.3 wt %–1.7 wt % of dispersed lanthanum oxide (La_2O_3) for enhanced arc starting and stability, reduced tip erosion rate, and extended operating current range. These electrodes can be used as nonradioactive substitutes for 2% thoriated tungsten, as the operating characteristics are very similar. Lanthanated tungsten can be used for both dc– (DCEN) and ac applications.

B7.3.3 EWLa-2 (WLa20) Electrode Classification (Blue). EWLa-2 designates a tungsten electrode containing 1.8 wt %–2.2 wt % of dispersed lanthanum oxide (La_2O_3). The EWLa-2 electrode has the highest volume of oxides of any of the specific single-additive AWS-specified electrodes types, which serves to enhance arc starting and stability, reduce tip erosion rate, and extend operating current range. Lanthanated tungsten electrodes can be used for both dcen and ac applications.

B7.4 EWTh-X Electrode Classifications. The EWTh-X electrodes are tungsten electrodes containing thorium oxide, referred to as thorium. The thorium in all classes is responsible for increasing the usable life of these electrodes over the EWP electrodes because of their higher electron emission, better arc starting and arc stability. They generally have longer life and provide greater resistance to tungsten contamination of the weld.

SAFETY NOTE

Thorium is a low-level radioactive material. The principal risk to health from thoriated electrodes occurs when grinding the ends of the electrodes. During grinding of these electrodes, radioactive dust is created, posing the potential hazard of internal radiation exposure by inhalation or ingestion unless care is taken to control the dust. The most effective way to avoid this hazard is to choose thorium-free tungsten electrodes such as those containing cerium, lanthanum, yttrium, or zirconium.

For further information on this hazard and means of reducing it, refer to AWS Safety and Health Fact Sheet No. 27 “Thoriated Tungsten Electrodes”. This publication can be found at: <https://www.aws.org/standards/page/safety-health-fact-sheets>

B7.4.1 EWTh-1 (WTh10) Electrode Classification (Yellow). These electrodes were designed for direct current applications. They have 0.8-1.2 percent of thorium content dispersed throughout their entire length. They maintain a sharpened point well, which is desirable for welding steel. They can be used on alternating current work, but a satisfactory balled end, which is desirable for the welding of nonferrous materials, is difficult to maintain.

B7.4.2 EWTh-2 (WTh20) Electrode Classification (Red). The higher thorium content (1.7 percent–2.2 percent) in the EWTh-2 electrode causes the operating characteristic improvements to be more pronounced than in the lower thorium content EWTh-1.

Should it be desired to use these electrodes for alternating current welding, then balling can be accomplished by briefly, and carefully, welding with direct current electrode positive prior to welding with alternating current. During alternating current welding, the balled end does not melt and so emission is not as good as from a liquid ball on an EWP electrode.

B7.4.3 (WTh30) Electrode Classification (Violet). This 3% thoriated electrode has no commercial significance in the United States.

B7.5 EWZr-X Electrode Classifications

B7.5.1 EWZr-1 (WZr3) Electrode Classification (Brown). The EWZr-1 electrode is a tungsten electrode containing about 0.3% zirconium oxide, referred to as zirconia. This electrode is preferred for applications where tungsten contamination of the weld must be minimized. This electrode performs well when used with alternating current, as it retains a balled end during welding and has a high resistance to contamination.

B7.5.2 EWZr-8 (WZr8) Electrode Classification (White). This 0.8% zirconiated electrode has no commercial significance in the United States.

B7.6 EWG Electrode Classification (manufacturer may select any color not already in use). The EWG electrode is a tungsten electrode containing an additive not specified by an existing classification. The purpose of the addition is to affect the nature or characteristics of the arc, as defined by the manufacturer. Although no additive is specified, the manufacturer must identify any specific additions and the nominal quantities added.

B8. General Recommendations

These recommendations, when followed, should maintain high weld quality and promote welding economy in any specific application.

B8.1 The appropriate current (type and magnitude) should be selected for the electrode size to be used. Too great a current will cause excessive melting, dripping, or volatilization of the electrode. A welding current which is too low to properly heat the electrode tip may cause instability of the welding arc or inability to maintain a welding arc.

B8.2 The electrode should be properly cut and ground tapered by following the supplier's suggested procedures. Breaking or severing an electrode is not recommended since it may cause a jagged end or a bent electrode, which usually results in a poorly shaped arc and excessive electrode heating.

B8.3 The electrodes should be handled carefully and kept as clean as possible. To obtain maximum cleanliness, they should be stored in their original package until used.

B8.4 The shielding gas flow should be maintained until the electrode has cooled. When the electrodes are properly cooled, the arc end will appear bright and polished. When improperly cooled, the end may oxidize and appear to have a colored film which can, unless removed, adversely affect the weld quality on subsequent welds. All connections, both gas and water, should be checked for tightness. Oxidized, discolored, or otherwise contaminated electrodes will cause difficult arc starting and may prevent starting depending upon conditions and the arc starting method used.

B8.5 The electrode extension within the gas shielding pattern should be kept to a minimum, generally dictated by the application and equipment. This is to ensure protection of the electrode by the gas even at low gas flow rates.

B8.6 The equipment and, in particular, the shielding gas nozzle should be kept clean and free of weld spatter. A dirty nozzle adversely influences the gas shielding. This contributes to improper gas flow patterns and arc wandering, which can result in poor weld quality. It may also contribute to excessive electrode consumption.

B9. Discontinued Classifications

Some classifications have been discontinued from one revision of this specification to another. This results either from changes in commercial practice or changes in the classification system used in the specification. The EWTh-3 classification was discontinued in the AWS A5.12-92 revision of this specification, as having no commercial significance. For information about this classification, the user is referred to the AWS A5.12-80 revision.

B10. General Safety Considerations

B10.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Annex Clause B.5. Safety and health information is available

from other sources, including, but not limited to Safety and Health Fact Sheets, ANSI Z49.1, *Safety in Welding, Cutting and Allied Processes*, and applicable federal and state regulations.

B10.2 Safety and Health Fact Sheets. Safety and Health Fact Sheets are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

ASME BPVC Section II part C) 2025

Click to view the full PDF of ASME BPVC.II.C

ASME BPVC Section II part C) 2025

Annex C (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

C1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

C2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

C3. General Procedure for all Requests

C3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

C3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

C3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

C3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

C3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

C3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

C4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

C5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the Welding Journal, and post it on the AWS website.

C6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The AWS Board Policy Manual requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

Annex D (Informative)

List of Deviations from ISO 6848:2015

This annex is not part of this standard but is included for informational purposes only.

Changed title to “Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting” globally.

Modified the layout and wording to comply with General Requirements and Standard Format for AWS Filler Metal and Allied Materials Specifications. These changes did not affect the requirements for classification.

Replaced explanation of ISO 6848 classification designation scheme with a clause on acceptance based on AWS A5.12/A5.12M.

Added requirement that electrodes classified under one classification shall not be classified under any other classification in this specification and that no electrode meeting the requirements of any other classification shall be classified under EWG

Added referee method for chemical analysis.

Added statement that “Such color coding shall have no adverse effect on the operation or use of the electrode.”

Table 1: Put ISO symbols in parentheses and added AWS designations. Added note that intentional additions of “doping oxides” other than indicated for a particular electrode classification is prohibited.

Combined Tables 2 and 3 into Table 2 and added sizes in US Customary Units. Decreased tolerances for metric sizes from 2.40 mm diameter through 6.40 mm diameter from ± 0.10 mm to ± 0.08 mm.

Added subclauses regarding electrode finish and roundness.

Replaced ambiguous electrode straightness text with language and illustration from AWS A5.12/A5.12M.

Added subclauses regarding marking of overpacking and warning label.

Table A.2: Added note a.

Added Additional Informative National Annexes B, C, and D.

AWS Filler Metal Specifications by Material and Welding Process

	OFW	SMAW	GTAW GMAW PAW	FCAW	SAW	ESW	EGW	Brazing
Carbon Steel	A5.2	A5.1, A5.35	A5.18	A5.20	A5.17	A5.25	A5.26	A5.8, A5.31
Low-Alloy Steel	A5.2	A5.5	A5.28	A5.29	A5.23	A5.25	A5.26	A5.8, A5.31
Stainless Steel		A5.4, A5.35	A5.9, A5.22	A5.22	A5.9, A5.22, A5.39	A5.9, A5.22, A5.39	A5.9	A5.8, A5.31
Cast Iron	A5.15	A5.15	A5.15	A5.15				A5.8, A5.31
Nickel Alloys		A5.11, A5.35	A5.14, A5.34	A5.34	A5.14, A5.34, A5.39	A5.14, A5.34, A5.39		A5.8, A5.31
Aluminum Alloys		A5.3	A5.10					A5.8, A5.31
Copper Alloys		A5.6	A5.7					A5.8, A5.31
Titanium Alloys			A5.16					A5.8, A5.31
Zirconium Alloys			A5.24					A5.8, A5.31
Magnesium Alloys			A5.19					A5.8, A5.31
Tungsten Electrodes			A5.12					
Brazing Alloys and Fluxes								A5.8, A5.31
Surfacing Alloys	A5.21	A5.13	A5.21	A5.21	A5.21			
Consumable Inserts			A5.30					
Shielding Gases			A5.32	A5.32			A5.32	

AWS Filler Metal Specifications and Related Documents

Designation	Title
A4.2M (ISO 8249 MOD)	<i>Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal</i>
A4.3	<i>Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding</i>
A4.4M	<i>Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings</i>
A4.5M/A4.5 (ISO 15792-3 MOD)	<i>Standard Methods for Classification Testing of Positional Capacity and Root Penetration of Welding Consumables in a Fillet Weld</i>
A5.01M/A5.01 (ISO 14344 MOD)	<i>Welding and Brazing Consumables—Procurement of Filler Metals and Fluxes</i>
A5.02/A5.02M	<i>Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes</i>
A5.1/A5.1M	<i>Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding</i>
A5.2/A5.2M	<i>Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding</i>
A5.3/A5.3M	<i>Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.4/A5.4M	<i>Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding</i>
A5.5/A5.5M	<i>Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding</i>
A5.6/A5.6M	<i>Specification for Copper and Copper-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.7/A5.7M	<i>Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes</i>
A5.8M/A5.8	<i>Specification for Filler Metals for Brazing and Braze Welding</i>
A5.9/A5.9M (ISO 14343 MOD)	<i>Specification for Bare Stainless Steel Welding Electrodes and Rods</i>
A5.10/A5.10M (ISO 18273 MOD)	<i>Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods</i>
A5.11/A5.11M	<i>Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding</i>
A5.12M/A5.12 (ISO 6848 MOD)	<i>Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting</i>
A5.13/A5.13M	<i>Specification for Surfacing Electrodes for Shielded Metal Arc Welding</i>
A5.14/A5.14M	<i>Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods</i>
A5.15	<i>Specification for Welding Electrodes and Rods for Cast Iron</i>
A5.16/A5.16M (ISO 24034 MOD)	<i>Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods</i>
A5.17/A5.17M	<i>Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.18/A5.18M	<i>Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.19	<i>Specification for Magnesium-Alloy Welding Electrodes and Rods</i>
A5.20/A5.20M	<i>Specification for Carbon Steel Electrodes for Flux Cored Arc Welding</i>
A5.21/A5.21M	<i>Specification for Bare Electrodes and Rods for Surfacing</i>
A5.22/A5.22M	<i>Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods</i>

A5.23/A5.23M	<i>Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.24/A5.24M	<i>Specification for Zirconium and Zirconium-Alloy Welding Electrodes and Rods</i>
A5.25/A5.25M	<i>Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding</i>
A5.26/A5.26M	<i>Specification for Carbon and Low-Alloy Steel Electrodes for Electrogas Welding</i>
A5.28/A5.28M	<i>Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.29/A5.29M	<i>Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding</i>
A5.30/A5.30M	<i>Specification for Consumable Inserts</i>
A5.31M/A5.31	<i>Specification for Fluxes for Brazing and Braze Welding</i>
A5.32M/A5.32 (ISO 14175 MOD)	<i>Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes</i>
A5.34/A5.34M	<i>Specification for Nickel-Alloy Electrodes for Flux Cored and Metal Cored Welding</i>
A5.35/A5.35M-AMD1	<i>Specification for Covered Electrodes for Underwater Wet Shielded Metal Arc Welding</i>
A5.39/A5.39M	<i>Specification for Stainless Steel and Nickel-Alloy Electrodes and Fluxes for Submerged Arc and Electroslag Welding</i>

SPECIFICATION FOR SURFACING ELECTRODES FOR SHIELDED METAL ARC WELDING



SFA-5.13/SFA-5.13M



(25)

(Identical with AWS Specification A5.13/A5.13M:2024. In case of dispute, the original AWS text applies.)

Specification for Surfacing Electrodes for Shielded Metal Arc Welding

1. Scope

1.1 This specification prescribes requirements for the classification of surfacing electrodes for shielded metal arc welding. Solid bare electrodes and rods for surfacing are classified in AWS A5.21/A5.21M, *Specification for Bare Electrodes and Rods for Surfacing*.

1.2 This standard makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently when referring to material properties. The specification with the designation A5.13 uses U.S. Customary Units. The specification A5.13M uses SI Units. The latter are shown within brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing filler metal or packaging or both under A5.13 or A5.13M specifications.

1.3 Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in Annex A, Clauses A5 and A9.

Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The following standards contain provisions that, through reference in this text, constitute provisions of this AWS standard. For dated references, subsequent amendments to or revisions of any of these publications do not apply.

American Welding Society (AWS) documents:

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

AWS A5.01M/A5.01(ISO 14344 MOD), *Welding and Brazing Consumables—Procurement of Filler Metals and Fluxes*

AWS A5.02/A5.02M, *Specification for Filler Metal Standards Sizes, Packaging, and Physical Attributes*

AWS A5.21/A5.21M, *Specification for Bare Electrodes and Rods for Surfacing*

AWS D15.2/D15.2M, *Specification for Joining Railroad Rail and Related Rail Components*

American National Standards Institute (ANSI) document:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

ASTM International (ASTM) documents:

ASTM A36/A36M, *Standard Specification for Carbon Structural Steel*

ASTM A285/A285M, *Standard Specification for Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength*

ASTM B214, *Standard Test Method for Sieve Analysis of Metal Powders*

ASTM E18, *Standard Test Methods for Rockwell Hardness of Metallic Materials*

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

ASTM E384, *Standard Test Method for Microindentation Hardness of Materials*

International Organization for Standardization (ISO) document:

ISO 80000-1:2022, *Quantities and units — Part 1: General*

3. Classification

3.1 Except for tungsten carbide electrodes, the surfacing electrodes covered by this A5.13/A5.13M specification are classified according to the chemical composition of the undiluted weld metal, as specified in Tables 1, 2, and 3.

3.2 Tungsten carbide surfacing electrodes are classified based on size and chemical composition of the tungsten carbide granules (see Tables 4 and 5).

3.3 Electrodes classified under one classification shall not be classified under any other classification in this specification, with the exception of the EFe-RBU and EFeMn-RBU classifications related to the railway weld repair procedures described in the AWS D15.2 specification.

4. Acceptance

Acceptance of the electrodes shall be in accordance with the provisions of AWS A5.01M/A5.01 and the tests and requirements of this specification. See A3 (in Annex A) for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

5. Certification

By affixing the AWS specification and classification designations to the package or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification. See A4 (in Annex A) for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

6. Rounding Procedure

For purposes of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfil the requirements for the classification under test.

7. Summary of Tests

7.1 Except for tungsten carbide electrodes, chemical analysis of undiluted weld metal is the only test required for classification of a product under this specification (see Tables 1, 2, and 3).

7.2 Tests required for tungsten carbide electrodes include:

7.2.1 Determination of the amount and mesh size distribution of the tungsten carbide granules (see Table 4). Sieve analysis shall be in accordance with ASTM B214.

7.2.2 Determination of the chemical composition of the tungsten carbide granules (see Table 5).

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Material, specimens, or samples for retest may be taken from the original test assembly or sample, or from one or two new test assemblies or samples. For chemical analysis, retest need be only for those specific elements that failed to meet the test requirement. If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that during preparation or after completion of any test it is clearly determined that specified or proper procedures were not followed in preparing the weld test assembly or test specimen(s) or in conducting the test, the test shall be considered invalid without regard to whether the test was actually completed or whether test results met or failed to meet the requirement. That test shall be repeated, following proper specified procedures. In this case, the requirement for doubling the number of test specimens does not apply.

9. Weld Test Assembly

9.1 One sample for chemical analysis is the only test assembly required. It may be prepared by any method that produces undiluted weld metal. In case of dispute, the weld pad described in 9.2 shall be the referee method.

9.2 The dimensions of the completed pad shall be as shown in Figure 1 for each size of electrode. Testing of this assembly shall be as specified in Clause 10, Chemical Analysis.

9.2.1 Welding shall be done in the flat position using welding conditions specified by the manufacturer.

9.2.2 Post-weld heat treatment may be used to facilitate subsequent sampling.

9.3 The base metal shall conform to one of the following specifications or its equivalent:

9.3.1 ASTM A285/A285M Grade A (UNS K01700).

9.3.2 ASTM A36/A36M (UNS K02600).

10. Chemical Analysis

10.1 For All Except Covered Tungsten Carbide Electrodes

10.1.1 Shielded metal arc welding surfacing electrodes shall be analyzed in the form of undiluted weld metal. The sample shall come from a weld metal pad. *Multiple layers should be welded onto the pad to get undiluted weld metal.*

10.1.2 The top surface of the pad described in Clause 9 and shown in Figure 1 shall be removed and discarded. A sample for analysis shall be obtained from the underlying metal by any means that will not affect the chemical composition. The sample shall be free of slag.

For electrodes 3/32 in [2.4 mm] in diameter and smaller, the sample shall be taken at least 1/2 in [13 mm] from the nearest surface of the base metal.

For electrodes larger than 3/32 in [2.4 mm] in diameter and less than or equal to 3/16 in [5.0 mm] in diameter, the sample shall be taken at least 5/8 in [16 mm] from the nearest surface of the base metal.

For electrodes larger than 3/16 in [5.0 mm] in diameter the sample shall be taken at least 3/4 in [19 mm] from the nearest surface of the base metal.

10.1.3 The sample may be removed from an undiluted weld metal pad by any convenient method that will not alter the chemical composition.

10.1.4 The sample shall be analyzed by accepted analytical methods. The referee method shall be the appropriate ASTM method for the element being determined.

10.1.5 The results of the analysis shall meet the requirements of Tables 1, 2, or 3 for the classification of electrode under test.

10.2 For Covered Tungsten Carbide Electrodes

10.2.1 The chemical composition of tungsten carbide granules shall conform to the requirements of Table 5. Chemical analysis may be made by any suitable method as agreed upon between the purchaser and supplier.

10.2.2 Tungsten carbide granules for chemical analysis shall be free of any surface contaminant.

10.2.3 The percentage by weight of the tungsten carbide, *considering a $\pm 3\%$ tolerance*, as specified in Table 4, can be determined by the following steps:

- (1) Record the weight of the tungsten carbide welding electrode after removing any covering present.
- (2) Remove the tungsten carbide from the tubular electrode core rod. Clean it by washing with water and treating with a 1-1 volume ratio of concentrated hydrochloric acid and distilled water, to remove any flux, powdered iron, graphite, etc. Heating of the acid may be required. A hot or cold 1-1 hydrochloric acid will not appreciably attack cast tungsten carbide in less than an hour.
- (3) Dry tungsten carbide for a minimum period of two hours by holding in an oven at $250^{\circ}\text{F} \pm 25^{\circ}\text{F}$ [$120^{\circ}\text{C} \pm 15^{\circ}\text{C}$].
- (4) Weigh the cleaned and dried tungsten carbide granules. Calculate the percentage of tungsten carbide from the initial weight of the tube using the following formula:

$$\text{Tungsten carbide \%} = 100 \times \frac{\text{Weight of clean and dry tungsten carbide granules}}{\text{Weight of electrode after removing covering}}$$

11. Method of Manufacture

The electrodes classified according to this specification may be manufactured by any method that will produce material that meets the requirements of this specification. For iron-based tungsten carbide surfacing electrodes, any carbon steel sheath material (typically SAE-AISI 1008 or ASTM A36 carbon steel) that will not alter the matrix significantly may be used. *For nickel base tungsten carbide surfacing electrodes, per ENiWCX-30/230 classification, the use of nickel alloy sheath is required.*

12. Standard Sizes and Lengths

Standard sizes (diameter of core wire) and lengths of electrodes and their respective tolerances are specified in Tables 6, 7, and 8.

13. Core Wire and Covering

Core wire and covering shall be free of defects that would interfere with uniform deposition of the electrode.

14. Exposed Core

14.1 The grip end of each electrode shall be bare (free of covering) for a distance of not less than 1/2 in [13 mm], nor more than 1-1/2 in [38 mm], to provide electrical contact with the electrode holder.

14.2 The arc end of each electrode shall be sufficiently bare and the covering sufficiently tapered to permit easy striking of the arc. The length of the bare portion, measured from the end of the core wire to the location where the full cross section of the covering is obtained, shall not exceed 1/8 in [3.2 mm] or the diameter of the core wire, whichever is less. Electrodes with chipped coverings near the arc end, baring the core wire slightly more than the prescribed distance, may be accepted provided no chip uncovers more than 50% of the circumference of the core.

14.3 Electrodes with electrically conductive coverings or strike tips may be exempt from the requirements of 14.2 providing they are capable of easy arc starting without stripping.

15. Electrode Identification

15.1 All electrodes, except dip-covered electrodes, shall be identified as follows:

15.1.1 At least one imprint of the electrode classification shall be applied to the electrode covering starting within 2-1/2 in [65 mm] of the grip end of the electrode.

15.1.2 The numbers and letters of the imprint shall be of bold block type of a size large enough to be legible.

15.1.3 The ink used for imprinting shall provide sufficient contrast with the electrode covering so that, in normal use, the numbers and letters are legible both before and after welding.

15.1.4 The prefix letter E in the electrode classification may be omitted from the imprint.

15.2 Identification of dip-covered electrodes shall be as agreed upon between the purchaser and supplier. Imprinting is not mandatory.

16. Packaging

16.1 Electrodes shall be suitably packaged to protect them against damage during shipment and storage under normal conditions.

16.2 Standard package weights shall be as agreed between purchaser and supplier.

17. Marking of Packages

17.1 The following product information (as a minimum) shall be legibly marked on the outside of each unit package:

- (1) AWS specification and classification designations (year of issue may be excluded)

- (2) Supplier's name and trade designation
- (3) Size and net weight
- (4) Lot, control, or heat number

17.2 The appropriate precautionary information as given in ANSI Z49.1, latest edition, (as a minimum) or its equivalent, shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages enclosed within a larger package. Typical examples of "warning labels" are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

ASMENORMDOC.COM : Click to view the full PDF of ASME BPVC.II.C (ASME BPVC Section II Part C) 2025

Table 1
Iron Base Surfacing Electrodes—Chemical Composition Requirements^a

AWS Classification	Annex A Reference	UNS Number ^e	Deposit Composition, weight percent ^{b, c, d}												
			C	Mn	Si	Cr	Ni	Mo	V	W	Ti	Nb	Al	Fe	Other Elements, Total
EFe-1	A7.1.1	W74001	0.03–0.20	0.2–3.0	1.5	4.0	—	1.5	—	—	1.5	—	2.0	Rem	1.0
EFe-2	A7.1.1	W74002	0.10–0.40	0.5–4.0	2.5	4.0	1.0	2.0	0.35	—	1.5	—	2.0	Rem	1.0
EFe-3	A7.1.2	W74003	0.30–0.80	0.3–2.0	1.0	4.0–8.0	—	1.0	—	—	—	—	2.0	Rem	1.0
EFe-4	A7.1.3	W74004	1.0–2.0	0.5–2.0	1.0	3.0–5.0	—	—	—	—	—	—	—	Rem	1.0
EFe-5	A7.1.4	W75110	0.30–0.80	1.5–2.5	0.90	1.5–3.0	—	—	—	—	—	—	—	Rem	1.0
EFe-6	A7.1.5	W77510	0.6–1.3	0.4–1.0	1.5	3.0–5.0	—	7.0–9.5	0.5–2.5	0.5–2.5	—	—	—	Rem	1.0
EFe-7	A7.1.6	W77610	1.5–3.0	0.5–2.0	1.5	4.0–8.0	—	1.0	—	—	—	—	—	Rem	1.0
EFe-8	A7.1.7	—	0.25–0.70	0.5–2.5	1.5	3.0–9.0	—	0.5–4.0	2.0	2.0	1.5	4.0	—	Rem	1.0
EFe-RBU	A7.1.8	—	0.03–0.40	0.2–4.0	2.5	4.0	4.0	2.0	0.35	—	1.5	—	2.0	Rem	1.0
EFeMn-A	A7.1.9	W79110	0.5–1.0	12–16	1.3	—	2.5–5.0	—	—	—	—	—	—	Rem	1.0
EFeMn-B	A7.1.9	W79310	0.5–1.0	12–16	1.3	—	—	0.5–1.5	—	—	—	—	—	Rem	1.0
EFeMn-C	A7.1.9	W79210	0.5–1.0	12–16	1.3	2.5–5.0	2.5–5.0	—	—	—	—	—	—	Rem	1.0
EFeMn-D	A7.1.9	W79410	0.5–1.0	15–20	1.5	7.5	—	1.5	1.2	—	—	—	2.0	Rem	1.0
EFeMn-E	A7.1.9	W79510	0.5–1.0	15–20	1.3	3.0–6.0	1.0	—	—	—	—	—	—	Rem	1.0
EFeMn-F	A7.1.9	W79610	0.5–1.5	16–27	1.5	2.0–7.0	1.0	—	—	—	—	—	2.0	Rem	1.0
EFeMn-G	A7.1.9	—	0.5–1.5	12–18	1.5	2.0–7.0	1.0	1.5	—	—	—	—	2.0	Rem	1.0
EFeMnCr	A7.1.10	W79710	0.25–0.75	12–18	1.5	11–18	2.0	2.0	1.0	—	—	—	2.0	Rem	1.0
EFeMn-RBU	A7.1.11	—	0.3–1.5	12–27	1.5	18	5.0	2.0	1.2	—	0.5	—	2.0	Rem	1.0
EFeCr-A1A	A7.1.12	W74011	3.5–4.5	4.0–6.0	0.5–2.0	20–25	—	0.5	—	—	—	—	—	Rem	1.0
EFeCr-A2	A7.1.13	W74012	2.5–3.5	0.5–1.5	0.5–1.5	7.5–9.0	—	—	—	—	1.2–1.8	—	—	Rem	1.0

(Continued)

Table 1 (Continued)
Iron Base Surfacing Electrodes—Chemical Composition Requirements^a

AWS Classification	Annex A Reference	UNS Number ^e	Deposit Composition, weight percent ^{b,c,d}												Other Elements, Total
			C	Mn	Si	Cr	Ni	Mo	V	W	Ti	Nb	Al	Fe	
EFeCr-A3	A7.1.14	W74013	2.0–4.5	2.5	2.5	14–24	—	1.5	—	—	—	—	—	Rem	1.0
EFeCr-A4	A7.1.12	W74014	3.5–5.0	0.5–3.5	2.0	20–29	—	0.5–3.0	—	—	—	—	—	Rem	2.0
EFeCr-A5	A7.1.15	W74015	1.5–3.0	0.3–2.5	2.5	23–32	4	4	—	—	—	—	—	Rem	1.0
EFeCr-A6	A7.1.16	W74016	2.0–3.5	0.5–1.5	2.5	20–30	—	0.5–2.0	—	—	—	—	—	Rem	1.0
EFeCr-A7	A7.1.16	W74017	3.5–5.0	0.5–2.0	2.5	23–30	—	2.0–4.5	—	—	—	—	—	Rem	1.0
EFeCr-A8	A7.1.17	W74018	2.5–4.5	0.2–1.5	1.5	30–40	—	2	—	—	—	—	—	Rem	1.0
EFeCr-A9	A7.1.18	—	3.0–7.5	4.5	2.5	24–40	—	2	—	—	—	—	—	Rem	3.0
EFeCr-E1	A7.1.19	W74211	5.0–6.5	2.0–3.0	0.8–1.5	12–16	—	—	—	—	4.0–7.0	—	—	Rem	1.0
EFeCr-E2	A7.1.19	W74212	4.0–6.0	0.5–1.5	1.5	14–20	—	5.0–7.0	1.5	—	—	—	—	Rem	1.0
EFeCr-E3	A7.1.19	W74213	5.0–7.0	2.0	2.0	18–28	—	4.0–7.0	—	3.0–5.0	—	—	—	Rem	1.0
EFeCr-E4	A7.1.19	W74214	4.0–7.0	1.5	1.5	18–30	—	2–8	3	4	—	8	—	Rem	2.0
EFeV	A7.1.20	—	2.5–6.0	2.5	2.5	2	1.5	1.5	12–24	3–12	0.1	—	—	Rem	3.0

^a Solid bare electrodes and rods previously classified in AWS A5.13-80 are now either discontinued or reclassified in AWS A5.21/A5.21M, *Specification for Bare Electrodes and Rods for Surfacing*.

^b Single values are maximum. Rem = Remainder.

^c Electrodes and rods shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for “Other Elements, Total” in the last column of the table.

^d Sulfur and phosphorus contents each shall not exceed 0.035%.

^e SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System*.

Table 2
Nickel and Cobalt Base Surfacing Electrodes—Chemical Composition Requirements

AWS Classification	Annex A Reference	UNS Number ^d	Deposit Composition, weight percent ^{a, b, c}											Other Elements, Total
			C	Mn	Si	Cr	Ni	Mo	Fe	W	Co	B	V	
ECoCr-A	A7.2.1	W73006	0.7–1.4	2.0	2.0	25–32	3.0	1.0	5.0	3.0–6.0	Rem	—	—	1.0
ECoCr-B	A7.2.2	W73012	1.0–1.7	2.0	2.0	25–32	3.0	1.0	5.0	7.0–9.5	Rem	—	—	1.0
ECoCr-C	A7.2.3	W73001	1.7–3.0	2.0	2.0	25–33	3.0	1.0	5.0	11–14	Rem	—	—	1.0
ECoCr-E	A7.2.4	W73021	0.15–0.40	1.5	2.0	24–29	2.0–4.0	4.5–6.5	5.0	0.50	Rem	—	—	1.0
ENiCr-C	A7.3.1	W89606	0.5–1.0	—	3.5–5.5	12–18	Rem	—	3.5–5.5	—	1.0	2.5–4.5	—	1.0
ENiCrMo-5A	A7.3.2	W80002	0.12	1.0	1.0	14–18	Rem ^e	14–18	4.0–7.0	3.0–5.0	—	—	0.40	1.0
ENiCrFeCo	A7.3.3	W83002	2.2–3.0	1.0	0.6–1.5	25–30	10–33	7.0–10.0	20–25	2.0–4.0	10–15	—	—	1.0

^a Single values are maximum percentages. Rem = Remainder.

^b The weld metal shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for “Other Elements, Total” in the last column of the table.

^c Sulfur and phosphorus contents each shall not exceed 0.03%.

^d SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System*.

^e Includes incidental cobalt.

Table 3
Copper Base Surfacing Electrodes—Chemical Composition Requirements

AWS Classification	Annex A Reference	UNS Number ^c	Deposit Composition, weight percent ^{a, b}											
			Cu	Mn	P	Si	Fe	Al	Zn	Ni ^d	Pb	Sn	Ti	Other Elements, Total
ECuAl-A2 ^f	A7.4.1.1	W60617	Rem	g	—	1.5	0.5–5.0	8.5–11.0	g	g	0.02	g	—	0.50
ECuAl-B ^f	A7.4.1.2	W60619	Rem	g	—	1.5	2.5–5.0	11–12	g	g	0.02	g	—	0.50
ECuAl-C	A7.4.1.2	W60625	Rem	—	—	1.0	3.0–5.0	12–13	0.02	—	0.02	—	—	0.50
ECuAl-D	A7.4.1.3	W61625	Rem	—	—	1.0	3.0–5.0	13–14	0.02	—	0.02	—	—	0.50
ECuAl-E	A7.4.1.3	W62625	Rem	—	—	1.0	3.0–5.0	14–15	0.02	—	0.02	—	—	0.50
ECuSi ^f	A7.4.1.4	W60656	Rem	1.5	g	2.4–4.0	0.50	0.01	g	g	0.02	1.5	—	0.50
ECuSn-A ^f	A7.4.1.5	W60518	Rem	g	0.05–0.35	g	0.25	0.01	g	g	0.02	4.0–6.0	—	0.50
ECuSn-C ^f	A7.4.1.5	W60521	Rem	g	0.05–0.35	g	0.25	0.01	g	g	0.02	7.0–9.0	—	0.50
ECuNi ^{e, f}	A7.4.1.6	W60715	Rem	1.0–2.5	0.02	0.50	0.40–0.75	—	g	29–33	0.02	g	0.50	0.50
ECuNiAl ^f	A7.4.1.7	W60632	Rem	0.5–3.5	—	1.5	3.0–6.0	8.5–9.5	g	4.0–6.0	0.02	g	—	0.50
ECuMnNiAl ^f	A7.4.1.8	W60633	Rem	11–14	—	1.5	2.0–4.0	7.0–8.5	g	1.5–3.0	0.02	g	—	0.50

^a Single values shown are maximum percentages. Rem = Remainder.

^b The weld metal shall be analyzed for the specific elements for which values, or a “g,” are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for “Other Elements, Total” in the last column of the table.

^c SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System*.

^d Includes cobalt.

^e Sulfur is restricted to 0.015% maximum.

^f This AWS classification is intended to correspond to the same classification that appears in AWS A5.6/A5.6M, *Specification for Copper and Copper-Alloy Covered Electrodes for Shielded Metal Arc Welding*. Because of revision dates the composition ranges may not be identical.

^g These elements must be included in “Other Elements, Total.”

Table 4
Mesh Size and Quantity of Tungsten Carbide (WC)
Granules in the Core of Tungsten Carbide Electrodes

AWS Classification ^{a, b}	U.S. Standard Mesh Size of Tungsten Carbide Granules ^c	SI Particle Size mm	Quantity of Tungsten Carbide (WC1 + WC2) Granules, Weight Percent
EWCX-10/30	thru 10—on 30	thru 2.00—on 0.60	60 ± 3
EWCX-20/30	thru 20—on 30	thru 0.85—on 0.60	60 ± 3
EWCX-30/40	thru 30—on 40	thru 0.60—on 0.43	60 ± 3
EWCX-40	thru 40	thru 0.43	60 ± 3
EWCX-40/120	thru 40—on 120	thru 0.43—on 0.13	60 ± 3
ENiWCX-30/230 ^d	thru 30—on 230	thru 0.60—on 0.06	60 ± 3

^a “X” designates the type of tungsten carbide granules; X = 1 for WC1 granules, X = 2 for WC2 granules, X = 3 for a blend of WC1 and WC2 granules.

^b These AWS classifications have been transferred to AWS A5.21:2001 without a change in classification for solid bare electrodes and rods and with the prefix “ERC” for electrode/rod made from metal or flux cored stock.

^c The mesh or SI particle size of the tungsten carbide granules may vary from that specified above, provided that no more than 5% of the granules are retained on the “thru” sieve, and that no more than 20% passes the “on” sieve.

^d This is constructed with a nickel-based sheath.

Table 5
Chemical Composition of Tungsten Carbide (WC) Granules

Element	Composition, weight percent ^a		
	WC1	WC2	WC3
C	3.6–4.2	6.0–6.2	As agreed between purchaser and supplier
Si	0.3	0.3	
Ni	0.3	0.3	
Mo	0.6	0.6	
Co	0.3	0.3	
W	94.0 min.	91.5 min.	
Fe	1.0	0.5	
Th	0.01	0.01	

^a Single values are maximum, unless noted otherwise.

Table 6
Standard Sizes and Lengths of Covered Electrodes Using Solid Drawn Core Wire^a

Electrode Sizes, Diameter of Solid Drawn Core Wire ^b		Standard Lengths	
in	mm	in	mm
5/64 (0.078)	2.0	9 ± 1/4	230 ± 10
3/32 (0.094) (0.097)	2.4 2.5	9 ± 1/4 or 12 ± 1/4	230 ± 10 or 300 ± 10
1/8 (0.125) 5/32 (0.156)	3.2 4.0	14 ± 1/4	350 ± 10
3/16 (0.187) (0.197)	4.8 5.0	14 ± 1/4 or 18 ± 1/4	350 ± 10 or 450 ± 10
7/32 (0.219) 1/4 (0.250)	5.6 6.4	14 ± 1/4 or 18 ± 1/4	350 ± 10 or 450 ± 10
5/16 (0.312)	8.0	18 ± 1/4	450 ± 10

^a Other electrode diameters and lengths may be supplied as agreed between the manufacturer and purchaser.

^b Tolerance on the diameter shall be ±0.002 in [±0.05 mm].

Table 7
Standard Sizes and Lengths for Covered Cast and Composite Tubular Electrodes^a

Electrode Sizes, Nominal Diameter of Core Wire ^b		Standard Lengths			
		For Cast Electrodes		For Composite Tubular Electrodes	
in	mm	in	mm	in	mm
1/8 (0.125) 5/32 (0.156) 3/16 (0.187) (0.197)	3.2 4.0 4.8 5.0	9 ± 3/8 or 14 ± 3/8	230 ± 10 or 350 ± 10	9 ± 3/8 or 14 ± 3/8	230 ± 10 or 350 ± 10
(0.236) (0.236) 1/4 (0.250) 1/4 (0.250)	6.0 6.0 6.4 6.4	12 ± 3/8 or 14 ± 3/8	300 ± 10 or 350 ± 10	14 ± 3/8 18 ± 3/8 14 ± 3/8 18 ± 3/8	350 ± 10 450 ± 10 350 ± 10 450 ± 10
5/16 (0.312) 5/16 (0.312)	8.0 8.0	12 ± 3/8 or 14 ± 3/8	300 ± 10 or 350 ± 10	14 ± 3/8 18 ± 3/8	350 ± 10 450 ± 10

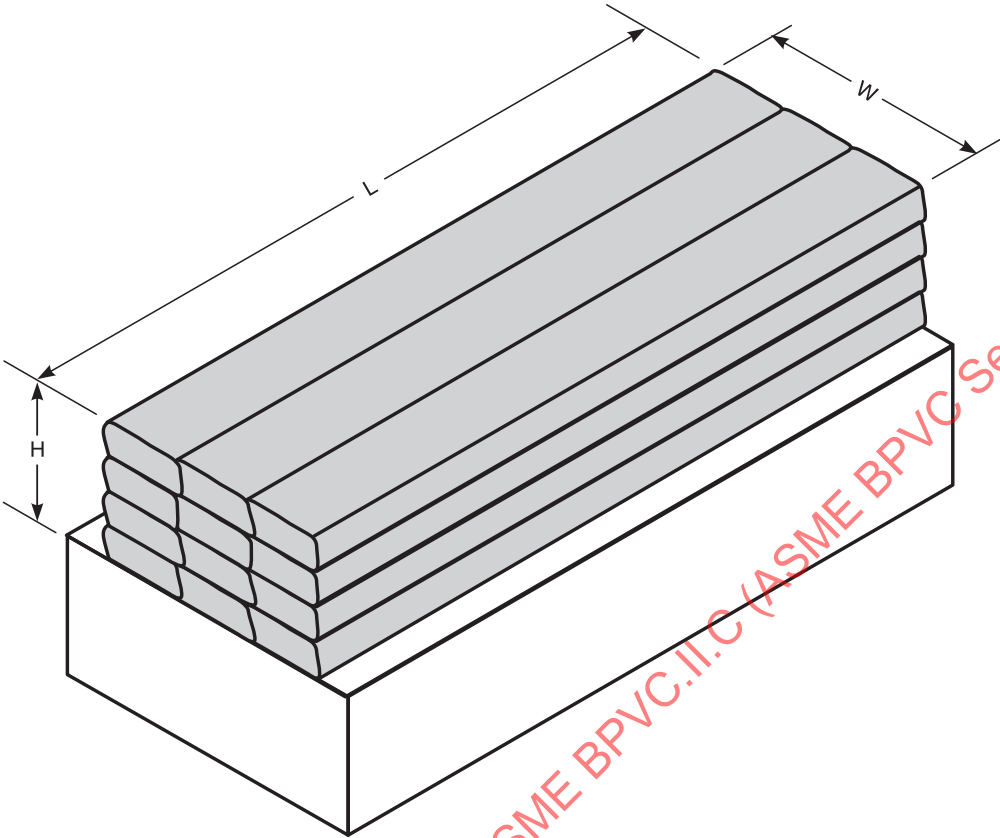
^a Other diameters and lengths of electrodes may be supplied as agreed between the manufacturer and the purchaser.

^b Diameter tolerance shall be ±0.02 in [±0.5 mm] from the nominal diameter.

Table 8
Standard Sizes and Lengths for Covered Tungsten Carbide (WC) Electrodes

Electrode Sizes, Nominal Diameter of Core Wire ^a		Standard Lengths	
in	mm	in	mm
3/32 (0.094) (0.098)	2.4 2.5	9 ± 3/8 or 14 ± 3/8	225 ± 10 or 350 ± 10
1/8 (0.125)	3.2	9 ± 3/8 or 14 ± 3/8	225 ± 10 or 350 ± 10
5/32 (0.156)	4.0	9 ± 3/8 or 14 ± 3/8	225 ± 10 or 350 ± 10
3/16 (0.187) (0.197)	4.8 5.0	9 ± 3/8 or 14 ± 3/8	225 ± 10 or 350 ± 10
(0.236) 1/4 (0.250)	6.0 6.4	14 ± 3/8 or 18 ± 3/8	350 ± 10 or 450 ± 10
5/16 (0.312)	8.0	14 ± 3/8 or 18 ± 3/8	350 ± 10 or 450 ± 10

^a Diameter tolerance shall be ±0.04 in [±1.0 mm] from the nominal diameter.



Electrode Size		Weld Pad Size, minimum	
in	mm	in	mm
5/64 (0.078)	2.0	L = 1-1/2	38
3/32 (0.094)	2.4	W = 1/2	13
(0.097)	2.5	H = 1/2	13
1/8 (0.125)	3.2	L = 2	50
5/32 (0.156)	4.0	W = 1/2	13
3/16 (0.187)	4.8	H = 5/8	16
(0.197)	5.0		
7/32 (0.219)		L = 2-1/2	64
(0.236)	6.0	W = 1/2	13
1/4 (0.250)	6.4	H = 3/4	19
5/16 (0.312)	8.0		

Figure 1—Pad for Chemical Analysis of Undiluted Weld Metal

Annex A (Informative)

Guide to AWS Specification for Surfacing Electrodes for Shielded Metal Arc Welding

This annex is not part of this standard but is included for informational purposes only.

A1. Introduction

The purpose of this guide is to correlate filler metal classifications with their intended applications, so the specification can be used effectively.

A2. Classification System

A2.1 The system for identifying the electrode classifications in this specification follows the standard pattern used in other AWS filler metal specifications. The prefix E at the beginning of each classification designation stands for electrode. The letters immediately after the E are the chemical symbols for the principal elements in the classification. Thus, CoCr is a cobalt-chromium alloy, CuAl is a copper-aluminum alloy, etc. Where more than one classification is included in a basic group, the individual classifications in the group are identified by the letters, A, B, C, etc., as in ECuSn-A. Further subdividing is done by using a 1, 2, etc., after the last letter, as the 2 in ECuAl-A2. An additional letter or number has been added to some designations if the composition requirements in this specification differ somewhat from those of the earlier versions for electrodes of the same basic classification.

A2.2 Request for Filler Metal Classification. When a surfacing electrode cannot be classified as given in this specification, the manufacturer may request that a classification be established for that welding electrode. The manufacturer shall do this using the following procedure.

(1) A request to establish a new filler metal classification must be submitted in writing. The request needs to provide sufficient detail to permit the Committee on Filler Metals and Allied Materials and the relevant Subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

- (a) A declaration that the new classification will be offered for sale commercially.
- (b) All classification requirements as given for existing classifications, such as chemical composition ranges, mechanical property requirements, and usability test requirements.
- (c) Any conditions for conducting the tests used to demonstrate that the filler metal meets the classification requirements. (It would be sufficient, for example, to state that welding conditions are the same as for other classifications.)
- (d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the annex).
- (e) Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.
- (f) A request for a new classification without the above information will be considered incomplete. The Secretary will return the request to the requester for further information.

(2) In order to comply with the AWS Policy on Patented Items, Trademarks, and Restraint of Trade, if the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester shall disclose this. In these cases, the patent holder must allow the use of this technology, such as by license. The Secretary will provide examples of acceptable wording to the patent holder, as required.

The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters for processing.

A2.3 From an application point of view, many classifications in this specification have a corresponding classification in AWS A5.21/A5.21M, *Specification for Bare Electrodes and Rods for Surfacing* (see Table A.1).

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01M/A5.01. Any testing a purchaser requires of the supplier for material shipped in accordance with this specification shall be clearly stated in the purchase order. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing the supplier normally conducts on material of that classification, as specified in Schedule 1 or F, Table 1, of AWS A5.01M/A5.01. Testing in accordance with any other schedule must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product or the classification on the product itself constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification.

The only testing requirement implicit in this *certification* is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that the material met the requirements of the specification. Representative material, in this case, is material from any production run of that classification using the same formulation. *Certification* is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the *certification* required by the specification is the classification test of *representative material*, cited above, and the Manufacturer's Quality Assurance Program in AWS A5.01M/A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes in the atmosphere, to which welders and welding operators are exposed during welding. They are:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling)
- (2) Number of welders and welding operators working in that space
- (3) Rate of evolution of fume, gases, or dust, according to the materials and processes used
- (4) The proximity of the welders or welding operators to the fumes, as they issue from the welding zone, and to the gases and dusts in the space in which they are working
- (5) The ventilation provided to the space in which the welding is done

A5.2 American National Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is particularly drawn to the clause on Ventilation in that document. See also AWS F3.2, *Ventilation Guide for Weld Fume* for more detailed descriptions of ventilation options.

A6. Welding Considerations

A6.1 Role of Hydrogen in Surfacing. Hydrogen can be detrimental to surfacing deposits. The effect varies widely from one alloy type to another. Hydrogen can be detrimental to weld ductility and result in hydrogen-assisted cracking in the weld metal or heat-affected zone (HAZ). In general, hydrogen's detrimental effect is the most pronounced for martensitic types, with austenitic types being the least affected. Other factors influencing hydrogen's effect include carbon and alloy contents plus in-service welding variables.

In welding, there are many sources for hydrogen contamination. Coating moisture is one of the most important. Most electrodes are manufactured and packaged to control moisture. When received, consideration must be given to proper storage, to prevent moisture pick-up. During use, improper regard to welding procedure and environmental variables can result in spalling or "hydrogen-induced" (underbead) cracking.

A6.2 Low equipment cost, great versatility, and general convenience make manual shielded metal arc welding very popular. The welding machine, which is essentially a power conversion device, is usually the main item of equipment needed. It may be a motor-generator, transformer, transformer-rectifier combination, or fuel-operated engine combined with a generator. The arc power may be either direct or alternating current. The filler metal is in the form of covered electrodes. (Bare electrode arc welding is a rarity today, though it is feasible with austenitic manganese steel electrodes.) Welding can be done in almost any location and is practicable for a variety of work, ranging from very small to quite large. For some applications, it is the only feasible method; and, for many others (especially where continuous methods do not offer significant benefits), it is the economical choice.

The operation is under the observation and control of the welder, who can easily cover irregular areas and often correct for adverse conditions. It is also helpful if the welder exercises judgment in other matters, such as holding the arc power down to minimize cracking, keeping a short arc and avoiding excessive puddling, or too large of a molten pool, to minimize the loss of expensive alloying elements in the filler metal, minimizing dilution with base metal, and restricting hydrogen pickup. This process is used extensively for hardfacing, buttering, build-up, and cladding.

Surfacing of carbon and low-alloy steels, high-alloy steels, and many nonferrous metals may be done with the shielded metal arc process. Base metal thicknesses may range from 1/4 in to 18 in [6 mm to 450 mm]. The surfacing metals employed include low-alloy and high-alloy steels, stainless steels, nickel-base alloys, cobalt-base alloys, and copper-base alloys.

The welding conditions for surfacing are not fundamentally different from those used in welding a joint. The arc and weld pool are shielded by slag or gases or both, produced by the electrode. The type of covering on the electrode has considerable effect on the characteristics of the weld metal. Surfacing can be done on work ranging in size from very small to quite large.

Table A.2 shows how the various shielded metal arc process variables affect the three most important surfacing characteristics: dilution, deposition rate, and deposit thickness.

The table indicates only general trends and does not cover questions of weldability or weld soundness. These factors may make it unwise to change only the indicated variable; this in turn may mean that the desired change in dilution, deposition rate, or deposit thickness may not be achieved. For example, a given welding procedure with a small electrode diameter may produce high dilution. The table indicates that a change to a large size electrode will decrease dilution. This is true, however, only if the amperage, travel speed, position, etc. also remain constant. In many cases, a larger amperage value must be used with the larger electrode size to obtain acceptable weld quality. In this case, the dilution may remain constant or even increase with the change to the larger electrode size.

The process usually achieves a deposition rate from 1 lb–4 lb [0.5 kg–2 kg] per hour at dilution levels from 30%–50%.

A7. Description and Intended Use of Surfacing Electrodes

A7.1 Iron-Base Electrodes

A7.1.1 EFe-1 and EFe-2 Electrodes

A7.1.1.1 Characteristics. Deposits made with these electrodes are a machinery grade steel, suitable for application on carbon and alloy steels. With care, they can be applied crack-free. Deposits are machinable with carbide tipped tools.

Deposit hardness generally, is in the range of 20 HRC–50 HRC, with EFe-2 electrodes providing weld metal with the higher hardness. These deposits contain sufficient alloy to attain full hardness without the need of heat treatment. Abrasion resistance is comparable to heat-treated steels of equal hardness.

A7.1.1.2 Applications. These electrodes are used to restore worn machinery parts to their original dimensions. Deposit surfaces are suitable for metal-to-metal rolling and sliding contact, such as occurs on large, low speed gear teeth, shafts, etc. High compressive strength makes these materials suitable as a base for more abrasion-resistant materials.

A7.1.2 EFe-3 Electrodes

A7.1.2.1 Characteristics. Weld metal deposited by these electrodes is an air-hardening tool steel type, with high room temperature hardness (55 HRC–60 HRC). Deposits can be applied crack-free with careful procedures. The deposits cannot be machined and generally, are ground when finishing is required.

A7.1.2.2 Applications. EFe-3 electrodes are used to overlay surfaces and edges requiring high hardness and crack-free deposits, such as the edges of tools and dies. Deposits are compatible with many tool steels. Although generally used for metal-to-metal applications, EFe-3 weld metal performs well in earth abrasion applications where high impact is encountered.

A7.1.3 EFe-4 Electrodes

A7.1.3.1 Characteristics. These electrodes will have a graphitic (black) coating and are suitable for application on cast iron. Although the deposited metal is relatively brittle, crack-free deposits are possible with controlled procedures. Deposits can be machined, providing they are slow cooled from an annealing temperature.

A7.1.3.2 Applications. EFe-4 weld metal is used to rebuild worn cast iron machinery parts subject to metal-to-metal rolling or sliding contact. Although EFe-4 weld deposits are compatible with carbon and low-alloy steel, EFe-2 electrodes are generally preferred for such applications.

A7.1.4 EFe-5 Electrodes

A7.1.4.1 Characteristics. EFe-5 electrodes deposit a cold work type of tool steel. Hardness, as-deposited, should be in the range of 50 HRC–55 HRC. Weld metal deposited by EFe-5 electrodes is air-hardening and machinable only after annealing.

A7.1.4.2 Applications. Typical applications include those requiring high compressive strength with moderate abrasion and metal-to-metal wear, such as machine components, shafts, and brake drums.

A7.1.5 EFe-6 Electrodes

A7.1.5.1 Characteristics. Weld metal deposited by EFe-6 electrodes is a high-speed tool steel with a hardness in range of 60 HRC or higher. The deposit maintains a high degree of hardness to 1100 °F [600 °C]. Weld metal deposited by EFe-6 electrodes is air-hardening and is machinable only after annealing.

A7.1.5.2 Applications. Weld deposits may be used for metal-to-metal wear applications at temperatures up to 1100 °F [600 °C]. Typical applications, which combine high temperature service with severe abrasion and metal-to-metal wear, include shear blades, trimming dies, and punching dies.

A7.1.6 EFe-7 Electrodes

A7.1.6.1 Characteristics. EFe-7 series electrodes are essentially a higher carbon modification of EFe-3 electrodes. Abrasion resistance of the weld deposit is improved with some sacrifice in impact resistance. Deposits air harden, and a two-layer deposit can be expected to have a hardness of 60 HRC or higher. Stress-relief cracks (cross-checks) typically occur through the overlay. Deposits cannot be machined.

A7.1.6.2 Applications. EFe-7 electrodes are used for overlaying surfaces that require good low-stress abrasion resistance. Applications include cement chutes, fan blades, bulldozer blades, and other parts and equipment used for earthmoving or construction. Carbon and alloy steels, tool steels, and stainless steels are compatible base metals.

A7.1.7 EFe-8 Electrodes

A7.1.7.1 Characteristics. Weld metal deposited by EFe-8 electrodes is a hot work tool steel with a hardness in the range of 50 HRC–60 HRC. The microstructure consists of martensite plus alloy carbides to produce a tough, hard

deposit on either carbon or low-alloy steel base metal. Proper preheating is essential to ensure crack-free deposits (consult the manufacturer for suggested temperatures). The deposit may be finished by grinding.

A7.1.7.2 Applications. This composition is used for overlaying surfaces subjected to moderate abrasive wear with high impact. Applications typically include machine tools and components subject to sliding metal-to-metal wear in hot forming processes.

A7.1.8 EFe-RBU Electrodes

A7.1.8.1 Characteristics. This is a general classification introduced to facilitate the specification of electrode composition in railway weld repair processes. Specific welding procedures may call on more restrictive A5.13 classifications like EFe-1 or EFe-2. Deposits made by EFe-RBU electrodes and rods tend to be mixtures of ferritic, bainitic, or martensitic microstructures depending on actual composition and welding process parameters. They contain sufficient alloy to attain full hardness without the need for heat treatment. Hardness is usually in the 25 HRC–50 HRC range. These filler metals provide good resistance to rolling, sliding and metal-to-metal wear. With care, the deposits can be applied crack-free. They can be machined with carbide-tipped tools.

A7.1.8.2 Applications. These electrodes are used for the rebuilding and repair of worn track rails, rail ends and rail crossing points. They exhibit low material deformation on impact and the ability to provide some work hardening without cracking. The related applications are described in the AWS D15.2/D15.2M specification.

A7.1.9 EFeMn Series Electrodes (except EFeMnCr and EFeMn-RBU)

A7.1.9.1 Characteristics. Deposits made with these electrodes nominally contain 14% manganese, although they may vary from 12% to 27%. This is an amount sufficient to yield austenitic weld deposits. Austenite is a nonmagnetic tough form of steel. To preserve the toughness, excessive heat must be avoided during welding, keeping a maximum interpass temperature of 500 °F [260 °C]. Stringer beads and skip welding are thus recommended. Additions of other elements, such as 4% nickel, give more stability to the austenite. Chromium and molybdenum can also be added to increase the yield strength. Abrasion resistance is only a little better than that of low-carbon steel unless there has been sufficient impact to cause work hardening. As deposited, surfaces generally are no harder than 20 HRC, but can work harden in service up to 55 HRC. Deposits are difficult to machine; grinding is preferred for finishing to dimensions.

Weld metal deposited by EFeMn-F electrodes differ from the other austenitic manganese classifications in that a single-layer deposit will be fully austenitic when deposited on carbon steel or low-alloy steel base metal. This is the direct result of the higher carbon and manganese contents of the filler metal.

A7.1.9.2 Applications. These electrodes are used for the rebuilding, repairing, and joining of austenitic manganese steels. Ability to absorb high impact makes such deposits ideal for rebuilding of worn rock-crushing equipment and other wear components subject to heavy impact loads such as railroad frogs.

A7.1.10 EFeMnCr Electrodes

A7.1.10.1 Characteristics. Weld metal deposited by EFeMnCr electrodes have similar characteristics to those of the austenitic manganese steel deposits. However, the high-chromium content improves the stability of austenite when compared to EFeMn deposits. These deposits cannot be flame cut due to their high chromium content, and care must be taken in application to avoid heat build-up beyond a maximum interpass temperature of 500 °F [260 °C].

A7.1.10.2 Applications. Like EFeMn-type electrodes, EFeMnCr electrodes are used for rebuilding, repairing, and joining of equipment made from austenitic manganese steels. EFeMnCr electrodes offer the added advantage of being usable for joining austenitic manganese steel to itself and to carbon steel. EFeMnCr weld metals are often used as a base layer for subsequent surfacing with EFeCr-AX(X) hardfacing filler metals on parts subject to both abrasion and impact.

A7.1.11 EFeMn-RBU Electrodes

A7.1.11.1 Characteristics. This is a general classification introduced to facilitate the specification of electrode composition in railway weld repair processes. Specific welding procedures may call on more restrictive A5.13 classifications like EFeMn-F, EFeMn-G or EFeMnCr. Deposits made by EFeMn-RBU electrodes nominally contain 14% manganese, although they may vary from 12% to 27%. This is an amount sufficient to yield austenitic weld deposits. To preserve the toughness, excessive heat must be avoided during welding, keeping a maximum interpass temperature of 500 °F [260 °C]. Stringer beads and skip welding are thus recommended. As deposited, surfaces generally are no harder than

20 HRC, but can work harden in service up to 55 HRC. Deposits are difficult to machine; grinding is preferred for finishing to dimensions.

A7.1.11.2 Applications. These electrodes are used for the rebuilding and repairing of high manganese steel railroad frogs and crossing diamonds. The related applications are described in the AWS D15.2/D15.2M specification. Such deposits can absorb high impact and heavy rolling loads.

A7.1.12 EFeCr-A1A and EFeCr-A4 Electrodes

A7.1.12.1 Characteristics. Weld metal deposited by these electrodes will contain hyper-eutectic coarse primary hexagonal chromium carbides in an austenitic matrix, providing great wear resistance and fair toughness. The typical hardness range is 50 HRC–60 HRC. Surface cross-checks are normal and provide a degree of stress-relief. To achieve the desired composition, a minimum of two layers is usually recommended. Additional layers may be prone to spalling and must be applied with caution per manufacturer instructions. These electrodes are suitable for welding on carbon, low-alloy, and austenitic manganese steels. The weld metal deposited by EFeCr-A1A electrodes generally provides greater impact resistance than EFeCr-A4. The deposit cannot be flame-cut. Finishing is done by grinding only.

A7.1.12.2 Applications. Typical applications include bucket lips and teeth, coal pulverizer rolls, impact hammers, and conveyor screws used for handling rock, ore, coal, etc. Very low coefficients of friction develop as a result of the wear surface polishing to a slick finish under mineral abrasion.

A7.1.13 EFeCr-A2 Electrodes

A7.1.13.1 Characteristics. The weld metal deposit contains titanium carbide in an austenitic matrix. It is machinable only by grinding. Build-up should be limited to three layers, to minimize relief check cracking.

A7.1.13.2 Applications. This weld metal group may be applied to both carbon steel and austenitic manganese base metal. Deposits are used to overlay mining, construction, earth moving, and quarrying equipment subject to abrasion and moderate impact.

A7.1.14 EFeCr-A3 Electrodes

A7.1.14.1 Characteristics. The microstructure of weld metal deposited by EFeCr-A3 electrodes resembles that of white cast iron with hypo- or near-eutectic chromium carbides with a hardness in the range of 45 HRC–55 HRC. The deposit has higher toughness than weld metal deposited by other EFeCr-AX electrodes with the exception of the EFeCr-A5 class but implies a reduction in abrasion resistance. Surface cross-checks are normal and provide a degree of stress-relief. The deposit cannot be flame-cut. Finishing is done by grinding only.

A7.1.14.2 Applications. This weld metal is a general-purpose hardfacing alloy typically used as a final overlay on roll crushers, mill hammers, cone crushers, and road work ground-engaging tools, often applied over a prior austenitic manganese steel build-up.

A7.1.15 EFeCr-A5 Electrodes

A7.1.15.1 Characteristics. The weld deposit contains fine secondary chromium carbides evenly dispersed in an austenitic matrix. The typical hardness range is 35 HRC–50 HRC. The nonmagnetic weld metal has fair machinability. Some free chromium provides fair corrosion resistance. Build-up should be restricted to three layers to minimize relief checking. Some electrode compositions can be applied crack-free.

A7.1.15.2 Applications. Components surfaced with these electrodes are frequently used for applications involving metal-to-metal friction wear or low-stress metal-to-earth abrasion. The corrosion resistance makes this deposit a good choice for process equipment like pulping screws.

A7.1.16 EFeCr-A6 and EFeCr-A7 Electrodes

A7.1.16.1 Characteristics. These are a higher carbon version of the EFeCr-A5 electrodes. The deposits contain coarse primary hexagonal chromium carbides in an austenitic matrix and show a hardness between 50 HRC and 60 HRC. Deposits develop stress-relief cracks. The addition of molybdenum increases the wear resistance to high-stress abrasion. The weld metal may be applied on carbon, alloy, or austenitic manganese steel base metal. The deposit cannot be flame-cut. Finishing is done by grinding only.

A7.1.16.2 Applications. Weld metal is frequently used for applications involving *low- to high-stress abrasive wear combined with moderate impact, like on ground-engaging tools or quarry crusher rolls.*

A7.1.17 EFeCr-A8 Electrodes

A7.1.17.1 Characteristics. EFeCr-A8 is a higher chromium version of EFeCr-A3. The deposit contains *coarse primary hexagonal chromium carbides in an austenitic matrix and gives a hardness between 50 HRC and 60 HRC.* The increased chromium content tends to decrease the toughness, while increasing the abrasion resistance. Maximum relief checking can be expected. The weld metal may be applied to carbon, alloy, or austenitic manganese base metals. *The deposit cannot be flame-cut. Finishing is done by grinding only.*

A7.1.17.2 Applications. Weld metal is frequently used for applications involving *low-stress sliding abrasion combined with minimum impact, especially in earthmoving, mineral processing, and many bulk handling applications.*

A7.1.18 EFeCr-A9 Electrodes

A7.1.18.1 Characteristics. *The deposit contains a high volume of hyper-eutectic coarse primary hexagonal chromium carbides in an austenitic matrix with a typical hardness of 55 HRC to 65 HRC. Such deposits develop dense stress-relief cracking patterns (cross-checks). To achieve the desired composition, a minimum of two layers is usually recommended. Additional layers may be prone to spalling and must be applied with caution per manufacturer instructions. The weld metal may be applied on carbon or low-alloy steel, austenitic manganese steel, or austenitic stainless steel base metal. The deposit cannot be flame-cut. Finishing is done by grinding only.*

A7.1.18.2 Applications. *These electrodes are frequently used for applications involving severe abrasive wear combined with moderate impact. They count numerous applications such as chute repairs, fan blades, oil sands slurry lines, mixer components, screw conveyors, brick extruders, bucket teeth, sugar mill rolls, shredder hammers, etc.*

A7.1.19 EFeCr-EX Series Electrodes

A7.1.19.1 Characteristics. Weld metal deposited by these electrodes will show a dense microstructure containing coarse primary hexagonal chromium carbides interlocked with finer refractory metal carbides (Mo, W, V, Nb/Cb, Ti) in an austenitic matrix. Such deposit provides excellent abrasive wear resistance under little to no impact. The typical undiluted metal hardness range is 60 HRC–65 HRC, which decreases progressively up to a temperature of 1400 °F [760 °C]. Surface cross-checks are normal and provide a degree of stress-relief. A maximum of two layers is usually recommended. Additional layers may be prone to fracture and/or spalling and must be applied with caution per manufacturer instructions. Deposits cannot be flame-cut and must be ground when finishing is required.

A7.1.19.2 Applications. This weld metal is generally the most appropriate for severe wear involving very fine and high-velocity abrading particles as well as for higher temperature service with little to no impact. Typical applications include coke pusher shoes, iron sinter breakers, exhaust fan liners, pug mills, brick extruders, etc.

A7.1.20 EFeV Electrodes

A7.1.20.1 Characteristics. Weld metal deposited by these electrodes will contain a large amount of evenly distributed vanadium carbides, as the primary wear resistance factor, along with secondary tungsten carbides. The deposit provides severe abrasion resistance against medium-size and coarse mineral particles under moderate impact. The typical hardness range is 55 HRC–65 HRC. Stress-relief micro-cracking can occur upon cooling. A maximum of three layers is usually recommended. The deposit can easily be repaired without compromising the microstructure. These electrodes are suitable for welding on carbon and low-alloy steels. Finishing is done by grinding only.

A7.1.20.2 Applications. The deposit provides enhanced metal-to-earth abrasion resistance over the EFeCr-AX series. Typical applications include ground-engaging tools, cultivator chisels, sweeps and plows, ammonia injectors, dry cement pump screws, pug mills, construction residues shredder hammers, sugar cane harvesters, civil works auger tips, etc.

A7.2 Cobalt-Base Surfacing Electrodes

A7.2.1 ECoCr-A Electrodes

A7.2.1.1 Characteristics. Weld metal deposited by ECoCr-A electrodes is characterized by a hypo-eutectic microstructure consisting of a network of about 13% eutectic chromium carbides distributed in a cobalt-chromium-tungsten solid solution matrix. The result is a material with a combination of overall resistance to low stress abrasive

wear, coupled with the necessary toughness to resist some degree of impact. Cobalt alloys also are inherently good for resisting metal-to-metal wear, particularly in high load situations that are prone to galling. The high alloy content of the matrix also affords excellent resistance to corrosion, oxidation, and elevated temperature retention of hot hardness, up to a maximum of 1200 °F [650 °C]. These alloys are not subject to allotropic transformation and therefore do not lose their properties if the base metal subsequently is heat treated.

A7.2.1.2 Applications. The alloy is recommended for cases where wear is accompanied by elevated temperatures and where corrosion is involved, or both. Typical applications include automotive and fluid flow valves, chain saw guides, hot punches, shear blades, and extruder screws.

A7.2.2 ECoCr-B Electrodes

A7.2.2.1 Characteristics. Weld metal deposited by ECoCr-B electrodes is similar in composition to ECoCr-A deposits, except for a slightly higher carbide content (approximately 16 percent). The alloy also has a slightly higher hardness, coupled with better abrasive and metal-to-metal wear resistance. Impact and corrosion resistance are lowered slightly. Deposits can be machined with carbide tools.

A7.2.2.2 Applications. ECoCr-B electrodes are used interchangeably with ECoCr-A. Choice will depend on the specific application.

A7.2.3 ECoCr-C Electrodes

A7.2.3.1 Characteristics. This alloy's deposits have a higher carbide content (19%) than those made using either ECoCr-A or ECoCr-B electrodes. In fact, the composition is such that primary hyper-eutectic carbides are found in the microstructure. This characteristic gives the alloy higher wear resistance, accompanied by reductions in the impact and corrosion resistance. The higher hardness also means a greater tendency to stress crack during cooling. The cracking tendency may be minimized by closely monitoring preheating, interpass temperature, and post heating techniques. While the cobalt-chromium deposits soften somewhat at elevated temperatures, they normally are considered immune to tempering.

A7.2.3.2 Applications. Weld metal deposited by ECoCr-C electrodes is used to build up mixer rotors and items that encounter severe abrasion and low impact.

A7.2.4 ECoCr-E Electrodes

A7.2.4.1 Characteristics. Welds made using ECoCr-E electrodes have very good strength and ductility at temperatures up to 1600 °F [870 °C]. Deposits are resistant to thermal shock as well as oxidizing and reducing atmospheres. Early applications of these types of alloys were found in jet engine components such as turbine blades and vanes. The deposit is a solid-solution-strengthened alloy with a relatively low weight-percent carbide phase in the microstructure. Hence, the alloy is very tough and will work harden. Deposits possess excellent self-mated galling resistance and are also very resistant to cavitation erosion.

A7.2.4.2 Applications. Welds made using ECoCr-E electrodes are used where resistance to thermal shock is important. Typical applications, similar to those of ECoCr-A deposits, include guide rolls, hot extrusion and forging dies, hot shear blades, tong bits, and valve trim.

A7.2.5 Typical hardness values for multilayer welds made using cobalt base electrodes are:

ECoCr-A	23–47 HRC
ECoCr-B	34–47 HRC
ECoCr-C	43–58 HRC
ECoCr-E	20–32 HRC

Hardness values for single layer deposits will be lower because of dilution from the base metal.

A7.3 Nickel Base Surfacing Electrodes

A7.3.1 ENiCr-C Electrodes

A7.3.1.1 Characteristics. Undiluted weld metal of this composition exhibits a structure consisting of chromium carbides and chromium borides in a nickel-rich matrix. The nickel base and high chromium content give these deposits

good heat and corrosion resistance. Care should be taken when cooling hardfacing deposits because of a tendency to stress crack. This alloy possesses excellent resistance to low stress abrasion.

A7.3.1.2 Applications. ENiCr-C weld metal flows very easily, has very high abrasion resistance, and normally takes on a high polish. Typical applications include cultivator sweeps, plow shares, extrusion screws, pump sleeves, pistons and impellers, capstan rings, glass mold faces, centrifuge filters, and sucker pump rods. The deposits have high corrosion resistance and normally require grinding for finishing. Single layer deposits typically have a hardness of 35 HRC to 45 HRC. Multilayer deposits typically have a hardness of 49 HRC to 56 HRC.

A7.3.2 ENiCrMo-5A Electrodes

A7.3.2.1 Characteristics. Undiluted weld metal deposited by ENiCrMo-5A electrodes is a solid-solution-strengthened alloy with relatively low weight-percent carbide phase, produced through secondary hardening. The resultant deposit is tough and work hardenable.

Deposits have the ability to retain hardness up to 1400 °F [760 °C]. Deposits are machinable with high-speed tool bits and have excellent resistance to high-temperature wear and impact.

A7.3.2.2 Applications. These electrodes are used to rebuild and repair hot extrusion dies, hot forging dies, sizing punches, hot shear blades, guide rolls, tong bits, blast furnace bells, etc.

A7.3.3 ENiCrFeCo Electrodes

A7.3.3.1 Characteristics. Weld metal deposited by these electrodes contain a fairly large volume fraction of hypereutectic chromium carbides distributed throughout the microstructure. The alloy offers many of the same high-performance characteristics of deposits made using ECoCr-C or ENiCr-C electrodes in terms of abrasive wear resistance. The reduced nickel or cobalt content, or both, lowers corrosion properties and galling resistance. The high-volume fraction of carbides makes this alloy sensitive to cracking during cooling.

A7.3.3.2 Applications. Welds made using ENiCrFeCo electrodes are preferred where high abrasion (low impact) is a major factor. Typical applications are feed screws, slurry pumps, and mixer components.

A7.4 Copper-Base Alloy Electrodes

A7.4.1 Introduction. The copper-base alloy electrodes classified by this specification are used to deposit overlays and inlays for bearing, corrosion-resistant, or wear-resistant surfaces.

A7.4.1.1 ECuAl-A2 electrodes are used for surfacing bearing surfaces between the hardness ranges of 130 HB to 150 HB, as well as corrosion-resistant surfaces.

A7.4.1.2 ECuAl-B and ECuAl-C electrodes are used primarily for surfacing bearing surfaces requiring hardness in the range of 140 HB–220 HB. These alloys are not recommended for applications that require resistance to corrosion.

A7.4.1.3 ECuAl-D and ECuAl-E electrodes are used to surface bearing and wear-resistant surfaces requiring hardness in the range of 230 HB–320 HB, such as gears, cams, sheaves, wear plates, and dies. These alloys are also used to surface dies that form or draw titanium, low-carbon, and stainless steels. These alloys are not recommended for applications that require resistance to corrosion.

A7.4.1.4 ECuSi electrodes are used primarily for surfacing corrosion-resistant surfaces. Copper-silicon deposits generally are not recommended for bearing service.

A7.4.1.5 Copper-tin (ECuSn-A and -C) electrodes are used primarily to surface bearing surfaces where the lower hardness of these alloys is required, for surfacing corrosion-resistant surfaces, and occasionally, for applications requiring wear resistance.

A7.4.1.6 Copper-nickel electrodes (ECuNi) are used for rebuilding 70/30%, 80/20%, and 90/10% copper-nickel alloy or the clad side of copper-nickel clad steel. Preheating generally is not necessary.

A7.4.1.7 Copper-nickel-aluminum electrodes (ECuNiAl) are used to rebuild nickel-aluminum-bronze castings or wrought components. Typical applications are those requiring a high resistance to corrosion, erosion, or cavitation in salt or brackish water.

A7.4.1.8 ECuMnNiAl electrodes are used to rebuild or surface cast manganese-nickel-aluminum bronze castings or wrought material. Typical applications include those requiring excellent resistance to corrosion, erosion, and cavitation.

A7.4.2 Applications

A7.4.2.1 Hardness Ranges. See Table A.3 for typical hardness ranges.

A7.4.2.2 Hot Hardness. The copper-base alloy filler metals are not recommended for use at elevated temperatures. Mechanical properties, especially hardness, will tend to decrease consistently as the temperature increases above 400 °F [200 °C].

A7.4.2.3 Impact. In general, as the aluminum content increases, impact resistance decreases rapidly. The impact resistance of deposits made by using ECuAl-A2 electrodes will be the highest of the copper-base alloy classifications. Deposits made using ECuSi electrodes have good impact properties. Deposits made using ECuSn electrodes have low impact properties.

A7.4.2.4 Oxidation Resistance. Weld metal deposited by any of the ECuAl family of electrodes forms a protective oxide coating upon exposure to the atmosphere. Oxidation resistance of the copper-silicon deposit is fair, while that of copper-tin deposits is comparable to the oxidation resistance of pure copper.

A7.4.2.5 Corrosion Resistance. Several copper base alloy filler metals are used rather extensively to surface areas subject to corrosion from reducing type acids, mild alkalies, and salt water. They should not be used in the presence of oxidizing acids such as HNO₃, or when sulfur compounds are present. Filler metals producing deposits of higher hardness may be used to surface areas subject to corrosive action as well as erosion from liquid flow for such applications as condenser heads and turbine runners.

A7.4.2.6 Abrasion. None of the copper-base alloy deposits are recommended for use where severe abrasion is encountered in service.

A7.4.2.7 Metal-to-Metal Wear. Copper-aluminum deposits with hardnesses of 130 HB to approximately 320 HB are used to overlay surfaces subjected to excessive wear from metal-to-metal contact. For example, ECuAl-E electrodes are used to surface dies and to draw and form stainless and carbon steels and aluminum.

All of the copper-base alloy filler metals classified by this specification are used to deposit overlays and inlays for bearing surfaces, with the exception of the CuSi filler metals. Silicon bronzes are considered poor bearing alloys. Copper-base alloy filler metals selected for a bearing surface should produce a deposit of 50 HB–75 HB under that of the mating part. Equipment should be designed so that the bearing will wear in preference to the mating part.

A7.4.2.8 Mechanical Properties in Compression. Deposits of the ECuAl filler metals have high elastic limits and ultimate strengths in compression ranging from 25 000 psi–65 000 psi [170 MPa–450 MPa] and 120 000 psi–171 000 psi [825 MPa–1180 MPa], respectively. The elastic limit of ECuSi deposits is around 22 000 psi [150 MPa] with an ultimate strength in compression of 60 000 psi [415 MPa]. The ECuSn deposits will have an elastic limit of 11 000 psi [75 MPa] and an ultimate strength of 32 000 psi [220 MPa].

A7.4.2.9 Machinability. All of these copper-based alloy deposits are machinable.

A7.4.2.10 Heat Treatment. Ordinarily, no heat treatment is needed in surfacing with copper-base alloy filler metals.

A7.4.2.11 Welding Characteristics. To minimize dilution from the base metal when surfacing with copper-base electrodes, the first layer should be deposited using as low an amperage as practical. Excessive base metal dilution can result in reduced machinability and service performance. The manufacturer should be consulted for specific welding parameters.

A7.4.2.12 Preheat. Generally, a preheat is not necessary unless the part is exceptionally large; in this case, a 200 °F [100 °C] preheat may be desirable to facilitate the smooth flow of the weld metal. At no time should the preheat temperature be above 400 °F [200 °C] when applying the first layer. On subsequent layers, an interpass temperature of approximately 200 °F–600 °F [100 °C–300 °C] will simplify deposition of the weld metal.

A7.5 Tungsten Carbide Electrodes

A7.5.1 EWCX Series Electrodes

A7.5.1.1 Characteristics. Tungsten carbide covered tubular electrodes in this classification contain 60% by weight of tungsten carbide particles in an iron base matrix. Most of the iron comes from the low carbon steel strip formed into a tube. The WC1 carbide is an eutectic mixture of WC and W₂C. The WC2 carbide is macrocrystalline WC. Hardness of the deposit matrix varies from 30 HRC to 60 HRC depending on welding technique. Hardness of individual carbide particles is typically between 2200 HV₁₀₀ and 2600 HV₁₀₀ for the eutectic tungsten carbide and between 1800 HV₁₀₀ and 2200 HV₁₀₀ for the macrocrystalline tungsten carbide. Abrasion resistance of tungsten carbide deposits is outstanding. Vickers microhardness (HV) of tungsten carbide particles to be measured according to ASTM E384, Standard Test Method for Microindentation Hardness of Materials.

A7.5.1.2 Applications. Iron-based tungsten carbide composite deposits are applied on surfaces subject to extreme sliding abrasion combined with a limited amount of impact. Such applications are encountered in earth drilling, earth-moving, brick making, and farming. Specific components that may require this type of a surfacing overlay include oil drill bits and tool joints, drilling augers, excavator teeth, ammonia injectors, cultivator chisels, shares and plows, pug knives, woodyard tools, grain mill hammers, etc.

A7.5.2 ENiWCX-30/230 Electrodes

A7.5.2.1 Characteristics. Tungsten carbide covered tubular electrodes under this classification contain 60% by weight of tungsten carbide particles in a nickel-based matrix, generally a self-fluxing nickel alloy (NiSiB or NiCrSiB) between 40 HRC and 50 HRC. Most of the nickel comes from the strip formed into a tube. The WC1 carbide is an eutectic mixture of WC and W₂C. The WC2 carbide is macrocrystalline WC. Hardness of the deposit matrix is generally between 40 HRC and 50 HRC depending on its composition and tungsten carbide dissolution. Hardness of individual carbide particles is typically 2200 HV₁₀₀–2600 HV₁₀₀ for the eutectic tungsten carbide and 1800 HV₁₀₀–2200 HV₁₀₀ for the macrocrystalline tungsten carbide. Abrasion resistance of tungsten carbide deposits is outstanding. A maximum of two layers is recommended to avoid fracture and spalling. Micro-cracking is very likely to occur upon cooling. Repairs and touch-up's are feasible. Finishing is done by grinding only. Vickers microhardness (HV) of tungsten carbide particles to be measured according to ASTM E384, Standard Test Method for Microindentation Hardness of Materials.

A7.5.2.2 Applications. Nickel-based tungsten carbide composite deposits are applied on surfaces subject to extreme sliding abrasion combined with little to no impact. Such applications are encountered in oil and gas drilling, earthmoving, mining, iron ore pellet plants, oil sands processes, brick making, cement plants, pigment refineries, pulp and paper, etc. Specific components that may require this type of a surfacing overlay include drill bits, drill string stabilizers, ground-engaging tools, oil sands crusher and sizer teeth, slurry lines, muller plows, pug knives, brick extruders, pigment cyclones and micronizers, anode paste mixers, drilling augers, screw conveyors, pump rotors, iron ore pellet crusher rolls, iron sinter breakers, dredge cutter teeth, press screws, etc.

A8. Discontinued Classifications

Some classifications have been discontinued from one revision of this specification to another. This results either from changes in commercial practice or changes in the classification system used in the specification. The classifications that have been discontinued are listed in Table A.4, along with the year in which they were last included in the specification.

A9. General Safety Considerations

A9.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in annex Clause A5. Safety and health information is available from other sources, including, but not limited to Safety and Health Fact Sheets, ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations.

A9.2 Safety and Health Fact Sheets. Safety and Health Fact Sheets are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

Table A.1
Comparison of Classifications

A5.13/A5.13M Classifications	A5.21 Classifications	A5.13/A5.13M Classifications	A5.21 Classifications
EFe1	ERFe-1	EFeCr-E1	
EFe2	ERFe-2	EFeCr-E2	
EFe3	ERFe-3	EFeCr-E3	
EFe4		EFeCr-E4	
EFe5	ERFe-5	ECoCr-A	ERCoCr-A
EFe6	ERFe-6	ECoCr-B	ERCoCr-B
EFe7		ECoCr-C	ERCoCr-C
EFeMn-A		ECoCr-E	ERCoCr-E
EFeMn-B		ENiCr-C	ERNiCr-C
EFeMn-C	ERFeMn-C	ENiCrMo-5A	ERNiCrMo-5A
EFeMn-D		ENiCrFeCo	ERNiCrFeCo
EFeMn-E		ECuAl-A2	ERCuAl-A2
EFeMn-F	ERFeMn-F	ECuAl-B	
EFeMnCr	ERFeMnCr	ECuAl-C	ERCuAl-C
EFeCr-A1A	ERFeCr-A1A	ECuAl-D	ERCuAl-D
EFeCr-A2		ECuAl-E	ERCuAl-E
EFeCr-A3	ERFeCr-A3A	ECuSi	ERCuSi-A
EFeCr-A4	ERFeCr-A4	ECuSn-A	ERCuSn-A
EFeCr-A5	ERFeCr-A5	ECuSn-C	
EFeCr-A6		ECuNi	
EFeCr-A7		ECuNiAl	
EFeCr-A8		ECuMnNiAl	

Table A.2
The Effect of Shielded Metal Arc Variables on the
Three Most Important Characteristics of Surfacing

Variable	Change of Variable ^a	Influence of Change on		
		Dilution	Deposition Rate	Deposit Thickness
Polarity	AC DCEP DCEN	Intermediate High Low	Intermediate Low High	Intermediate Thin Thick
Amperage	High Low	High Low	High Low	Thick Thin
Technique	Stringer Weave	High Low	No effect No effect	Thick Thin
Bead spacing	Narrow Wide	Low High	No effect No effect	Thick Thin
Electrode diameter	Small Large	High Low	High Low	Thick Thin
Arc length	Long Short	Low High	No effect No effect	Thin Thick
Travel speed	Fast Slow	High Low	No effect No effect	Thin Thick

^a This table assumes that only one variable at a time is changed. However, for acceptable surfacing conditions, a change in one variable may require a change in one or more other variables.

Table A.3
Approximate Weld Deposit Hardness (SMAW)

AWS Classification	Brinell Hardness ^a	
	3000 kg Load	500 kg Load
ECuAl-A2	130–150	—
ECuAl-B	140–180	—
ECuAl-C	180–220	—
ECuAl-D	230–270	—
ECuAl-E	280–320	—
ECuSi	—	80–100
ECuSn-A	—	70–85
ECuSn-C	—	85–100
ECuNi	—	60–80
ECuNiAl	160–200	—
ECuMnNiAl	160–200	—

^a As-welded condition.

Table A.4
Discontinued Electrode and Rod Classifications

AWS Classification	Last A5.13 Publication Date	AWS Classification	Last A5.13 Publication Date
RFeCr-A2	1956	ERCuAl-A3 ^b	1980
EFeCr-A2	1956	RCuAl-C ^a	1980
ECuZn-E	1956	RCuAl-D ^a	1980
RCuAl-B	1970	RCuAl-E ^b	1980
RCuSn-E	1970	ERCuSn-A	1980
ECuSn-E	1970	RCuSn-D ^b	1980
RFe5-A	1980	RNiCr-A ^a	1980
RFe5-B	1980	RNiCr-B ^a	1980
RFeCr-A1	1980	RNiCr-C ^a	1980
RCoCr-A ^a	1980	EFe5-A	1980
RCoCr-B ^a	1980	EFe5-B	1980
RCoCr-C ^a	1980	EFe5-C	1980
RCuZn-E	1980	EFeCr-A1	1980
ERCuSi-A ^b	1980	ENiCr-A	1980
ERCuAl-A2 ^b	1980	ENiCr-B	1980

^a These AWS classifications have been transferred to AWS A5.21:2001 with the revised prefix of “ER” for electrode/rod made from solid stock or prefix of “ERC” for electrode/rod made from metal or flux cored composite stock.

^b These AWS classifications have been transferred to AWS A5.21:2001 without a change in the classification designation for solid bare electrodes and rods or with the prefix “ERC” for electrode/rod made from metal or flux cored stock.

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

B6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

AWS Filler Metal Specifications by Material and Welding Process

	OFW	SMAW	GTAW GMAW PAW	FCAW	SAW	ESW	EGW	Brazing
Carbon Steel	A5.2	A5.1, A5.35	A5.18	A5.20	A5.17	A5.25	A5.26	A5.8, A5.31
Low-Alloy Steel	A5.2	A5.5	A5.28	A5.29	A5.23	A5.25	A5.26	A5.8, A5.31
Stainless Steel		A5.4, A5.35	A5.9, A5.22	A5.22	A5.9, A5.22, A5.39	A5.9, A5.22, A5.39	A5.9	A5.8, A5.31
Cast Iron	A5.15	A5.15	A5.15	A5.15				A5.8, A5.31
Nickel Alloys		A5.11, A5.35	A5.14, A5.34	A5.34	A5.14, A5.34, A5.39	A5.14, A5.34, A5.39		A5.8, A5.31
Aluminum Alloys		A5.3	A5.10					A5.8, A5.31
Copper Alloys		A5.6	A5.7					A5.8, A5.31
Titanium Alloys			A5.16					A5.8, A5.31
Zirconium Alloys			A5.24					A5.8, A5.31
Magnesium Alloys			A5.19					A5.8, A5.31
Tungsten Electrodes			A5.12					
Brazing Alloys and Fluxes								A5.8, A5.31
Surfacing Alloys	A5.21	A5.13	A5.21	A5.21	A5.21			
Consumable Inserts			A5.30					
Shielding Gases			A5.32	A5.32			A5.32	

AWS Filler Metal Specifications and Related Documents

Designation	Title
A4.2M (ISO 8249 MOD)	<i>Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal</i>
A4.3	<i>Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding</i>
A4.4M	<i>Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings</i>
A4.5M/A4.5 (ISO 15792-3 MOD)	<i>Standard Methods for Classification Testing of Positional Capacity and Root Penetration of Welding Consumables in a Fillet Weld</i>
A5.01M/A5.01 (ISO 14344 MOD)	<i>Welding and Brazing Consumables—Procurement of Filler Materials and Fluxes</i>
A5.02/A5.02M	<i>Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes</i>
A5.1/A5.1M	<i>Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding</i>
A5.2/A5.2M	<i>Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding</i>
A5.3/A5.3M	<i>Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.4/A5.4M	<i>Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding</i>
A5.5/A5.5M	<i>Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding</i>
A5.6/A5.6M	<i>Specification for Copper and Copper-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.7/A5.7M	<i>Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes</i>
A5.8M/A5.8	<i>Specification for Filler Metals for Brazing and Braze Welding</i>
A5.9/A5.9M (ISO 14343 MOD)	<i>Specification for Bare Stainless Steel Welding Electrodes and Rods</i>
A5.10/A5.10M (ISO 18273 MOD)	<i>Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods</i>
A5.11/A5.11M	<i>Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding</i>
A5.12M/A5.12 (ISO 6848 MOD)	<i>Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting</i>
A5.13/A5.13M	<i>Specification for Surfacing Electrodes for Shielded Metal Arc Welding</i>
A5.14/A5.14M	<i>Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods</i>
A5.15	<i>Specification for Welding Electrodes and Rods for Cast Iron</i>
A5.16/A5.16M (ISO 24034 MOD)	<i>Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods</i>
A5.17/A5.17M	<i>Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.18/A5.18M	<i>Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.19	<i>Specification for Magnesium-Alloy Welding Electrodes and Rods</i>
A5.20/A5.20M	<i>Specification for Carbon Steel Electrodes for Flux Cored Arc Welding</i>
A5.21/A5.21M	<i>Specification for Bare Electrodes and Rods for Surfacing</i>
A5.22/A5.22M	<i>Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods</i>
A5.23/A5.23M	<i>Specification for Low-Alloy and High Manganese Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.24/A5.24M	<i>Specification for Zirconium and Zirconium-Alloy Welding Electrodes and Rods</i>
A5.25/A5.25M	<i>Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding</i>
A5.26/A5.26M	<i>Specification for Carbon and Low-Alloy Steel Electrodes for Electrogas Welding</i>
A5.28/A5.28M	<i>Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.29/A5.29M	<i>Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding</i>
A5.30/A5.30M	<i>Specification for Consumable Inserts</i>
A5.31M/A5.31	<i>Specification for Fluxes for Brazing and Braze Welding</i>
A5.32M/A5.32 (ISO 14175 MOD)	<i>Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes</i>
A5.34/A5.34M	<i>Specification for Nickel-Alloy Flux Cored and Metal Cored Welding Electrodes</i>
A5.35/A5.35M-AMD1	<i>Specification for Covered Electrodes for Underwater Wet Shielded Metal Arc Welding</i>
A5.39/A5.39M	<i>Specification for Stainless Steel and Nickel-Alloy Electrodes and Fluxes for Submerged Arc and Electroslag Welding</i>

INTENTIONALLY LEFT BLANK

SPECIFICATION FOR NICKEL AND NICKEL-ALLOY BARE WELDING ELECTRODES AND RODS



SFA-5.14/SFA-5.14M



(25)

(Identical with AWS Specification A5.14/A5.14M:2024. In case of dispute, the original AWS text applies.)

Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods

1. Scope

1.1 This specification prescribes requirements for the classification of bare nickel and nickel-alloy welding electrodes, strip electrodes, and welding rods. It includes those compositions where the nickel content exceeds that of any other element.

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to material properties. The specification with the designation A5.14 uses U.S. Customary Units. The specification A5.14M uses SI Units. The latter are shown within brackets ([]) or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing of filler metal or packaging or both under A5.14 or A5.14M specifications.

1.3 Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in the nonmandatory annex, Clauses A5 and A10.

Safety and Health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments or revisions of any of these publications do not apply.

The following AWS standards are referenced in the mandatory sections of this document:

- (1) AWS A1.1, *Metric Practice Guide for the Welding Industry*

(2) AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

(3) AWS A5.01M/A5.01 (ISO 14344 MOD), *Welding Consumables—Procurement of Filler Metals and Fluxes*

(4) AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*

The following ANSI standard is referenced in the mandatory sections of this document:

ANSI Z49.1 *Safety in Welding, Cutting, and Allied Processes*

The following ASTM standards are referenced in the mandatory sections of this document:

(1) ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

(2) ASTM E76, *Standard Test Methods for Chemical Analysis of Nickel-Copper Alloys*

(3) ASTM E354, *Standard Test Methods for Chemical Analysis of High-Temperature, Electrical, Magnetic and Other Similar Iron, Nickel, and Cobalt Alloys*

(4) ASTM E1019, *Standard Test Methods for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel, Iron, Nickel, and Cobalt Alloys by Various Combustion and Fusion Techniques*

(5) ASTM E1473, *Standard Test Methods for Chemical Analysis of Nickel, Cobalt, and High-Temperature Alloys*

The following ISO standards are referenced in the mandatory sections of this document

(1) ISO 544, *Welding Consumables — Technical Delivery Conditions for Filler Materials and Fluxes—Type of Product, Dimensions, Tolerances and Markings*

(2) ISO 18274, *Welding Consumables — Wire and Strip Electrodes, Wires and Rods for Arc Welding of Nickel and Nickel Alloys — Classifications.*

(3) ISO 80000-1, *Quantities and Units — Part 1: General*

The following MIL standard is referenced in the mandatory sections of this document:

MIL-E-21562 *Military Specification — Electrodes and Rods — Welding, Bare, Nickel Alloy*

3. Classification

3.1 The welding filler metals covered by this A5.14/A5.14M specification are classified using a system that is independent of U.S. Customary Units and the International System of Units (SI). Classification is according to the chemical composition of the filler metal, as specified in Table 1.

3.2 A filler metal classified under one classification shall not be classified under any other classification in this specification.

3.3 The filler metals classified under this specification are intended for use with the plasma arc, gas metal arc, gas tungsten arc, and submerged arc welding processes, but this is not to prohibit their use with any other process for which they are found suitable.

4. Acceptance

Acceptance¹ of the filler metal shall be in accordance with the provisions of AWS A5.01M/A5.01 (ISO 14344 MOD).

¹ See Annex Clause A3 for further information concerning acceptance and testing of the material shipped, and AWS A5.01M/A5.01 (ISO 14344 MOD).

Table 1
Chemical Composition Requirements for Nickel and Nickel-Alloy Electrodes and Rods

AWS Classification ^c	UNS Number ^d	Weight Percent ^{a, b}																Other Required Elements
		C	Mn	Fe	P	S	Si	Cu	Ni ^e	Co	Al	Ti	Cr	Nb Plus Ta	Mo	V	W	
ERNi-1 ^f	N02061	0.15	1.0	1.0	0.03	0.015	0.75	0.25	93.0 min.	—	1.5	2.0 to 3.5	—	—	—	—	—	—
ERNiCu-7 ^f	N04060	0.15	4.0	2.5	0.02	0.015	1.25	Rem	62.0 to 69.0	—	1.25	1.5 to 3.0	—	—	—	—	—	—
ERNiCu-8 ^f	N05504	0.25	1.5	2.0	0.03	0.015	1.00	Rem	63.0 to 70.0	—	2.0 to 4.0	0.25 to 1.00	—	—	—	—	—	—
ERNiCr-3 ^{f, g}	N06082	0.10	2.5 to 3.5	3.0	0.03	0.015	0.50	0.50	67.0 min.	(h)	—	0.75	18.0 to 22.0	2.0 to 3.0 ⁱ	—	—	—	—
ERNiCr-4	N06072	0.01 to 0.10	0.20	0.50	0.02	0.015	0.20	0.50	Rem	—	—	0.3 to 1.0	42.0 to 46.0	—	—	—	—	—
ERNiCr-6 ^f	N06076	0.08 to 0.15	1.00	2.00	0.03	0.015	0.30	0.50	75.0 min.	—	0.40	0.15 to 0.50	19.0 to 21.0	—	—	—	—	—
ERNiCr-7	N06073	0.03	0.50	1.0	0.02	0.015	0.30	0.30	Rem.	1.0	0.75 to 1.20	0.25 to 0.75	36.0 to 39.0	0.25 to 1.00	0.50	—	—	B: 0.003 Zr: 0.02
ERNiCr-8	N06699	0.005 to 0.10	0.50	2.5	0.02	0.01	0.50	0.50	Rem.	—	1.9 to 3.0	0.60 to 30.0	26.0 to 30.0	0.50	—	—	—	N: 0.05 B: 0.008 Zr: 0.10
ERNiCrCo-1	N07740	0.01 to 0.06	1.0	3.0	0.03	0.015	1.0	0.50	Rem	15.0 to 22.9	0.5 to 2.0	0.8 to 2.5	23.5 to 25.5	0.5 to 2.5	2.0	—	—	—

(Continued)

Table 1
Chemical Composition Requirements for Nickel and Nickel-Alloy Electrodes and Rods

AWS Classification ^c	UNS Number ^d	Weight Percent ^{a, b}																Other Required Elements
		C	Mn	Fe	P	S	Si	Cu	Ni ^e	Co	Al	Ti	Cr	Nb Plus Ta	Mo	V	W	
ERNiCrCoMo-1	N06617	0.05 to 0.15	1.0	3.0	0.03	0.015	1.0	0.50	Rem	10.0 to 15.0	0.8 to 1.5	0.60	20.0 to 24.0	—	8.0 to 10.0	—	—	—
ERNiCrCoMo-2	N07208	0.04 to 0.08	0.30	1.5	0.015	0.015	0.15	0.1	Rem	9.0 to 11.0	1.38 to 1.65	1.90 to 2.30	18.5 to 20.5	0.3 ^j	8.0 to 9.0	—	0.50	B: 0.003 to 0.010 Zr: 0.02
ERNiCrFe-5 ^f	N06062	0.08	1.0	6.0 to 10.0	0.03	0.015	0.35	0.50	70.0 min.	(h)	—	—	14.0 to 17.0	1.5 to 3.0 ⁱ	—	—	—	—
ERNiCrFe-6 ^f	N07092	0.08	2.0 to 2.7	8.0	0.03	0.015	0.35	0.50	67.0 min.	—	—	2.5 to 3.5	14.0 to 17.0	—	—	—	—	—
ERNiCrFe-7	N06052	0.04	1.0	7.0 to 11.0	0.02	0.015	0.50	0.30	Rem	—	1.10	1.0	28.0 to 31.5	0.10	0.50	—	—	Al + Ti: 1.5
ERNiCrFe-7A	N06054	0.04	1.0	7.0 to 11.0	0.02	0.015	0.50	0.30	Rem	0.12	1.10	1.0	28.0 to 31.5	0.5 to 1.0	0.50	—	—	Al + Ti: 1.5 B: 0.005 Zr: 0.02
ERNiCrFe-8 ^f	N07069	0.08	1.0	5.0 to 9.0	0.03	0.015	0.50	0.50	70.0 min.	—	0.4 to 1.0	2.00 to 2.75	14.0 to 17.0	0.70 to 1.20	—	—	—	—
ERNiCrFe-11	N06601	0.10	1.0	Rem	0.03	0.015	0.50	1.0	58.0 to 63.0	—	1.0 to 1.7	—	21.0 to 25.0	—	—	—	—	—
ERNiCrFe-12	N06025	0.15 to 0.25	0.50	8.0 to 11.0	0.020	0.010	0.5	0.1	Rem	1.0	1.8 to 2.4	0.10 to 0.20	24.0 to 26.0	—	—	—	—	—

(Continued)

Table 1
Chemical Composition Requirements for Nickel and Nickel-Alloy Electrodes and Rods

AWS Classification ^c	UNS Number ^d	Weight Percent ^{a, b}																Other Required Elements
		C	Mn	Fe	P	S	Si	Cu	Ni ^e	Co	Al	Ti	Cr	Nb Plus Ta	Mo	V	W	
ERNiCrFe-13	N06055	0.03	1.0	Rem	0.02	0.015	0.50	0.30	52.0 to 62.0	0.10	0.50	0.50	28.5 to 31.0	2.1 to 4.0	3.0 to 5.0	—	—	B: 0.003 Zr: 0.02
ERNiCrFe-14	N06043	0.04	3.0	7.0 to 12.0	0.020	0.015	0.50	0.30	Rem	—	0.50	0.50	28.0 to 31.5	1.0 to 2.5 ^k	0.50	—	—	—
ERNiCrFe-15	N06056	0.020 to 0.055	2.5 to 3.5	1.0 to 3.0	0.02	0.015	0.50	0.3	Rem	0.10	0.60	0.10 to 0.40	26.0 to 28.0	2.0 to 2.8	—	—	—	—
ERNiCrFeSi-1	N06045	0.05 to 0.12	1.0	21.0 to 25.0	0.020	0.010	2.5 to 3.0	0.3	Rem	1.0	0.30	—	26.0 to 29.0	—	—	—	—	—
ERNiCrFeAl-1	N06693	0.15	1.0	2.5 to 6.0	0.03	0.01	0.5	0.5	Rem	—	2.5 to 4.0	1.0	27.0 to 31.0	0.5 to 2.5	—	—	—	—
ERNiFeCr-1 ^f	N08065	0.05	1.0	22.0 min.	0.03	0.03	0.50	1.5 to 3.0	38.0 to 46.0	—	0.20	0.6 to 1.2	19.5 to 23.5	—	2.5 to 3.5	—	—	—
ERNiFeCr-2	N07718	0.08	0.35	Rem	0.015	0.015	0.35	0.30	50.0 to 55.0	—	0.20 to 0.80	0.65 to 1.15	17.0 to 21.0	4.75 to 5.50	2.80 to 3.30	—	—	B: 0.006
ERNiFeCr-3	N09946	0.005 to 0.040	1.0	Rem	0.03	0.015	0.5	1.5 to 3.0	45.0 to 55.0	—	0.01 to 0.70	0.5 to 2.5	19.5 to 23.0	2.5 to 4.5	3.0 to 4.0	—	—	—
ERNiMo-1	N10001	0.08	1.0	4.0 to 7.0	0.025	0.03	1.0	0.50	Rem	2.5	—	—	1.0	—	26.0 to 30.0	0.20 to 0.40	1.0	—

(Continued)

Table 1
Chemical Composition Requirements for Nickel and Nickel-Alloy Electrodes and Rods

AWS Classification ^c	UNS Number ^d	Weight Percent ^{a, b}														Nb Plus Ta	Mo	V	W	Other Required Elements
		C	Mn	Fe	P	S	Si	Cu	Ni ^e	Co	Al	Ti	Cr							
ERNiMo-2	N10003	0.04 to 0.08	1.0	5.0	0.015	0.02	1.0	0.50	Rem	0.20	—	—	6.0 to 8.0	—	15.0 to 18.0	0.50	0.50	—		
ERNiMo-3	N10004	0.12	1.0	4.0 to 7.0	0.04	0.03	1.0	0.50	Rem	2.5	—	—	4.0 to 6.0	—	23.0 to 26.0	0.60	1.0	—		
ERNiMo-7	N10665	0.02	1.0	2.0	0.04	0.03	0.10	0.50	Rem	1.0	—	—	1.0	—	26.0 to 30.0	—	1.0	—		
ERNiMo-8	N10008	0.10	1.0	10.0	0.015	0.015	0.50	0.50	60.0 min.	—	—	—	0.5 to 3.5	—	18.0 to 21.0	—	2.0 to 4.0	—		
ERNiMo-9	N10009	0.10	1.0	5.0	0.015	0.015	0.50	0.3 to 1.3	65.0 min.	—	1.0	—	—	—	19.0 to 22.0	—	2.0 to 4.0	—		
ERNiMo-10	N10675	0.01	3.0	1.0 to 3.0	0.03	0.01	0.10	0.20	65.0 min.	3.0	0.50	0.20	1.0 to 3.0	0.20	27.0 to 32.0	0.20	3.0	Ni + Mo: 94.0 to 98.0 Ta: 0.02 Zr: 0.10		
ERNiMo-11	N10629	0.010	1.0	2.0 to 5.0	0.020	0.010	0.10	0.5	Rem	1.0	0.1 to 0.5	0.30	0.5 to 1.5	0.50	26.0 to 30.0	—	—	—		
ERNiMo-12	N10242	0.03	0.80	2.0	0.030	0.015	0.80	0.50	Rem	1.0	0.50	—	7.0 to 9.0	—	24.0 to 26.0	—	—	B: 0.006		
ERNiMoCr-1	N10362	0.010	0.60	1.25	0.025	0.010	0.08	—	Rem	—	0.50	—	13.8 to 15.6	—	21.5 to 23.0	—	—	—		

(Continued)

Table 1
Chemical Composition Requirements for Nickel and Nickel-Alloy Electrodes and Rods

Weight Percent ^{a, b}																		
AWS Classification ^c	UNS Number ^d	C	Mn	Fe	P	S	Si	Cu	Ni ^e	Co	Al	Ti	Cr	Nb Plus Ta	Mo	V	W	Other Required Elements
ERNiCrMo-1	N06007	0.05	1.0 to 2.0	18.0 to 21.0	0.04	0.03	1.0	1.5 to 2.5	Rem	2.5	—	—	21.0 to 23.5	1.75 to 2.50	5.5 to 7.5	—	1.0	—
ERNiCrMo-2	N06002	0.05 to 0.15	1.0	17.0 to 20.0	0.04	0.03	1.0	0.50	Rem	0.5 to 2.5	—	—	20.5 to 23.0	—	8.0 to 10.0	—	0.2 to 1.0	—
ERNiCrMo-3 ^f	N06625	0.10	0.50	5.0	0.02	0.015	0.50	0.50	58.0 min.	—	0.40	0.40	20.0 to 23.0	3.15 to 4.15	8.0 to 10.0	—	—	—
ERNiCrMo-4	N10276	0.02	1.0	4.0 to 7.0	0.04	0.03	0.08	0.50	Rem	2.5	—	—	14.5 to 16.5	—	15.0 to 17.0	0.35	3.0 to 4.5	—
ERNiCrMo-7	N06455	0.015	1.0	3.0	0.04	0.03	0.08	0.50	Rem	2.0	—	0.70	14.0 to 18.0	—	14.0 to 18.0	—	0.50	—
ERNiCrMo-8	N06975	0.03	1.0	Rem	0.03	0.03	1.0	0.7 to 1.2	47.0 to 52.0	—	—	0.70 to 1.50	23.0 to 26.0	—	5.0 to 7.0	—	—	—
ERNiCrMo-9	N06985	0.015	1.0	18.0 to 21.0	0.04	0.03	1.0	1.5 to 2.5	Rem	5.0	—	—	21.0 to 23.5	0.50	6.0 to 8.0	—	1.5	—
ERNiCrMo-10	N06022	0.015	0.50	2.0 to 6.0	0.02	0.010	0.08	0.50	Rem	2.5	—	—	20.0 to 22.5	—	12.5 to 14.5	0.35	2.5 to 3.5	—
ERNiCrMo-11	N06030	0.03	1.5	13.0 to 17.0	0.04	0.02	0.80	1.0 to 2.4	Rem	5.0	—	—	28.0 to 31.5	0.30 to 1.50	4.0 to 6.0	—	1.5 to 4.0	—

(Continued)

Table 1
Chemical Composition Requirements for Nickel and Nickel-Alloy Electrodes and Rods

AWS Classification ^c	UNS Number ^d	Weight Percent ^{a, b}															Other Required Elements	
		C	Mn	Fe	P	S	Si	Cu	Ni ^e	Co	Al	Ti	Cr	Nb Plus Ta	Mo	V		W
ERNiCrMo-13	N06059	0.010	0.5	1.5	0.015	0.010	0.10	0.50	Rem	0.3	0.1 to 0.4	—	22.0 to 24.0	—	15.0 to 16.5	—	—	—
ERNiCrMo-14	N06686	0.01	1.0	5.0	0.02	0.02	0.08	0.5	Rem	—	0.5	0.25	19.0 to 23.0	—	15.0 to 17.0	—	3.0 to 4.4	—
ERNiCrMo-15	N07725	0.03	0.35	Rem	0.015	0.01	0.20	—	55.0 to 59.0	—	0.35	1.0 to 1.7	19.0 to 22.5	2.75 to 4.00	7.0 to 9.5	—	—	—
ERNiCrMo-16	N06057	0.02	1.0	2.0	0.04	0.03	1.0	—	Rem	—	—	—	29.0 to 31.0	—	10.0 to 12.0	0.4	—	—
ERNiCrMo-17	N06200	0.010	0.5	3.0	0.025	0.010	0.08	1.3 to 1.9	Rem	2.0	0.50	—	22.0 to 24.0	—	15.0 to 17.0	—	—	—
ERNiCrMo-18	N06650	0.03	0.5	12.0 to 16.0	0.020	0.010	0.50	0.30	Rem	1.0	0.05 to 0.50	—	19.0 to 21.0	0.05 to 0.50	9.5 to 12.5	0.30	0.5 to 2.5	N: 0.05 to 0.20
ERNiCrMo-19	N06058	0.01	0.5	1.5	0.015	0.010	0.10	0.50	Rem	0.3	0.4	—	20.0 to 23.0	—	18.5 to 21.0	—	0.3	N: 0.02 to 0.15
ERNiCrMo-20	N06660	0.03	0.5	2.0	0.015	0.015	0.5	0.3	Rem	0.2	0.4	0.4	21.0 to 23.0	0.2	9.0 to 11.0	—	2.0 to 4.0	—
ERNiCrMo-21	N06205	0.03	0.5	1.0	0.015	0.015	0.5	0.2	Rem	0.2	0.4	0.4	24.0 to 26.0	—	14.0 to 16.0	—	0.3	—

(Continued)

Table 1
Chemical Composition Requirements for Nickel and Nickel-Alloy Electrodes and Rods

AWS Classification ^c	UNS Number ^d	Weight Percent ^{a, b}																Other Required Elements
		C	Mn	Fe	P	S	Si	Cu	Ni ^e	Co	Al	Ti	Cr	Nb Plus Ta	Mo	V	W	
ERNiCrMo-22	N06035	0.050	0.50	2.00	0.030	0.015	0.60	0.30	Rem	1.00	0.40	0.2	32.25 to 34.25	0.5	7.60 to 9.00	0.20	0.60	—
ERNiCrMoWNB-1	N06680	0.03	—	0.50	0.02	0.015	0.1	—	56.0 to 65.0	1.0	0.5	1.2 to 3.0	17.0 to 23.0	3.0 to 5.0	5.0 to 8.0	—	4.0 to 8.0	—
ERNiCoCrSi-1	N12160	0.02 to 0.10	1.0	3.5	0.030	0.015	2.4 to 3.0	0.50	Rem	27.0 to 32.0	0.40	0.20 to 0.60	26.0 to 29.0	0.30	0.7	—	0.5	—
ERNiCrWMo-1	N06231	0.05 to 0.15	0.3 to 1.0	3.0	0.03	0.015	0.25 to 0.75	0.50	Rem	5.0	0.2 to 0.5	—	20.0 to 24.0	—	1.0 to 3.0	—	13.0 to 15.0	B: 0.003 La: 0.050

^a The weld metal shall be analyzed for the specific elements for which values are shown in this table. If the presence of unspecified elements is identified, the amount of these identified elements shall be determined to ensure that their total does not exceed 0.50%. An identified element is an element whose concentration exceeds the calibrated limit of detection of the instrument or procedure being used to measure that particular element. AWS A5.01M/A5.01 is a useful tool for imposing limits by agreement between purchaser and supplier on particular unspecified elements.

^b Single values are maximum except where otherwise specified. Rem = remainder.

^c For strip, the classification designator "R" shall be replaced with "Q."

^d ASTM D5-56/SAE HS-1086, Metals & Alloys in the Unified Numbering System.

^e Includes incidental cobalt.

^f MIL-E-21562 grade; Pb < 0.010. "Other Elements Total" shall include Pb, Sn, Zn.

^g MIL-E-21562 grades EN82H or RN82H; Carbon is 0.03 to 0.10.

^h Co is 0.12 maximum when specified by the purchaser.

ⁱ MIL-E-21562 grade, Ta is 0.30 maximum.

^j Nb(Cb) is 0.2 maximum and Ta is 0.1 maximum.

^k Ta is 0.10 maximum.

5. Certification

By affixing the AWS Specification and Classification designations to the packaging, or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification.²

6. Rounding Procedure

For the purpose of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfill the requirements for the classification under test.

7. Summary of Tests

Chemical analysis of the filler metal, or the stock from which it was made, is the only test required for classification of a product under this specification.

8. Retest

If the results of any test fail to meet the requirement of that test, that test shall be repeated twice. The results of both retests shall meet the requirement. Material for retest may be taken from the original test sample or from a new sample. Retest need be only for those specific elements that failed to meet the test requirement.

If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that, during preparation or after completion of any test, it is clearly determined that prescribed or proper procedures were not followed in preparing test specimen(s) or in conducting the test, the test shall be considered invalid, without regard to whether the test was actually completed, or whether test results met, or failed to meet, the requirement. That test shall be repeated, following proper prescribed procedures. In this case, the requirement for doubling of the number of test specimens does not apply.

9. Chemical Analysis

9.1 A sample of the filler metal, or the stock from which it was made, shall be prepared for chemical analysis.

9.2 The sample shall be analyzed by accepted analytical methods. The referee method shall be ASTM E1473, supplemented by ASTM E1019 and ASTM E354 for nickel-base alloys, and ASTM E76 for nickel-copper alloys, as appropriate.

9.3 The results of the analysis shall meet the requirements set forth in Table 1, for the classification of filler metal under test.

10. Method of Manufacture

The filler metals classified according to this specification may be made by any method that will produce material that meets the requirements of this specification.

² See Annex Clause A4 for further information concerning certification and the testing called for to meet this requirement.

11. Standard Sizes

11.1 Standard sizes for filler metal in the different package forms (straight lengths, coils with support, coils without support, and spools) are as specified in AWS A5.02/A5.02M.

11.2 Standard sizes for strip electrodes in coils are as specified in AWS A5.02/A5.02M.

12. Finish and Uniformity

Finish and uniformity shall be as given in AWS A5.02/A5.02M.

13. Standard Package Forms

Standard package forms are straight lengths, coils with support, coils without support, and spools. Packaging shall be as given in AWS A5.02/A5.02M.

14. Winding Requirements

14.1 Filler metal on spools and in coils shall be wound per AWS A5.02/A5.02M.

14.2 The cast and helix of filler metal in coils and spools shall be per AWS A5.02/A5.02M.

15. Filler Metal Identification

Filler metal identification shall be in accordance with AWS A5.02/A5.02M.

16. Packaging

Filler metal shall be suitably packaged to ensure against damage during shipment and storage under normal conditions.

17. Marking of Packages

17.1 The following product information (as a minimum) shall be legibly marked so as to be visible from the outside of each unit package:

(1) AWS specification and classification designation (year of issue may be excluded). Additionally, the numerical classification number from ISO 18274 may be applied as a reference designation, provided all the requirements of ISO 18274 are satisfied (see A2.4 in Annex A and Table A.1).

(2) Supplier's name and trade designation

(3) Size and net weight

(4) Lot, control, or heat number

17.2 The appropriate precautionary information³ given in ANSI Z49.1(as a minimum), shall be prominently displayed in legible print on all packages, including individual unit packages within a larger package.

³Typical examples of "warning labels" and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

Annex A (Informative)

Guide to AWS Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods

This annex is not part of this standard but is included for informational purposes only.

A1. Introduction

The purpose of this guide is to correlate the nickel and nickel-alloy bare welding electrodes and rods classifications with their intended applications so they can be used effectively. Reference to appropriate base-metal specifications is made whenever that can be done and when it would be helpful. Such references are intended only as examples rather than a complete listing of the materials for which each filler metal is suitable.

A2. Classification System

A2.1 The system for classifying the filler metals in this specification follows the standard pattern used in other AWS filler metal specifications. The letters “ER” at the beginning of each classification designation stand for electrode and rod, indicating that the filler metal may be used either way. The substitution of the letters “EQ” for “ER” at the beginning of a classification indicates that the product is being supplied as strip electrode (see Table 1, Note c).

A2.2 Since the filler metals are classified according to their chemical composition, the chemical symbol “Ni” appears immediately after the “ER” (or “EQ”) as a means of identifying the filler metal as a nickel-base alloy. The other symbols (Al, Cr, Co, Cu, Fe, Mo, Nb, Si, and W) in the designations are intended to group the filler metals according to their principal alloying elements. The individual designations are made up of these symbols plus a number at the end of the designation (ERNiMo-1 or ERNiMo-2, for example). These numbers separate one composition from another within a group and are not repeated within that group.

A2.3 Request for Filler Metal Classification. When a filler metal cannot be classified, a manufacturer may request that a new classification be established. The manufacturer shall do this using the following procedure:

(1) A request to establish a new (filler metal) classification must be submitted in writing. The request needs to provide sufficient detail to permit the AWS A5 Committee on Filler Metals and Allied Materials and the relevant subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

- (a) A declaration that the new classification will be offered for sale commercially.
- (b) All classification requirements as given for existing classifications, such as, chemical composition ranges, mechanical property requirements, and usability test requirements.
- (c) Any conditions for conducting the tests used to demonstrate that the filler metal meets the classification requirements. (It would be sufficient, for example, to state that welding conditions are the same as for other classifications.)
- (d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the annex).

(e) Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.

(f) A request for a new classification without the above information will be considered incomplete. The Secretary will return the request to the requester for further information.

(2) In order to comply with the AWS Policy on Patented Items, Trademarks, and Restraint of Trade, if the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester shall disclose this. In these cases, the patent holder must allow the use of this technology, such as by license. The Secretary will provide examples of acceptable wording to the patent holder, as required.

(3) The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters for processing.

A2.4 From an application point of view, most of the filler metal classifications in this specification have a corresponding classification in AWS A5.11/A5.11M, *Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding*. For those cases in which there is a corresponding application for a bare electrode or rod “ER” and a covered electrode “E,” Table A.1 correlates the “ER” classification in this edition with the corresponding covered electrode “E” classification in AWS A5.11/A5.11M. It also lists the current designation for each classification as it is given in Military Specification MIL-E-21562, when such a designation exists.

A2.5 An international system for designating welding filler metals, developed by the International Institute of Welding (IIW), has been adopted in many ISO specifications. Table A.1 also shows the ISO 18274 designations for comparison with comparable classifications in this specification.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01M/A5.01 (ISO 14344 MOD), *Welding Consumables—Procurement of Filler Metals and Fluxes*, as the specification states. Any testing a purchaser requires of the supplier, for material shipped in accordance with this specification, shall be clearly stated in the purchase order, according to the provisions of AWS A5.01M/A5.01 (ISO 14344 MOD). In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing is normally conducted on material of that classification, as specified in Schedule F, Table 1, of AWS A5.01M/A5.01 (ISO 14344 MOD). Testing in accordance with any other Schedule in that Table must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product, or the classification on the product itself, constitutes the supplier’s (manufacturer’s) certification that the product meets all of the requirements of the specification.

The only testing requirement implicit in this certification is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that the material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation. “Certification” is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been made. The basis for the certification required by the specification is the classification tests of “representative material” cited above, and the “Manufacturer’s Quality Assurance System” in AWS A5.01M/A5.01 (ISO 14344 MOD).

Table A.1
Comparison of Classifications^a

Present Classification ^b	UNS Number	Military Designation ^c	Corresponding Classification in A5.11/A5.11M	ISO 18274 Designation ^d
ERNi-1	N02061	EN61 & RN61	ENi-1	S Ni 2061
ERNiCu-7	N04060	EN60 & RN60	ENiCu-7	S Ni 4060
ERNiCu-8	N05504	EN64 & RN64	—	S Ni 5504
ERNiCr-3	N06082	EN82 & RN82 EN82H & RN82H	ENiCrFe-3	S Ni 6082
ERNiCr-4	N06072	—	—	S Ni 6072
ERNiCr-6	N06076	EN6N & RN6N	—	S Ni 6076
ERNiCr-7	N06073	—	—	S Ni 6073
ERNiCr-8	N07740	—	—	—
ERNiCrCo-1	N07740	—	—	—
ERNiCrCoMo-1	N06617	—	ENiCrCoMo-1	S Ni 6617
ERNiCrCoMo-2	N07208	—	—	—
ERNiCrFe-5	N06062	EN62 & RN62	ENiCrFe-1	S Ni 6062
ERNiCrFe-6	N07092	EN6A & RN6A	ENiCrFe-2	S Ni 7092
ERNiCrFe-7	N06052	—	ENiCrFe-7	S Ni 6052
ERNiCrFe-7A	N06054	—	—	S Ni 6054
ERNiCrFe-8	N07069	RN69	—	S Ni 7069
ERNiCrFe-11	N06601	—	—	S Ni 6601
ERNiCrFe-12	N06025	—	ENiCrFe-12	S Ni 6025
ERNiCrFe-13	N06055	—	—	S Ni 6055
ERNiCrFe-14	N06043	—	—	S Ni 6043
ERNiCrFe-15	N06056	—	—	—
ERNiCrFeSi-1	N06045	—	ENiCrFeSi-1	S Ni 6045
ERNiCrFeAl-1	N06693	—	—	S Ni 6693
ERNiFeCr-1	N08065	RN65	—	S Ni 8065
ERNiFeCr-2	N07718	—	—	S Ni 7718
ERNiFeCr-3	N09946	—	—	—
ERNiMo-1	N10001	—	ENiMo-1	S Ni 1001
ERNiMo-2	N10003	—	—	S Ni 1003
ERNiMo-3	N10004	—	ENiMo-3	S Ni 1004
ERNiMo-7	N10665	—	ENiMo-7	S Ni 1066

(Continued)

Table A.1 (Continued)
Comparison of Classifications^a

Present Classification ^b	UNS Number	Military Designation ^c	Corresponding Classification in A5.11/A5.11M	ISO 18274 Designation ^d
ERNiMo-8	N10008	—	ENiMo-8	S Ni 1008
ERNiMo-9	N10009	—	ENiMo-9	S Ni 1009
ERNiMo-10	N10675	—	ENiMo-10	S Ni 1067
ERNiMo-11	N10629	—	ENiMo-11	S Ni 1069
ERNiMo-12	N10242	—	—	S Ni 1024
ERNiMoCr-1	N10362	—	—	—
ERNiCrMo-1	N06007	—	ENiCrMo-1	—
ERNiCrMo-2	N06002	—	ENiCrMo-2	S Ni 6002
ERNiCrMo-3	N06625	EN625 & RN625	ENiCrMo-3	S Ni 6625
ERNiCrMo-4	N10276	—	ENiCrMo-4	S Ni 6276
ERNiCrMo-7	N06455	—	ENiCrMo-7	S Ni 6455
ERNiCrMo-8	N06975	—	—	S Ni 6975
ERNiCrMo-9	N06985	—	ENiCrMo-9	S Ni 6985
ERNiCrMo-10	N06022	—	ENiCrMo-10	S Ni 6022
ERNiCrMo-11	N06030	—	ENiCrMo-11	S Ni 6030
ERNiCrMo-13	N06059	—	ENiCrMo-13	S Ni 6059
ERNiCrMo-14	N06686	—	ENiCrMo-14	S Ni 6686
ERNiCrMo-15	N07725	—	—	S Ni 7725
ERNiCrMo-16	N06057	—	—	S Ni 6057
ERNiCrMo-17	N06200	—	ENiCrMo-17	S Ni 6200
ERNiCrMo-18	N06650	—	ENiCrMo-18	S Ni 6650
ERNiCrMo-19	N06058	—	ENiCrMo-19	S Ni 6058
ERNiCrMo-20	N06660	—	—	S Ni 6660
ERNiCrMo-21	N06205	—	—	S Ni 6205
ERNiCrMo-22	N06035	—	ENiCrMo-22	S Ni 6035
ERNiCrMoWMNb-1	N06680	—	—	—
ERNiCoCrSi-1	N12160	—	—	S Ni 6160
ERNiCrWMo-1	N06231	—	ENiCrWMo-1	S Ni 6231

^a The requirements for the equivalent classifications shown are not necessarily identical in every respect.

^b For strip, the classification designator “R” shall be replaced with “Q.”

^c MIL E-21562. All designations are prefixed with “MIL.”

^d For strip, the classification designator “S” shall be replaced with “B.”

A5. Ventilation During Welding

A5.1 Five major factors that govern the quantity of fumes in the atmosphere to which welders and welding operators are exposed during welding are listed below:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling);
- (2) Number of welders and welding operators working in the space;
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes involved;
- (4) The proximity of the welder or welding operator to the fumes as they issue from the welding zone and to the gases and dust in the space in which the welder is working; and
- (5) The ventilation provided to the space in which the welding is done.

A5.2 American National Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the clause of that document dealing with ventilation. See also AWS F3.2M/F3.2, *Ventilation Guide for Weld Fume*, for more detailed description of ventilation options.

A6. Welding Considerations

A6.1 The filler metals in this specification can be used with any of a variety of welding processes. Most notable among them are gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), submerged arc welding (SAW), electroslag welding (ESW), and plasma arc welding (PAW). SAW, ESW, and PAW are quite specialized, and the supplier of the filler metals should be consulted for recommendations concerning their use. General suggestions are given below for the other two processes.

A6.2 Before welding or heating any nickel-base alloy, the base metal must be clean. Oil, grease, paint, lubricants, marking pencils, temperature indicating materials, threading compounds and other such materials frequently contain sulfur or lead that may cause cracking (embrittlement) of the base metal or the weld metal if present during welding or heating.

A6.3 For GTAW, direct current electrode negative (DCEN) is used. Either argon or helium (or a combination of the two) are used as a shielding gas.

A6.4 For GMAW, direct current electrode positive (DCEP) is often employed. Argon shielding gas is often used, but mixtures of argon and helium are also commonly used.

A7. Description and Intended Use of Electrodes and Rods

A7.1 ERNi-X Classification

A7.1.1 ERNi-1. The nominal composition (wt %) of filler metal of this classification is 96 Ni and 3 Ti. Filler metal of this classification is intended for welding wrought and cast forms of commercially pure nickel alloy (ASTM B160, B161, B162, and B163 having UNS number N02200 or N02201) to itself using the GTAW, GMAW, SAW, and PAW processes. The filler metal contains sufficient titanium to control weld-metal porosity with these welding processes.

A7.2 ERNiCrCo-X Classification

A7.2.1 ERNiCrCo-1. The nominal composition (wt %) of filler metal of this classification is 45 Ni, 25 Cr, 20 Co, 2 Nb, and 1 Ti. Filler metal of this classification is used for welding nickel-chromium-cobalt alloy (UNS N07740) for power boiler and coal ash applications to itself, to steels, and to weld overlay steels using the GTAW and GMAW processes. The weld metal will age harden on heat treatment. For specific information concerning age hardening, consult the supplier or the supplier's technical literature. The alloy is resistant to oxidation, sulfidation, chlorination, and coal ash corrosion environments.

A7.3 ERNiCu-X Classifications

A7.3.1 ERNiCu-7. The nominal composition (wt %) of filler metal of this classification is 65 Ni, 30 Cu, 3 Mn, and 2 Ti. Filler metal of this classification is used for welding nickel-copper alloy (ASTM B127, B163, B164, and B165 having UNS number N04400) to itself using the GTAW, GMAW, SAW, and PAW processes. The filler metal contains sufficient titanium to control porosity with these welding processes.

A7.3.2 ERNiCu-8. The nominal composition (wt %) of filler metal of this classification is 66 Ni, 29 Cu, 3 Al, 1 Fe, and 0.5 Ti. Filler metal of this classification is used for welding age-hardening nickel-copper alloy (ASTM F467 and F468 having UNS number N05500) to itself using the GTAW, GMAW, SAW, and PAW processes. The filler metal will age harden on heat treatment. For specific information concerning age hardening, consult the supplier or the supplier's technical literature.

A7.4 ERNiCr-X Classifications

A7.4.1 ERNiCr-3. The nominal composition (wt %) of filler metal of this classification is 72 Ni, 20 Cr, 3 Mn, and 2.5 Nb plus Ta. Filler metal of this classification is used for welding nickel-chromium-iron alloy (ASTM B163, B166, B167, and B168 having UNS number N06600) to itself, for the clad side of joints in steel clad with nickel-chromium-iron alloy, for surfacing steel with nickel-chromium-iron weld metal, for dissimilar welding of nickel-base alloys, and for joining steel to stainless steel or nickel-base alloys using the GTAW, GMAW, SAW, and PAW processes.

A7.4.2 ERNiCr-4. The nominal composition (wt %) of filler metal of this classification is 55 Ni and 44 Cr. Filler metal of this classification is used for GTAW of 50/50 nickel/chromium alloy, cladding nickel/chromium alloy onto nickel-iron-chromium tubing, and casting repair. The filler metal is resistant to high-temperature corrosion, including fuel-ash corrosion in atmospheres containing sulfur and vanadium.

A7.4.3 ERNiCr-6. The nominal composition (wt %) of filler metal of this classification is 78 Ni, 20 Cr, 1 Fe, and 0.4 Ti. Filler metal of this classification is used for welding nickel-chromium-iron alloy (ASTM B163, B166, B167, and B168 having UNS number N06600) to itself, for the clad side of joints in steel clad with nickel-chromium-iron alloy, for surfacing steel with nickel-chromium-iron weld metal, and for joining steel to nickel-base alloys using the GTAW, GMAW, SAW, and PAW processes.

A7.4.4 ERNiCr-7. The nominal composition (wt %) of filler metal of this classification is 60 Ni, 37.5 Cr, 0.95 Al, and 0.6 Nb plus Ta. Filler metal of this classification is used for the overlay cladding of ferrous materials used in high temperature applications, and the welding of nickel-chromium-iron alloy (ASTM B163, B166, B167, and B168 having UNS number N06690) to itself, and to steels using the GTAW, GMAW, SAW, ESW, and PAW processes. Welds made with this composition are particularly resistant to high temperature oxidation, carburization, and sulfidation.

A7.4.5 ERNiCr-8. The nominal composition (wt %) of filler metal of this classification is 28 Cr, 2.5 Al, balance Ni. Consumables of this classification are used for welding of matching base material UNS N06699 and other high temperatures materials. The weld metal is in particular characterized by high resistance against metal dusting in chemical or petrochemical applications.

A7.5 ERNiCrCoMo-X Classifications

A7.5.1 ERNiCrCoMo-1. The nominal composition (wt %) of filler metal of this classification is 53 Ni, 23 Cr, 12 Co, 9 Mo, and 1 Fe. Filler metal of this classification is used for welding nickel-chromium-cobalt-molybdenum alloy (UNS number N06617) to itself using the GTAW and GMAW processes.

A7.5.2 ERNiCrCoMo-2. The nominal composition (wt %) of filler metal of this classification is 57 Ni, 19.5 Cr, 10 Co, 8.5 Mo, 2.1 Ti, and 1.5 Al. Filler metal of this classification is used for welding nickel-chromium-cobalt-molybdenum alloy to itself (UNS N07208) and for welding other solid-solution strengthened and precipitation-strengthened nickel base alloys using the GTAW and GMAW processes. The weld metal will age harden on heat treatment. For specific information concerning age hardening, consult the supplier or the supplier's technical literature.

A7.6 ERNiCrFe-X Classifications

A7.6.1 ERNiCrFe-5. The nominal composition (wt %) of filler metal of this classification is 74 Ni, 16 Cr, 8 Fe, and 2 Nb plus Ta. Filler metal of this classification is used for welding nickel-chromium-iron alloy (ASTM B163, B166, B167, and B168 having UNS number N06600) to itself using the GTAW, GMAW, SAW, and PAW processes. The higher

niobium content of the filler metal is intended to minimize cracking where high welding stresses are encountered, as in thick-section base metal.

A7.6.2 ERNiCrFe-6. The nominal composition (wt %) of filler metal of this classification is 71 Ni, 16 Cr, 6 Fe, 3 Ti, and 2.5 Mn. Filler metal of this classification is used for cladding steel with nickel-chromium-iron weld metal and for joining steel to nickel-base alloys using the GTAW, GMAW, SAW, and PAW processes. The filler metal will age harden on heat treatment. For specific information concerning age hardening, consult the supplier or the supplier's technical literature.

A7.6.3 ERNiCrFe-7. The nominal composition (wt %) of filler metal of this classification is 60 Ni, 29 Cr, and 9 Fe. Filler metal of this classification is used for welding nickel-chromium-iron alloy (ASTM B163, B166, B167, and B168 having UNS number N06690) to itself, to steels, to overlay on steels, and to weld steels clad with the nickel-chromium-iron alloys using the GTAW, GMAW, SAW, and PAW processes.

A7.6.4 ERNiCrFe-7A. The nominal composition (wt %) of filler metal of this classification is 60 Ni, 29 Cr, 9 Fe, and 0.75 Nb plus Ta. Filler metal of this composition is used for welding nickel-chromium-iron alloy (ASTM B163, B166, B167, and B168 having UNS number N06690) to itself, to steels, and to weld overlay steels using the GTAW, GMAW, SAW, ESW, and PAW processes. Welds made with this composition are particularly resistant to ductility-dip-cracking (DDC), and oxide inclusions.

A7.6.5 ERNiCrFe-8. The nominal composition (wt %) of filler metal of this classification is 73 Ni, 15.5 Cr, 7 Fe, 2.4 Ti, 1 Nb, and 0.7 Al. Filler metal of this classification is used for cladding steel with nickel-chromium-iron weld metal and for joining steel to nickel-base alloys using the GTAW, GMAW, SAW, and PAW processes. The weld metal will age harden on heat treatment. For specific information concerning age hardening, consult the supplier or the supplier's technical literature.

A7.6.6 ERNiCrFe-11. The nominal composition (wt %) of filler metal of this classification is 61 Ni, 23 Cr, 14 Fe, and 1.4 Al. Filler metal of this classification is used for welding nickel-chromium-iron-aluminum alloy (ASTM B166, B167, and B168 having UNS number N06601) to itself and to other high-temperature compositions using the GTAW process. It is used for severe applications where the exposure temperature can exceed 2100 °F [1150 °C]. For specific information concerning age hardening, consult the supplier or the supplier's technical literature.

A7.6.7 ERNiCrFe-12. The nominal composition (wt %) of filler metal of this classification is 63 Ni, 25 Cr, 9.5 Fe, and 2.1 Al. Filler metal of this classification is used for welding UNS number N06025, welding nickel-chromium-iron to steel and to other nickel base alloys. The ASTM specifications for UNS number N06025 are B163, B166, B167, B168, B366, B516, B517, B546, and B564. For specific information concerning age hardening, consult the supplier or the supplier's technical literature.

A7.6.8 ERNiCrFe-13. The nominal composition (wt %) of filler metal of this classification is 55 Ni, 30 Cr, 8 Fe, 4 Mo, and 3 Nb plus Ta. Filler metal of this classification is used for welding nickel-chromium-iron alloy (ASTM B163, B166, B167, and B168 having UNS number N06690) to itself, to steels, and to weld overlay steels using the GTAW, GMAW, SAW, ESW, and PAW processes. Welds made with this composition are particularly resistant to ductility-dip-cracking (DDC) and oxide inclusions.

A7.6.9 ERNiCrFe-14. The nominal composition (wt %) of filler metal of this classification is 57 Ni, 30 Cr, 9 Fe, and 1.8 Nb plus Ta. Filler metal of this classification is used to produce nickel-chromium-iron weld overlays on steel comparable to UNS number N06690. Weld deposits made with this composition are particularly resistant to ductility-dip-cracking (DDC), especially in the case of wire/flux combination.

A7.6.10 ERNiCrFe-15. The nominal composition (wt %) of filler metal of this classification is 63 Ni, 27 Cr, 3 Mn, 2.4 Nb plus Ta, 2.0 Fe, and 0.25 Ti. Filler metal of this classification is used for welding nickel-chromium-iron alloy 690 (ASTM B163, B166, B167, B168, and B564 having UNS number N06690) to itself, to steels, and to weld overlay steels in nuclear pressure vessel applications. It also shows excellent resistance to primary water stress corrosion cracking (PWSCC) in intended service conditions (similar to the base metal UNS N06690).

A7.7 ERNiCrFeSi-X Classification

A7.7.1 ERNiCrFeSi-1. The nominal composition (wt %) of filler metal of this classification is 46 Ni, 28 Cr, 23 Fe, and 2.75 Si. Filler metal of this classification is used for welding nickel-chromium-iron alloy (ASTM B163, B166,

B167, B168, B366, B516, B517, B546 and B564 having UNS number N06045) to itself, to steel, and to other nickel base alloys.

A7.8 ERNiCrFeAl-X Classification

A7.8.1 ERNiCrFeAl-1. The nominal composition (wt %) of filler metal of this classification is 59 Ni, 29 Cr, 4 Fe, and 3 Al. Filler metal of this classification is used for welding nickel-chromium-iron alloy (ASTM B166, B167, and B168 having UNS number N06693) to itself, to steels, and to weld overlay steels using the GTAW and GMAW processes. Welds made with this composition are particularly resistant to metal dusting in chemical and petrochemical applications. The alloy is resistant to carburization, sulfidation, and other high temperature corrosion forms. This alloy is subject to precipitation hardening when exposed to intermediate temperatures of 1000 °F–1400 °F [538 °C–760 °C]. For specific information concerning age hardening, consult the supplier or the supplier's technical literature.

A7.9 ERNiFeCr-X Classifications

A7.9.1 ERNiFeCr-1. The nominal composition (wt %) of filler metal of this classification is 42 Ni, 30 Fe, 21 Cr, 3 Mo, and 2 Cu. Filler metal of this classification is used for welding the nickel-iron-chromium-molybdenum-copper alloy (ASTM B423 having UNS number N08825) to itself using the GTAW and GMAW processes.

A7.9.2 ERNiFeCr-2. The nominal composition (wt %) of filler metal of this classification is 52 Ni, 18 Fe, 19 Cr, 5 Nb plus Ta, 3 Mo, and 1 Ti. Filler metal of this classification is used for welding nickel-chromium-niobium-molybdenum alloy (ASTM B637 and AMS 5589 having UNS number N07718) to itself using the GTAW process. The weld metal will age harden on heat treatment. For specific information concerning age hardening, consult the supplier or the supplier's technical literature.

A7.9.3 ERNiFeCr-3. The nominal composition (wt %) of filler metal of this classification is 47 Ni, 23 Fe, 20.5 Cr, 2 Cu, 3 Nb, 3.2 Mo, and 1.5 Ti. Filler metal of this classification is used for welding nickel-iron-chromium alloy approved by NACE MR0175/ISO-15156-3 for oil and gas applications (having UNS number N09945 or N09946) to itself, to steels, and to weld overlay steels using the GTAW and GMAW processes. The weld metal will age harden on heat treatment. For specific information concerning age hardening consult the supplier or the supplier's technical literature. The alloy is resistant to sulfide-induced stress corrosion cracking and stress cracking in hydrogen sulfide environments.

A7.10 ERNiMo-X Classifications

A7.10.1 ERNiMo-1. The nominal composition (wt %) of filler metal of this classification is 66 Ni, 28 Mo, and 5.5 Fe. Filler metal of this classification is used for welding nickel-molybdenum alloy (ASTM B333 having UNS number N10001) to itself using the GTAW and GMAW processes.

A7.10.2 ERNiMo-2. The nominal composition (wt %) of filler metal of this classification is 71 Ni, 16 Mo, 7 Cr, and 3 Fe. Filler metal of this classification is used for welding nickel-molybdenum alloy (ASTM B366, B434, and B573 having UNS number N10003) to itself, to steel, to other nickel-base alloys, and for cladding steel with nickel-molybdenum weld metal using the GTAW and GMAW processes.

A7.10.3 ERNiMo-3. The nominal composition (wt %) of filler metal of this classification is 63 Ni, 24 Mo, 6 Fe, and 5 Cr. Filler metal of this classification is used for weld repair of various nickel, cobalt-, and iron-base alloys and for dissimilar joining applications of nickel, cobalt, and iron base alloys.

A7.10.4 ERNiMo-7. The nominal composition (wt %) of filler metal of this classification is 69 Ni and 28 Mo. Filler metal of this classification is used for welding nickel-molybdenum alloy (ASTM B333 and B335 having UNS number N10665) to itself and for cladding steel with nickel-molybdenum weld metal using the GTAW and GMAW processes.

A7.10.5 ERNiMo-8. The nominal composition (wt %) of filler metal of this classification is 70 Ni, 19 Mo, 5 Fe, 3 W, and 2 Cr. Filler metal of this classification is used for welding 9% nickel steel (ASTM A333, A334, A353, and A553 having UNS number K81340) to itself using the GTAW and SAW processes.

A7.10.6 ERNiMo-9. The nominal composition (wt %) of filler metal of this classification is 70 Ni, 20 Mo, 1 Fe, and 3 W. Filler metal of this classification is used for welding 9% nickel steel (ASTM A333, A334, A353, and A553 having UNS number K81340) to itself using the GTAW and SAW processes.

A7.10.7 ERNiMo-10. The nominal composition (wt %) of filler metal of this classification is 68 Ni, 28.5 Mo, 1.5 Cr, 1.5 Fe, and low carbon. Filler metal of this classification is used for welding nickel-molybdenum alloy (ASTM B333,

B335, B366, B564, B619, B622, and B626 having UNS number N10675) to itself, for welding the clad side of joints in steel clad with nickel-molybdenum alloy, and for welding nickel-molybdenum alloys to steel and to other nickel-base alloys using the GTAW, GMAW, and PAW processes.

A7.10.8 ERNiMo-11. The nominal composition (wt %) of filler metal of this classification is 67 Ni, 28 Mo, 3 Fe, 1.3 Cr, and low carbon. Filler metal of this classification is used for welding nickel-molybdenum alloy (ASTM B333, B335, B366, B564, B619, B622, and B626 having UNS number N10629) to itself, for welding the clad side of joints clad with nickel-molybdenum alloy, and for welding nickel-molybdenum alloys to steel and other nickel-base alloys using the GTAW, GMAW, and PAW processes.

A7.10.9 ERNiMo-12. The nominal composition (wt %) of filler metal of this classification is 65 Ni, 25 Mo, and 8 Cr. Filler metal of this classification is used for welding nickel-molybdenum alloy (ASTM B366, B434, B564, B619, B622, and B626 having UNS number N10242) to itself and for cladding steel with nickel-molybdenum weld metal using the GTAW and GMAW processes.

A7.11 ERNiMoCr-X Classification

A7.11.1 ERNiMoCr-1. The nominal composition (wt %) of filler metal of this classification is 62 Ni, 22 Mo, and 15 Cr. Filler metal of this classification is used for welding nickel-molybdenum-chromium alloy (ASTM B366, B462, B564, B575, B619, B622, and B626 having UNS number N10362) to itself and for cladding steel with nickel-molybdenum-chromium weld metal using the GTAW and GMAW processes.

A7.12 ERNiCrMo-X Classifications

A7.12.1 ERNiCrMo-1. The nominal composition (wt %) of filler metal of this classification is 44 Ni, 22 Cr, 20 Fe, 6.5 Mo, 2 Nb plus Ta, 2 Cu, and 1.5 Mn. Filler metal of this classification is used for welding nickel-chromium-molybdenum alloy (ASTM B581 and B582 having UNS number N06007) to itself, to steel, to other nickel-base alloys, and for cladding steel with nickel-chromium-molybdenum weld metal using the GTAW, GMAW, and PAW processes.

A7.12.2 ERNiCrMo-2. The nominal composition (wt %) of filler metal of this classification is 47 Ni, 22 Cr, 18 Fe, 9 Mo, and 1.5 Co. Filler metal of this classification is used for welding nickel-chromium-molybdenum alloy (ASTM B366, B435, and B572 having UNS number N06002) to itself, to steel, to other nickel-base alloys, and for cladding steel with nickel-chromium-molybdenum weld metal using the GTAW, GMAW, and PAW processes.

A7.12.3 ERNiCrMo-3. The nominal composition (wt %) of filler metal of this classification is 61 Ni, 22 Cr, 9 Mo, and 3.5 Nb plus Ta. Filler metal of this classification is used for welding nickel-chromium-molybdenum alloy (ASTM B443, B444, and B446 having UNS number N06625) to itself, to steel, to other nickel-base alloys, for cladding steel with nickel-chromium-molybdenum weld metal, and for welding the clad side of joints in steel with nickel-chromium-molybdenum alloy using the GTAW, GMAW, SAW, and PAW processes. This filler metal is recommended for applications where the operating temperature ranges from cryogenic to 1000 °F [540 °C].

A7.12.4 ERNiCrMo-4. The nominal composition (wt %) of filler metal of this classification is 57 Ni, 16 Cr, 15.5 Mo, 5.5 Fe, and 4 W. Filler metal of this classification is used for welding nickel-chromium-molybdenum alloy (ASTM B574, B575, B619, B622, and B628 having UNS number N10276) to itself, to steel, to other nickel-base alloys, and for cladding steel with nickel-chromium-molybdenum weld metal using the GTAW and GMAW processes.

A7.12.5 ERNiCrMo-7. The nominal composition (wt %) of filler metal of this classification is 65 Ni, 16 Cr, 15.5 Mo, and 2 Fe. Filler metal of this classification is used for welding nickel-chromium-molybdenum alloy (ASTM B574, B575, B619, B622, and B628 having UNS number N06455) to itself, to steel, to other nickel-base alloys, and for cladding steel with nickel-chromium-molybdenum weld metal using the GTAW, GMAW, and PAW processes.

A7.12.6 ERNiCrMo-8. The nominal composition (wt %) of filler metal of this classification is 50 Ni, 25 Cr, 17 Fe, 6 Mo, and 1 Cu. Filler metal of this classification is used for welding nickel-chromium-molybdenum alloy (ASTM B581, B582, B619, B622, and B626 having UNS number N06975) to itself, to steel, to other nickel-base alloys, and for cladding steel with nickel-chromium-molybdenum weld metal using the GTAW, GMAW, and PAW processes.

A7.12.7 ERNiCrMo-9. The nominal composition (wt %) of filler metal of this classification is 44 Ni, 22 Cr, 20 Fe, 7 Mo, 2 Co, and 2 Cu. Filler metal of this classification is used for welding nickel-chromium-molybdenum alloy (ASTM B581, B582, B619, B622, and B626 having UNS number N06007 or N06985) to itself, to steel, to other nickel-base

alloys, and for cladding steel with nickel-chromium-molybdenum weld metal using the GTAW, GMAW, and PAW processes.

A7.12.8 ERNiCrMo-10. The nominal composition (wt %) of filler metal of this classification is 56 Ni, 22 Cr, 13 Mo, 4 Fe, and 3 W. Filler metal of this classification is used for welding nickel-chromium-molybdenum alloy (ASTM B574, B575, B619, B622 and B628 having UNS number N06022) to itself, to steel, to other nickel-base alloys, and for cladding steel with nickel-chromium-molybdenum weld metal using the GTAW, GMAW, and PAW processes.

A7.12.9 ERNiCrMo-11. The nominal composition (wt %) of filler metal of this classification is 43 Ni, 30 Cr, 15 Fe, 5 Mo, 2 Co, 3 W, and 2 Cu. Filler metal of this classification is used for welding nickel-chromium-molybdenum alloy (ASTM B581, B582, B619, B622, and B626 having UNS number N06030) to itself, to steel, to other nickel-base alloys, and for cladding steel with nickel-chromium-molybdenum weld metal using the GTAW, GMAW, and PAW processes.

A7.12.10 ERNiCrMo-13. The nominal composition (wt %) of filler metal of this classification is 59 Ni, 23 Cr, 16 Mo, 1 Fe, and low carbon. Filler metal of this classification is used for welding nickel-chromium-molybdenum alloy (B564, B574, B575, B619, B622, and B626 having UNS number N06059) to itself, to steel, to other nickel-base alloys, and for cladding steel using the GTAW, GMAW, SAW, and PAW processes.

A7.12.11 ERNiCrMo-14. The nominal composition (wt %) of filler metal of this classification is 57 Ni, 21 Cr, 16 Mo, and 4 W. Filler metal of this classification is used for welding nickel-chromium-molybdenum alloy (ASTM B574, B575, B619, B622, and B628 having UNS number N06686) to itself, to steel, to other nickel-base alloys, and for cladding steel using the GTAW, GMAW, and SAW processes.

A7.12.12 ERNiCrMo-15. The nominal composition (wt %) of filler metal of this classification is 57 Ni, 21 Cr, 8 Mo, 7 Fe, 3 Nb plus Ta, and 1.4 Ti. Filler metal of this classification is used for welding nickel-chromium-molybdenum alloy (ASTM B805, UNS number N07725) to itself and for cladding steel using the GMAW and GTAW processes. The weld metal age hardens on heat treatment. For specific information concerning age hardening, consult the supplier or the supplier's technical literature.

A7.12.13 ERNiCrMo-16. The nominal composition (wt %) of filler metal of this classification is 60 Ni, 30 Cr, and 10 Mo. Filler metal of this classification is used for corrosion-resistant (especially excellent to crevice corrosion) overlaying by the GTAW, GMAW, and PAW processes.

A7.12.14 ERNiCrMo-17. The nominal composition (wt %) of filler metal of this classification is 59 Ni, 23 Cr, 16 Mo, and 1.6 Cu. Filler metal of this classification is used for welding nickel-chromium-molybdenum alloy (ASTM B574, B575, B619, B622 and B629 having UNS number N06200) to itself, to steel, to other nickel-base alloys, and for cladding steel with nickel-chromium-molybdenum weld metal using the GTAW, GMAW, and PAW processes.

A7.12.15 ERNiCrMo-18. The nominal composition (wt %) of filler metal of this classification is 50 Ni, 20 Cr, 11.5 Mo, 14 Fe, and 1.5 W. Filler metal of this classification is used for welding nickel-chromium-molybdenum alloys having UNS number N06650 to itself, to steel, to super-austenitic stainless steels, to other nickel-base alloys, and for cladding steel with nickel-chromium-molybdenum weld metal using the GTAW, GMAW, and PAW processes.

A7.12.16 ERNiCrMo-19. The nominal composition (wt %) of filler metal of this classification is 58 Ni, 21 Cr, 20 Mo, and 1 Fe. Filler metal of this classification is used for welding nickel-chromium-molybdenum alloy (ASTM B574, B575, B366, B564, B619, B622, and B626 having UNS N06058) to itself, to steel, to other nickel-base alloys, and for cladding steel with nickel-chromium-molybdenum weld metal using the GTAW, GMAW, and PAW processes.

A7.12.17 ERNiCrMo-20. The nominal composition (wt %) of filler metal of this classification is 64 Ni, 22 Cr, and 9 Mo (niobium free). The properties of this filler metal are suitable to weld super duplex stainless steels for low-temperature applications with high impact toughness. Filler metal of this composition is used for welding of nickel-chromium-molybdenum alloys of similar composition as well as for cladding using GTAW, GMAW, SAW, and PAW processes.

A7.12.18 ERNiCrMo-21. The nominal composition (wt %) of filler metal of this classification is 55 Ni, 25 Cr, 15 Mo, and 1 Fe. Filler metal of this classification is used for welding of nickel-chromium-molybdenum alloys (ASTM B574, B575, B366, B564, B619, B622 and B626 having UNS number N06205) to itself, to steel, to other nickel-base alloys, and for cladding steel with nickel-chromium-molybdenum weld metal using the GTAW, GMAW, and PAW processes.

A7.12.19 ERNiCrMo-22. The nominal composition (wt %) of filler metal of this classification is 58 Ni, 33 Cr, and 8 Mo. Filler metal of this classification is used for welding nickel-chromium-molybdenum alloy (ASTM B366, B434, B564, B619, B622, and B626 having UNS number N06035) to itself and for cladding steel with nickel-chromium-molybdenum weld metal using the GTAW and GMAW processes.

A7.13 ERNiCrMoWNb-X Classification

A7.13.1 ERNiCrMoWNb-1. The nominal composition (wt %) of filler metal of this classification is 60 Ni, 20 Cr, 7 Mo, 6 W, 3.5 Nb, and 1.5 Ti. Filler metal of this classification is used for welding high strength steel materials for oil and gas applications to themselves, to dissimilar metals, and to weld overlay steels using the GTAW and GMAW processes. The alloy is resistant to sulfide-induced stress corrosion cracking and stress cracking in hydrogen sulfide environments. For specific information concerning age hardening, consult the supplier or the supplier's technical literature.

A7.14 ERNiCoCrSi-X Classification

A7.14.1 ERNiCoCrSi-1. The nominal composition (wt %) of filler metal of this classification is 38 Ni, 30 Co, 28 Cr, 2.8 Si and 1 Fe. Filler metal of this classification is used for welding nickel-cobalt-chromium-silicon alloy (ASTM B435, B572, B619 and B626 having UNS number N12160) to itself using the GTAW, GMAW, and PAW processes. This alloy is sensitive to iron pick-up; therefore its use is not recommended for the welding of the nickel-cobalt-chromium-silicon alloy to iron-base alloys.

A7.15 ERNiCrWMo-X Classification

A7.15.1 ERNiCrWMo-1. The nominal composition (wt %) of filler metal of this classification is 57 Ni, 22 Cr, 14 W, 2 Co, 2 Fe, and 2 Mo. Filler metal of this classification is used for welding nickel-chromium-tungsten-molybdenum-lanthanum alloy (ASTM B366, B435, B564, and B572 having UNS number N06230) to itself using the GTAW and GMAW processes.

A8. Special Tests

It is recognized that supplementary tests may be required for certain applications. In such cases, tests to determine specific properties such as corrosion resistance, scaling resistance, or strength at elevated or cryogenic temperatures may be required. AWS A5.01M/A5.01 (ISO 14344 MOD) contains provisions for ordering such tests. This clause is included to give guidance to those who desire to specify such special tests. Those tests shall be conducted as agreed upon between the purchaser and supplier.

A8.1 Corrosion or Scaling Tests. Although welds made with electrodes and rods classified in this specification are commonly used in corrosion and heat-resisting applications, tests for those properties are not included in the specification. When required for a particular application, testing can be conducted on specimens taken from either a weld pad or a welded joint.

A8.1.1 Specimens from a joint are suitable for qualifying the welding procedure (for a specific application involving corrosion or oxidation resistance), but not for qualifying the filler metal. Tests on specimens from a joint have the disadvantage of being a combined test of the properties of the weld metal, the heat-affected zone, and the unaffected base metal. With such specimens, it is more difficult to obtain reproducible data (when a difference exists in the properties of the metal in the various parts of the specimen). Specimens taken from a joint do have the advantage of being able to duplicate the joint design and the welding sequence planned for fabrication.

A8.1.2 Specimens for testing corrosion or oxidation resistance of the weld metal alone are prepared by following the procedure normally used for the preparation of pads for chemical analysis (see 9.3 in AWS A5.11/A5.11M). The pad size should be at least 3/4 in [19 mm] in height by 2-1/2 in [65 mm] in width by $(1 + 0.625n)$ in $[25 + 16n]$ mm in length where n represents the number of specimens required from the pad. Specimens measuring 1/2 in by 2 in by 1/4 in [13 mm by 50 mm by 6.5 mm] are machined from the top of the pad, in a manner such that the 2 in [50 mm] dimension of the specimen is parallel to the 2-1/2 in [65 mm] dimension of the pad and the 1/2 in [13 mm] dimension is parallel with the length of the pad. The heat treatment, surface finish, and marking of the specimens prior to testing should be in accordance with standard practices for tests of similar alloys in the wrought or cast forms. The testing procedures should correspond to ASTM G4, *Standard Guide for Conducting Corrosion Tests in Field Applications*.

A8.2 Test for Mechanical Properties. The filler metals in this specification are used with a variety of welding processes and procedures. For this reason, weld metal tests have not been included in the specification. The tensile properties, bend ductility, and soundness of welds produced with these filler metals are determined during qualification of the procedure.

Welding variables (current, voltage, and welding speed), the shielding medium (the specific gas mixture or the flux), the manual dexterity of the welder, and the composition of the base and filler metal may all influence the mechanical properties that can be obtained. Typical tensile strength values for weld metals are shown in Table A.2. When supplementary tests for mechanical properties are specified, the testing procedures should be in accordance with AWS B4.0, *Standard Methods for Mechanical Testing of Welds*.

A9. Discontinued Classifications

During some previous revisions a number of classifications have been omitted from one revision of this specification to another. This resulted from either changes in commercial practice or changes in the classification system used in the specification. The discontinued classifications are listed in Table A3, along with the year last included in the specification.

A10. Safety Considerations

A10.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Annex Clause A5. Safety and health information is available from other sources, including, but not limited to, Safety and Health Fact Sheets, ANSI Z49.1, and applicable federal and state regulations.

A10.2 Safety and Health Fact Sheets. The Safety and Health Fact Sheets are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

Table A.2
Typical Weld Metal Tensile Strengths^a

Tensile Strength (Typical)		
AWS Classification	ksi	MPa
ERNi-1	55	380
ERNiCu-7	70	490
ERNiCu-8	100 ^b	690 ^b
ERNiCr-3	80	550
ERNiCr-4	100	690
ERNiCr-6	80	550
ERNiCr-7	100	690
ErNiCr-8	88	610
ERNiCrCo-1	155 ^g	1070 ^g
ERNiCrCoMo-1	90	620
ERNiCrCoMo-2 ^f	140	965
ERNiCrFe-5	80	550
ERNiCrFe-6	80	550

(Continued)

Table A.2 (Continued)
Typical Weld Metal Tensile Strengths^a

Tensile Strength (Typical)		
AWS Classification	ksi	MPa
ERNiCrFe-7	80	550
ERNiCrFe-7A	85	590
ERNiCrFe-8	125 ^c	860 ^c
ERNiCrFe-11	94	650
ERNiCrFe-12	95	660
ERNiCrFe-13	85	590
ERNiCrFe-14	80	550
ERNiCrFe-15	90	620
ERNiCrFeSi-1	90	620
ERNiCrFeAl-1	85	590
ERNiFeCr-1	80	550
ERNiFeCr-2	165 ^d	1140 ^d
ERNiFeCr-3	170 ^h	1170 ^h
ERNiMo-1	100	690
ERNiMo-2	100	690
ERNiMo-3	100	690
ERNiMo-7	110	760
ERNiMo-8	95	660
ERNiMo-9	95	660
ERNiMo-10	110	760
ERNiMo-11	100	690
ERNiMo-12	100	690
ERNiMoCr-1	105	725
ERNiCrMo-1	85	590
ERNiCrMo-2	95	660
ERNiCrMo-3	110	760
ERNiCrMo-4	100	690
ERNiCrMo-7	100	690
ERNiCrMo-8	85	590
ERNiCrMo-9	85	590
ERNiCrMo-10	100	690
ERNiCrMo-11	85	590
ERNiCrMo-13	110	760
ERNiCrMo-14	110	760
ERNiCrMo-15	174 ^e	1200 ^e

(Continued)

Table A.2 (Continued)
Typical Weld Metal Tensile Strengths^a

Tensile Strength (Typical)		
AWS Classification	ksi	MPa
ERNiCrMo-16	85	590
ERNiCrMo-17	100	690
ERNiCrMo-18	95	660
ERNiCrMo-19	120	830
ERNiCrMo-20	110	750
ERNiCrMo-21	115	780
ERNiCrMo-22	85	590
ERNiCrMoWNb-1	130	900
ERNiCoCrSi-1	90	620
ERNiCrWMo-1	110	760

^a Tensile strength in the as-welded condition, unless otherwise specified.

^b Age-hardened condition: Heat treated at 1475 °F [802 °C] for 2 hours plus 1100 °F [593 °C] for 16 hours, then furnace cooled at 25 °F [14 °C] per hour to 900 °F [482 °C], then air cooled.

^c Age-hardened condition: Heat treated at 1950 °F [1066 °C] for 2 hours plus 1300 °F [704 °C] for 20 hours, then air cooled.

^d Age-hardened condition: Heat treated at 1325 °F [718 °C] for 8 hours, then furnace cooled at 100 °F [56 °C] per hour to 1150 °F and, held for 8 hours, then air cooled.

^e Age-hardened condition: Heat treated at 1900 °F [1038 °C] for 1 hour plus 1350 °F [732 °C] for 8 hours, then furnace cooled at 100 °F [56 °C] per hour to 1150 °F [621 °C] and held for 8 hours, then air cooled.

^f Age-hardened condition: Heat treated at 2075 °F [1135 °C] for 30 minutes plus 1850 °F [1010 °C] for 2 hours plus 1450 °F [790 °C] for 8 hours, then air cooled.

^g Age-hardened condition: Solution annealed at 2050 °F [1121 °C] for 1 hour, then water quenched and aged at 1472 °F [800 °C] for 4 hours then air cooled.

^h Age-hardened condition: Annealed at 1900 °F [1038 °C] for 1 hour, then aged at 1325 °F [718 °C] for 8 hours and furnace cooled at 100 °F [56 °C] per hour to 1150 °F [620 °C] held for 8 hours and air cooled.

Table A.3
Discontinued Classifications

Discontinued Classification	Last Year Published
RNi-2	1969
ERNi-3	1969
RNiCrFe-4	1969
RNiCu-5	1969
RNiCu-6	1969
ERNiMo-4 ^a	1969
ERNiMo-5	1969
ERNiMo-6 ^b	1969

^a Reclassified as ERNiMo-1 in 1976.

^b Reclassified as ERNiMo-3 in 1976.

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1/D1.1M:2012) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

B6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

AWS Filler Metal Specifications by Material and Welding Process

	OFW	SMAW	GTAW GMAW PAW	FCAW	SAW	ESW	EGW	Brazing
Carbon Steel	A5.2	A5.1, A5.35	A5.18	A5.20	A5.17	A5.25	A5.26	A5.8, A5.31
Low-Alloy Steel	A5.2	A5.5	A5.28	A5.29	A5.23	A5.25	A5.26	A5.8, A5.31
Stainless Steel		A5.4, A5.35	A5.9, A5.22	A5.22	A5.9, A5.22, A5.39	A5.9, A5.22, A5.39	A5.9	A5.8, A5.31
Cast Iron	A5.15	A5.15	A5.15	A5.15				A5.8, A5.31
Nickel Alloys		A5.11, A5.35	A5.14, A5.34	A5.34	A5.14, A5.34, A5.39	A5.14, A5.34, A5.39		A5.8, A5.31
Aluminum Alloys		A5.3	A5.10					A5.8, A5.31
Copper Alloys		A5.6	A5.7					A5.8, A5.31
Titanium Alloys			A5.16					A5.8, A5.31
Zirconium Alloys			A5.24					A5.8, A5.31
Magnesium Alloys			A5.19					A5.8, A5.31
Tungsten Electrodes			A5.12					
Brazing Alloys and Fluxes								A5.8, A5.31
Surfacing Alloys	A5.21	A5.13	A5.21	A5.21	A5.21			
Consumable Inserts			A5.30					
Shielding Gases			A5.32	A5.32			A5.32	

AWS Filler Metal Specifications and Related Documents

Designation	Title
A4.2M (ISO 8249 MOD)	<i>Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal</i>
A4.3	<i>Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding</i>
A4.4M	<i>Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings</i>
A4.5M/A4.5 (ISO 15792-3 MOD)	<i>Standard Methods for Classification Testing of Positional Capacity and Root Penetration of Welding Consumables in a Fillet Weld</i>
A5.01M/A5.01 (ISO 14344 MOD)	<i>Welding and Brazing Consumables—Procurement of Filler Metals and Fluxes</i>
A5.02/A5.02M	<i>Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes</i>
A5.1/A5.1M	<i>Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding</i>
A5.2/A5.2M	<i>Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding</i>
A5.3/A5.3M	<i>Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.4/A5.4M	<i>Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding</i>
A5.5/A5.5M	<i>Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding</i>
A5.6/A5.6M	<i>Specification for Copper and Copper-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.7/A5.7M	<i>Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes</i>
A5.8M/A5.8	<i>Specification for Filler Metals for Brazing and Braze Welding</i>
A5.9/A5.9M (ISO 14343 MOD)	<i>Specification for Bare Stainless Steel Welding Electrodes and Rods</i>
A5.10/A5.10M (ISO 18273 MOD)	<i>Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods</i>
A5.11/A5.11M	<i>Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding</i>
A5.12M/A5.12 (ISO 6848 MOD)	<i>Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting</i>
A5.13/A5.13M	<i>Specification for Surfacing Electrodes for Shielded Metal Arc Welding</i>
A5.14/A5.14M	<i>Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods</i>
A5.15	<i>Specification for Welding Electrodes and Rods for Cast Iron</i>
A5.16/A5.16M (ISO 24034 MOD)	<i>Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods</i>
A5.17/A5.17M	<i>Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.18/A5.18M	<i>Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.19	<i>Specification for Magnesium-Alloy Welding Electrodes and Rods</i>
A5.20/A5.20M	<i>Specification for Carbon Steel Electrodes for Flux Cored Arc Welding</i>
A5.21/A5.21M	<i>Specification for Bare Electrodes and Rods for Surfacing</i>
A5.22/A5.22M	<i>Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods</i>
A5.23/A5.23M	<i>Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.24/A5.24M	<i>Specification for Zirconium and Zirconium-Alloy Welding Electrodes and Rods</i>
A5.25/A5.25M	<i>Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding</i>
A5.26/A5.26M	<i>Specification for Carbon and Low-Alloy Steel Electrodes for Electrode Gas Welding</i>
A5.28/A5.28M	<i>Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.29/A5.29M	<i>Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding</i>
A5.30/A5.30M	<i>Specification for Consumable Inserts</i>
A5.31M/A5.31	<i>Specification for Fluxes for Brazing and Braze Welding</i>
A5.32M/A5.32 (ISO 14175 MOD)	<i>Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes</i>
A5.34/A5.34M	<i>Specification for Nickel-Alloy Flux Cored and Metal Cored Welding Electrodes</i>
A5.35/A5.35M-AMD1	<i>Specification for Covered Electrodes for Underwater Wet Shielded Metal Arc Welding</i>
A5.39/A5.39M	<i>Specification for Stainless Steel and Nickel-Alloy Electrodes and Fluxes for Submerged Arc and Electroslag Welding</i>

SPECIFICATION FOR WELDING ELECTRODES AND RODS FOR CAST IRON



SFA-5.15



(25)

(Identical with AWS Specification A5.15-1990 (S2023). In case of dispute, the original AWS text applies.)

Specification for Welding Electrodes and Rods for Cast Iron

1. Scope

This specification prescribes requirements for the classification of the following:

- (1) Rods for oxyfuel gas welding
- (2) Electrodes for gas metal arc welding
- (3) Electrodes for flux cored arc welding
- (4) Electrodes for shielded metal arc welding

These filler metals are suitable for welding gray cast iron, malleable cast iron, nodular cast iron, compacted graphite cast iron, and certain alloy cast irons.¹

2. Classification

2.1 The electrodes and rods covered by this specification are classified according to chemical composition, as specified in Tables 1A, 1B, and 1C.

2.2 Electrodes and rods classified under one classification shall not be classified under any other classification in this specification.

2.3 The electrodes and rods classified under this specification are intended for oxyfuel gas welding, shielded metal arc welding, gas metal arc welding, or flux cored arc welding, as applicable, but that is not to prohibit their use with any other process for which they are found suitable.

3. Acceptance

Acceptance² of the welding electrodes shall be in accordance with the provisions of AWS A5.01, *Welding and Brazing Consumables—Procurement of Filler Metals and Fluxes*.³

4. Certification

By affixing the AWS specification and classification designations to the packaging, or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification.⁴

¹ Copper-base filler metals frequently used in the braze welding of cast iron are no longer included in this specification. For more information pertaining to these materials see A7.6 in the Annex A.

² See section A3 (in the Annex A) for further information concerning acceptance, testing of the material shipped, and AWS A5.01, *Welding and Brazing Consumables—Procurement of Filler Metals and Fluxes*.

³ AWS standards are published by the American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.

⁴ See section A4 (in the Annex A) for further information concerning certification and the testing called for to meet this requirement.

5. Units of Measure and Rounding-Off Procedure

5.1 U.S. Customary Units are the standard units of measure in this specification. The SI Units are given as equivalent values to the U.S. Customary Units. The standard sizes and dimensions in the two systems are not identical, and for this reason, conversion from a standard size or dimension in one system will not always coincide with a standard size or dimension in the other. Suitable conversions, encompassing standard sizes of both, can be made, however, if appropriate tolerances are applied in each case.

5.2 For the purpose of determining conformance with this specification, an observed or calculated value shall be rounded to the “nearest unit” in the last right-hand place of figures used in expressing the limiting value in accordance with the rounding off method given in ANSI/AWS A1.1, *Metric Practice Guide for the Welding Industry*.

Table 1A*
**Chemical Composition Requirements for Undiluted Weld Metal for
Shielded Metal Arc and Flux Cored Arc Welding Electrodes**

AWS Classification ^d	UNS Number ^e	Weight Percent ^{a, b, c}										Other Elements, Total
		C	Mn	Si	P	S	Fe	Ni ^f	Mo	Cu ^g	Al	
		Shielded Metal Arc Welding Electrodes										
ENi-CI	W82001	2.0	2.5	4.0	—	0.03	8.0	85 min.	—	2.5	1.0	1.0
ENi-CI-A	W82003	2.0	2.5	4.0	—	0.03	8.0	85 min.	—	2.5	1.0–3.0	1.0
ENiFe-CI	W82002	2.0	2.5	4.0	—	0.03	Rem.	45–60	—	2.5	1.0	1.0
ENiFe-CI-A	W82004	2.0	2.5	4.0	—	0.03	Rem.	45–60	—	2.5	1.0–3.0	1.0
ENiFeMn-CI	W82006	2.0	10–14	1.0	—	0.03	Rem.	35–45	—	2.5	1.0	1.0
ENiCu-A	W84001	0.35–0.55	2.3	0.75	—	0.025	3.0–6.0	50–60	—	35–45	—	1.0
ENiCu-B	W84002	0.35–0.55	2.3	0.75	—	0.025	3.0–6.0	60–70	—	25–35	—	1.0
Flux Cored Arc Welding Electrodes												
ENiFeT3-CI ^h	W82032	2.0	3.0–5.0	1.0	—	0.03	Rem.	45–60	—	2.5	1.0	1.0

*See notes on following page.

Table 1B*
**Chemical Composition Requirements for Core Wire for
Shielded Metal Arc Welding Electrodes**

Weight Percent ^{a, b, c}												
AWS Classification ^d	UNS Number ^e	C	Mn	Si	P	S	Fe	Ni	Mo	Cu	Al	Other Elements, Total
Shielded Metal Arc Welding Electrodes												
ES _t	K01520	0.15	0.60	0.15	0.04	0.04	Rem.	—	—	—	—	—

*See notes on following page.

(Continued)

Table 1C
Chemical Composition Requirements for Rods and Bare Electrodes

AWS Classification ^d	UNS Number ^e	Weight Percent ^{a, b, c}												Other Elements, Total
		C	Mn	Si	P	S	Fe	Ni ^f	Mo	Cu ^g	Mg	Al	Ce	
Cast Iron Welding Rods for OFW														
RCI	F10090	3.2–3.5	0.60–0.75	2.7–3.0	0.50–0.75	0.10	Rem.	Trace	Trace	—	—	—	—	—
RCI-A	F10091	3.2–3.5	0.50–0.70	2.0–2.5	0.20–0.40	0.10	Rem.	1.2–1.6	0.25–0.45	—	—	—	—	—
RCI-B	F10092	3.2–4.0	0.10–0.40	3.2–3.8	0.05	0.015	Rem.	0.50	—	—	0.04–0.10	—	0.20	—
Electrodes for Gas Metal Arc Welding														
ERNi-CI	N02215	1.0	2.5	0.75	—	0.03	4.0	90 min.	—	4.0	—	—	—	1.0
ERNiFeMn-CI	N02216	0.50	10–14	1.0	—	0.03	Rem.	35–45	—	2.5	—	1.0	—	1.0

Notes:

a. The weld metal, core wire, or the filler metal, as specified, shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated, in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for “Other Elements, Total” in the last column of the table.

b. Single values shown are maximum, unless otherwise noted.

c. “Rem.” stands for Remainder.

d. Copper-base filler metals frequently used in the braze welding of cast irons are no longer included in this specification. For information pertaining to these materials see A7.6.

e. SAE/ASTM Unified Numbering System for Metals and Alloys.

f. Nickel plus incidental cobalt.

g. Copper plus incidental silver.

h. No shielding gas shall be used for classification ENiFeT3-CI.

6. Summary of Tests

Chemical analysis, as specified in Table 2, of the filler metal or rod stock from which the filler metal is made, or the core wire, or the undiluted weld metal is the only test required for classification of a product under this specification.

7. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both tests shall meet the requirement. Specimens for retest may be taken from the original test assembly or sample, or from new test assemblies or samples. For chemical analysis, retest need only be for those specific elements that failed to meet the test requirement.

8. Weld Test Assembly

8.1 One test assembly is required. It is the weld pad in Figure 1 for chemical analysis of undiluted weld metal from electrodes for shielded metal arc or flux cored arc welding electrodes, except for the ESt classification for which the core is analyzed.

8.2 Preparation of the weld test assembly shall be as prescribed in 8.3 and Figure 1. The base metal for the assembly shall be gray iron, nodular iron, or carbon steel. Testing of the assembly shall be as prescribed in 9.2 and 9.3

Table 2
Required Tests

AWS Classification	Chemical Analysis of Undiluted Weld Metal from Weld Pad¹	Chemical Analysis of Filler Metal¹
ENi-CI	Required	N.R.
ENi-CI-A	Required	N.R.
ENiFe-CI	Required	N.R.
ENiFe-CI-A	Required	N.R.
ENiFeMn-CI	Required	N.R.
ENiCu-A	Required	N.R.
ENiCu-B	Required	N.R.
ENiFeT3-CI	Required	N.R.
RCI	N.R.	Required
RCI-A	N.R.	Required
RCI-B	N.R.	Required
ERNi-CI	N.R.	Required
ERNiFeMn-CI	N.R.	Required
ESt	N.R.	Required ²

Notes:

1. "N.R." means that the test is not required.

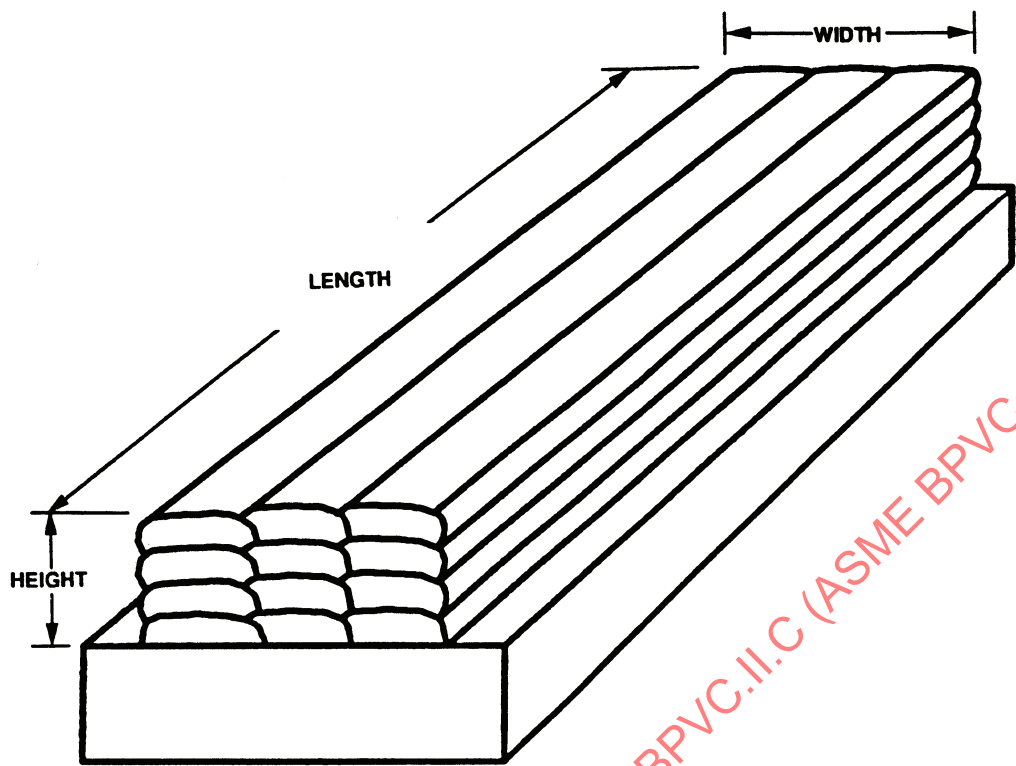
2. Chemical requirements for the ESt classification are based on the composition of the core wire without any flux coatings.

8.3 Weld Pad. When required by Table 2, a weld pad shall be prepared as specified in Figure 1. Base metal of any convenient size, of the type specified in 8.2, shall be used as the base for the weld pad. The surface of the base metal on which the filler metal is deposited shall be clean. The pad shall be welded in the flat position with multiple beads and multiple layers to obtain undiluted weld metal. The preheat temperature shall not be less than 60 °F (16 °C) and the interpass temperature shall not exceed 300 °F (150 °C). The slag shall be removed after each pass. The pad may be quenched in water between passes. The dimensions of the completed pad shall be as shown in Figure 1, for each size of electrode. Testing of this assembly shall be as specified in 9.2.

9. Chemical Analysis

9.1 For solid filler metal classified in Table 1C, and the core wire for electrodes classified in Table 1B, a sample of the filler metal, core wire, or the rod stock from which the filler metal or core wire is made, shall be prepared for chemical analysis. Solid filler metal, when analyzed for elements that are present in a coating (copper flashing, for example), shall be analyzed without removing the coating. When the filler metal is analyzed for elements other than those in the coating, the coating shall be removed if its presence affects the results of the analysis for other elements. Rod stock analyzed for elements not in the coating may be analyzed prior to applying the coating.

9.2 For electrodes classified in Table 1A, a sample shall be analyzed in the form of weld metal, not filler metal. The sample for analysis shall be taken from weld metal obtained with the filler metal. The sample shall come from a weld pad as shown in Figure 1. The top surface of the pad described in 8.3 and shown in Figure 1 shall be removed, discarded, and a sample for analysis shall be obtained from the underlying metal by any appropriate mechanical means. The sample shall be free of slag.



Shielded Metal Arc Welding			Flux Cored Arc Welding			
Electrode Diameter	Minimum Height (H)	Minimum Length (L)	Electrode Diameter	Minimum Height (H)	Minimum Length (L)	Min. No. of Layers
1/8 in (3.2 mm) and less	1/2 in (13 mm)	1-1/2 in (38 mm)	.052 in (1.3 mm) and less	5/8 in (16 mm)	3 in (76 mm)	4
Greater than 1/8 in (3.2 mm)	7/8 in (22 mm)	2 in (51 mm)	Greater than .052 in (1.3 mm)	1 in (25 mm)	4 in (102 mm)	4

Note: The width (W) of the weld metal shall be sufficient for the method of analysis. No shielding gas shall be used for classification ENiFeT3-Cl.

Figure 1—Pad for Chemical Analysis of Undiluted Weld Metal

For covered electrodes 1/8 in (3.2 mm) and smaller and flux cored electrodes .052 in (1.3 mm) diameter and smaller, the sample shall be taken at least 7/16 in (11 mm) from the nearest surface of the base metal. For covered electrodes larger than 1/8 in (3.2 mm) diameter and flux cored electrodes larger than .052 in (1.3 mm), the sample shall be taken at least 9/16 in (14 mm) from that surface.

9.3 The sample shall be analyzed by accepted analytical methods. The referee method shall be the appropriate one of the following:⁵

- (1) ASTM E39, Standard Methods for Chemical Analysis of Nickel
- (2) ASTM E76, Standard Test Methods for Chemical Analysis of Nickel-Copper Alloys
- (3) ASTM E350, Standard Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron

⁵ ASTM standards are published by ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

- (4) ASTM E351, Standard Test Methods for Chemical Analysis of Cast Iron—All types
- (5) ASTM E353, Standard Test Methods for Chemical Analysis of Stainless, Heat Resisting, Maraging, and Other Similar Chromium-Nickel-Iron Alloys
- (6) ASTM E354, Standard Test Methods for Chemical Analysis of High-Temperature Electrical, Magnetic, and Other Similar Iron, Nickel, and Cobalt Alloys

9.4 The results of the analysis shall meet the requirements of Table 1 for the classification of filler metal under test.

10. Welding Rods

10.1 Method of Manufacture. The welding rods classified according to this specification may be manufactured by any method that will produce rods that meet the requirements of this specification.

10.2 Standard Sizes and Lengths. Standard sizes for welding rod shall be as shown in Table 3.

10.3 Finish and Uniformity. All rods shall have a smooth finish that is free from slivers, depressions, scratches, scale, seams, laps, and foreign matter that would adversely affect the welding characteristics or the properties of the weld metal.

10.4 Standard Package Forms. Standard package forms are straight lengths. Standard package dimensions are not specified. Welding rods shall be packed in containers of 5, 10, 25, 30, 50, 60, or 100 lb (2.3, 4.5, 11, 14, 23, 27 or 45 kg) net weight. Other package weights shall be as agreed upon by supplier and purchaser.

10.5 Packaging. Welding rods shall be suitably packaged to ensure against damage during shipment and storage under normal conditions.

10.6 Marking of Packages

10.6.1 The following product information (as a minimum) shall be legibly marked on the outside of each unit package.

- (1) AWS specification and classification designations (year of issue may be excluded)
- (2) Supplier's name and trade designation
- (3) Size and net weight
- (4) Lot, control, or heat number

10.6.2 Marking of any overpacking of unit packages with the items listed in 10.6.1 shall be optional with the manufacturer.

10.6.3 The following precautionary information (as a minimum) shall be prominently displayed in legible print on all packages of welding rods, including individual unit packages enclosed within a larger package.

WARNING:

PROTECT yourself and others. Read and understand this information.

FUMES AND GASES can be dangerous to health.

HEAT RAYS (INFRARED RADIATION from flame or hot metal) can injure eyes.

- Before use read and understand the manufacturer's instructions, the Safety Data Sheets (SDSs), and your employer's safety practices.
- Keep your head out of the fumes.
- Use enough ventilation, exhaust at the arc, or both, to keep fumes and gases away from your breathing zone and the general area.
- Wear correct eye, ear and body protection.
- See American National Standard Z49.1, *Safety in Welding, Cutting, and Allied Processes*, published by the American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166, and OSHA Safety and Health Standards, 29 CFR 1910, published by the Government Printing Office, Washington, DC 20402.

DO NOT REMOVE THIS INFORMATION

Table 3
Standard Sizes and Lengths of Welding Rods^a

AWS Classification	Size, in	Size Tolerance, in	Length in	Length Tolerance, in
RCI	1/8 round	$\pm 1/32$	18	$+ 1/2, -2$
	1/8 square	$\pm 1/32$	20	$+ 1/4, -2$
	3/16, 1/4, 5/16, 3/8, 1/2, round or square	$\pm 1/32$	24	$\pm 1/4, -2$
RCI-A	1/8, 3/16, 1/4, 5/16, 3/8, 1/2, round or square	$\pm 1/32$	24	$+ 1/4, -2$
RCI-B	3/16, 1/4, 3/8, 1/2 round or square	$\pm 1/32$	24	$+ 1/4, -2$

Notes:

a. Sizes and lengths other than these shall be as agreed to by supplier and purchaser.

SI Equivalents

in	mm
1/32 (0.031)	0.8
1/8 (0.125)	3.2
5/32 (0.156)	4.0
3/16 (0.188)	4.8
1/4 (0.250)	6.4
5/16 (0.313)	8.0
3/8 (0.375)	9.5
1/2 (0.500)	12.7
2	51
18	450
20	500
24	600

11. Shielded Metal Arc Welding Electrodes

11.1 Method of Manufacture. The welding electrodes classified according to this specification may be manufactured by any method that will produce electrodes that meet the requirements of this specification.

11.2 Standard Sizes and Lengths

11.2.1 Standard sizes (diameter of the core wire) and lengths for electrodes are shown in Table 4.

11.2.2 The diameter of the core wire shall not vary more than ± 0.003 in (0.08 mm) from the diameter specified. The length shall not vary more than $\pm 1/4$ in (± 6.4 mm) from that specified.

Table 4
Standard Sizes and Lengths for Shielded
Metal Arc Welding Electrodes

AWS Classification	Diameter in	Size Tolerance in	Length in	Length Tolerance in
ENi-CI ENi-CI-A	3/32	± 0.003	9, 12, and 14	$\pm 1/4$
ENiFe-CI				
ENiFe-CI-A				
ENiFeMn-CI				
ESi	{ 1/8, 5/32, } 3/16, 1/4 }	± 0.003	12 and 14	$\pm 1/4$
ENiCu-A				
ENiCu-B	{ 3/32, 1/8, } 5/32, 3/16 }	± 0.003	12 and 14	$\pm 1/4$

Notes:

Sizes and lengths other than these shall be available as agreed upon by the supplier and purchaser.

SI Equivalents

in	mm
0.003	0.08
3/32	2.4
1/8	3.2
5/32	4.0
3/16	4.8
1/4	6.4
9	230
12	300
14	350

11.3 Core Wire and Covering

11.3.1 The core wire and covering shall be free of defects that would interfere with uniform deposition of the electrode.

11.3.2 The core wire and covering shall be concentric to the extent that the maximum core-plus-one-covering dimension shall not exceed the minimum core-plus-one-covering dimension by more than:

- (1) seven percent of the mean dimension in sizes 3/32 in (2.4 mm) and smaller,
- (2) five percent of the mean dimension in sizes 1/8 in (3.2 mm) and 5/32 in (4.0 mm), and
- (3) four percent of the mean dimension in sizes 3/16 in (4.8 mm) and larger.

The concentricity may be measured by any suitable means.

11.3.3 The covering of electrodes shall be such that it is not readily damaged by ordinary handling.

11.4 Exposed Core

11.4.1 The grip end of each electrode shall be bare (free of covering) for a distance of not less than 1/2 in (12 mm) nor more than 1-1/4 in (32 mm) for electrodes 5/32 in (4.0 mm) and smaller, and not less than 3/4 in (19 mm) nor more than 1-1/2 in (38 mm) for electrodes 3/16 in (4.8 mm) and larger, to provide for electrical contact with the electrode holder.

11.4.2 The arc end of each electrode shall be sufficiently bare and the covering sufficiently tapered to permit easy striking of the arc. The length of the bare portion (measured from the end of the core wire to the location where the full cross-section of the covering is obtained) shall not exceed 1/8 in (3.2 mm) or the diameter of the core wire, whichever is less. Electrodes with chipped covering near the arc end, baring the core wire no more than the lesser of 1/2 in (13 mm) or twice the diameter of the core wire, meet the requirements of this specification, provided no chip uncovers more than 50 percent of the circumference of the core.

11.5 Electrode Identification. All electrodes shall be identified as follows:

11.5.1 At least one imprint of the electrode classification shall be applied to the electrode covering within 2-1/2 in (65 mm) of the grip end of the electrode.

11.5.2 The numbers and letters of the imprint shall be of bold block type of a size large enough to be legible.

11.5.3 The ink used for imprinting shall provide sufficient contrast with the electrode covering so that in normal use the numbers and letters are legible both before and after welding.

11.5.4 The prefix letter “E” in the electrode classification may be omitted from the imprint.

11.6 Packaging

11.6.1 Electrodes shall be suitably packaged to protect against damage during shipment and storage under normal conditions.

11.6.2 Standard package weights shall be as specified in 10.4 or as agreed upon by supplier and purchaser.

11.7 Marking of Packages

11.7.1 The following product information (as a minimum) shall be legibly marked on the outside of each unit package.

- (1) AWS specification and classification designations (year of issue may be excluded)
- (2) Supplier's name and trade designation
- (3) Size and net weight
- (4) Lot, control, or heat number

11.7.2 The following precautionary information (as a minimum) shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages enclosed within a larger package:

WARNING:

PROTECT yourself and others. Read and understand this information.

FUMES AND GASES can be dangerous to health.

ARC RAYS can injure eyes and burn skin.

ELECTRIC SHOCK can kill.

- Before use read and understand the manufacturer's instructions, the Safety Data Sheets (SDSs), and your employer's safety practices.
- Keep your head out of the fumes.
- Use enough ventilation, exhaust at the arc, or both, to keep fumes and gases away from your breathing zone and the general area.
- Wear correct eye, ear and body protection.
- Do not touch live electrical parts.
- See American National Standard Z49.1, *Safety in Welding, Cutting, and Allied Processes*, published by the American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166, and OSHA Safety and Health Standards, 29 CFR 1910, published by the Government Printing Office, Washington, DC 20402.

DO NOT REMOVE THIS INFORMATION

12.1 Method of Manufacture. The filler metals classified according to this specification may be manufactured by any method that will produce filler metals that meet the requirements of this specification.

12.3 Finish and Uniformity

12.3.2 Each continuous length of filler metal shall be from a single lot of material, and welds, when present, shall have been made so as not to interfere with the uniform, uninterrupted feeding of the filler metal on automatic and semi-automatic equipment.

12.4 Standard Package Forms

12.4.2 The liners in coils with support shall be designed and constructed to prevent distortion of the coil during normal handling and use and shall be clean and dry enough to maintain the cleanliness of the filler metal.

12.4.3 Spools shall be designed (see Figures 2 and 3) and constructed to prevent distortion of the filler metal during normal handling and use and shall be clean and dry enough to maintain the cleanliness of the filler metal.

Table 5
Standard Sizes and Tolerances for Gas Metal Arc and Flux Cored Arc Welding Electrodes

Standard Package Form	Standard Sizes Diameter			Tolerance	
	in		mm	in	MM
Coils With Support Spools } Coils Without Support, Coils With Support, Spools, Drums } Coils With Support Drums }	{ — — — 1/16	{ 0.035 0.045 0.052 0.063	{ 0.9 1.1 1.3 1.6	± 0.002	± 0.051
	{ 5/64 3/32 7/64	{ 0.078 0.094 0.109 0.120	{ 2.0 2.4 2.8 3.0	± 0.003	± 0.076
	{ 1/8 5/32	{ 0.125 0.156	{ 3.2 4.0	± 0.004	± 0.10

Dimensions and tolerances other than those shown shall be as agreed between the purchaser and supplier.

Table 6
Standard Dimensions for Coils With and Without Support and Drums

Coils Without Support		Coils With Support				Drums	
Inside Diameter of Coil		Inside Diameter of Liner		Width of Wound Electrode, max,		Outside Diameter	
in	mm	in	mm	in	mm	in	mm
12	300	$12 \pm 1/8$	300 ± 3.2	$4-5/8$	120	15-1/2	390
22-1/2	570					20	510
						23	580

Table 7
Standard Package Dimensions and Weights^a

Type of Package	Package Size		Net Weight of Electrode, ^b	
	ID			
	in	mm	lb	kg
Coils Without Support	12	300	50	23
	22-1/2	570	100	45
Coils With Support	12	300	50	27
			60	23
Spools	12	300	25	11
	14	360	50	23
			60	27
	30	760	600	273
Drums	15-1/2	390	200	90
	20	510	500	230
	23	580	1100	500

Notes:

a. Sizes and net weights other than those specified shall be as agreed between supplier and purchaser.

b. Net weights shall not vary more than $\pm 10\%$.

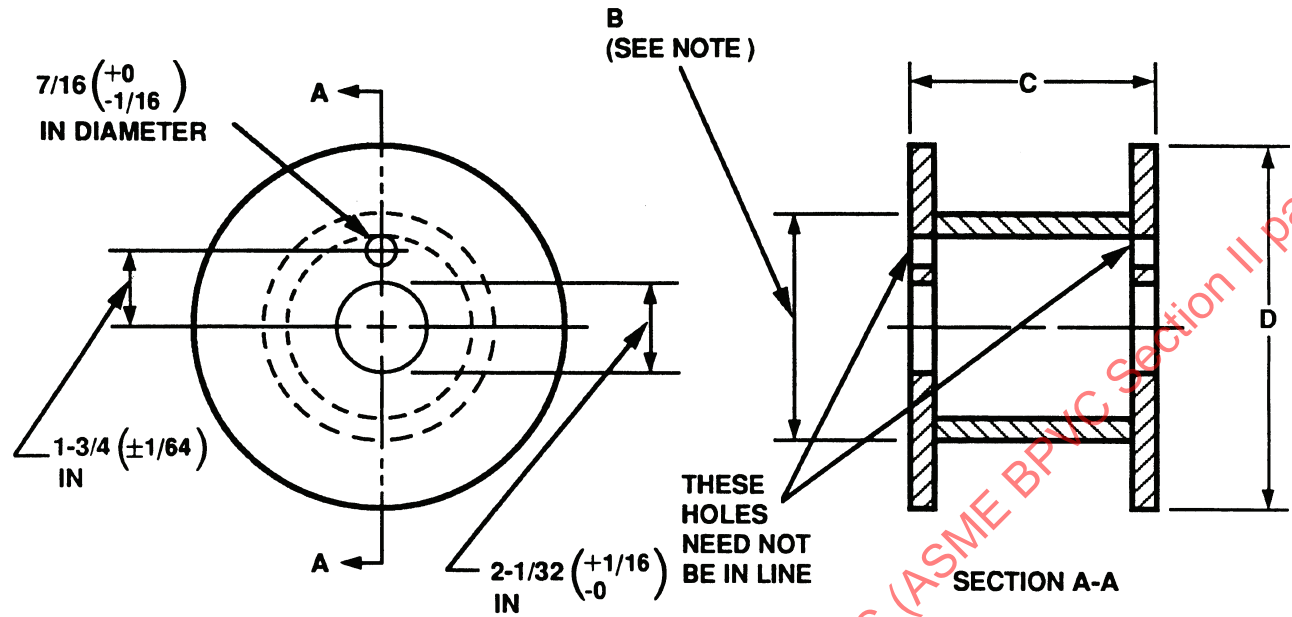
12.5 Winding Requirements

12.5.1 The filler metal shall be wound so that kinks, waves, sharp bends, overlapping, or wedging are not encountered, leaving the filler metal free to unwind without restriction. The outside end of the filler metal (the end welding is to begin with) shall be identified so it can be located readily and shall be fastened to avoid unwinding.

12.5.2 The cast and helix of filler metal in coils, spools, and drums shall be such that the filler metal will feed in an uninterrupted manner in semi-automatic and automatic equipment.

12.6 Filler Metal Identification

12.6.1 The product information and the precautionary information required in 12.8 for marking each package shall also appear on each coil, each spool, and each drum.



Note:

Dimension B, outside diameter of barrel, shall be such as to permit proper feeding of the filler metals.

Dimensions		
Spool size	C	D, maximum
in.	in	in
12	$4 \pm 1/16$	12
14	$4 \pm 1/16$	14

SI Equivalents	
in	mm
1/64 (.016)	0.4
1/32 (.031)	0.8
1/16 (.062)	1.6
7/16 (.438)	11.1
1/2 (.500)	13
3/4 (.750)	19.0
1	25.4
2	50.8
4	102
12	305
14	356

Figure 2—Dimensions of 12 and 14 in (300 and 360 mm) Spools

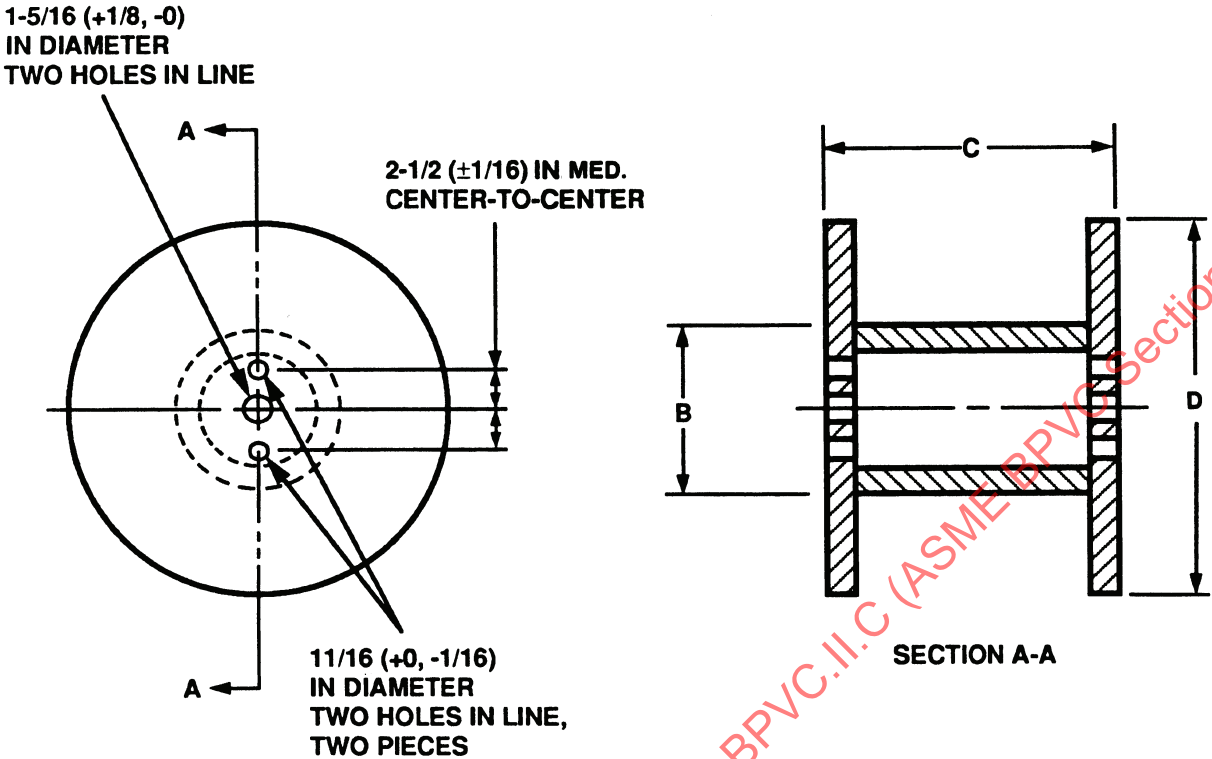
12.6.2 Coils without support shall have a tag containing this information securely attached to the filler metal at the inside end of the coil.

12.6.3 Coils with support shall have the information securely affixed in a prominent location on the support.

12.6.4 Spools shall have the information securely affixed in a prominent location on the outside of at least one flange of the spool.

12.6.5 Drums shall have the information securely affixed in a prominent location on the side of the drum.

12.7 Packaging. Filler metal shall be suitably packaged to ensure against damage during shipment and storage under normal conditions.



Notes:

1. Dimension B, outside diameter of barrel, shall be such as to permit proper feeding of the filler metals.

Dimensions			SI Equivalents	
Spool size	C, maximum	D	in	mm
in	in	in		
30	13 ± 1/2	30 ± 1/2	1/16 (.062)	1.6
			1/8 (.125)	3.2
			5/16 (.312)	7.9
			1/2 (.500)	12.7
			11/16 (.688)	17.5
			1	25.4
			2	50.8
			13	330
			30	762

Figure 3—Dimensions of 30 in (760 mm) Spools

12.8 Marking of Packages

12.8.1 The following product information (as a minimum) shall be legibly marked so as to be visible from the outside of each unit package:

- (1) AWS specification and classification designations (year of issue may be excluded)
- (2) Supplier's name and trade designation
- (3) Size and net weight
- (4) Lot, control, or heat number

12.8.2 The following precautionary information (as a minimum) shall be prominently displayed in legible print on all packages of welding electrodes, including individual unit packages enclosed within a larger package.

WARNING:

PROTECT yourself and others. Read and understand this information.

FUMES AND GASES can be dangerous to health.

ARC RAYS can injure eyes and burn skin.

ELECTRIC SHOCK can kill.

- Before use read and understand the manufacturer's instructions, the Safety Data Sheets (SDSs), and your employer's safety practices.
- Keep your head out of the fumes.
- Use enough ventilation, exhaust at the arc, or both, to keep fumes and gases away from your breathing zone and the general area.
- Wear correct eye, ear and body protection.
- See American National Standard Z49.1, Safety in Welding, Cutting, and Allied Processes, published by the American Welding Society, NW 36 St, # 130, Miami, FL 33166, and OSHA Safety and Health Standards, 29 CFR 1910, published by the Government Printing Office, Washington, DC 20402.

DO NOT REMOVE THIS INFORMATION

Annex A (Informative)

Guide to AWS Specification for Welding Electrodes and Rods for Cast Iron

This annex is not part of this standard, but is included for informational purposes only.⁶

A1. Introduction

The purpose of this Annex is to correlate the classifications with their intended applications so the specification can be used effectively. Reference to appropriate base metal specifications is made whenever that can be done, and when it would be helpful. Such references are intended only as examples rather than complete listings of the base metal for which each filler metal is suitable.

A2. Classification System

A2.1 The system for identifying welding rod and electrode classifications used in this specification follows the standard pattern used in other AWS filler metal specifications. The letter “E” at the beginning of each classification designation stands for electrode, the letters “ER” at the beginning of each classification designation stands for a filler metal which is suitable for use as either an electrode or rod, and the letter “R” at the beginning of each classification designation stands for a welding rod. The next letters in the filler metal designation are based on the chemical composition of the filler metal or undiluted weld metal. Thus, NiFe is a nickel-iron alloy, NiCu is a nickel-copper alloy, etc. Where different compositional limits in filler metals of the same alloy family result in more than one classification, the individual classifications are differentiated by the designators “A” or “B”, as in ENiCu-A and ENiCu-B.

A2.2 For flux cored electrodes the designator “T” indicates a tubular electrode. The number “3” indicates that the electrode is used primarily without an external shielding gas.

A2.3 Most of the classifications within this specification contain the usage designator “CI” after the hyphen which indicates that these filler metals are intended for cast iron applications. The usage designator is included to eliminate confusion with other filler metal classifications from other specifications which are designed for alloys other than cast irons. The two exceptions, ENiCu-A and ENiCu-B, preceded the introduction of the usage designator and have never had the “CI” added.

A2.4 The chemical symbols have been used in all the filler metals except the cast iron and mild steel groups. Since there are no chemical symbols for cast iron and mild steel, the letters “CI” and “St” have been assigned to this group to designate cast iron and mild steel filler metals, respectively. The suffixes “A” and “B” are used to differentiate two alloys of the cast iron filler metals from other cast iron rod classifications.

A3. Acceptance

A3.1 Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01, *Welding and Brazing Consumables—Procurement of Filler Metal Procurement Guidelines*, as the specification states. Any testing a purchaser requires of the supplier, for material shipped in accordance with this specification, shall be clearly stated in

⁶ For additional information, refer to AWS D11.2. Guide for Welding Iron Castings

the purchase order, according to the provisions of AWS A5.01. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing is normally conducted on material of that classification, as specified in Schedule F, Table 1, of AWS A5.01. Testing in accordance with any other Schedule in that Table shall be specifically required by the purchase order. In such cases, acceptance of the material shipped shall be in accordance with those requirements.

A4. Certification

A4.1 The act of placing the AWS Specification and Classification designations on the packaging enclosing the product, or the classification on the product itself, constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification.

A4.2 The only testing requirement implicit in this certification is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped, and that the material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation. "Certification" is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been made. The basis for the certification required by the specification is the classification test of "representative material" cited above, and the "Manufacturer's Quality Assurance System" in AWS A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes to which welders and welding operators can be exposed during welding:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling)
- (2) Number of welders and welding operators working in that space
- (3) Rate of evolution of fumes, gases, or dusts, according to the materials and processes used
- (4) The proximity of the welder and welding operators to the fumes as the fumes issue from the welding zone, and to the gases and dusts in the space in which they are working
- (5) The ventilation provided to the space in which the welding is done

A5.2 American National Standard Z49.1, *Safety in Welding, Cutting and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the section entitled Health Protection and Ventilation.

A6. Welding Considerations

A6.1 Welding Considerations for Electrodes

A6.1.1 The casting skin should be removed from the weld area by machining, grinding, chipping or other suitable means. When repairing casting defects, care should be exercised to ensure removal of any defective metal to sound base metal before welding. Also, all oil, grease, dirt, or other foreign material should be eliminated by the use of suitable solvents. If oil, grease, or solvents have impregnated the casting, heat should be applied to the area to be welded until volatilization is no longer observed. A temperature of 750 °F (400 °C) generally is sufficient for this operation. If the casting is too greasy, flash heating the welding surfaces to about 1000 °F (540 °C) should drive off the grease in a gaseous state.

A6.1.2 For V-groove welds, the edges should be beveled to form a 60 to 80 degree groove angle. For very thick base metal, a U-groove weld with a 20–25 degree groove angle and a groove radius of at least 3/16 to 1/2 in (4.8 to 13 mm) should be used.

A6.1.3 Welding currents should be within the range recommended by the supplier of the electrode, and as low as possible, consistent with smooth operation, good bead contour, and securing good fusion of the groove face. If welding

is in other than the flat and horizontal positions, the recommended currents should be reduced to some extent for vertical position and overhead position welding.

A6.1.4 The electrode should be manipulated so that the width of the weld bead is no greater than three times the nominal diameter of the electrode being used. If a large cavity must be filled, the sides may be surfaced, and the cavity gradually filled toward the center of the repaired area.

A6.1.5 When continuous welding is employed, heat input from the previous passes serves as moderate preheating or to maintain the preheat temperature. Use of preheating is not always necessary, but it is often used. In large castings, it may occasionally be found desirable to use intermittent welding to provide a more even temperature distribution, keeping the casting warm to the touch, but not permitting it to get too hot.

A6.1.6 The hardness of the heat-affected zone is a function of the composition and cooling rate of the base metal. An increase in the cooling rate for a given composition will increase the hardness of the heat-affected zone. Thus, any steps taken to retard the cooling rate such as preheating or the use of insulating material combined with preheating will be beneficial in lowering the hardness of the heat-affected zone. The hardness of the weld metal depends to a great extent upon the amount of dilution, and can be controlled within reasonable limits during welding. Single layer weld metal which has high dilution may have a hardness as high as 350 Brinell for ENiFe-CI, ENiFe-CI-A, and ESt electrodes, and around 210 Brinell for the ENi-CI, ENi-CI-A, and ENiCu-B weld metal.

Moderately thick weld beads, where the dilution is reduced by directing the arc onto the weld pool, or the later layers of multiple-layer welds, may give lower hardness ranges. Typical ranges for mechanical properties of undiluted filler metal are listed in Table A1.

A6.1.7 Preheating is especially helpful in overcoming the differential mass effect encountered when welding a thick to a thin base metal. The use of preheat in conjunction with welding for pressure tightness also increases the resistance to cracking at the weld interface. Judicious use of preheating when welding cast iron will permit the weld and surrounding area to cool at a more uniform rate.

Table A1
Typical Mechanical Properties of Undiluted Weld Metal

Electrode	Tensile Strength		Yield Strength 0/2% offset		Elongation % in 2 in	Hardness BHN
	ksi	MPa	ksi	MPa		
RCI	20–25	138–172	—	—	—	150–210
RCI-A	35–40	241–276	—	—	—	225–290
RCI-B (As-welded)	80–90	552–621	70–75	483–517	3–5	220–310
RCI-B (Annealed)	50–60	345–414	40–45	276–310	5–15	150–200
ESt	—	—	—	—	—	250–400
ENi-CI	40–65	276–448	38–60	262–414	3–6	135–218
ENi-CI-A	40–65	276–448	38–60	262–414	3–6	135–218
ENiFe-CI	58–84	400–579	43–63	296–434	6–18	165–218
ENiFe-CI-A	58–84	400–579	43–63	296–434	4–12	165–218
ENiFeMn-CI	75–95	517–655	60–70	414–483	10–18	165–210
ENiFeT3-CI	65–80	448–552	40–55	276–379	12–20	150–165
ERNiFeMn-CI	75–100	517–689	65–80	448–552	15–35	165–210

A6.1.8 Peening often is used to reduce stresses and decrease distortion. Peening should be done with repeated moderate blows of a round-nose or needle tool with sufficient force to move the metal, but not enough to rupture it. Peening should be done while the metal is still above 1000 °F (540 °C). Peening is not recommended for root beads or weld beads at the weld face.

A6.1.9 The possibility of cracking makes it generally advisable in welding any sizable casting to employ studs that fasten the weld to the unaffected base metal below the weld interface. Studs are usually 1/4 to 5/8 in (6.4 to 16 mm) in diameter, projecting 3/16 to 1/4 in (4.8 to 6.4 mm) above the surface to be welded, and screwed or pressed in to a depth at least equal to their diameter. The cross-sectional area of the studs should be 25 to 35% of the area of the weld surface.

A6.2 Welding Considerations for Rods Classified as RCI and RCI-A

A6.2.1 The casting should be prepared as described in A6.1.1.

A6.2.2 Castings to be welded with a V-groove should have the edges beveled to form a 60 to 90 degree included angle. The groove should have a root face greater than zero, so that there is less difficulty in aligning the joint members and there is no melting through of the entire thickness.

A6.2.3 Next, the casting should be preheated as a whole, or locally in critical sections, if a closed or rigid construction is involved. Ideally, this involves preheating the entire casting to 800 to 1050 °F (430 to 566 °C), or in the case of alloy castings, as high as 1250 °F (677 °F). The preheating not only tends to equalize expansion and contraction stresses and ensure the machinability of the final weld, but also enables the weld to be made more rapidly. Such preheating preferably should be done in a charcoal fire or a furnace. In the case of small castings, however, preheating with a welding torch may be employed.

A6.2.4 A neutral oxyfuel gas flame is preferred for welding cast iron. Some authorities, however, recommended the occasional use of a reducing flame where decarburization is to be avoided. A flux is required. The purpose of the flux is to increase the fluidity of the iron silicate slag that forms on the weld pool.

A6.2.5 After the groove has been beveled and cleaned, and the casting preheated, the welding torch is directed over an area extending 1 in (25 mm) around the weld until the entire area is a dull red. Then the flame is directed at the bottom of the groove, keeping the tip of the cone 1/8 to 1/4 in (3.2 to 6.4 mm) from the metal, until a weld pool approximately 1 in (25 mm) long has been formed. The flame is then gradually moved from side to side until the groove faces begin to melt into the weld pool. The flame is directed on the rod, and filler metal is added to the weld pool. The groove faces are melted ahead of the advancing pool. The thickness of each layer of weld metal should not exceed 3/8 in (9.5 mm).

A6.2.6 In the case of rigid structures requiring extensive machining, it is advisable to stress relieve at the preheat temperature after welding. In any case, the casting should be allowed to cool slowly by furnace cooling, or by covering with, or immersion in, an insulating material such as dry sand.

A6.3 Welding Considerations for RCI-B Rods

A6.3.1 Preparation of castings for welding is similar to that called for in A6.2.1 and A6.2.2. Preheating should be uniform.

A6.3.2 The application of RCI-B welding rods is the same as that described for the other RCI filler metals. The weld zone can withstand higher residual stresses without cracking. However, it is advisable to apply slow cooling to prevent stress cracks in the base metal. It is recommended that residual stress be reduced by preheating castings uniformly to 1600 °F (870 °C), and providing slow furnace cooling by covering with, or immersion in, an insulating material such as dry sand. After such treatment, the castings will withstand exposure to considerable thermal expansion and will permit heavy machining.

A7. Description and Intended Use of Electrodes and Rods for Welding Cast Iron.

The following are guidelines for the application of welding rods and welding electrodes in conjunction with various types of cast iron. These guidelines are general and are subject to modification based on the experience of the welder and information supplied by the filler metal manufacturer. Only rods employed in conjunction with an oxyfuel gas heat source, and electrodes intended for the SMAW, GMAW, or FCAW processes are discussed. This limitation, defined in the scope, is not intended to deter a prospective user from considering other welding processes for which these filler metals might prove satisfactory.

A7.1 Cast Iron Welding Rods

A7.1.1 RCI (Cast Iron) Classification

A7.1.1.1 Ordinary machinable gray iron castings may vary from 20 to 40 ksi (140 to 280 MPa) tensile strength, and 150 to 250 Brinell hardness. The use of a gray iron welding rod for oxyfuel gas welding can produce a machinable weld metal of the same color, composition and structure as the base metal. The weld, if properly made, may be as strong as the original casting. See Table A1.

A7.1.1.2 RCI welding rods are used for filling in or building up new or worn castings, and for general fabrication, salvage and repair.

A7.1.2 RCI-A (Cast Iron) Classification

A7.1.2.1 This cast iron welding rod contains small amounts of molybdenum and nickel, which give it a slightly higher melting point than the ordinary cast iron welding rod, RCI. The molten weld metal is more fluid. Welding can be done more rapidly.

A7.1.2.2 The RCI-A welding rod (with a weld metal hardness of approximately 230 Brinell) may be used if an alloy cast iron is being welded, and when greater tensile strength and finer grain structure are desired. The weld metal is generally considered machinable.

A7.1.3 RCI-B (Nodular Cast Iron) Classification. These nodular (ductile) cast iron welding rods are capable of producing sound weld metal when used to weld higher-strength gray iron, malleable, and nodular iron castings with the oxyfuel gas process. Under optimum conditions, the welds produced have mechanical properties of 60 000 psi (410 MPa) minimum ultimate tensile strength; 45 000 psi (310 MPa) minimum yield strength; 5 to 15 percent elongation; and a maximum Brinell hardness of 200. These mechanical properties are due to the fact that most of the graphite content in the weld metal is in nodular form, which results in good ductility and machining properties for the weld. Color match to the base metal generally is good.

A7.2 Nickel-Base Electrodes for SMAW of Cast Irons. Arc welding with nickel-base covered electrodes is widely employed for welding cast iron. Weld metal made with these electrodes, even without preheating, usually can be machined (the heat affected zone may not be machinable). Welding is fairly rapid when compared to processes such as oxyfuel gas welding. Although welding in the flat position only is required in this specification, some electrodes may be capable of use in other positions. Tensile properties are not specified for the nickel base SMAW electrodes classified in this specification. The tensile and yield strengths may vary widely among manufacturers as shown in Table A1. The filler metal supplier or manufacturer should be contacted for product recommendations.

A7.2.1 ENi-CI (Nickel) Classification. This electrode can be used to join ordinary gray irons to themselves, or to other ferrous and nonferrous materials, and to reclaim or repair castings. Satisfactory welds can be produced on small and medium size castings where the welding stresses are not overly severe, or where the phosphorus content of the iron is not high. Because of lower strength than the ENiFe-CI and lower ductility of the weld metal, these electrodes should be used only in applications where maximum machinability of highly diluted filler metal is necessary. Otherwise, the ENiFe-CI classification is preferred. The ENi-CI classification may also be used on malleable or ductile iron.

A7.2.2 ENi-CI-A (Nickel) Classification. ENi-CI-A electrodes frequently are used interchangeably with ENi-CI electrodes. The covering of ENi-CI-A electrodes contains more aluminum to improve operating characteristics such as slag coverage and flowability. However, the aluminum becomes an alloy of the weld metal and may affect ductility.

A7.2.3 ENiFe-CI (Nickel-Iron) Classification. This electrode may be used for making repair welds on, as well as for joining, work pieces of various types of cast iron, including nodular iron, and for welding them to steel and some nonferrous base metals. Castings containing phosphorus levels higher than normal (approximately 0.20% phosphorus) are more readily welded using these electrodes than with an electrode of the ENi-CI classification. Experience has shown that satisfactory welds can be made on thick and highly restrained weldments, and on high-strength and engineering grades of cast iron.

A7.2.4 ENiFe-CI-A (Nickel-Iron) Classification. ENiFe-CI-A electrodes frequently are used interchangeably with ENiFe-CI electrodes. The covering of ENiFe-CI-A electrodes contains more aluminum to improve operating characteristics such as slag coverage and flowability. However, the aluminum becomes an alloy of the weld metal and may affect ductility.

A7.2.5 ENiFeMn-CI (Nickel-Iron-Manganese) Classification. This electrode has a nominal addition of 12% manganese to the nickel-iron system which improves the flow of the molten metal and somewhat increases the crack resistance of the weld metal. The manganese also increases the tensile strength and improves ductility, which provides properties closer to those of the higher strength grades of nodular cast iron base metals than can be achieved with the ENiFe-CI. ENiFeMn-CI electrodes are also used for surfacing to improve wear resistance or for buildup.

A7.2.6 ENiCu-A and ENiCu-B (Nickel-Copper) Classifications. These electrodes have been used in many of the same applications as the ENiFe-CI, ENiFe-CI-A, and ENiFeMn-CI electrodes. They are used to produce a low depth of fusion weld, since high dilution by the base metal may cause weld cracking.

A7.3 ESt (Steel) Classification for SMAW of Cast Iron

A7.3.1 This covered electrode for all welding positions is designed specifically for the welding of cast iron. It has a low-melting-point covering and differs from the ordinary mild steel electrodes included in ANSI/AWS A5.1, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*. Weld metal from this electrode is not readily machinable.

A7.3.2 Since it is virtually impossible to prevent the formation of a hard zone or layer in the weld metal because of dilution from the base metal, this type of electrode is largely confined to the repair of small pits and cracks, with some application in the repair of castings that require no postweld machining. Since the shrinkage of steel is greater than that of cast iron, high stresses develop as the weld cools. Residual stresses may be severe enough to cause cracking.

A7.3.3 Preheating is employed only when necessary to prevent excessive stresses in other parts of the casting. ESt electrodes generally are used at low amperage to minimize the dilution effect in the fusion zone and consequent weld and base metal cracking. The usual recommended amperages are 60 to 95 amps for 3/32 in (2.4 mm), 80 to 110 amps for 1/8 in (3.2 mm), and 110 to 150 amps for 5/32 in (4.0 mm) electrodes using deep (electrode positive) or ac. The beads should be short and widely separated, to distribute the heat, and each bead should be peened lightly. The slag volume is low but very alkaline. Residual slag should be removed completely if the weld area is to be painted.

A7.4 Nickel-Base Filler Metal for GMAW of Cast Iron. Only gas metal arc welding of classifications ERNiFeMn-CI and ERNi-CI are addressed by this specification. The requirements for rods for gas tungsten arc welding and other welding methods have not been included. Since these filler metals could be manufactured as rods, they have been assigned the "ER" designation.

A7.4.1 ERNiFeMn-CI (Nickel-Iron-Manganese) Classification. This solid continuous bare electrode can be used for the same applications as the ENiFeMn-CI covered SMAW electrode. The strength and ductility of this classification makes it suitable for welding the higher strength grades of nodular iron castings.

A7.4.2 ERNi-CI (Nickel) Classification. This solid continuous bare electrode is composed of essentially pure nickel (99%) and contains no deoxidizers. The electrode is used to weld iron castings when weld metal with highly diluted filler metal is to be machined.

A7.4.3 Shielding Gases. Shielding gases should be used as recommended by the manufacturer.

A7.5 Nickel-Base Electrode for FCAW of Cast Iron. The ENiFeT3-CI (nickel-iron electrode) is a continuous flux cored electrode that has been designed to operate without an external shielding gas. For this reason, it is commonly referred to as a self-shielded flux-cored electrode, but it may also be used with an external shielding gas if recommended by the manufacturer. The composition of this classification is similar to that of an ENiFe-CI except for a higher manganese content. It can be used in the same types of applications as the ENiFe-CI electrode. It is generally used for thick base metal or where processes can be automated. This electrode contains 3–5% manganese to aid in resisting weld metal hot cracking and to improve strength and ductility of the weld metal.

A7.6 In addition to the electrodes and rods classified in this specification, a number of copper-base welding rods frequently are used for braze welding cast iron. The lower temperatures associated with depositing these filler metals and their generally low strength and high ductility frequently offers advantages when welding cast iron. Copper-base welding electrodes and rods have been classified in other specifications and are listed in Table A2 for reference purposes.

Table A2
Copper-Base Welding Electrodes and Rods from
AWS Specifications Suitable for Welding Cast Irons

Classification	Type	Specification
Cast Filler Metals (OFW)		
RBCuZn-A	Naval brass	A5.27
RCuZn-B	Low fuming brass [Ni]	A5.27
RCuZn-C	Low fuming brass	A5.27
RBCuZn-D	Nickel brass	A5.27
Covered Electrodes (SMAW)		
ECuSn-A	Phosphor bronze	A5.6
ECuSn-C	Copper-tin	A5.6
ECuAl-A2	Copper-aluminum	A5.6

Note:

ANSI/AWS A5.6, Specification for Covered Copper and Copper Alloy Arc Welding Electrodes.

ANSI/AWS A5.27, Specification for Copper and Copper Alloy Rods for Oxyfuel Gas Welding.

A8. Postweld Heat Treatment

Postweld heat treatment may also be used to improve the machineability of the heat-affected zone adjacent to the weld metal. Tempering beads sometimes are employed to achieve the desired improvement. These beads, consisting entirely of filler metal and a previous bead, are made in such a manner that the heat input tempers any martensite present from a previous bead.

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered “yes” or “no”. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the Welding Journal, and post it on the AWS website.

B6. AWS Technical Committees

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

AWS Filler Metal Specifications by Material and Welding Process

	OFW	SMAW	GTAW GMAW PAW	FCAW	SAW	ESW	EGW	Brazing
Carbon Steel	A5.2	A5.1, A5.35	A5.18	A5.20	A5.17	A5.25	A5.26	A5.8, A5.31
Low-Alloy Steel	A5.2	A5.5	A5.28	A5.29	A5.23	A5.25	A5.26	A5.8, A5.31
Stainless Steel		A5.4, A5.35	A5.9, A5.22	A5.22	A5.9, A5.22, A5.39	A5.9, A5.22, A5.39	A5.9	A5.8, A5.31
Cast Iron	A5.15	A5.15	A5.15	A5.15				A5.8, A5.31
Nickel Alloys		A5.11, A5.35	A5.14, A5.34	A5.34	A5.14, A5.34, A5.39	A5.14, A5.34, A5.39		A5.8, A5.31
Aluminum Alloys		A5.3	A5.10					A5.8, A5.31
Copper Alloys		A5.6	A5.7					A5.8, A5.31
Titanium Alloys			A5.16					A5.8, A5.31
Zirconium Alloys			A5.24					A5.8, A5.31
Magnesium Alloys			A5.19					A5.8, A5.31
Tungsten Electrodes			A5.12					
Brazing Alloys and Fluxes								A5.8, A5.31
Surfacing Alloys	A5.21	A5.13	A5.21	A5.21	A5.21			
Consumable Inserts			A5.30					
Shielding Gases			A5.32	A5.32			A5.32	

AWS Filler Metal Specifications and Related Documents

Designation	Title
A4.2M (ISO 8249 MOD)	<i>Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal</i>
A4.3	<i>Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding</i>
A4.4M	<i>Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings</i>
A4.5M/A4.5 (ISO 15792-3 MOD)	<i>Standard Methods for Classification Testing of Positional Capacity and Root Penetration of Welding Consumables in a Fillet Weld</i>
A5.01M/A5.01 (ISO 14344 MOD)	<i>Welding and Brazing Consumables—Procurement of Filler Metals and Fluxes</i>
A5.02/A5.02M	<i>Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes</i>
A5.1/A5.1M	<i>Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding</i>
A5.2/A5.2M	<i>Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding</i>
A5.3/A5.3M	<i>Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.4/A5.4M	<i>Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding</i>
A5.5/A5.5M	<i>Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding</i>
A5.6/A5.6M	<i>Specification for Copper and Copper-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.7/A5.7M	<i>Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes</i>
A5.8M/A5.8	<i>Specification for Filler Metals for Brazing and Braze Welding</i>
A5.9/A5.9M (ISO 14343 MOD)	<i>Specification for Bare Stainless Steel Welding Electrodes and Rods</i>
A5.10/A5.10M (ISO 18273 MOD)	<i>Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods</i>
A5.11/A5.11M	<i>Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding</i>
A5.12M/A5.12 (ISO 6848 MOD)	<i>Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting</i>
A5.13/A5.13M	<i>Specification for Surfacing Electrodes for Shielded Metal Arc Welding</i>
A5.14/A5.14M	<i>Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods</i>
A5.15	<i>Specification for Welding Electrodes and Rods for Cast Iron</i>
A5.16/A5.16M (ISO 24034 MOD)	<i>Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods</i>
A5.17/A5.17M	<i>Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.18/A5.18M	<i>Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.19	<i>Specification for Magnesium-Alloy Welding Electrodes and Rods</i>
A5.20/A5.20M	<i>Specification for Carbon Steel Electrodes for Flux Cored Arc Welding</i>
A5.21/A5.21M	<i>Specification for Bare Electrodes and Rods for Surfacing</i>
A5.22/A5.22M	<i>Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods</i>
A5.23/A5.23M	<i>Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.24/A5.24M	<i>Specification for Zirconium and Zirconium-Alloy Welding Electrodes and Rods</i>
A5.25/A5.25M	<i>Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding</i>
A5.26/A5.26M	<i>Specification for Carbon and Low-Alloy Steel Electrodes for Electrode Gas Welding</i>
A5.28/A5.28M	<i>Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.29/A5.29M	<i>Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding</i>
A5.30/A5.30M	<i>Specification for Consumable Inserts</i>
A5.31M/A5.31	<i>Specification for Fluxes for Brazing and Braze Welding</i>
A5.32M/A5.32 (ISO 14175 MOD)	<i>Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes</i>
A5.34/A5.34M	<i>Specification for Nickel-Alloy Flux Cored and Metal Cored Welding Electrodes</i>
A5.35/A5.35M-AMD1	<i>Specification for Covered Electrodes for Underwater Wet Shielded Metal Arc Welding</i>
A5.39/A5.39M	<i>Specification for Stainless Steel and Nickel-Alloy Electrodes and Fluxes for Submerged Arc and Electroslag Welding</i>

SPECIFICATION FOR TITANIUM AND TITANIUM-ALLOY WELDING ELECTRODES AND RODS



SFA-5.16/SFA-5.16M



(Identical with AWS Specification A5.16/A5.16M:2023 (ISO 24034:2010 MOD). In case of dispute, the original AWS text applies.)

Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods

1. Scope

1.1 This specification specifies requirements for the classification of solid wire electrodes, solid wires and rods for fusion welding of titanium and titanium-alloys. The classification of the solid wires, cut lengths and spools of wire is based on their chemical composition. *In this standard, the word “titanium” is used for “titanium and titanium alloys.”*

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements may not be exact equivalents; therefore, each system must be used independently when referring to material properties. *The specification with the designation A5.16 uses U.S. Customary Units. The specification A5.16M uses SI Units. The latter are shown within brackets [] or in appropriate columns in tables.* Standard dimensions based on either system may be used for sizing of electrodes or packaging or both under A5.16 or A5.16M specifications.

1.3 Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. *Some safety and health information can be found in Annex Clauses A5 and A10.*

Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. Unless otherwise defined in this document, welding terms are as defined in AWS A3.0M/A3.0. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to or revisions of any of these publications do not apply.

2.1 American Welding Society (AWS) documents:

- (1) AWS A1.1, *Metric Practice Guide for the Welding Industry*
- (2) AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*
- (3) AWS A5.01M/A5.01 (ISO 14344 MOD), *Welding and Brazing Consumables – Procurement of Filler Metals and Fluxes*
- (4) AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*

2.2 American National Standards Institute (ANSI) document:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

2.3 ASTM International (ASTM) documents:

- (1) ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*
- (2) ASTM E539, *Standard Test Method for Analysis of Titanium Alloys by X-Ray Fluorescence Spectrometry*
- (3) ASTM E1409, *Standard Test Method for Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by Inert Gas Fusion Technique*
- (4) ASTM E1447, *Standard Test Method for Determination of Hydrogen in Titanium and Titanium Alloys by Inert Gas Fusion Thermal Conductivity/Infrared Detection Method*
- (5) ASTM E1941, *Standard Test Method for Determination of Carbon in Refractory and Reactive Metals and Their Alloys by Combustion Analysis*
- (6) ASTM E2371, *Standard Test Method for Analysis of Titanium and Titanium Alloys by Direct Current Plasma and Inductively Coupled Plasma Atomic Emission Spectrometry (Performance-Based Test Methodology)*
- (7) ASTM E2994, *Standard Test Method for Analysis of Titanium and Titanium Alloys by Spark Atomic Emission Spectrometry and Glow Discharge Atomic Emission Spectrometry (Performance-Based Method)*

2.4 International Organization for Standardization (ISO) document:

- (1) ISO 80000-1:2009, *Quantities and units — Part 1: General. Corrected by ISO 80000-1:2009/Cor 1:2011*

3. Classification

3.1 The electrodes and rods covered by this A5.16/A5.16M specification are classified using a system that is independent of U.S. Customary Units and the International System of Units (SI).

The composition requirements of electrodes and rods are the same.

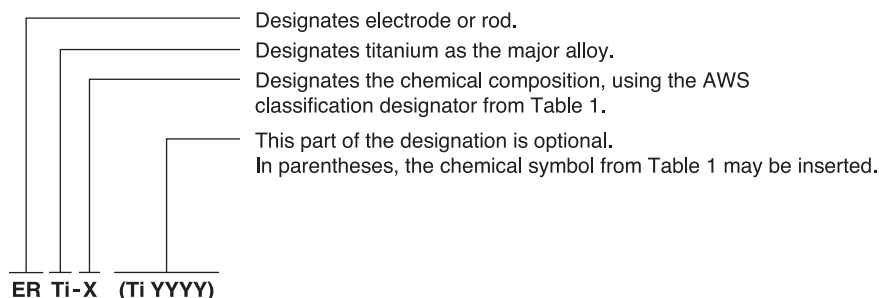
The welding consumables may be classified with a numerical designation, an AWS designation, or both. The numerical designation mimics that of ISO 24034.

3.1.1 AWS designation:

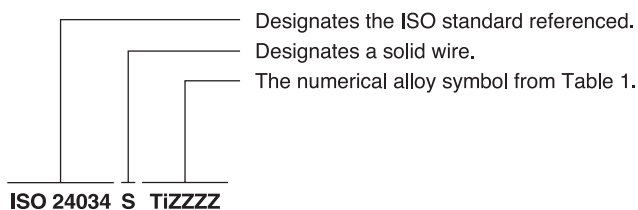
- (a) The first part indicates the product form. The symbol for electrodes and rods shall be ER.
- (b) The second part is a symbol for the main alloy type and shall be Ti.
- (c) The third part is a numerical symbol indicating chemical composition. See Table 1, Figure 1(a), and Clause 8.

3.1.2 Numerical designation:

- (a) The first part indicates the product form. The symbol for the electrodes and rods shall be S.
- (b) The second part is a numerical symbol indicating the chemical composition. See Table 1, Figure 1(b), and Clause 8.



(a)—AWS Classification System



(b)—ISO Classification System

Figure 1—Classification Systems

3.2 Electrodes and rods classified under one classification shall not be classified under any other classification in this specification. However, material may be classified under both A5.16 and A5.16M specifications and using both the numerical and the AWS designations.

3.3 The electrodes and rods classified under this specification are intended for GMAW, GTAW, EBW, LBW and PAW processes, but that is not to prohibit their use with any other process for which they are found suitable.

4. Acceptance

Acceptance of the electrodes and rods shall be in accordance with the provisions of AWS A5.01M/A5.01 and the tests and requirements of this specification. See A3 (in Annex A) for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

5. Certification

By affixing the AWS specification and classification designations to the packaging or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification. See A4 (in Annex A) for further information concerning certification and the testing called for to meet this requirement.

6. Rounding Procedure

For the purpose of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified

Table 1
Symbols for Chemical Composition and Composition Requirements

Alloy Symbols			Chemical Composition Requirements, % (by mass) ^{a,b,c,d}											
AWS A5.16/ A5.16M Classification	Numerical	Chemical	C	O	N	H	Fe	Al	V	Pd	Ru	Ni	Mo	Other
ERTi-1	Ti 0100	Ti99,8	0.03	0.03 to 0.10	0.012	0.005	0.08	—	—	—	—	—	—	—
ERTi-2	Ti 0120	Ti99,6	0.03	0.08 to 0.16	0.015	0.008	0.12	—	—	—	—	—	—	—
ERTi-3	Ti 0125	Ti99,5	0.03	0.13 to 0.20	0.02	0.008	0.16	—	—	—	—	—	—	—
ERTi-4	Ti 0130	Ti99,3	0.03	0.18 to 0.32	0.025	0.008	0.25	—	—	—	—	—	—	—
ERTi-5	Ti 6402	TiAl6V4B	0.05	0.12 to 0.20	0.030	0.015	0.22	5.50 to 6.75	3.50 to 4.50	—	—	—	—	—
ERTi-7	Ti 2401	TiPd0,2A	0.03	0.08 to 0.16	0.015	0.008	0.12	—	—	0.12 to 0.25	—	—	—	—
ERTi-9 ^e	Ti 6321	TiAl3V2,5A	0.03	0.06 to 0.12	0.012	0.005	0.20	2.5 to 3.5	2.0 to 3.0	—	—	—	—	—
ERTi-11	Ti 2251	TiPd0,2	0.03	0.03 to 0.10	0.012	0.005	0.08	—	—	0.12 to 0.25	—	—	—	—
ERTi-12	Ti 3401	TiNi0,7Mo0,3	0.03	0.08 to 0.16	0.015	0.008	0.15	—	—	—	—	0.6 to 0.9	0.2 to 0.4	—
ERTi-13	Ti 3423	TiNi0,5	0.03	0.03 to 0.10	0.012	0.005	0.08	—	—	—	0.04 to 0.06	0.4 to 0.6	—	—
ERTi-14	Ti 3424	TiNi0,5A	0.03	0.08 to 0.16	0.015	0.008	0.12	—	—	—	0.04 to 0.06	0.4 to 0.6	—	—
ERTi-15A	Ti 3416	TiRu0,05Ni0,5	0.03	0.13 to 0.20	0.02	0.008	0.16	—	—	—	0.04 to 0.06	0.4 to 0.6	—	—
ERTi-16	Ti 2403	TiPd0,06A	0.03	0.08 to 0.16	0.015	0.008	0.12	—	—	0.04 to 0.08	—	—	—	—
ERTi-17	Ti 2253	TiPd0,06	0.03	0.03 to 0.10	0.012	0.005	0.08	—	—	0.04 to 0.08	—	—	—	—
ERTi-18	Ti 6326	TiAl3V2,5Pd	0.03	0.06 to 0.12	0.012	0.005	0.20	2.5 to 3.5	2.0 to 3.0	0.04 to 0.08	—	—	—	—
ERTi-19	Ti 8641	TiV8Cr6Mo4Zr4Al3	0.03	0.06 to 0.10	0.015	0.015	0.20	3.0 to 4.0	7.5 to 8.5	—	—	3.5 to 4.5 Cr: 5.5 to 6.5 Zr: 3.5 to 4.5		

(Continued)

Table 1 (continued)
Symbols for Chemical Composition and Composition Requirements

Alloy Symbols			Chemical Composition Requirements, % (by mass) ^{a,b,c,d}											
AWS A5.16/ A5.16M Classification	Numerical	Chemical	C	O	N	H	Fe	Al	V	Pd	Ru	Ni	Mo	Other
ERTi-20	Ti 8646	TiV8Cr6Mo4Zr4Al3Pd	0.03	0.06 to 0.10	0.015	0.015	0.20	3.0 to 4.0	7.5 to 8.5	0.04 to 0.08	—	—	3.5 to 4.5	Cr: 5.5 to 6.5 Zr: 3.5 to 4.5
ERTi-21	Ti 8211	TiMo15Al3Nb3	0.03	0.10 to 0.15	0.012	0.005	0.20 to 0.40	2.5 to 3.5	—	—	—	—	14.0 to 16.0	Nb: 2.2 to 3.2 Si: 0.15 to 0.25
ERTi-23	Ti 6408	TiAl6V4A	0.03	0.03 to 0.11	0.012	0.005	0.20	5.5 to 6.5	3.5 to 4.5	—	—	—	—	—
ERTi-24	Ti 6415	TiAl6V4Pd	0.05	0.12 to 0.20	0.030	0.015	0.22	5.5 to 6.7	3.5 to 4.5	0.04 to 0.08	—	—	—	—
ERTi-25	Ti 6413	TiAl6V4Ni0,5Pd	0.05	0.12 to 0.20	0.030	0.015	0.22	5.5 to 6.7	3.5 to 4.5	0.04 to 0.08	—	0.3 to 0.8	—	—
ERTi-26	Ti 2405	TiRu0,1A	0.03	0.08 to 0.16	0.015	0.008	0.12	—	—	—	0.08 to 0.14	—	—	—
ERTi-27	Ti 2255	TiRu0,1	0.03	0.03 to 0.10	0.012	0.005	0.08	—	—	—	0.08 to 0.14	—	—	—
ERTi-28	Ti 6324	TiAl3V2,5Ru	0.03	0.06 to 0.12	0.012	0.005	0.20	2.5 to 3.5	2.0 to 3.0	—	0.08 to 0.14	—	—	—
ERTi-29	Ti 6414	TiAl6V4Ru	0.03	0.03 to 0.11	0.012	0.005	0.20	5.5 to 6.5	3.5 to 4.5	—	0.08 to 0.14	—	—	—
ERTi-30	Ti 3531	TiCo0,5	0.03	0.08 to 0.16	0.015	0.008	0.12	—	—	0.04 to 0.08	—	—	—	Co: 0.20 to 0.80
ERTi-31	Ti 3533	TiCo0,5A	0.03	0.13 to 0.20	0.02	0.008	0.16	—	—	0.04 to 0.08	—	—	—	Co: 0.20 to 0.80
ERTi-32	Ti 5112	TiAl5V1SnMo1Zr1	0.03	0.05 to 0.10	0.012	0.008	0.20	4.5 to 5.5	0.6 to 1.4	—	—	—	0.6 to 1.2	Zr: 0.6 to 1.4 Si: 0.06 to 0.14 Sn 0.6 to 1.4
ERTi-33	Ti 3443	TiNi0,45Cr0,15	0.03	0.08 to 0.16	0.015	0.008	0.12	—	—	0.01 to 0.02	0.02 to 0.04	0.35 to 0.55	—	Cr: 0.1 to 0.2

(Continued)

Table 1 (continued)
Symbols for Chemical Composition and Composition Requirements

Alloy Symbols			Chemical Composition Requirements, % (by mass) ^{a,b,c,d}											
AWS A5.16/ A5.16M Classification	Numerical	Chemical	C	O	N	H	Fe	Al	V	Pd	Ru	Ni	Mo	Other
ERTi-34	Ti 3444	TiNi0,45Cr0,15A	0.03	0.13 to 0.20	0.02	0.008	0.16	—	—	0.01 to 0.02	0.02 to 0.04	0.35 to 0.55	—	Cr: 0.1 to 0.2
ERTi-36	Ti 8451	TiNb45	0.03	0.06 to 0.12	0.02	0.0035	0.03	—	—	—	—	—	—	Nb: 42.0 to 47.0
ERTi-38	Ti 4251	TiAl4V2Fe	0.05	0.20 to 0.27	0.02	0.010	1.2 to 1.8	3.5 to 4.5	2.0 to 3.0	—	—	—	—	Sn: 0.6 to 1.4
ERTi-G	—	—	Not Specified. Chemical composition as agreed upon between supplier and user.											

^a Single values are maxima, unless otherwise noted.

^b The remainder of the alloy is titanium.

^c Analysis of Fe and the interstitial elements C, O, H, and N shall be conducted on samples of rod/wire taken after the rod/wire has been reduced to its final diameter and all processing operations have been completed. Analysis of the other elements may be conducted on these same samples or it may have been conducted on samples taken from the ingot or the rod stock from which the rod/wire is made. In case of dispute, samples from the finished rod/wire shall be the referee method.

^d Any element intentionally added (O, Fe, N, and C) shall be measured and reported. Residual elements, total, shall not exceed 0.20 percent, with no single element exceeding 0.05 percent, except for yttrium, which shall not exceed 0.005 percent. Residual elements need not be reported unless specifically required by the purchaser. A residual element is any element present in the metal in small quantities that is inherent in the sponge or scrap additions, but not intentionally added. In titanium these elements include, among others, aluminum, vanadium, tin, chromium, molybdenum, niobium, zirconium, hafnium, bismuth, ruthenium, palladium, yttrium, copper, silicon, and cobalt.

^e Formerly ERTi-9 ELI

Note: Corresponding national classifications are shown in Annex B.

limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfill the requirements for the classification under test.

7. Mechanical Properties

Mechanical properties of weld metal or welded joints are not part of this classification.

8. Chemical Analysis

Chemical analysis shall be performed on specimens of the product or the stock from which it is made with the following stipulations. Analysis of Fe and the interstitial elements C, O, H, and N shall be conducted on samples of filler metal taken after it has been reduced to its final diameter and all processing operations have been completed. Analysis of the other elements may be conducted on these same samples, or it may be conducted on samples taken from the ingot or the rod stock from which the filler metal is made. In case of dispute, samples from the finished rod/wire shall be the referee method. Any element intentionally added (O, Fe, N, and C) shall be measured and reported. Residual elements, total, shall not exceed 0.20 percent, with no single element exceeding 0.05 percent, except for yttrium, which shall not exceed 0.005 percent. Residual elements need not be reported unless specifically required by the purchaser. A residual element is any element present in the metal in small quantities that is inherent in the sponge or scrap additions, but not intentionally added. In titanium these elements include, among others, aluminum, vanadium, tin, chromium, molybdenum, niobium, zirconium, hafnium, bismuth, ruthenium, palladium, yttrium, copper, silicon, and cobalt. Carbon shall be determined in accordance with ASTM E1941, hydrogen in accordance with ASTM E1447, oxygen and nitrogen in accordance with ASTM E1409, and other elements in accordance with ASTM E539, ASTM E2371, or ASTM E2994. Other analytical methods may be used if acceptable to the purchaser.

9. Retest

If any test fails to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Specimens for retest may be taken from the original test sample or from a new test sample *taken from the same heat and lot of material as the original sample*. For chemical analysis, retest need be only for those specific elements that failed to meet their test requirement. If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that during preparation or after completion of any test it is clearly determined that prescribed or proper procedures were not followed in preparing the weld test sample or test specimen(s) or in conducting the tests, the test shall be considered invalid without regard to whether the test was actually completed or whether the test results met or failed to meet the requirement. That test shall be repeated, following proper prescribed procedures. In this case, the requirement for doubling the number of test specimens does not apply. *For any sample that is invalidated, a new sample shall be cut from the same heat and lot of wire and tested for all original elements.*

10. Standard Sizes

10.1 *Standard sizes for electrodes and rods in the different package forms (straight lengths, coils, spools and drums) are as specified in AWS A5.02/A5.02M.*

11. Finish and Uniformity

11.1 *Finish and uniformity shall be as specified in AWS A5.02/A5.02M.*

12. *Standard Package Forms*

12.1 *Standard package forms are straight lengths, coils with support, coils without support, spools, and drums. Standard package dimensions and other requirements for each form shall be as specified in AWS A5.02/A5.02M. Package forms, sizes, and weights other than these shall be as agreed upon between purchaser and supplier.*

13. *Winding Requirements*

13.1 *Winding requirements shall be as specified in AWS A5.02/A5.02M.*

13.2 *The cast and helix of filler metal shall be as specified in AWS A5.02/A5.02M.*

14. *Filler Metal Identification*

14.1 *Filler metal identification, including marking of bare straight lengths of filler rod, product information and precautionary information shall be as specified in AWS A5.02/A5.02M.*

15. *Packaging*

Electrodes and rods shall be suitably packaged to prevent damage during shipment and storage under normal conditions.

16. *Marking of Packages*

16.1 *The product information (as a minimum) that shall be legibly marked and visible from the outside of each unit package shall be as specified in AWS A5.02/A5.02M.*

16.2 *The appropriate precautionary information as given in ANSI Z49.1, (as a minimum) or its equivalent, shall be prominently displayed in legible print on all packages of electrodes and rods, including individual unit packages enclosed within a larger package. Typical examples of "warning labels" and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.*

Annex A (Informative)

Guide to AWS Specification for Titanium and Titanium–Alloy Welding Electrodes and Rods

This annex is not part of this standard but is included for informational purposes only.

A1. Introduction

The purpose of this guide is to correlate the electrode classifications with their intended applications so the specification can be used effectively.

A2. Classification System

A2.1 *The system for identifying the electrode and rod classifications in this specification follows the standard pattern used in other AWS filler metal specifications. The prefix letter ER at the beginning of each classification designation stands for electrode and rod. The numbering designation Ti-xx is based on historical AWS designations. The four digit numerical symbols for chemical composition are taken from the last four digits of the UNS (metals and alloys in the Unified Numbering System, SAE HS-1086/ASTM DS-56J) designations for the alloy compositions. The first two digits indicate the general alloy group. The UNS number is the numerical designations preceded by a R5 (e.g. R52251, R50100, etc.) The last two digits indicate modifications of the basic alloy within the group. See Figure 1 for details.*

A2.2 “G” Classification

A2.2.1 *This specification includes filler metals classified as ERTi-G. The “G” indicates that the filler metal is of a general classification. It is general because not all the particular requirements specified for each of the other classifications are specified for this classification. The intent in establishing this classification is to provide a means by which filler metals that differ in one respect or another (chemical composition, in this case) from all other classifications (meaning that the composition of the filler metal does not meet the composition specified for any of the classifications in the specification) can still be classified according to the specification. The purpose is to allow a useful filler metal – one that otherwise would have to await a revision of the specification—to be classified immediately, under the existing specification. This means that two filler metals – each bearing the same “G” classification—may be quite different in chemical composition.*

A2.2.2 *The point of difference between filler metal of a “G” classification and filler metal of a similar classification without the “G” (or even with it, for that matter) may be further clarified from the use of the words “not required” and “not specified” in the specification. The use of these words is as follows:*

Not Required is used in those areas of the specification that specify the tests that must be conducted in order to classify a filler metal. It indicates that that test is not required because the results for the particular test are not a requirement for that particular classification. When a test is “not required,” it is not necessary to conduct the corresponding test in order to classify a filler metal to that classification. When a purchaser wants the information provided by that test in order to consider a particular product of that classification for a certain application, the purchaser will have to arrange for that information with the supplier of the product. The purchaser will have to establish with that supplier just what the testing procedure and the acceptance requirements are to be for that test. The purchaser may want to incorporate that information (via AWS A5.01M/A5.01) in the purchase order.

Not Specified is used in those areas of the specification that refer to the results of some particular test. It indicates that the requirements for that test are not specified for that particular classification. If the required results from a specific test are listed as "not specified" but the test in question is shown as "required" then the test results must be reported.

A2.2.3 Request for Filler Metal Classification

When a filler metal cannot be classified other than as a "G" classification, a manufacturer may request that a new classification be established. The manufacturer shall do this using the following procedure;

(1) A request to establish a new classification must be submitted in writing. The request needs to provide sufficient detail to permit the Committee on Filler Metals and Allied Materials and the relevant Subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

- (a) A declaration that the new classification will be offered for sale commercially.
- (b) All classification requirements as given for existing classifications, such as chemical composition ranges, mechanical property requirements, and usability test requirements.
- (c) Any conditions for conducting the tests used to demonstrate that the filler metal meets the classification requirements. (It would be sufficient, for example, to state that welding conditions are the same as for other classifications.)
- (d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the Annex).
- (e) Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided.
- (f) A request for a new classification without the above information will be considered incomplete. The Secretary will return the request to the requester for further information.

(2) In order to comply with the AWS Policy on Patented Items, Trademarks, and Restraint of Trade, if the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester shall disclose this. In these cases, the patent holder must allow the use of this technology, such as by license. The Secretary will provide examples of acceptable wording to the patent holder, as required.

(3) The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters for processing.

A3. Acceptance

Acceptance of all filler metal classified under this specification is in accordance with AWS A5.01M/A5.01 and the tests and requirements of this specification. Any testing a purchaser requires of the supplier for filler metal shipped in accordance with this specification shall be clearly stated in the purchase order. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing the supplier normally conducts on filler metal of that classification, as specified in Schedule F of AWS A5.01M/A5.01, Table 1. Testing in accordance with any other Schedule must be specifically required by the purchase order. In such cases, acceptance of the material shipped shall be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product or of placing the classification on the product itself constitutes the supplier's (manufacturer's) certification that the product meets all the requirements of the specification.

The only testing requirement implicit in this certification is that the manufacturer has conducted the tests required by the specification on material that is representative of that being shipped and that the material met the requirements of the specification. Certification is not to be construed to mean that tests of any kind were necessarily conducted on samples

of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the *certification* required by the specification is the classification test of *representative material* cited above and the Manufacturer's Quality Assurance Program in AWS A5.01M/A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes to which welders and welding operators are exposed during welding:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling).
- (2) Number of welders and welding operators working in that space.
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes used.
- (4) The proximity of the welders or welding operators to the fumes as the fumes issue from the welding zone, and to the gases and dusts in the space in which they are working.
- (5) The ventilation provided to the space in which the welding is done.

A5.2 American National Standard Z49.1, *Safety in Welding, Cutting, and Allied Processes*, discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the Clause on Ventilation in that document. See also AWS F3.2M/F3.2, *Ventilation Guide for Welding Fume*, for more detailed descriptions of ventilation options.

A6. Welding Considerations

A6.1 Titanium and titanium-alloys can be welded by gas tungsten arc, gas metal arc, plasma arc, laser beam, and electron beam welding processes. Titanium is a reactive metal and is sensitive to embrittlement by oxygen, nitrogen, and hydrogen, at elevated temperatures. Consequently, the metal must be protected from atmospheric contamination. This can be provided by shielding the metal with welding grade inert gas as specified in AWS A5.32M/A5.32 (ISO 14175 MOD), *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes*, for classes AWS A5.32-I1 or AWS A5.32-I2 or having mixtures of these single shielding gas classes surrounding the arc and molten or just solidified but still hot weld metal. Welding can also be done remotely in a chamber or in a glove bag. These chambers can be purged of air and back filled with inert gas, or, if they are rigid gas tight walls, can be evacuated to at least 10^{-4} torr [0.013 Pa] to remove any air contaminants.

During arc welding, the titanium should be shielded from the ambient air atmosphere until it has cooled below about 800 °F [430 °C]. Adequate protection by auxiliary inert gas shielding can be provided when welding is being performed in an ambient air atmosphere. Ventilation and exhaust at the arc must be carried out in such a manner that the protective inert gas shielding (arc shielding, trailing shielding, or root shielding) is not impaired.

A6.2 The titanium metal should be free of thick oxide and chemically clean prior to welding, as contamination from oxide, water, grease, or dirt will also cause embrittlement.

A6.3 Titanium welding rods should be chemically clean and free of heavy oxide, absorbed moisture, grease, and dirt. If the hot end of the filler metal is removed from the gas shield prior to cooling and then reused, it contributes to weld contamination. Welding rod should be added by a technique that keeps the hot end within the torch gas blanket. If the rod tip becomes contaminated, the discolored end should be cut off before reusing.

A7. Description and Intended Use of Titanium Filler Metal

A7.1 Titanium-alloys can exist at room temperature as hexagonal close-packed crystal structure (alpha alloys), body-centered cubic crystal structure (beta alloys), or a mixture of the two crystal structures. Pure titanium exists at room temperature as the alpha crystal structure. Addition of alloying elements can change the room temperature structure to traces of beta in alpha (often termed "near-alpha" alloys) or part beta (termed "alpha + beta" alloys), depending upon the

alloy elements and amounts added. Aluminum and tin act to stabilize alpha, while vanadium, molybdenum, chromium, and copper act to stabilize beta.

NOTE: All percentages mentioned in this annex are “by mass.”

A7.2 Alloy Group 01 Alloy group 01 (alloys 0100, 0120, 0125, and 0130) consists of commercially pure titanium. The alloys differ only in respect to their oxygen content. In general, higher oxygen results in higher strength, 80 ksi [550 MPa] (for alloy 0130) instead of 62 ksi [425 MPa] (for alloy 0100), but lower ductility. These are alpha alloys.

A7.3 Alloy Group 22 Alloy group 22 (alloys 2251, 2253, and 2255) consists of low oxygen titanium with small amounts of palladium or ruthenium deliberately added. Palladium and ruthenium enhance the corrosion resistance of titanium in reducing acid media, crevice corrosion situations, and hot oxidizing chloride brines. These are alpha alloys.

A7.4 Alloy Group 24 Alloy group 24 (alloys 2401, 2403, and 2405), like Group 22, has small amounts of palladium and ruthenium deliberately added but consists of higher oxygen content giving higher strength. These are alpha alloys.

A7.5 Alloy Group 34 Alloy group 34 (alloys 3401, 3416, 3423, 3424, 3443, and 3444) contains about 0.5% Ni as a deliberate alloying element. Nickel enhances the corrosion resistance of titanium in reducing acid media, crevice corrosion situations, and hot oxidizing chloride brines. These are alpha alloys.

A7.6 Alloy Group 35 Alloy group 35 (alloys 3531 and 3533) contains about 0.5% Co as a deliberate alloying addition. Cobalt enhances the corrosion resistance of titanium in reducing acid media, crevice corrosion situations, and hot oxidizing chloride brines. These are alpha alloys.

A7.7 Alloy Group 42 Alloy group 42 (alloy 4251) contains about 4% aluminum, 2.5% vanadium, and 1.5% iron. This is an alpha + beta alloy, having an ultimate tensile strength of around 130 ksi [896 MPa].

A7.8 Alloy Group 51 Alloy group 51 (alloy 5112) contains about 5% aluminum, 1% molybdenum, 0.2% silicon, 1% tin, 1% vanadium, and 1% zirconium. This is an alpha + beta alloy, having an ultimate tensile strength of around 123 ksi [850 MPa].

A7.9 Alloy Group 63 Alloy group 63 (alloys 6321, 6324, and 6326) contains about 3% aluminum and 2.5% vanadium. These are alpha + beta alloys, having an ultimate tensile strength of around 102 ksi [700 MPa].

A7.10 Alloy Group 64 Alloy group 64 (alloys 6402, 6408, 6413, 6414, and 6415) contains about 6% aluminum and 4% vanadium. These are alpha + beta alloys, having an ultimate tensile strength of around 145 ksi [1,000 MPa].

A7.11 Alloy Group 82 Alloy group 82 (alloy 8211) contains about 15% molybdenum, 3% aluminum, 2.7% niobium, and 0.25% silicon. This is a weldable and heat treatable beta alloy, having an ultimate tensile strength of around 115 ksi [793 MPa].

A7.12 Alloy Group 84 Alloy group 84 (alloy 8451) contains 42% to 47% niobium. This is an alpha + beta alloy, having an ultimate tensile strength of around 65 ksi [448 MPa]. It has unique shape memory properties.

A7.13 Alloy Group 86 Alloys in group 86 (alloys 8641 and 8646) contain about 3% aluminum, 8% vanadium, 6% chromium, 4% zirconium, and 4% molybdenum. This is a weldable and heat treatable beta alloy, having an ultimate tensile strength of around 115 ksi [793 MPa]. Alloy 8646 includes 0.04% to 0.08% palladium for improved corrosion resistance.

A8. Discontinued Classifications

Some classifications have been discontinued from one revision of this specification to another. This resulted from either changes in commercial practice or changes in the classification system used in the specification. The discontinued classifications are listed in Table A.1, along with the year last included in the specification.

A9. Special Tests

It is recognized that for certain applications, supplementary tests may be required. In such cases, additional tests to determine specific properties, such as corrosion-resistance, scale-resistance, or strength at elevated temperatures may be

Table A.1
Discontinued Titanium Filler Metal Classifications

AWS Classification	Last Year Published
ERTi-6	1990
ERTi-6ELI	1990
ERTi-15	1990
ERTi-8Al-2Cb-1Ta-1Mo-1V	1970
ERTi-8Al-1Mo-1V	1970
ERTi-13V-11Cr-3Al	1970

required. AWS A5.01M/A5.01 (ISO 14344 MOD) provides a means by which such tests can be incorporated into the purchase order. This section is included for the guidance of those who desire to specify such special tests. Those tests may be conducted as agreed by supplier and purchaser.

A10. General Safety Considerations

A10.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Annex Clause A5. Safety and health information is available from other sources, including, but not limited to Safety and Health Fact Sheets, ANSI Z49.1, *Safety in Welding, Cutting and Allied Processes*, and applicable federal and state regulations.

A10.2 Safety and Health Fact Sheets. The Safety and Health Fact Sheets are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised, and additional sheets added periodically.

Annex B (Informative)

Corresponding National Classifications

This annex is not part of this standard but is included for informational purposes only.

ASMENORMDOC.COM : Click to view the full PDF of ASME BPVC.II.C (ASME BPVC Section II part C) 2025

Table B.1
Corresponding National Classifications

Alloy Symbols										
AWS A5.16/A5.16M:2023 (ISO 24034:2010 MOD)		USA							Japan	Germany
Numerical	Chemical	AWS A5.16/ A5.16M:2023	AWS A5.16/ A5.16M:2013	AWS A5.16/ A5.16M:2007	AWS A5.16/ A5.16M:2004	ANSI/AWS A5.16-90	AWS A5.16-70	Aerospace Materials	JIS Z3331:2011 ^a	DIN 1737- 1:1984
Ti 0100	Ti99,8	ERTi-1	ERTi-1	ERTi-1	ERTi-1	ERTi-1	ERTi-1	—	STi 0100 STi 0100J	3.7026
Ti 0120	Ti99,6	ERTi-2	ERTi-2	ERTi-2	ERTi-2	ERTi-2	ERTi-2	—	STi 0120 STi 0120J	—
Ti 0125	Ti99,5	ERTi-3	ERTi-3	ERTi-3	ERTi-3	ERTi-3	ERTi-3	AMS 4951	STi 0125 STi 0125J	—
Ti 0130	Ti99,3	ERTi-4	ERTi-4	ERTi-4	ERTi-4	ERTi-4	ERTi-4	—	STi 0130 STi 0130J	3.7036
Ti 2251	TiPd0,2	ERTi-11	ERTi-11	ERTi-11	ERTi-11	—	—	—	STi 2251 STi 2251J	3.7226
Ti 2253	TiPd0,06	ERTi-17	ERTi-17	ERTi-17	ERTi-17	—	—	—	STi 2253	—
Ti 2255	TiRu0,1	ERTi-27	ERTi-27	ERTi-27	ERTi-27	—	—	—	STi 2255	—
Ti 2401	TiPd0,2A	ERTi-7	ERTi-7	ERTi-7	ERTi-7	ERTi-7	ERTi-0.2Pd	—	STi 2401 STi 2401J	3.7236
Ti 2403	TiPd0.06A	ERTi-16	ERTi-16	ERTi-16	ERTi-16	—	—	—	STi 2403	—
Ti 2405	TiRu0,1A	ERTi-26	ERTi-26	ERTi-26	ERTi-26	—	—	—	STi 2405	—
Ti 3401	TiNi0,7Mo0,3	ERTi-12	ERTi-12	ERTi-12	ERTi-12	ERTi-12	—	—	STi 3401	—
Ti 3416	TiRu0,05Ni0,05	ERTi-15A	ERTi-15A	ERTi-15A	ERTi-15A	—	—	—	STi 3416	—
Ti 3423	TiNi0,5	ERTi-13	ERTi-13	ERTi-13	ERTi-13	—	—	—	STi 3423	—
Ti 3424	TiNi0,5A	ERTi-14	ERTi-14	ERTi-14	ERTi-14	—	—	—	STi 3424	—
Ti 3443	TiNi0,45Cr0,15	ERTi-33	ERTi-33	ERTi-33	ERTi-33	—	—	—	STi 3443	—
Ti 3444	TiNi0,45Cr0,15A	ERTi-34	ERTi-34	ERTi-34	ERTi-34	—	—	—	STi 3444	—
Ti 3531	TiCo0,5	ERTi-30	ERTi-30	ERTi-30	ERTi-30	—	—	—	STi 3531	—
Ti 3533	TiCo0,5A	ERTi-31	ERTi-31	ERTi-31	ERTi-31	—	—	—	STi 3533	—
Ti 4251	TiAl4V2.5	ERTi-38	ERTi-38	ERTi-38	—	—	—	—	—	—
Ti 5112	TiAl5V1Sn1Mo1Zr1	ERTi-32	ERTi-32	ERTi-32	ERTi-32	—	—	—	STi 5112	—

(Continued)

Table B.1 (continued)
Corresponding National Classifications

Alloy Symbols										
AWS A5.16/A5.16M:2023 (ISO 24034:2010 MOD)		USA						Aerospace Materials	Japan	Germany
Numerical	Chemical	AWS A5.16/ A5.16M:2023	AWS A5.16/ A5.16M:2013	AWS A5.16/ A5.16M:2007	AWS A5.16/ A5.16M:2004	ANSI/AWS A5.16-90	AWS A5.16-70		JIS Z3331:2011 ^a	DIN 1737- 1:1984
Ti 6321	TiAl3V2,5A	ERTi-9	ERTi-9	ERTi-9ELI	ERTi-9ELI	ERTi-9ELI	ErTi-3AL- 2.5V-1	—	STi 6321 STi 6321J	—
Ti 6324	TiAl3V2,5Ru	ERTi-28	ERTi-28	ERTi-28	ERTi-28	—	—	—	STi 6324	—
Ti 6326	TiAl3V2,5Pd	ERTi-18	ERTi-18	ERTi-18	ERTi-18	—	—	—	STi 6326	—
Ti 6400	TiAl6V4	—	—	—	—	—	—	—	STi 6400 STi 6400J	—
Ti 6402	TiAl6V4B	ERTi-5	ERTi-5	ERTi-5	ERTi-5	ERTi-5	ERTi-6Al-4V	AMS 4954	STi 6402	—
Ti 6408	TiAl6V4A	ERTi-23	ERTi-23	ERTi-23	ERTi-23	ERTi-5ELI	ERTi-6Al-4V-1	AMS 4956	STi 6408 STi 6408J	—
Ti 6413	TiAl6V4Ni0,5Pd	ERTi-25	ERTi-25	ERTi-25	ERTi-25	—	—	—	STi 6413	—
Ti 6114	TiAl6V4Ru	ERTi-29	ERTi-29	ERTi-29	ERTi-29	—	—	—	STi 6114	—
Ti 6415	TiAl6V4Pd	ERTi-24	ERTi-24	ERTi-24	ERTi-24	—	—	—	STi 6415	—
Ti 8211	TiMo15Al3Nb3	ERTi-21	ERTi-21	ERTi-21	—	—	—	—	—	—
Ti 8451	TiNb45	ERTi-36	ERTi-36	ERTi-36	—	—	—	—	—	—
Ti 8641	TiV8Cr6Mo4Zr4Al3	ERTi-19	ERTi-19	ERTi-19	—	—	—	—	—	—
Ti 8646	TiV8Cr6Mo4Zr4Al3Pd	ERTi-20	ERTi-20	ERTi-20	—	—	—	—	—	—

^a “J” designates alloys that consist of Japanese original range of chemical composition.

Annex C (Informative)

Informative References

This annex is not part of this standard but is included for informational purposes only.

AWS A5.32M/A5.32 (ISO 14175 MOD), *Welding Consumables -Gases and Gas Mixtures for Fusion Welding and Allied Processes*

AWS G2.4/G2.4M, *Guide for the Fusion Welding of Titanium and Titanium Alloys*

AMS 4951, *Titanium welding wire commercially pure environment controlled packaging*

AMS 4952, *Titanium alloy, welding wire, 6Al – 2Sn – 4Zr – 2Mo*

AMS 4954, *Titanium alloy, welding wire, 6Al – 4V*

AMS 4955, *Titanium alloy, welding wire, 8Al – 1Mo – 1V*

AMS 4956, *Titanium alloy welding wire, 6Al – 4V, extra low interstitials environment controlled packaging*

JIS Z3331, *Titanium and titanium alloy welding rods and solid wires*

Annex D (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

D1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

D2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

D3. General Procedure for all Requests

D3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36th Street # 130
Miami, FL 33166

D3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

D3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

D3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

D3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

D3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

D4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

D5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

D6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

Annex E (Informative)

List of Deviations from ISO 24034:2010

This annex is not part of this standard but is included for informational purposes only.

Numerous editorial changes to wording, layout and format have been made to this standard to comply with the current requirements of the AWS A5 Committee on Filler Metals and Allied Materials. These changes will not affect the classification of gases or gas mixtures. Some of the more significant of these are shown below.

Some substantive changes were made to this document that may influence the classification of gases or gas mixtures. These are shown below.

Editorial Changes:

ISO uses comma (,) for decimal, but AWS uses period (.) for decimal. Decimal commas have been changed to decimal periods.

Editorial rewording and numbering of clauses, table and figures in this document were modified or added to comply with AWS standards.

Substantive Changes:

A designator ERTi-G was added for nonlisted compositions, as is the norm in AWS standards.

Rules for Acceptance and Certification have been added, as is the norm in AWS standards.

INTENTIONALLY LEFT BLANK

SPECIFICATION FOR CARBON STEEL ELECTRODES AND FLUXES FOR SUBMERGED ARC WELDING



SFA-5.17/SFA-5.17M



(Identical with AWS Specification AWS A5.17/A5.17M:2019. In case of dispute, the original AWS text applies.)

Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding

1. Scope

1.1 This specification prescribes requirements for the classification of carbon steel electrodes (both solid and composite) and flux-electrode combinations for submerged arc welding. Two-run flux-electrode classification is not addressed in this specification, but is addressed in AWS A5.23/A5.23M.

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to weld metal properties. The specification with the designation A5.17 uses U.S. Customary Units. The specification A5.17M uses SI units. The latter are shown within brackets [], in appropriate columns in tables and figures and in paragraphs numbered with an “M” suffix. Standard dimensions based on either system may be used for the sizing of electrodes, packaging or both under A5.17 or A5.17M specifications.

1.3 Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in Annex A, Clauses A5 and A9. Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to or revisions of any of these publications do not apply.

2.1 American Welding Society (AWS) Documents:

- (1) AWS A1.1, *Metric Practice Guide for the Welding Industry*
- (2) AWS A4.3, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*

- (3) AWS A5.01M/A5.01, *Welding Consumables—Procurement of Filler Metals and Fluxes*
- (4) AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*
- (5) AWS B4.0, *Standard Methods for Mechanical Testing of Welds*
- (6) AWS B4.0M, *Standard Methods for Mechanical Testing of Welds*

2.2 American National Standards Institute (ANSI) Document:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*.

2.3 ASTM International (ASTM) Documents:

- (1) ASTM A29/A29M, *Specification for Steel Bars, Carbon and Alloy, Hot-Wrought and Cold-Finished*
- (2) ASTM A36/A36M, *Specification for Carbon Structural Steel*
- (3) ASTM A285/A285M, *Specification for Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength*
- (4) ASTM A515/A515M, *Specification for Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service*
- (5) ASTM A516/A516M, *Specification for Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service*
- (6) ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*
- (7) ASTM E350, *Standard Test Methods for Chemical Analysis of Carbon Steel, Low Alloy Steel, Silicon Electrical Steel, Ingot Iron and Wrought Iron*
- (8) ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*
- (9) ASTM E2033, *Standard Practice for Computed Radiology (Photostimulable Luminescence Method)*
- (10) ASTM E2698, *Standard Practice for Radiological Examination Using Digital Detector Arrays*

2.4 International Organization for Standardization (ISO) Document:

- (1) ISO 80000-1, *Quantities and Units — Part 1 General*

3. Classification

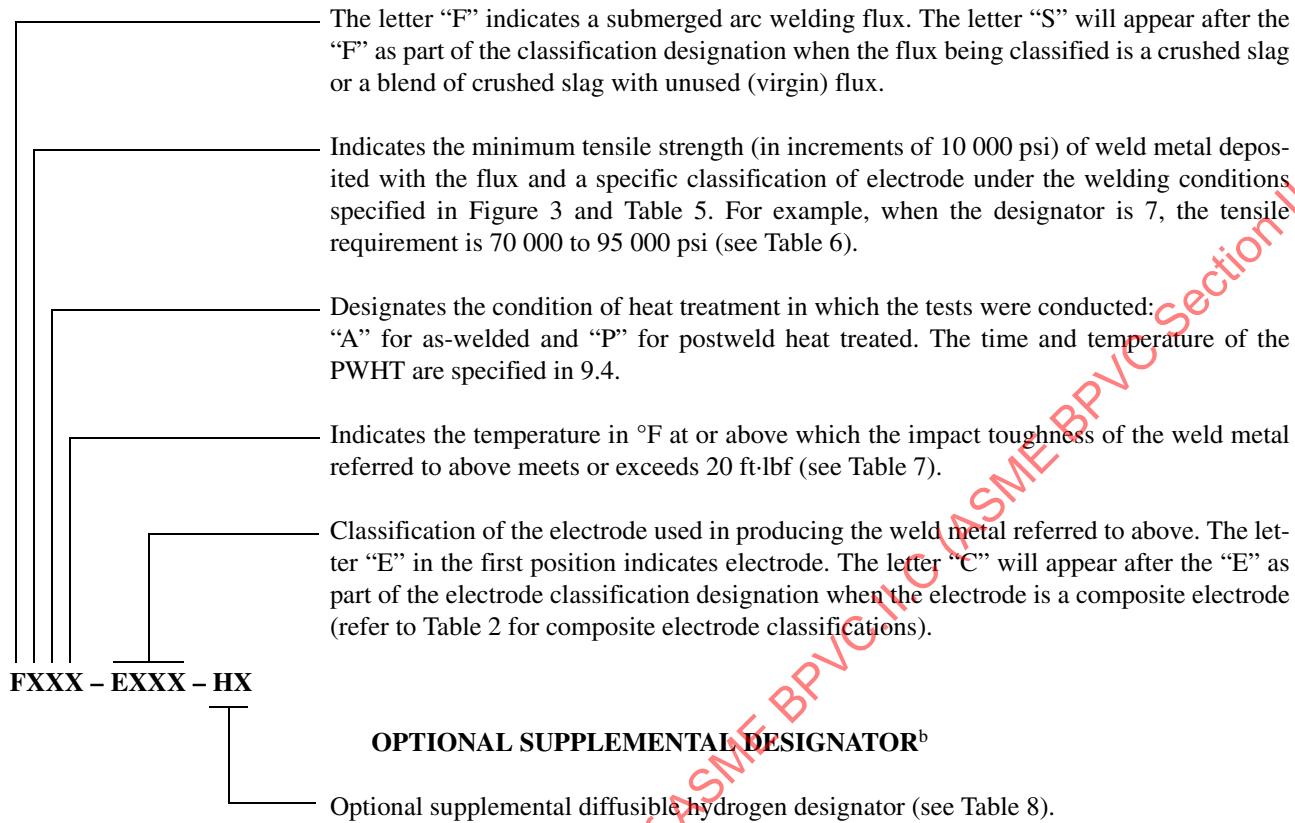
3.1 The submerged arc welding electrodes and fluxes covered by this A5.17 specification utilize a classification system based upon U.S. Customary Units and are classified according to the following:

- (1) The mechanical properties of the weld metal obtained from a multiple pass groove weld made with a combination of a particular flux and a particular classification of electrode, as specified in Tables 6 and 7.
- (2) The condition of heat treatment in which the properties are obtained, as specified in 9.4 and as shown in Figure 1.
- (3) The chemical composition of the electrode (for solid electrodes) as specified in Table 1, or the weld metal produced with a particular flux (for composite electrodes) as specified in Table 2.

3.1M The submerged arc welding electrodes and fluxes covered by this A5.17M specification utilize a classification system based upon the International System of Units (SI) and are classified according to the following:

- (1) The mechanical properties of the weld metal obtained from a multiple pass groove weld made with a combination of a particular flux and a particular classification of electrode, as specified in Tables 6M and 7.
- (2) The condition of heat treatment in which the properties are obtained, as specified in 9.4 and as shown in Figure 1M.
- (3) The chemical composition of the electrode (for solid electrodes) as specified in Table 1, or the weld metal produced with a particular flux (for composite electrodes) as specified in Table 2.

MANDATORY CLASSIFICATION DESIGNATORS^a



^a The combination of these designators constitutes the flux-electrode classification.

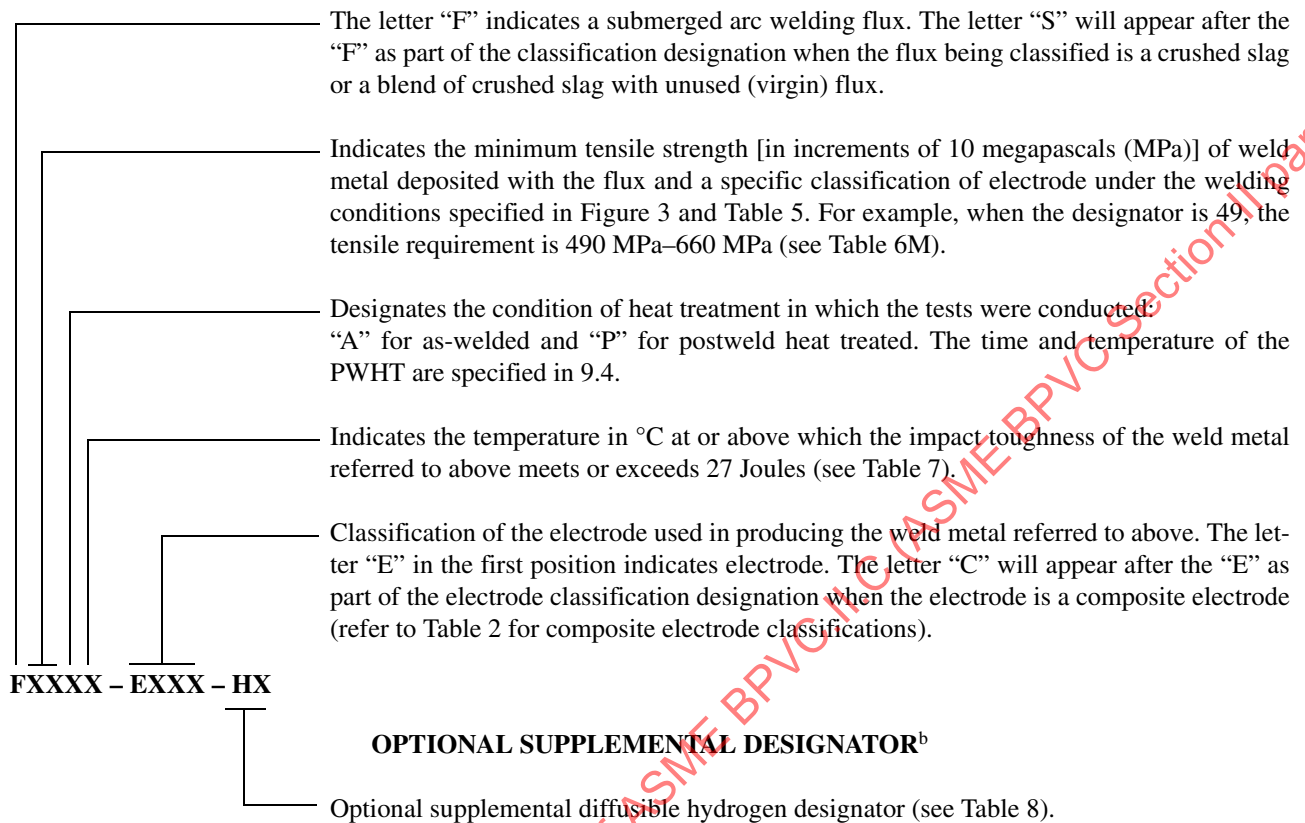
^b This designator is optional.

EXAMPLES

F7A2-EM12K is a complete designation for a flux-electrode classification. It refers to a flux that will produce weld metal which, in the as-welded condition, will have a tensile strength of 70 000 to 95 000 psi and Charpy V-Notch impact toughness of at least 20 ft-lbf at –20°F when produced with an EM12K electrode under the conditions called for in this specification.

F6P6-EC1 is a complete designation for a flux-electrode classification when the trade name of the flux used for classification is indicated as well [see 16.7.1(3)]. It refers to a flux that will produce weld metal with that electrode which, in the postweld heat treated condition, will have a tensile strength of 60 000 to 80 000 psi and Charpy V-Notch impact toughness of at least 20 ft-lbf at –60°F under the conditions called for in this specification.

Figure 1—A5.17M Classification System for U.S. Customary Units

MANDATORY CLASSIFICATION DESIGNATORS^a

^aThe combination of these designators constitutes the flux-electrode classification.

^bThis designator is optional.

EXAMPLES

F43A2-EM12K is a complete designation for a flux-electrode classification. It refers to a flux that will produce weld metal which, in the as-welded condition, will have a tensile strength of 430 MPa to 560 MPa and Charpy V-Notch impact toughness of at least 27 Joules at –20°C when produced with an EM12K electrode under the conditions called for in this specification.

F49P6-EC1 is a complete designation for a flux-electrode classification when the trade name of the flux used for classification is indicated as well [see 16.7.1(3)]. It refers to a flux that will produce weld metal with that electrode which, in the postweld heat treated condition, will have a tensile strength of 490 MPa to 660 MPa and Charpy V-Notch impact toughness of at least 27 Joules at –60°C under the conditions called for in this specification.

Figure 1M—A5.17M Classification System for the International System of Units (SI)

Table 1
Chemical Composition Requirements for Solid Electrodes

weight percent ^{a, b}								
Electrode Classification	UNS Number ^c	C	Mn	Si	S	P	Cu ^d	Ti
Low Manganese Electrode								
EL8	K01008	0.10	0.25–0.60	0.07	0.030	0.030	0.35	—
EL8K	K01009	0.10	0.25–0.60	0.10–0.25	0.030	0.030	0.35	—
EL12	K01012	0.04–0.14	0.25–0.60	0.10	0.030	0.030	0.35	—
Medium Manganese Electrodes								
EM11K	K01111	0.07–0.15	1.00–1.50	0.65–0.85	0.030	0.025	0.35	—
EM12	K01112	0.06–0.15	0.80–1.25	0.10	0.030	0.030	0.35	—
EM12K	K01113	0.05–0.15	0.80–1.25	0.10–0.35	0.030	0.030	0.35	—
EM13K	K01313	0.06–0.16	0.90–1.40	0.35–0.75	0.030	0.030	0.35	—
EM14K	K01314	0.06–0.19	0.90–1.40	0.35–0.75	0.025	0.025	0.35	0.03–0.17
EM15K	K01515	0.10–0.20	0.80–1.25	0.10–0.35	0.030	0.030	0.35	—
High Manganese Electrodes								
EH10K	K01210	0.07–0.15	1.30–1.70	0.05–0.25	0.025	0.025	0.35	—
EH11K	K11140	0.06–0.15	1.40–1.85	0.80–1.15	0.030	0.030	0.35	—
EH12K	K01213	0.06–0.15	1.50–2.00	0.20–0.65	0.025	0.025	0.35	—
EH14	K11585	0.10–0.20	1.70–2.20	0.10	0.030	0.030	0.35	—
EG	Not Specified							

^a The electrode shall be analyzed for the specific elements for which values are shown in this table. In addition, analysis is required to be reported for boron (B) if intentionally added, or if it is known to be present at levels greater than 0.0010%. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total (excluding iron) does not exceed 0.50%.

^b Single values are maximum.

^c ASTM DS-56 (SAE HS-1086), Metals & Alloys in the Unified Numbering System.

^d The copper limit includes any copper coating that may be applied to the electrode.

Table 2
Chemical Composition Requirements for Composite Electrode Weld Metal

weight percent ^{a, b, c}							
Electrode Classification	UNS Number ^d	C	Mn	Si	S	P	Cu
EC1	W06041	0.15	1.80	0.90	0.035	0.035	0.35
ECC	Not Specified						

^a The weld metal shall be analyzed for the specific elements for which values are shown in this table. In addition, analysis is required to be reported for boron (B) if intentionally added, or if it is known to be present at levels greater than 0.0010%. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total (excluding iron) does not exceed 0.50%.

^b Single values are maximum.

^c As a substitute for the weld pad in Figure 2, the sample for chemical analysis may be taken from the reduced section of the fractured tension test specimen or from a corresponding location (or any location above it) in the weld metal in the groove weld in Figure 3. In case of dispute the weld pad shall be the referee method.

^d SAE HS-1086/ASTM DS-56, Metals & Alloys in the Unified Numbering System.

3.2 Fluxes may be classified under any number of classifications: for weld metal in either or both the as-welded and post weld heat treated conditions, for weld metal deposited using different electrode classifications, or any combination thereof. Flux-electrode combinations may be classified under A5.17 with U.S. Customary Units, under A5.17M using the International System of Units (SI), or both. Flux-electrode combinations classified under both A5.17 and A5.17M must meet all of the requirements for classification under each system. The classification systems are shown in Figures 1 and 1M.

3.3 The electrodes and fluxes classified under this specification are intended for submerged arc welding, but may be used with any other process for which they are found suitable.

4. Acceptance

Acceptance of the electrodes and fluxes shall be in accordance with the provisions of AWS A5.01M/A5.01, or the tests and requirements of this specification. See A3 (in Annex A) for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

5. Certification

By affixing the AWS specification and classification designations to the packaging or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification. See A4 (in Annex A) for further information concerning certification and the testing called for to meet this requirement.

6. Rounding Procedure

For purpose of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest 1000 psi (1 ksi) for tensile and yield strength for A5.17, to the nearest 10 MPa for tensile and yield strength for A5.17M and to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfil the requirements for the classification under test.

7. Summary of Tests

7.1 Chemical analysis of the electrode is the only test required for classification of a solid electrode under this specification. The chemical analysis of the rod stock from which the solid electrode is made may also be used provided the electrode manufacturing process does not alter the chemical composition. For composite electrodes, chemical analysis of the weld metal produced with the composite electrode and a particular flux is required.

7.2 The tests required for each flux-electrode classification are specified in Table 3. The purpose of these tests is to determine the mechanical properties and soundness of the weld metal. The base metal for test assemblies, preparation of the tests samples, the welding and testing procedures to be employed, and the results required are given in Clauses 9 through 14.

7.3 Classification is based upon a 5/32 in [4.0 mm] electrode size as standard. If this size electrode is not manufactured, the closest size shall be used for classification tests. See Note d of Table 5.

Table 3
Tests Required for Classification

AWS Classification	Chemical Analysis		Radiographic Test	Tension Test	Impact Test	Diffusible Hydrogen Test
	Electrode	Weld Metal				
All Solid Electrodes	Required	Not Required	Not Required	Not Required	Not Required	Not Required
All Composite Electrodes	Not Required	Required	Not Required	Not Required	Not Required	Not Required
All Flux—Solid or Composite Electrode Classifications	Not Required	Not Required	Required	Required	Required ^a	Note b

^a When the “Z” impact designator (no impact requirement per Table 7) is used, the Impact Test is not required.

^b Diffusible hydrogen test is required only when specified by the purchaser or when the manufacturer puts the diffusible hydrogen designator on the label (see Table 8 and Clause A8).

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Material, specimens or samples for retest may be taken from the original test assembly or sample or from new test assemblies or samples. For chemical analysis, retest need be only for those specific elements that failed to meet the test requirement. If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that, during preparation or after completion of any test, it is clearly determined that prescribed or proper procedures were not followed in preparing the weld test assembly or test specimen(s) or in conducting the test, the test shall be considered invalid, without regard to whether the test was actually completed or whether test results met or failed to meet the requirement. That test shall be repeated following proper prescribed procedures. In this case, the requirement for doubling the number of test specimens does not apply.

9. Weld Test Assemblies

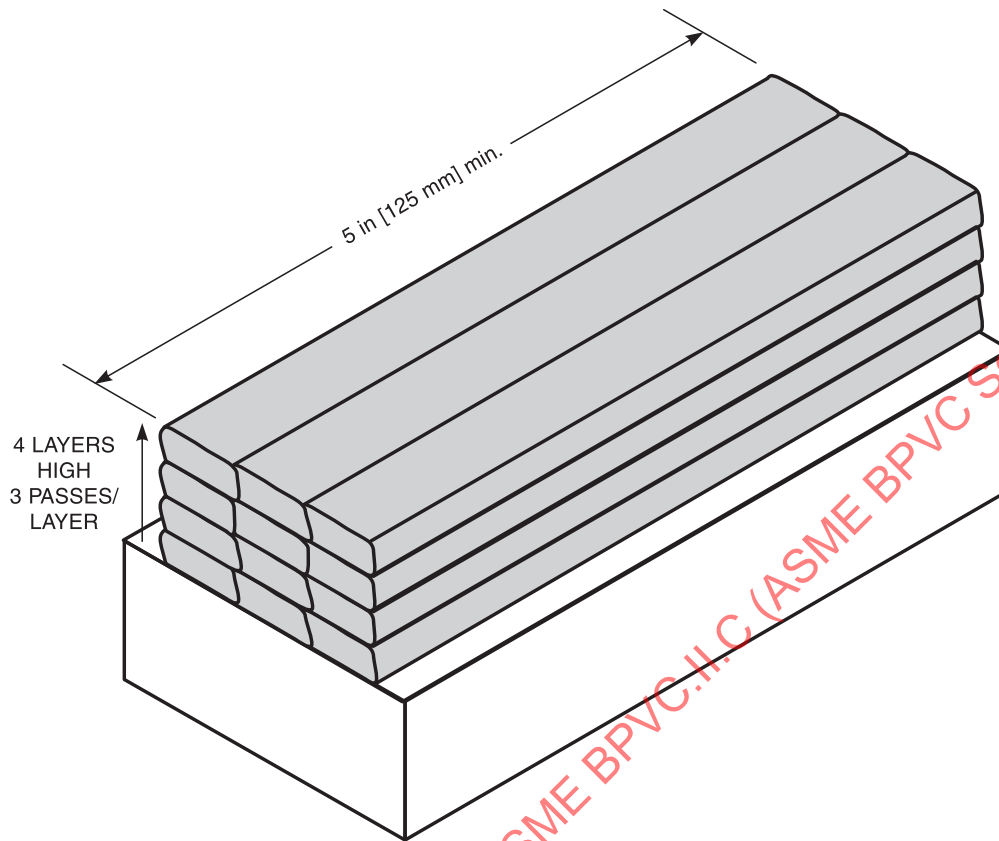
9.1 Requirements for Classification

9.1.1 Classification of Solid Electrodes. No weld test assembly is required for classification of solid electrodes.

9.1.2 Classification of Composite Electrodes. The chemical analysis of weld metal produced with the composite electrode and a particular flux is required for classification of a composite electrode under this specification. The weld pad shown in Figure 2 is used to meet this requirement for the classification of composite electrodes. The welding parameters for the groove weld, as specified in Table 5, shall be used. As an alternative to the weld pad, the sample for chemical analysis of composite electrode weld metal may be taken from the groove weld in Figure 3. Note c to Table 2 allows the sample for chemical analysis in the case of a composite electrode to be taken from the reduced section of the fractured tension test specimen or from a corresponding location (or any location above it) in the weld metal of the groove weld in Figure 3. In case of dispute, the weld pad shall be the referee method.

9.1.3 Classification of Flux-Electrode Combinations. One groove weld test assembly is required for each classification of a flux-solid electrode combination or a flux-composite electrode combination. This is the groove weld in Figure 3 for mechanical properties and soundness of weld metal.

9.2 Weld Test Assemblies. Preparation of each weld test assembly shall be as specified in 9.3 and 9.4. The base metal for the weld pad and groove weld assemblies shall be as specified in Table 4 and shall meet the requirements of the ASTM specification shown there or a chemically equivalent steel. Testing of these assemblies shall be as prescribed in Clauses 10 through 13.



Notes:

1. Width and thickness of the base metal plate may be any dimensions suitable for the electrode diameter and current in use.
2. Weld beads shall be deposited without oscillation. The welding conditions shall be in accordance with the manufacturer's recommendations.
3. The first and last 2 in [50 mm] of the weld length shall be discarded. The top surface shall be removed, and chemical analysis samples shall be taken from the underlying metal of the fourth layer of the weld pad.

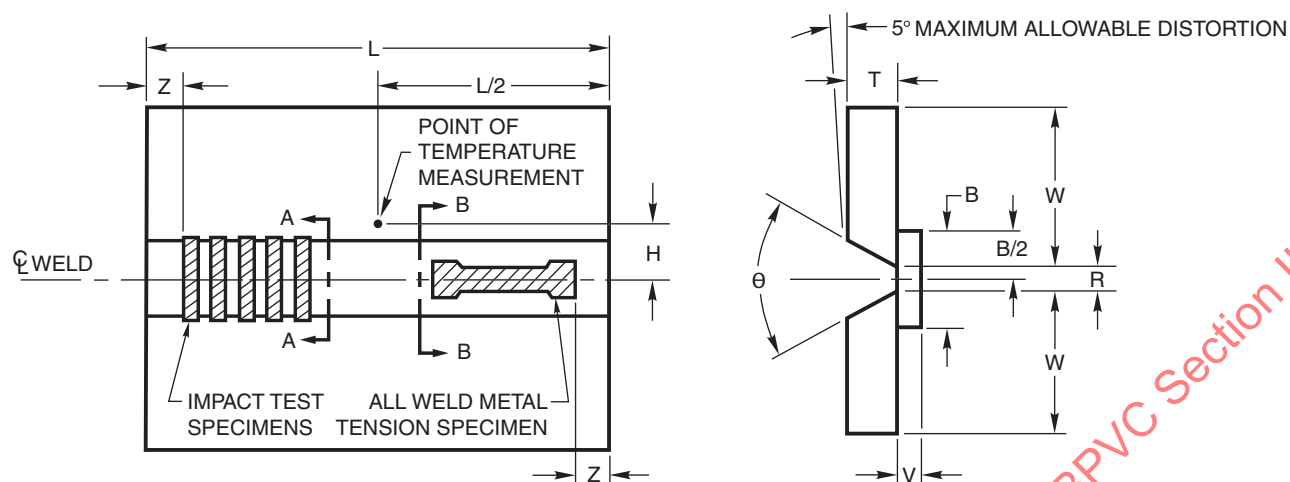
Figure 2—Weld Pad for Chemical Analysis of Weld Metal from Composite Electrodes

9.3 Weld Pad. For composite electrodes only, a weld pad shall be prepared as specified in Figure 2, except when the alternative in 9.1.2 is selected.

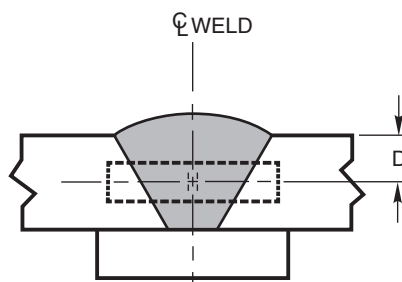
Base metal of any convenient size and of the type specified in Table 4 shall be used as the base metal for the weld pad. The surface of the base metal on which the filler metal is deposited shall be clean and free from scale. The pad shall be welded in the flat position, three beads per layer, four layers high, using the flux for which classification of the composite electrode is intended.

The preheat temperature shall not be less than 60°F [15°C] and the interpass temperature shall not exceed 300°F [150°C]. The welding parameters for the groove weld, as specified in Table 5, shall be used. The slag shall be removed after each pass. The pad may be quenched in water between passes but shall be dry before the start of each pass. Testing of this assembly shall be as specified in Clause 10, Chemical Analysis.

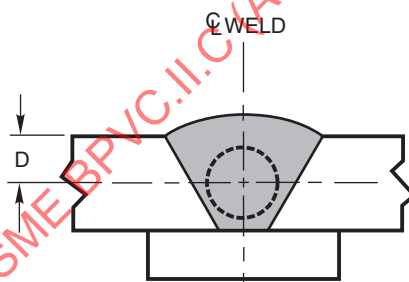
9.4 Groove Weld for Mechanical Properties and Soundness. For mechanical properties and soundness testing of a flux-electrode combination, a test assembly shall be prepared and welded as specified in Figure 3 and Table 5 using base metal of the appropriate type specified in Table 4. Preheat and interpass temperatures shall be as specified in Table 5.



(A) JOINT CONFIGURATION AND LOCATION OF TEST SPECIMENS



(B) LOCATION OF IMPACT TEST SPECIMENS



(C) LOCATION OF ALL WELD METAL TENSION TEST SPECIMEN

Dimension	Description	A5.17, in	A5.17M, mm
L	Length (min.)	12	300
T	Thickness	$1 \pm 1/16$	25 ± 1.5
W	Width (min.)	5	130
D	Specimen center	$3/8 \pm 1/32$	9.5 ± 1.0
B	Backup width (min.)	2	50
R	Root opening	$1/2 \pm 1/16$	13 ± 1.5
Z	Discard (min.)	1	25
θ	Groove angle—prior to optional preset	$30^\circ \pm 5^\circ$	$30^\circ \pm 5^\circ$
H	Approximate temperature measurement distance	1	25
V	Backing thickness (min.)	1/2	13

Figure 3—Groove Weld Test Assembly

Table 4
Base Metals for Test Assemblies

Test Assembly	Type	ASTM Specification ^a	UNS Number ^b
Weld Pad for Chemical Analysis (Figure 2)	Carbon Steel	A29 Grade 1015 A29 Grade 1020 A36 A285 Grade A A285 Grade B A285 Grade C A285 Grade D A515 Grade 70 A516 Grade 70	G10150 G10200 K02600 K01700 K02200 K02801 K02702 K03101 K02700
Groove Weld Test Assembly (Figure 3)	Carbon Steel	A36 A285 Grade A A285 Grade B A285 Grade C A285 Grade D A515 Grade 70 A516 Grade 70	K02600 K01700 K02200 K02801 K02702 K03101 K02700

^a Chemically equivalent steel may be used. In case of dispute, ASTM A36 shall be used as the referee steel.

^b As listed in SAE HS-1086/ASTM DS-56, Metals & Alloys in the Unified Numbering System.

The surfaces to be welded shall be clean and free of scale. Prior to welding, the assembly may be preset so that the welded joint will be sufficiently flat to facilitate removal of the test specimens. As an alternative, restraint or a combination of restraint and presetting may be used to keep the welded joint within 5° of plane. A welded test assembly that is more than 5° out of plane shall be discarded. Straightening of the test assembly is prohibited.

Testing of this assembly shall be as specified in Clauses 11 through 13, with the assembly in either the as-welded or the postweld heat treated condition, according to the classification of the weld metal (see Figures 1 and 1M). When tests are to be conducted in each condition (as-welded and postweld heat treated) two such assemblies, or one single assembly of sufficient length to provide the specimens required for both conditions, shall be prepared. In the latter case, the single assembly shall be cut transverse to the weld into two pieces. One of the pieces shall be tested in the as-welded condition and the other piece shall be heat treated prior to testing.

9.4.1 When postweld heat treatment (PWHT) is required, the heat treatment shall be applied to the test assembly before the specimens for mechanical testing are removed. This heat treatment may be applied either before or after the radiographic examination.

9.4.2 For any test assembly that will be heat treated, the test assembly shall be put in a suitable furnace at a temperature not greater than 600°F [315°C]. The temperature shall be raised at the rate of 150°F [85°C] to 500°F [280°C] per hour until the postweld heat treatment temperature of 1150°F ± 25°F [620°C ± 15°C] is attained. This temperature shall be maintained for one hour (–0, +15 minutes).

The test assembly shall then be allowed to cool in the furnace at a rate not greater than 350°F [200°C] per hour. After the test assembly has reached 600°F [315°C] it may be removed from the furnace and allowed to cool in still air.

9.5 Diffusible Hydrogen. In those cases in which an optional supplemental diffusible hydrogen designator is to be added to the flux-electrode classification designation, diffusible hydrogen test assemblies shall be prepared, welded, and tested as specified in Clause 14, Diffusible Hydrogen Test.

Table 5
Welding Parameters for Groove Weld Test Assembly

Welding Conditions for Solid Electrodes ^{a, b, c}										
Electrode Size ^d		Welding Current (amperes) ^e	Arc Voltage (volts)	Electrode Extension ^f		Travel Speed		Current Type ^g	Preheat Temp ^h	Interpass Temp ^h
in	mm			in	mm	ipm (±1)	mm/sec (±0.5)			
1/16	1.6	250 to 350	26 to 29	1/2 to 3/4	13 to 19	12	5.0	A.C. or D.C. either polarity	60°F to 325°F [15°C to 165°C]	275°F to 325°F [135°C to 165°C]
5/64	2.0	300 to 400	26 to 29	1/2 to 3/4	13 to 19	13	5.5			
3/32	2.4	350 to 450	27 to 30	3/4 to 1-1/4	19 to 32	14	6.0			
—	2.5	350 to 450	27 to 30	3/4 to 1-1/4	19 to 32	14	6.0			
7/64	2.8	400 to 500	27 to 30	3/4 to 1-1/4	19 to 32	14	6.0			
—	3.0	400 to 500	27 to 30	1 to 1-1/2	25 to 38	15	6.5			
1/8	3.2	425 to 525	27 to 30	1 to 1-1/2	25 to 38	15	6.5			
5/32	4.0	475 to 575	27 to 30	1 to 1-1/2	25 to 38	16	7.0			
3/16	4.8	525 to 625	27 to 30	1 to 1-1/2	25 to 38	17	7.0			
—	5.0	550 to 650	27 to 30	1 to 1-1/2	25 to 38	17	7.0			
7/32	5.6	575 to 675	28 to 31	1-1/4 to 1-3/4	32 to 44	18	7.5			
—	6.0	625 to 725	28 to 31	1-1/4 to 1-3/4	32 to 44	19	8.0			
1/4	6.4	700 to 800	28 to 32	1-1/2 to 2	38 to 50	20	8.5			

^a Values specified in inches or ipm apply to A5.17. Values specified in mm or mm/sec apply to A5.17M.

^b These welding conditions are intended for machine or automatic welding with straight progression (no weaving). Welding shall be performed in the flat position. The first layer shall be produced in either 1 or 2 passes. All other layers shall be produced in 2 or 3 passes per layer except the last, which shall be produced in 2, 3, or 4 passes. The completed weld shall be at least flush with the surface of the test plate.

^c Welding conditions for composite electrodes shall be as agreed between purchaser and supplier.

^d Classification is based on the properties of weld metal with 5/32 in [4.0 mm] electrodes or the closest size manufactured, if 5/32 in [4.0 mm] is not manufactured. The conditions given above for sizes other than 5/32 in [4.0 mm] are to be used when classification is based on those sizes, or when they are required for lot acceptance testing under AWS A5.01M/A5.01 (unless other conditions are specified by the purchaser).

^e Lower currents may be used for the first layer.

^f The electrode extension is the contact tube-to-work distance. When an electrode manufacturer recommends a contact tube-to-work distance outside the range shown, that recommendation shall be followed ± 1/4 in [6.5 mm].

^g In case of dispute, DCEP (direct current electrode positive) shall be used as the referee current.

^h The first bead shall be produced with the assembly at any temperature between 60°F and 325°F [15°C to 165°C]. Welding shall continue, bead by bead, until a temperature within the interpass temperature range has been attained. Thereafter, production of subsequent beads may begin only when the assembly is within the interpass temperature range. The point of temperature measurement shall be at mid-length of the test assembly, approximately 1 in [25 mm] from the weld centerline.

10. Chemical Analysis

10.1 For solid electrodes, a sample of the electrode or the rod stock from which it is made shall be prepared for chemical analysis. Solid electrodes, when analyzed for elements that are present in a coating (copper flashing, for example), shall be analyzed without removing the coating. Rod stock analyzed for elements not in the coating may be analyzed prior to reducing the rod to the finished electrode diameter and applying the coating.

10.2 For composite electrodes, the sample for analysis shall be taken from weld metal produced with the electrode and the flux with which it is classified. The sample shall be taken from the weld pad in Figure 2, from the reduced section of the fractured tension test specimen in Figure 3 or from a corresponding location (or any location above it) in the weld metal in the groove weld in Figure 3. In case of dispute, the weld pad in Figure 2 shall be used as the referee method.

The top surface of the pad described in 9.3 and shown in Figure 2 shall be removed and discarded and a sample for analysis shall be obtained from the underlying metal of the fourth layer of the weld pad by any appropriate means that will not change the composition. The sample shall be free of slag.

The sample taken as provided by the alternatives to the weld pad in 9.1.2 shall be prepared for analysis by any suitable means that will not change the composition. The sample shall be taken at least 3/8 in [10 mm] from the nearest surface of the base metal.

10.3 The sample shall be analyzed by accepted analytical methods. The referee method shall be the procedure in the latest edition of ASTM E350.

10.4 For solid electrodes, the results of the analysis shall meet the requirements of Table 1 for the classification of electrode being tested. For composite electrodes, the results of the analysis shall meet the requirements of Table 2 for the classification of electrode being tested.

11. Radiographic Test

11.1 The groove weld described in 9.4 and shown in Figure 3 shall be radiographed to evaluate the soundness of the weld metal. In preparation for radiography, the backing shall be removed and both surfaces of the weld shall be machined or ground smooth and flush with the original surfaces of the base metal or with a uniform reinforcement not exceeding 3/32 in [2.5 mm]. It is permitted on both sides of the test assembly to remove base metal to a depth of 1/16 in [1.5 mm] less than the nominal base metal thickness, to facilitate backing or buildup removal. The thickness of the weld metal shall not be reduced by more than 1/16 in [1.5 mm] so that the thickness of the prepared radiographic test specimen equals at least the thickness of the base metal minus 1/16 in [1.5 mm].

Both surfaces of the test assembly, in the area of the weld, shall be smooth enough to avoid difficulty in interpreting the radiograph.

11.2 The weld shall be radiographed in accordance with one of the following. The quality level of inspection shall be 2-2T.

(1) *Film Radiology*: ASTM E1032.

(2) *Computed Radiology (CR)*: ASTM E2033 and the requirements of ASTM E1032 except where CR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2033, refers to phosphor imaging plate.

(3) *Digital Radiology (DR)*: ASTM E2698 and the requirements of ASTM E1032 except where DR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2698, refers to digital detector array (DDA).

11.3 The soundness of the weld metal meets the requirements of this specification if the radiograph shows:

(1) No cracks, no incomplete fusion, no incomplete penetration;

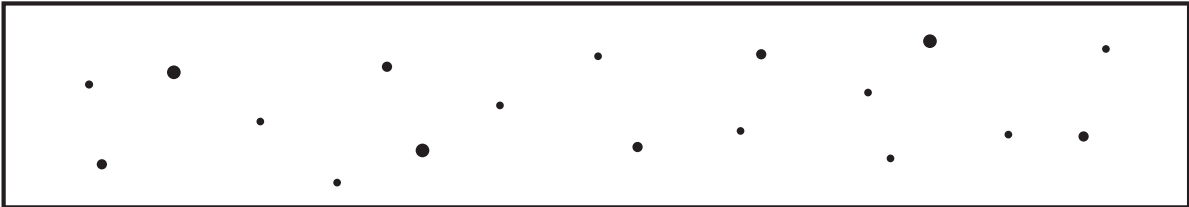
(2) No slag inclusions longer than 5/16 in [8 mm], no groups of slag inclusions in line that have an aggregate length greater than the thickness of the weld in a length 12 times the thickness of the weld except when the distance between the successive inclusions exceeds six times the length of the longest inclusion in the group; and

(3) No rounded indications in excess of those permitted by the radiographic standards in Figure 4.

In evaluating the radiograph, 1 in [25 mm] of the weld on each end of the test assembly shall be disregarded.

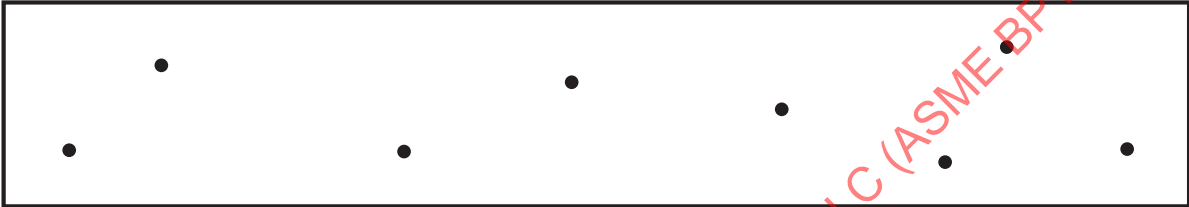
11.3.1 A rounded indication is an indication (on the radiograph) whose length is no more than 3 times its width. Rounded indications may be circular or irregular in shape and they may have tails. The size of a rounded indication is the largest dimension of the indication, including any tail that may be present. The indication may be of porosity or slag inclusions.

11.3.2 Indications whose largest dimension does not exceed 1/64 in [0.4 mm] shall be disregarded. Test assemblies with any rounded indications larger than the large indications permitted in Figure 4 do not meet the requirements of this specification.



(A) ASSORTED ROUNDED INDICATIONS

MAXIMUM SIZE PERMITTED: 1/16 in [1.6 mm] max.
NUMBER OF INDICATIONS PERMITTED IN ANY 6 in [150 mm] OF WELD: 18 max.,
WITH THE FOLLOWING RESTRICTIONS IN THE NUMBER OF INDICATIONS OF EACH SIZE:
LARGE INDICATIONS (3/64 in [1.2 mm] to 1/16 in [1.6 mm]): 3 max.
MEDIUM INDICATIONS (1/32 in [0.8 mm] to 3/64 in [1.2 mm]): 5 max.
SMALL INDICATIONS (1/64 in [0.4 mm] to 1/32 in [0.8 mm]): 10 max.



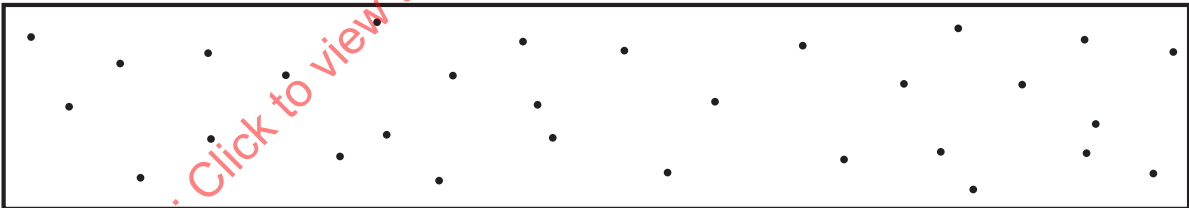
(B) LARGE ROUNDED INDICATIONS

SIZE PERMITTED: 3/64 in [1.2 mm] to 1/16 in [1.6 mm]
NUMBER OF INDICATIONS PERMITTED IN ANY 6 in [150 mm] OF WELD: 8 max.



(C) MEDIUM ROUNDED INDICATIONS

SIZE PERMITTED: 1/32 in [0.8 mm] TO 3/64 in [1.2 mm]
NUMBER OF INDICATIONS PERMITTED IN ANY 6 in [150 mm] OF WELD: 15 max.



(D) SMALL ROUNDED INDICATIONS

SIZE PERMITTED: 1/64 in [0.4 mm] to 1/32 in [0.8 mm]
NUMBER OF INDICATIONS PERMITTED IN ANY 6 in [150 mm] OF WELD: 30 max.

- Notes:
1. The chart which is most representative of the size of the rounded indications in the radiograph of the test assembly shall be used for determination of conformance with this specification. Rounded indications smaller than 1/64 in [0.4 mm] shall be disregarded. The largest dimension of the indication (including any tail) is the size of the indication.
 2. These radiographic requirements are for test welds made in the laboratory specifically for classification purposes. They are more restrictive than those usually encountered in general fabrication.

Figure 4—Radiographic Standards for Rounded Indications

Table 6
A5.17 Tension Test Requirements

Flux-Electrode Classifications ^a	Tensile Strength (psi)	Yield Strength ^b (psi)	Elongation ^b (%)
F6XX-EXXX	60 000 to 80 000	48 000	22
F7XX-EXXX	70 000 to 95 000	58 000	22

^a The letter “S” will appear after the “F” as part of the classification designation when the flux being classified is a crushed slag or a blend of crushed slag with unused (virgin) flux. The letter “C” will appear after the “E” as part of the classification designation when the electrode used is a composite electrode. The letter “X” used in various places in this table stands for, respectively, the condition of heat treatment, the toughness of the weld metal, and the classification of the electrode. See Figure 1 for a complete explanation of the classification designators.

^b Yield strength shall be determined at 0.2% offset. The requirements listed for yield strength and % elongation (in 2 in gage length) are minimum requirements.

Table 6M
A5.17M Tension Test Requirements

Flux-Electrode Classifications ^a	Tensile Strength (MPa)	Yield Strength ^b (MPa)	Elongation ^b (%)
F43XX-EXXX	430–560	330	22
F49XX-EXXX	490–660	400	22

^a The letter “S” will appear after the “F” as part of the classification designation when the flux being classified is a crushed slag or a blend of crushed slag with unused (virgin) flux. The letter “C” will appear after the “E” as part of the classification designation when the electrode used is a composite electrode. The letter “X” used in various places in this table stands for, respectively, the condition of heat treatment, the toughness of the weld metal, and the classification of the electrode. See Figure 1M for a complete explanation of the classification designators.

^b Yield strength shall be determined at 0.2% offset. The requirements listed for yield strength and % elongation (in 2 in gage length) are minimum requirements.

12. Tension Test

12.1 One all-weld metal tension test specimen, as specified in the Tension Test section of AWS B4.0 or B4.0M shall be machined from the groove weld described in 9.4 and shown in Figure 3. The all-weld-metal tensile specimen shall have a nominal diameter of 0.500 in [12.5 mm] and a nominal gage length to diameter ratio of 4:1.

12.2 The specimen shall be tested in the manner described in the Tension Test section of the latest edition of AWS B4.0 or B4.0M.

12.3 The results of the tension test shall meet the requirements specified in Table 6 [or Table 6M], as applicable.

13. Impact Test

13.1 Five full-size Charpy V-Notch impact specimens, as specified in the Fracture Toughness Test section of AWS B4.0 or B4.0M shall be machined from the test assembly shown in Figure 3 for those classifications for which impact testing is required in Table 3. The Charpy V-Notch specimens shall have the notched surface and the struck surface parallel within 0.002 in [0.05 mm]. The other two surfaces of the specimen shall be square with the notched or struck surfaces within 10 minutes of a degree. The notch shall be smoothly machined and shall be square with the longitudinal edge of the specimen within one degree. The geometry of the notch shall be measured on at least one specimen in a set of five specimens. Measurement shall be done at a minimum 50X magnification on either a shadowgraph or metallograph. The correct location of the notch shall be verified by etching before or after machining.

13.2 The five specimens shall be tested in accordance with the Fracture Toughness test section of AWS B4.0 or B4.0M. The test temperature shall be that specified in Table 7 for the classification under test.

Table 7
A5.17/A5.17M Impact Test Requirements^{a, b, c}

A5.17 Requirements			A5.17M Requirements		
A5.17 Impact Designator	Maximum Test Temperature (°F)	Minimum Average Energy Level	A5.17M Impact Designator	Maximum Test Temperature (°C)	Minimum Average Energy Level
0	0	20 ft-lbf	0	0	27 Joules
2	−20		2	−20	
4	−40		3	−30	
5	−50		4	−40	
6	−60		5	−50	
8	−80		6	−60	
Z	No Impact Requirements		Z	No Impact Requirements	

^a Based on the results of the impact tests of the weld metal, the manufacturer shall insert in the classification the appropriate designator from the Table above, as indicated in Figure 1 or Figure 1M, as applicable.

^b Weld metal from a specific flux-electrode combination that meets the impact requirements at a given temperature also meets the requirements at all higher temperatures in this Table. For example, weld metal meeting the A5.17 requirements for designator "5" also meets the requirements for designators 4, 2, 0, and Z. [Weld metal meeting the A5.17M requirements for designator "5" also meets the requirements for designators 4, 3, 2, 0, and Z.]

^c When classifying flux-electrode combinations to A5.17 using U.S. Customary Units the Impact Designator indicates the impact test temperature in °F. When classifying to A5.17M using the International System of Units (SI) the Impact Designator indicates the impact test temperature in °C. With the exception of the Impact Designator "4" a given Impact Designator will indicate different temperatures depending upon whether classification is according to A5.17 in U.S. Customary Units or according to A5.17M in the International System of Units (SI). For example, a "2" Impact Designator when classifying to A5.17 indicates a test temperature of -20°F. When classifying to A5.17M the "2" Impact Designator indicates a test temperature of -20°C, which is -4°F.

13.3 In evaluating the test results, the lowest and the highest values obtained shall be disregarded. Two of the remaining three values shall equal or exceed the specified 20 ft-lbf [27 J] energy level. One of the three may be lower, but not lower than 15 ft-lbf [20 J] and the average of the three shall be not less than the required 20 ft-lbf [27 J] energy level.

14. Diffusible Hydrogen Test

14.1 Each flux-electrode combination to be identified by an optional supplemental diffusible hydrogen designator shall be tested according to one of the methods given in AWS A4.3. Based upon the average value of test results which satisfy the requirements of Table 8, the appropriate diffusible hydrogen designator may be added to the end of the flux-electrode classification.

14.2 The welding procedure shown in Table 5 for the Groove Weld Test assembly shall be used for the diffusible hydrogen test. The travel speed, however, may be increased up to a maximum of 28 in/min [12 mm/s]. This adjustment in travel speed is permitted in order to establish a weld bead width that is appropriate for the specimen. The flux, electrode, or both, may be baked to restore the moisture content before testing to the as-manufactured condition. When this is done, the baking time and temperature shall be noted on the certificate. The manufacturer of the flux, electrode, or both, should be consulted for their recommendation regarding the time and temperature for restoring their products to the as-manufactured condition.

14.3 For purposes of certifying compliance with diffusible hydrogen requirements, the reference atmospheric condition shall be an absolute humidity of ten (10) grains of moisture/lb [1.43 g/kg] of dry air at the time of welding. The actual atmospheric conditions shall be reported along with the average diffusible hydrogen value for the test according to AWS A4.3.

14.4 When the absolute humidity equals or exceeds the reference condition at the time of preparation of the test assembly, the test shall be acceptable as demonstrating compliance with the requirements of this specification provided the actual test results satisfy the diffusible hydrogen requirements for the applicable designator. Likewise, if the actual test results for a flux meet the requirements for the lower, or lowest hydrogen designator, as specified in Table 8, the flux and electrode combination also meets the requirements for all higher designators in Table 8 without need to retest.

Table 8
Diffusible Hydrogen Requirements^a

AWS A5.17/A5.17M Flux-Electrode Classifications	Optional Supplemental Diffusible Hydrogen Designator ^b	Average Diffusible Hydrogen, Maximum ^c (ml/100g Deposited Metal)
All	H16	16
	H8	8
	H4	4
	H2	2

^a The diffusible hydrogen test is required only when specified by the purchaser or when the manufacturer puts the diffusible hydrogen designator on the label (see also Clause A8).

^b This designator is added to the end of the flux-electrode classification (see Figures 1 or 1M, as applicable).

^c Flux-electrode combinations meeting the requirements for an H2 designator also meet the requirements for H4, H8, and H16. Flux-electrode combinations meeting requirements for an H4 designator also meet the requirements for H8 and H16. Flux-electrode combinations meeting the requirements for an H8 designator also meet the requirements for H16.

15. Method of Manufacture

15.1 Electrodes and Fluxes. The electrodes and fluxes classified according to this specification may be manufactured by any method that will produce material that meets the requirements of this specification.

15.2 Crushed Slag. Slag formed during the welding process that is subsequently crushed for use as a welding flux is defined as crushed slag. Crushed slag and blends of crushed slag with the original brand of unused (virgin) flux may be classified as welding fluxes under this specification. When classifying a blend of crushed slag with virgin flux, the ratio of the blend mixture shall not vary from nominal by more than 10% by weight of the minor component. For example, a nominal blend of 40% crushed slag with 60% virgin flux shall contain at least 36%, but no more than 44% crushed slag. The classification of more than one blend ratio of crushed slag with the original brand of unused (virgin) flux is permitted under this specification. In each case, however, the nominal blend ratio shall be noted on the packaging or on the corresponding lot certificate, as applicable. See A6.1.4 in Annex A.

Slag generated by a fabricator from a specific brand of flux under controlled welding conditions and crushed for subsequent reuse by the same fabricator is further defined as a closed-loop crushed slag. Closed-loop crushed slag and blends of closed-loop crushed slag with the original brand of unused (virgin) flux are classified under this specification using the same requirements specified for crushed slags and blends of crushed slag with virgin flux. See A6.1.4 in Annex A.

16. Electrode Requirements

16.1 Standard Sizes. Standard sizes for electrode in the different package forms (coils with support, coils without support, spools and drums) are as specified in AWS A5.02/A5.02M.

16.2 Finish and Uniformity

16.2.1 Finish and uniformity shall be as specified in AWS A5.02/A5.02M.

16.2.2 A suitable protective coating may be applied to any filler metal in this specification, however the coating composition must be included when analyzing and reporting the composition of the electrode.

16.3 Standard Package Forms. Standard package forms are coils with support, coils without support, spools and drums. Standard package dimensions for each form shall be as specified in AWS A5.02/A5.02M. Package forms and sizes other than these shall be as agreed between purchaser and supplier.

16.4 Winding Requirements

16.4.1 Winding requirements shall be as specified in AWS A5.02/A5.02M.

16.4.2 The cast and helix of the electrode shall be as specified in AWS A5.02/A5.02M.

16.5 Electrode Identification

16.5.1 Filler Metal Identification. Product information and the precautionary information shall be as specified in AWS A5.02/A5.02M. Coils without support shall have a tag containing this information securely attached to the filler metal at the inside end of the coil.

16.6 Packaging. Electrodes shall be suitably packaged to ensure against damage during shipment and storage under normal conditions.

16.7 Marking of Packages

16.7.1 The product information specified in AWS A5.02/A5.02M and the following (as a minimum) shall be legibly marked so as to be visible from the outside of each unit package.

(1) AWS specification and classification along with the applicable optional and supplemental designators. The year of issuance may be excluded. It is not required that all classifications published for the electrode (with various fluxes, with and without PWHT, etc.) be included on the packaging.

(2) Supplier's name, trade designation, and country of manufacture.

(3) In the case of a composite electrode, the trade designation of the flux (or fluxes) with which it is classified.

(4) Size and net weight.

(5) Lot, control or heat number.

16.7.2 The appropriate precautionary information as given in ANSI Z49.1 (as a minimum), or its equivalent shall be prominently displayed in legible print on all packages of electrode, including individual unit packages enclosed within a larger package. Typical examples of "warning labels" and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

17. Flux Requirements

17.1 Form and Particle Size. Flux shall be granular in form and shall be capable of flowing freely through the flux feeding tubes, valves, and nozzles of standard submerged arc welding equipment. Particle size is not specified here, but when addressed, shall be a matter of agreement between the purchaser and the supplier.

17.2 Usability. The flux shall permit the production of uniform, well-shaped beads that merge smoothly with each other and the base metal. Undercut, if any, shall not be so deep or so widespread that a subsequent bead will not remove it.

17.3 Packaging

17.3.1 Flux shall be suitably packaged to ensure against damage during shipment.

17.3.2 Flux in its original unopened container shall withstand storage under normal conditions for at least six months without damage to its welding characteristics or the properties of the weld. Heating of the flux to assure dryness may be necessary when the very best properties (of which the materials are capable) are required. For specific recommendations, consult the manufacturer.

17.4 Marking of Packages

17.4.1 The following product information (as a minimum) shall be legibly marked so as to be visible from the outside of each unit package.

(1) AWS specification and classification along with the applicable optional, supplemental designators. The year of issuance may be excluded. It is not required that all classifications published for the flux (with various electrodes, with and without PWHT, etc.) be included on the packaging.

(2) Supplier's name, trade designation, and country of manufacture. In the case of crushed slags (or blends of crushed slag with virgin flux), the crusher (or crusher/blender), not the original producer, shall be considered the supplier. Crushed slag or a blend of crushed slag with virgin flux shall have a unique trade designation that clearly differentiates it from the original virgin flux used in its manufacture. For blends of crushed slag with virgin flux, the nominal blend composition shall be noted on the packaging or on the corresponding certificate of test, as applicable. See also A6.1.4 in Annex A.

(3) Net Weight.

(4) Lot, control, or heat number.

(5) Particle size, if more than one particle size of flux of that trade designation is produced.

17.4.2 The appropriate precautionary information as given in ANSI Z49.1 (as a minimum), or its equivalent shall be prominently displayed in legible print on all packages of flux, including individual unit packages enclosed within a larger package. Typical examples of "warning labels" and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

Annex A (Informative)

Guide to AWS Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding

This annex is not a part of this standard and is included for information purposes only.

A1. Introduction

The purpose of this guide is to correlate the electrode and flux classifications with their intended applications so the specification can be used effectively. Appropriate base metal specifications are referred to whenever that can be done and when it would be helpful. Such references are intended only as examples rather than complete listings of the materials for which each flux or electrode is suitable.

A2. Classification System

A2.1 Classification of Electrodes. The system for identifying the electrode classifications in this specification follows the standard pattern used in other AWS filler metal specifications. The letter “E” (or “EC” for composite electrodes) at the beginning of each classification designation stands for electrode. The remainder of the designation indicates the chemical composition of the electrode or, in the case of composite electrodes, the chemical composition of the weld metal obtained with a particular flux. See Figure 1 or Figure 1M, as applicable.

The letter “L” indicates that the solid electrode is comparatively low in manganese content. The letter “M” indicates a medium manganese content, while the letter “H” indicates a comparatively high manganese content. The one or two digits following the manganese designator indicate the nominal carbon content of the electrode. The letter “K”, which appears in some designations, indicates a higher silicon content in the electrode. Solid electrodes are classified only on the basis of their chemical composition, as specified in Table 1 of this specification.

A composite electrode is indicated by the letter “C” after the “E” and a numerical suffix. The composition of a composite electrode may include metallic elements in the core material that are also present as oxides, fluorides, etc., of those same elements. Therefore, the chemical analysis of a composite electrode may not be directly comparable to an analysis made on a solid electrode. For this reason, the composition of composite electrodes is not used for classification purposes under this specification, and the user is referred to weld metal composition (Table 2) with a particular flux, rather than to electrode composition.

A2.2 “G” Classification

A2.2.1 This specification includes electrodes classified as “EG” (or “ECG”). The “G” indicates that the electrode is of a general classification. It is general because not all of the particular requirements specified for each of the other classifications are specified for this classification. The intent, in establishing this classification is to provide a means by which electrodes that differ in one respect or another (chemical composition, for example) from all other classifications (meaning that the composition of the electrode, in the case of the example, does not meet the composition specified for any of the classifications in the specification) can still be classified according to the specification. The purpose is to allow a useful electrode, one that otherwise would have to wait for a revision of the specification, to be classified immediately under the existing specification. This means that two electrodes, each bearing the same “G” classification, may be quite different (chemical composition, for example).

A2.2.2 The point of difference (although not necessarily the amount) between an electrode of a “G” classification and an electrode of a similar classification, with or without the “G,” will be readily apparent from the use of the words not required and not specified in the specification. The use of these words is as follows:

(1) *Not Specified* is used in those areas of the specification that refer to the results of some particular test. It indicates that the requirements for that test are not specified for that particular classification.

(2) *Not Required* is used in those areas of the specification that refer to the tests that must be conducted in order to classify a welding flux or electrode. It indicates that that test is not required because the requirements (results) for the test have not been specified for that particular classification.

Restating the case, when a requirement is not specified, it is not necessary to conduct the corresponding test in order to classify a flux or electrode to that classification. When a purchaser wants the information provided by that test, in order to consider a particular product of that classification for a certain application, the purchaser will have to arrange for that information with the supplier. The purchaser will have to establish with the supplier what the testing procedure and the acceptance requirements are to be, for that test. The purchaser may want to incorporate that information via AWS A5.01M/A5.01 in the purchase order.

A2.2.3 Request for Filler Metal Classification. When a filler metal cannot be classified other than with a “G” classification, the manufacturer may request that a classification be established. The manufacturer shall do this using the following procedure.

(1) A request to establish a new filler metal classification must be submitted in writing. The request needs to provide sufficient detail to permit the Committee on Filler Metals and Allied Materials and the relevant Subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

- (a) A declaration that the new classification will be offered for sale commercially.
- (b) All classification requirements as given for existing classifications, such as chemical composition ranges, mechanical property requirements, and usability test requirements.
- (c) Any conditions for conducting the tests used to demonstrate that the product meets the classification requirements. It would be sufficient, for example, to state that welding conditions are the same as for other classifications.
- (d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the Annex).
- (e) Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.
- (f) A request for a new classification without the above information will be considered incomplete. The secretary will return the request to the requester for further information.

(2) In order to comply with the AWS Policy on Patented Items, Trademarks, and Restraint of Trade, if the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester shall disclose this. The affected classification shall be identified in all drafts and eventually the published standard identifying the patent owner. The requester shall also provide written assurance to AWS that:

- (a) [Name of the requester] has filed a patent application [patent application number] for alloy [classification number]. [Name of the requester] does not hold and does not currently intend holding any essential patent claims.
- (b1) [Name of the requester] has filed a patent application [patent application number] for alloy [classification number]. [Name of the requester] will make a license available to such essential patent claims to applicants desiring to utilize the license for the purpose of implementing the standard. The license will be under reasonable terms and conditions that are demonstrably free of any unfair discrimination.

or

(b2) [Name of the requester] has filed a patent application [patent application number] for alloy [classification number]. [Name of the requester] will make a license available to such essential patent claims to applicants desiring to utilize the license for the purpose of implementing the standard. The license will be without compensation and under reasonable terms and conditions that are demonstrably free of any unfair discrimination.

(c) [Name of the requester] indicates that the patent holder (or third party authorized to make above assurances on its behalf) will include in any documents transferring ownership of patents subject to the assurance, provisions sufficient to ensure that the commitments in the assurance are binding on the transferee, and that the transferee will similarly include appropriate provisions in the event of future transfers with the goal of binding each successor-in-interest.

(d) [Name of the requester] indicates that it is intended to be binding on successors-in-interest regardless of whether such provisions are included in the relevant transfer documents.

The status for the patent shall be checked before publication of the document and the patent information included in the document will be updated as appropriate.

Neither AWS, the Committee on Filler Metals and Allied Materials, nor the relevant Subcommittee is required to consider the validity of any patent or patent application.

The published standard shall include a note as follows:

“NOTE: The user’s attention is called to the possibility that compliance with this standard may require use of an invention covered by patent rights.

By publication of this standard, no position is taken with respect to the validity of any such claim(s) or of any patent rights in connection therewith. If a patent holder has filed a statement of willingness to grant a license under these rights on reasonable and nondiscriminatory terms and conditions to applicants desiring to obtain such a license, then details may be obtained from the standards developer.”

(3) The request should be sent to the secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters.

(4) Upon receipt of the request, the secretary will:

- (a) Assign an identifying number to the request. This number will include the date the request was received.
- (b) Confirm receipt of the request and give the identification number to the person who made the request.
- (c) Send a copy of the request to the Chair of the Committee on Filler Metals and Allied Materials and the Chair of the particular Subcommittee involved.
- (d) File the original request.
- (e) Add the request to the log of outstanding requests.

(5) All necessary action on each request will be completed as soon as possible. If more than 12 months lapse, the secretary shall inform the requestor of the status of the request, with copies to the Chairs of the Committee and of the Subcommittee. Requests outstanding after 18 months shall be considered not to have been answered in a “timely manner.” The Secretary shall report these to the Chair of the Committee on Filler Metals and Allied Materials for action.

(6) The secretary shall include a copy of the log of all requests pending and those completed during the preceding year with the agenda for each of the Committee on Filler Metals and Allied Materials meetings. Any other publication of requests that have been completed will be at the discretion of the American Welding Society, as appropriate.

A2.3 Classification of Fluxes

A2.3.1 Fluxes are classified on the basis of the mechanical properties of the weld metal they produce with a certain classification of electrode under the test conditions called for in this specification. Refer to Tables 6, 6M, and 7, as applicable.

A2.3.2 It should be noted that flux of any specific trade designation may have many classifications. The number is limited only by the number of different electrode classifications and the condition of heat treatment (as-welded and postweld heat treated) with which the flux can meet the classification requirements. The flux marking lists at least one, and may list all, classifications to which the flux conforms. It should also be noted that the specific usability or operating characteristics of the various fluxes of the same classification often differ in one respect or another.

A2.3.3 Solid electrodes having the same classification are generally interchangeable when used with a specific flux; composite electrodes may not be.

A2.4 An international system for designating welding filler metals developed by the International Institute of Welding (IIW) has been adopted in many ISO specifications. Table A.1 shows those used in ISO 14171, *Welding consumables — Wire electrodes and wire-flux combinations for submerged arc welding of non-alloy and fine grain steels — Classification*, with comparable classifications in this specification.

A3. Acceptance

Acceptance of all fluxes and electrodes classified under this specification is in accordance with AWS A5.01M/A5.01, as the specification states. Any testing a purchaser requires of the supplier for fluxes or electrodes shipped in accordance with this specification needs to be clearly stated in the purchase order according to the provisions of AWS A5.01M/A5.01. In the absence of any such statement in the purchase order, the supplier may ship the fluxes or electrodes with whatever testing the supplier normally conducts on flux or electrode of that classification, as specified in Schedule F, Table 1, of AWS A5.01M/A5.01. Testing in accordance with any other Schedule in that table must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

Table A.1
Comparison of Electrode Designations^a

AWS A5.17/A5.17M Classification	ISO Designations	
	14171A	14171B
EL8	S1	SU11
EL8K	S1Si	SU12
EL12	S1	SU11
EM11K		
EM12	S2	SU22
EM12K	S2Si	SU21
EM13K	S2Si2	SU25
EM14K		SU24
EM15K		SU23
EH10K		SU32
EH11K		SU31
EH12K		SU42
EH14	S4	SU41

^a The electrodes listed on the same line are similar, but not identical.

A4. Certification

The act of placing the AWS specification and classification designations and optional supplemental designators, if applicable, on the packaging enclosing the product, or the classification on the product itself constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification. The only testing requirement implicit in this *certification* is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that material met the requirements of the specification. Representative material, in this case, is material from any production run of that classification using the same formulation. *Certification* is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the *certification* required by the specification is the classification test of *representative material* cited above, and the Manufacturer's Quality Assurance Program in AWS A5.01M/A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes in the atmosphere to which welding operators are exposed during welding. They are:

- (1) Dimensions of the space in which the welding is done (with special regard to the height of the ceiling).
- (2) Number of welding operators working in that space.
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes used.
- (4) The proximity of the welding operators to the fumes, as these fumes issue from the welding zone, and to the gases and dusts in the space in which they are working.
- (5) The ventilation provided to the space in which the welding is done.

A5.2 American National Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the Clause on Ventilation in that document. See also AWS F3.2, *Ventilation Guide for Weld Fume*, for more detailed descriptions of ventilation options.

A6. Description and Intended Use of Fluxes and Electrodes

A6.1 Types of Flux. Submerged arc welding fluxes are granular, fusible mineral compounds of various proportions and quantities, manufactured by any of several different methods. Some fluxes may contain intimately mixed metallic ingredients to deoxidize the weld pool. Any flux is likely to produce weld metal of somewhat different composition from that of the electrode used with it due to chemical reactions in the arc and sometimes to the presence of metallic ingredients in the flux. A change in the arc voltage during welding will change the quantity of flux interacting with a given quantity of electrode and may therefore change the composition of the weld metal. This latter change provides a means of describing fluxes as "neutral," "active," or "alloy."

A6.1.1 Neutral Fluxes. Neutral fluxes are those which will not produce any significant change in the weld metal chemical analysis as a result of a large change in the arc voltage and thus, the amount of flux melted. The primary use for neutral fluxes is in multipass welding, especially when the base metal exceeds 1 in [25mm] in thickness. Note the following considerations concerning neutral fluxes:

- (1) Since neutral fluxes contain little or no deoxidizers, they must rely on the electrode to provide deoxidation. Single-pass welds with insufficient deoxidation on heavily oxidized base metal may be prone to porosity, centerline cracking, or both.

(2) While neutral fluxes maintain the chemical composition of the weld metal even when the voltage is changed, the chemical composition of the weld metal may not be the same as that of the electrode. Some neutral fluxes decompose in the heat of the arc and release oxygen, resulting in a lower carbon value in the weld metal than the carbon content of the electrode itself. Some neutral fluxes contain manganese silicate, which can decompose in the heat of the arc and add manganese and silicon to the weld metal even though no metallic manganese or silicon was added to these particular fluxes. These changes in the chemical composition of the weld metal are fairly consistent, even when there are large changes in voltage.

(3) Even when a neutral flux is used to maintain the weld metal chemical composition through a range of welding voltages, weld metal properties such as strength level and impact properties can change because of changes in other welding parameters such as depth of fusion, heat input, and number of passes.

A6.1.2 Active Fluxes. Active fluxes are those which contain small amounts of manganese, silicon, or both. These deoxidizers are added to the flux to provide improved resistance to porosity and weld cracking caused by contaminants on or in the base metal. The primary use for active fluxes is to make single-pass welds, especially on oxidized base metal. Note the following considerations concerning active fluxes:

(1) Since active fluxes do contain some deoxidizers, the manganese, silicon, or both in the weld metal will vary with changes in arc voltage. An increase in manganese or silicon will increase the strength and hardness of the weld metal in multipass welds but may lower the impact properties. For this reason, the voltage may need to be more tightly controlled for multipass welds with active fluxes than when using neutral fluxes.

(2) Some fluxes are more active than others. This means they offer more resistance to porosity due to base metal surface oxides in single-pass welds than a flux which is less active, but may pose more problems in multipass welding.

A6.1.3 Alloy Fluxes. Alloy fluxes are those which can be used with a carbon steel electrode to make alloy weld metal. The alloys for the weld metal are added as ingredients in the flux. As with active fluxes, where the recovery of manganese and silicon is affected significantly by arc voltage, so with alloy fluxes, the recovery of alloy elements from the flux is affected significantly by the arc voltage. With alloy fluxes, the manufacturer's recommendations should be closely followed if desired weld metal compositions are to be obtained. The use of crushed slags generated from alloy flux is not recommended.

A6.1.4 Crushed Slags. Slag formed during the welding process that is subsequently crushed for use as a welding flux is defined as a *crushed slag*. This is different from a recycled flux which was never fused into a slag and can often be collected from a clean surface and reused without crushing. Crushed slags and blends of crushed slag with unused (virgin) flux may be classified as a welding flux under this specification, but shall not be considered to be the same as a virgin flux. Although it is possible to crush and reuse submerged arc slag as a welding flux, the crushed slag, regardless of any addition of virgin flux to it, is a new and chemically different flux. This is because the slag formed during submerged arc welding does not have the same chemical composition or welding characteristics as the virgin flux. Its composition is affected by the composition of the original flux, chemical reactions which occur due to the welding arc, the base metal and electrode compositions, and the welding parameters.

Blends of crushed slag with the original brand of virgin flux from which it was generated cannot be assumed to conform to the classification of either component, even when both the crushed slag and virgin flux conform to the same classification (except for the "S" designator). It shall be the responsibility of the crusher or fabricator partner who performs the blending to verify that any intended blend of crushed slag with the original brand of virgin flux is in full conformance with the classification requirements of this specification.

As with any flux product, the manufacturer (crusher) shall follow a detailed processing procedure with controlled input material, preparation, crushing, and blending, to ensure that a standard flux product meeting the requirements of the classification is attained.

Slag generated by a fabricator from a specific brand of flux under controlled welding conditions, segregated at all points during collection and processing from other sources of slag or contaminants, crushed by the fabricator or another crushing organization, possibly blended with a specific virgin flux and returned to the same fabricator for use as a welding flux is defined as closed-loop crushed slag.

Closed-loop crushed slags, or blends of closed-loop crushed slag with the original brand of virgin flux ensures better control of input material by virtue of the inherent partnering of the fabricator with the crusher. In some instances, these partners may be one and the same. When blending crushed slag with virgin flux, changes in the original virgin flux trade designation or in the blending ratio can affect the quality of the final product.

A6.2 Wall Neutrality Number. The Wall Neutrality Number (N) is a convenient measure of relative flux neutrality. The Wall Neutrality Number addresses fluxes and electrodes for welding carbon steel with regard to the weld metal manganese and silicon content. It does not address alloy fluxes. For a flux-electrode combination to be considered neutral, it should have an N value of 35 or lower. The lower the number, the more neutral the flux.

Determination of the Wall Neutrality Number can be done in accordance with the following:

(1) A weld pad of the type shown in Figure 2 is welded with the flux-electrode combination being tested. The welding parameters shall be as specified in Table 5 for the groove weld test assembly for the diameter of electrode being used.

(2) A second weld pad is welded using the same parameters, except that the arc voltage is increased by 8 volts.

(3) The top surface of each of the weld pads is ground or machined smooth to clean metal. Samples sufficient for analysis are removed by machining. Weld metal is analyzed only from the top (fourth) layer of the weld pad. The samples are analyzed separately for silicon and manganese.

(4) The Wall Neutrality Number depends on the change in silicon, regardless of whether it increases or decreases, and on the change in manganese, regardless of whether it increases or decreases. The Wall Neutrality Number is the absolute value (ignoring positive or negative signs) and is calculated as follows:

$$N = 100 (|\Delta\%Si| + |\Delta\%Mn|)$$

where $\Delta\%Si$ is the difference in silicon content of the two pads and $\Delta\%Mn$ is the corresponding difference in manganese content.

A6.3 Choice of Electrodes. In choosing an electrode classification for submerged arc welding of carbon steel, the most important considerations are the manganese and silicon contents of the electrode, the effect of the flux on recovery of manganese and silicon in the weld metal, whether the weld is to be single pass or multiple pass, and the mechanical properties expected of the weld metal.

A certain minimum weld metal manganese content is necessary to avoid centerline cracking. This minimum depends upon restraint of the joint and upon the weld metal composition. In the event that centerline cracking is encountered, especially with a low manganese electrode (see Table 1) and neutral flux, a change to a higher manganese electrode, a change to a more active flux, or both, may eliminate the problem.

Certain fluxes, generally considered to be neutral, tend to remove carbon and manganese to a limited extent and to replace these elements with silicon. With such fluxes, a silicon-killed electrode is often not necessary though it may be used. Other fluxes add no silicon and may therefore require the use of a silicon-killed electrode for proper wetting and freedom from porosity. The flux manufacturer should be consulted for electrode recommendations suitable for a given flux.

When welding single-pass fillet welds, especially on base metal with mill scale, it is important that the flux, electrode, or both, provide sufficient deoxidation to avoid unacceptable porosity. Silicon is a more powerful deoxidizer than manganese. In such applications, use of a silicon-killed electrode or of an active flux, or both may be essential. Again, the manufacturer's recommendations should be consulted.

The EM14K electrodes are alloyed with small additions of titanium, although they are considered as carbon steel electrodes. The titanium functions to improve strength and toughness under certain conditions of high heat input welding or PWHT. The manufacturer's recommendations should be consulted.

Electrodes of the EH12K classification are high manganese electrodes with the Mn and Si balanced to enhance mechanical properties on applications that require high deposition rates or multiple arc procedures, or both, in both the as-welded and PWHT conditions.

Composite electrodes are generally designed for a specific flux. The flux identification is required (see 16.7.1) to be marked on the electrode package. Before using a composite electrode with a flux not listed on the electrode package, the electrode producer should be contacted for recommendations. A composite electrode might be chosen for a higher melting rate and lower depth of fusion at a given current level than would be obtained under the same conditions with a solid electrode.

A6.4 Mechanical Properties of Submerged Arc Welds. Tables 6, 6M, and 7 list the mechanical properties required for flux-electrode classifications (the electrodes are classified in Tables 1 and 2 of this specification). The mechanical properties are determined from specimens prepared according to the procedures called for in this specification. The multiple pass procedure minimizes dilution from the base metal and thereby more accurately reflects the properties of the undiluted weld metal from each flux-electrode classification.

While electrodes are generally interchangeable, fluxes are not. For this reason, a classification system with standardized test methods is necessary to relate the fluxes and electrodes to the properties of their weld metal. Chemical reactions between the molten portion of the flux and electrode and dilution by the base metal all affect the composition of the weld metal.

The mechanical properties of a weld are a function of its chemical composition, cooling rate, and PWHT. High amperage, single-pass welds have a greater depth of fusion and hence, greater dilution by the base metal than lower current, multi-pass welds. Large, single-pass welds solidify and cool more slowly than the smaller weld beads of a multipass weld, and succeeding passes of a multi-pass weld subject the weld metal of previous passes to a variety of temperature and cooling cycles that alter the metallurgical structure of different portions of those beads. For these reasons, the properties of a single-pass weld may be different than those of a multi-pass weld made with the same electrode and flux.

The weld metal properties in this specification are determined in either the as-welded condition or after a PWHT, or both. For multiple pass classifications tested in the postweld heat treated condition ("P" designator, see Figure 1 or 1M, as applicable) the PWHT procedure is one hour at 1150°F [620°C] as prescribed in 9.4. Most of the weld metals are suitable for service in either condition, but the specification cannot cover all of the conditions that such weld metal may encounter in fabrication or service. Hence, the classifications in this specification require that the weld metals be produced and tested under specific conditions.

Procedures employed in practice may require voltage, amperage, type of current, and travel speeds that are considerably different from those required in this specification. In addition, differences encountered in electrode size, electrode composition, electrode extension, joint configuration, preheat temperature, interpass temperature, and PWHT can have a significant effect on the properties of the weld. Within a particular electrode classification, the electrode composition can vary sufficiently to produce variations in the mechanical properties of the weld deposit in both the as-welded and PWHT conditions. PWHT times in excess of the one hour used for classification purposes in this specification may have a major influence on the strength and toughness of the weld metal. The strength can be substantially reduced and the toughness increased or reduced. The user should be aware of this and should understand that the mechanical properties of carbon steel weld metal produced with other procedures than those required in this specification may differ from the properties required by Tables 6, 6M, and 7 of this specification.

A7. Special Tests

It is recognized that supplementary tests may be required for certain applications. In such cases, tests to determine specific properties such as corrosion resistance, scaling resistance or strength at elevated or cryogenic temperatures may be required. AWS A5.01M/A5.01 contains provisions for ordering such tests. This clause is included for the guidance of those who choose to specify such special tests. These tests may be conducted as agreed upon between the purchaser and supplier.

A8. Diffusible Hydrogen Test

A8.1 Hydrogen-induced cracking of weld metal or the heat-affected zone is not generally a problem with carbon steels containing 0.3% or less carbon, nor with lower-strength alloy steels. However, the fluxes and electrodes classified in this specification are sometimes used to join higher carbon steels or low-alloy, high-strength steels where hydrogen-induced cracking may be a serious problem.

A8.2 Submerged arc welding is generally considered to be a low-hydrogen welding process. As the weld metal or heat-affected zone strength or hardness increases, the concentration of diffusible hydrogen that will cause cracking under given conditions of restraint and heat input becomes lower. This cracking (or its detection) is usually delayed some hours after cooling. It may appear as transverse weld cracks, longitudinal cracks (especially in the root beads), and toe or under-bead cracks in the heat-affected zone.

A8.3 Since the available diffusible hydrogen level strongly influences the tendency towards hydrogen-induced cracking, it may be desirable to measure the diffusible hydrogen content resulting from welding with a particular flux-electrode combination. This specification has, therefore, included the use of optional designators for diffusible hydrogen to indicate the maximum average value obtained under a clearly defined test condition in AWS A4.3, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*.

A8.4 The user of this information is cautioned that actual fabrication conditions may result in different diffusible hydrogen values from those indicated by the designator.

A8.5 Fluxes and composite electrodes can be contaminated by the condensation of moisture from the atmosphere and in some cases can absorb significant moisture if stored in a humid environment in damaged or open packages, especially if unprotected for long periods of time. In extreme cases of high humidity, even overnight exposure of unprotected flux or composite electrode can lead to a significant increase of diffusible hydrogen. In the event the flux or composite electrode has been exposed, the manufacturer should be consulted regarding probable damage to its low hydrogen characteristics and possible reconditioning of the flux or composite electrode. Solid electrodes can also be contaminated under the same conditions. In this case, the moisture contamination is on the surface and can be seen as surface rust.

A8.6 Flux/electrode combinations for some classifications may not be available in the H16, H8, H4, or H2 diffusible hydrogen levels. The manufacturer of a given flux or composite electrode should be consulted for availability of products meeting these limits.

A9. General Safety Considerations

A9.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Annex Clause A5. Safety and health information is available from other sources, including, but not limited to Safety and Health Fact Sheets listed in A9.3, ANSI Z49.1 *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations. ANSI Z49.1 is published by the American Welding Society.

A9.2 Safety and Health Fact Sheets. The Safety and Health Fact Sheets listed below are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

A9.3 AWS Safety and Health Fact Sheets Index (SHF)

No.	Title
1	<i>Fumes and Gases</i>
2	<i>Radiation</i>
3	<i>Noise</i>
4	<i>Chromium and Nickel in Welding Fume</i>
5	<i>Electrical Hazards</i>
6	<i>Fire and Explosion Prevention</i>
7	<i>Burn Protection</i>
8	<i>Mechanical Hazards</i>
9	<i>Tripping and Falling</i>
10	<i>Falling Objects</i>
11	<i>Confined Spaces</i>
12	<i>Contact Lens Wear</i>
13	<i>Ergonomics in the Welding Environment</i>
14	<i>Graphic Symbols for Precautionary Labels</i>

No.	Title
15	<i>Style Guidelines for Safety and Health Documents</i>
16	<i>Pacemakers and Welding</i>
17	<i>Electric and Magnetic Fields (EMF)</i>
18	<i>Lockout/Tagout</i>
19	<i>Laser Welding and Cutting Safety</i>
20	<i>Thermal Spraying Safety</i>
21	<i>Resistance Spot Welding</i>
22	<i>Cadmium Exposure from Welding and Allied Processes</i>
23	<i>California Proposition 65</i>
24	<i>Fluxes for Arc Welding and Brazing: Safe Handling and Use</i>
25	<i>Metal Fume Fever</i>
26	<i>Arc Viewing Distance</i>
27	<i>Thoriated Tungsten Electrodes</i>
28	<i>Oxyfuel Safety: Check Valves and Flashback Arrestors</i>
29	<i>Grounding of Portable and Vehicle Mounted Welding Generators</i>
30	<i>Cylinders: Safe Storage, Handling, and Use</i>
31	<i>Eye and Face Protection for Welding and Cutting Operations</i>
33	<i>Personal Protective Equipment (PPE) for Welding and Cutting</i>
34	<i>Coated Steels: Welding and Cutting Safety Concerns</i>
35	<i>Welding Safety in Education and Schools</i>
36	<i>Ventilation for Welding and Cutting</i>
37	<i>Selecting Gloves for Welding and Cutting</i>
38	<i>Respiratory Protection Basics for Welding Operations</i>
39	<i>Welding Cables</i>
40	<i>Asbestos Hazards Encountered in the Welding and Cutting Environment</i>
41	<i>Combustible Dust Hazards in the Welding and Cutting Environment</i>
42	<i>Ultraviolet Reflectance by Paint</i>

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1/D1.1M:2012) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

B6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

INTENTIONALLY LEFT BLANK

SPECIFICATION FOR CARBON STEEL ELECTRODES AND RODS FOR GAS SHIELDED ARC WELDING



SFA-5.18/SFA-5.18M



(25)

(Identical with AWS Specification A5.18/A5.18M:2023. In case of dispute, the original AWS text applies.)

Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding

1. Scope

1.1 This specification prescribes requirements for the classification of carbon steel electrodes and rods (solid, composite stranded, and composite metal cored) for gas metal arc (GMAW), gas tungsten arc (GTAW), and plasma arc (PAW) welding. Rod is understood to include both cut lengths and spooled wires for GTAW or PAW.

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore each system must be used independently of the other without combining in any way when referring to weld metal properties. The specification with the designation A5.18 uses U.S. Customary Units. The specification A5.18M uses SI Units. The SI Units are shown within brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for the sizing of electrodes or packaging or both under the A5.18 or A5.18M specifications.

1.3 Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in the non-mandatory Annex Clauses A5 and A10.

Safety and Health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. Unless otherwise defined in this document, welding terms are as defined in AWS A3.0M/A3.0. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to or revisions of any of these publications do not apply.

American Welding Society (AWS) documents:

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

AWS A4.3-ADD1, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*

AWS A5.01M/A5.01 (ISO 14344 MOD), *Welding Consumables—Procurement of Filler Metals and Fluxes*

AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*

AWS A5.32M/A5.32 (ISO 14175 MOD), *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes*

AWS B4.0, *Standard Methods for Mechanical Testing of Welds*

ASTM International (ASTM) documents:

ASTM A36/A36M, *Standard Specification for Carbon Structural Steel*

ASTM A285/A285M, *Standard Specification for Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength*

ASTM A515/A515M, *Standard Specification for Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service*

ASTM A516/A516M, *Standard Specification for Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service*

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

ASTM E350, *Standard Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron*

ASTM E1032, *Standard Practice for Radiographic Examination of Weldments Using Industrial X-Ray Film*

ASTM E2033, *Standard Practice for Radiographic Examination Using Computed Radiography (Photostimulable Luminescence Method)*

ASTM E2698, *Standard Practice for Radiographic Examination Using Digital Detector Arrays*

American National Standards Institute (ANSI) document:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

International Organization for Standardization (ISO) documents:

ISO 15792-1:2020, *Welding Consumables — Test Methods — Part I: Test Methods for All-Weld Metal Test Specifications in Steel, Nickel and Nickel-Alloys*

ISO 80000-1:2022, *Quantities and Units — Part 1: General*

3. Classification

3.1 Solid Electrodes

3.1.1 The solid electrodes and rods covered by the A5.18 specification utilize a classification system based upon U.S. Customary Units and are classified according to the chemical composition of the electrode or rod as specified in Table 1 and according to the as-welded mechanical properties of the weld metal as specified in Table 4. The solid electrodes and rods covered by the A5.18M specification utilize a classification system based upon the International System of Units (SI) and are classified according to the chemical composition of the electrode or rod as specified in Table 1 and according to the as-welded mechanical properties of the weld metal as specified in Table 4. The GMAW test assembly in Figure 2, using a shielding gas as described in Table 4, is required and sufficient to classify products offered as an electrode or an electrode and rod.

The GTAW test assembly in Figure 2, using argon shielding gas, is required for products offered as a rod only. The GTAW test assembly may be requested in addition to the GMAW test assembly as an option and as agreed upon between the purchaser and supplier.

3.2 Composite Metal Cored and Composite Stranded Electrodes

3.2.1 The composite metal cored and stranded electrodes and rods covered by the A5.18 specification utilize a classification system based upon U.S. Customary Units and are classified according to the chemical composition of weld metal as specified in Table 2 and according to the as-welded mechanical properties of the weld metal as specified in Table 4. The composite metal cored and stranded electrodes and rods covered by the A5.18M specification utilize a classification system based upon the International System of Units (SI) and are classified according to the chemical composition of weld metal as specified in Table 2 and according to the as-welded mechanical properties of the weld metal as specified in Table 4. The GMAW test assembly in Figure 2, using the shielding gas specified in Table 4, is required to classify products offered as an electrode. The GTAW test assembly in Figure 2, using argon shielding gas, is required for products offered as a rod. Both test assemblies are required to classify composite metal cored and stranded filler metals as both an electrode and a rod (ERC-XX).

3.3 Electrodes and rods classified under one classification shall not be classified under any other classification in this specification, with the following two exceptions for composite stranded or composite metal cored electrodes. Electrodes classified as E70C-XC [E49C-XC] may also be classified as E70C-XM [E49C-XM] and electrodes classified as E70C-6X [E49C-6X] may also be classified as an E70C-12X [E49C-12X], or vice versa, provided the product meets all requirements for both classifications. Electrodes may be classified under A5.18 using U.S. Customary Units or under A5.18M using the International System of Units (SI), or they may be classified under both systems. Electrodes classified under either classification system must meet all requirements for classification under that system.

3.4 The welding electrodes and rods classified under this specification are intended for gas shielded arc welding, but that is not to prohibit their use with any other process (or any other shielding gas, or combination of shielding gases) for which they are found suitable. See 15.2 and A8.4 for information on optional shielding gas range designators.

4. Acceptance

Acceptance of the electrodes and rods shall be in accordance with the provisions of AWS A5.01M/A5.01 and the tests and requirements of this specification. See Clause A3 for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

5. Certification

By affixing the AWS specification and classification designations to the packaging or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification. See Clause A4 for further information concerning certification and the testing called for to meet this requirement.

6. Rounding Procedure

For purposes of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest 1000 psi (1 ksi) for tensile and yield strength for the U.S. Customary Unit standard and to the nearest 10 MPa for tensile and yield strength for the SI unit standard, and to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfill the requirements for the classification under test.

7. Summary of Tests

7.1 The tests required for each classification are specified in Table 3. The purpose of these tests is to determine the chemical composition of the solid filler metal or the chemical composition of the weld metal for composite filler metal, as well as the mechanical properties, and soundness of the weld metal. The base metal for the weld test assemblies, the welding and testing procedures to be employed, and the results required are given in Clauses 9 through 14.

7.2 The optional test for diffusible hydrogen in 15.1, Diffusible Hydrogen Test, is not required for classification (see Table 3, note e).

7.3 The optional tests for an oxygen equivalent gas range supplemental designator are not required for classification, but may be used to indicate that the electrode being classified meets the same classification requirements, including any optional supplemental designators when tested with other shielding gases. See 15.2 and Table 3, note f.

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Specimens for retest may be taken from the original test assembly or sample or from one or two new test assemblies or samples. For chemical analysis, retest need be only for those specific elements that failed to meet their requirement. If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that during preparation or after completion of any test it is clearly determined that prescribed or proper procedures were not followed in preparing the weld test assembly or test specimens or in conducting the test, the test shall be considered invalid without regard to whether the test was actually completed or whether the test results met or failed to meet the requirement. That test shall be repeated, following proper prescribed procedures. In that case, the requirement for doubling the number of test specimens does not apply.

9. Weld Test Assemblies

9.1 At least one weld test assembly is required and two may be required (depending on the electrode—solid as opposed to composite—and the manner in which the sample for chemical analysis is taken), as specified in Table 3. They are:

(1) The GMAW weld test assembly in Figure 2 for mechanical properties and soundness of the weld metal for both composite and solid electrodes, the GTAW weld test assembly in Figure 2 for mechanical properties and soundness of the weld metal for both composite and solid electrodes, or the weld test assembly in Figure 3 for mechanical properties of the single-pass electrode classification E70C-GSX [E49C-GSX].

(2) The weld pad in Figure 4 for chemical analysis of the weld metal from composite stranded and composite metal cored electrodes.

The sample for chemical analysis of weld metal from composite electrodes may be taken from the reduced section of the fractured all-weld-metal tension test specimen or from the corresponding location (or any location above it) in the weld test assembly in Figure 2, thereby avoiding the need to make a weld pad. In case of dispute, this sample from the groove weld in Figure 2 (including the tension specimen) shall be the referee method.

Chemical analysis of weld metal from composite stranded and composite metal cored electrodes designated for single pass applications should not be obtained from the weld test assembly shown in Figure 3 due to the high amount of base metal dilution.

9.2 Preparation of each weld test assembly shall be as prescribed in 9.3 and 9.4. The base metal for each assembly shall be as required in Table 5 and shall meet the requirements of the ASTM specification shown there or an equivalent specification. Testing of the weld test assembly shall be as prescribed in Clauses 10 through 14.

9.3 Weld Pad. A weld pad shall be prepared using composite stranded and composite metal cored electrodes as shown in Figure 4, except when, as permitted in 9.1, the sample for analysis is taken from the weld test assembly (Figure 2) or the fractured all-weld-metal tension test specimen. Base metal of any convenient size that will satisfy the minimum require-

ments of Figure 4 and is of a type specified in Table 5, shall be used as the base for the weld pad. The surface of the base metal on which the filler metal is deposited shall be clean. The pad shall be welded in the flat position using test conditions as specified in Table 6. Multiple layers shall be deposited to obtain undiluted weld metal (4 layers minimum thickness). The electrode size shall be 0.045 in or 1/16 in [1.2 mm or 1.6 mm] (or the size that the manufacturer produces that is closest to one of these, if these sizes are not produced). The preheat temperature shall not be less than 60 °F [15 °C] and the interpass temperature shall not exceed 325 °F [165 °C]. Any slag shall be removed after each pass. The pad may be quenched in water between passes (temperature of the water not specified). The dimensions of the completed pad shall be as shown in Figure 4. Testing of this assembly shall be as specified in 10.2 and 10.3. The results shall meet the requirements of 10.4.

9.4 Groove Weld

9.4.1 For Multiple Pass Classifications. For all classifications except E70C-GS(X) [E49C-GS(X)], a GMAW and/or GTAW test assembly shall be prepared and welded as specified in Figure 2 and Table 6 or 7, using base metal of the appropriate type specified in Table 5.

The electrode diameter used for the GMAW test assembly shall be 0.045 in or 1/16 in [1.2 mm or 1.6 mm] (or the diameter the manufacturer produces that is closest to one of these, if these diameters are not produced) and welded as specified in Table 6. Welding shall use a constant voltage welding process on direct current, electrode positive polarity with spray or globular transfer except E70C-8X [E49C-8X] shall be welded using direct current, electrode negative polarity. The heat input per pass range in Table 6 must be followed for all electrode classifications.

The rod diameter used for the GTAW test assembly shall be 3/32 in or 1/8 in [2.4 mm or 3.2 mm] (or the diameter the manufacturer produces that is closest to one of these, if these diameters are not produced). The GTAW test assembly shall be prepared and welded, when required in 3.1 or 3.2 as specified in Figure 2 and Table 7.

Welding shall be in the flat position, and the weld test assembly shall be restrained or preset during welding to prevent warpage in excess of 5°. A completed weld assembly that is more than 5° out of plane shall be discarded. Test assemblies shall not be straightened.

The weld test assembly shall be tack welded at room temperature and welding shall begin at that temperature (60 °F [15 °C] minimum). Welding shall continue until the weld test assembly has reached a maximum interpass temperature of 325 °F [165 °C], measured by temperature indicating crayons or surface thermometers at the location shown in Figure 2. For the remainder of the weld, a minimum preheat temperature of 275 °F [135 °C] and maximum interpass temperature of 325 °F [165 °C] shall be maintained. Should it be necessary to interrupt welding, the weld test assembly shall be allowed to cool in still air at room temperature. The weld test assembly shall be preheated to a temperature of 300 °F $\pm$ 25 °F [150 °C $\pm$ 15 °C] before welding is resumed.

When welding has been completed and the weld test assembly has cooled in still air at room temperature, the weld test assembly shall be prepared and tested as specified in Clauses 11, Radiographic Test; 12, Tension Test; and 14, Impact Test. All testing will be performed in the as-welded condition except for the optional aging specified in 12.1.1.

9.4.2 For Single-Pass Classification. For the single-pass electrode classification E70C-GSX [E49C-GSX] a weld test assembly, using base metal as specified in Table 5 and shielding gas as specified in Figure 1, shall be prepared and welded as shown in Figure 3. After tack welding the plates at each end, the weld test assembly shall be welded in the flat position, with one bead on each side. Welding shall begin with the weld test assembly at room temperature (60 °F [15 °C] minimum). When the weld bead has been completed on one side, the weld test assembly shall be turned over and a second bead deposited on the second side in the flat position, as shown in Figure 3. This sequence shall not be interrupted. The electrode diameter shall be 0.045 in or 1/16 in [1.2 mm or 1.6 mm] (or the diameter the manufacturer produces that is closest to one of these, if these diameters are not produced).

After welding has been completed and the weld test assembly has cooled in still air to room temperature, the weld test assembly shall be prepared and tested as specified in 12.2 and Clause 13, Bend Test. All testing shall be performed in the as-welded condition except for the optional aging specified in 13.2.

10. Chemical Analysis

10.1 A sample of the solid electrode or rod stock from which it is made shall be prepared for chemical analysis. Solid filler metal, when analyzed for elements that are present in a coating (copper flashing, for example), shall be analyzed without removing the coating. When the filler metal is analyzed for elements other than those in the coating, the coating shall be removed if its presence affects the results of the analysis for the other elements. Rod stock analyzed for elements not in the coating may be analyzed prior to reducing the rod to finished electrode diameter and applying the coating.

10.2 For composite (stranded or metal cored) filler metals, the sample for analysis shall be taken from weld metal produced with the filler metal and shielding gas with which it is classified.

The sample shall be taken from a weld pad prepared in accordance with 9.3 or from the reduced section of the fractured tension test specimen, or from a corresponding location or any location above it along the weld centerline in the groove weld in Figure 2. In case of dispute, the area of the groove weld described in 9.1 (including the tension specimen) is the referee method.

The top surface of the pad described in 9.3 and shown in Figure 4 shall be removed and discarded. A sample for analysis shall be obtained from the underlying metal, no closer than 3/8 in [9.5 mm] above the surface of the base metal in Figure 4 by any means that will not affect the chemical composition. The sample shall be free of slag.

When the sample is taken from the groove weld or the reduced section of the fractured tension test specimen, that material shall be prepared for analysis by any means that will not affect the chemical composition.

10.3 The sample obtained as specified in 10.1 or 10.2 shall be analyzed by accepted analytical methods. The referee method shall be ASTM E350.

10.4 The results of the analysis shall meet the requirements of Table 1 for solid electrodes or Table 2 for composite electrodes for the classification of electrode under test.

11. Radiographic Test

11.1 The groove weld described in 9.4 and shown in Figure 2, shall be radiographed to evaluate the soundness of the weld metal. In preparation for radiography, the backing shall be removed and both surfaces of the weld shall be machined or ground smooth and flush with the original surfaces of the base metal or with a uniform reinforcement not exceeding 3/32 in [2.5 mm]. It is permitted on both sides of the test assembly to remove base metal to a depth of 1/16 in [1.5 mm] nominal below the original base metal surface in order to facilitate backing and/or buildup removal. Thickness of the weld metal shall not be reduced by more than 1/16 in [1.5 mm], so that the thickness of the prepared radiographic test specimen equals at least the thickness of the base metal minus 1/16 in [1.5 mm].

Both surfaces of the test assembly in the area of the weld shall be smooth enough to avoid difficulty in interpreting the radiograph.

11.2 The weld shall be radiographed in accordance with one of the following. The quality level of inspection shall be 2-2T.

(1) Film Radiography: ASTM E1032.

(2) Computed Radiography (CR): ASTM E2033 and the requirements of ASTM E1032 except where CR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2033, refers to phosphor imaging plate.

(3) Digital Radiography (DR): ASTM E2698 and the requirements of ASTM E1032 except where DR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2698, refers to digital detector array (DDA).

11.3 The soundness of the weld metal meets the requirements of this specification if the radiograph shows:

- (1) no cracks, no incomplete fusion, and no incomplete penetration; and
- (2) no rounded indications in excess of those permitted by the radiographic standards in Figure 5.

In evaluating the radiograph, 1 in [25 mm] of the weld on each end of the test assembly shall be disregarded.

A rounded indication is an indication on the radiograph whose length is no more than three times its width. Rounded indications may be circular or irregular in shape and they may have tails. The size of a rounded indication is the largest dimension of the indication, including any tail that may be present. The indication may be of porosity or slag. Indications whose largest dimension does not exceed 1/64 in [0.4 mm] shall be disregarded. Test assemblies with indications larger than the largest indications permitted in the radiographic standards (Figure 5) do not meet the requirements of this specification.

12. Tension Test

12.1 One all-weld-metal tension test specimen, as specified in the Tension Test clause of AWS B4.0, shall be machined from the welded test assembly described in 9.4.1 and shown in Figure 2, as required in Table 3. The all-weld-metal tension specimen, when machined from the GMAW test assembly shown in Figure 2, shall have a nominal diameter of 0.50 in [12.5 mm] and a nominal gage length-to-diameter ratio of 4:1. The tension specimen, when machined from the GTAW test assembly shown in Figure 2, shall have a nominal diameter of 0.350 in [9 mm] and a nominal gage length-to-diameter ratio of 4:1.

12.1.1 For composite electrode classifications, the welded test assembly or tension test specimen may be aged at a temperature not to exceed 220 °F [105 °C] for up to 48 hours then allowed to cool to room temperature. In case of dispute, aging the tension specimen shall be the referee method. No aging shall be performed prior to radiographic examination. Refer to A8.3 for a discussion on the purpose of aging.

12.1.2 The tension test specimen shall be tested in the manner described in the Tension Test clause of AWS B4.0.

12.1.3 The results of the tension test shall meet the requirements specified in Table 4. Test reports shall indicate if the specimen was tested in the aged condition (composite electrodes only).

12.2 One transverse rectangular tension test specimen, as specified in the Tension Tests clause of AWS B4.0, shall be machined from the weld test assembly described in 9.4.2 and shown in Figure 3, as required in Table 3. The transverse tension specimen shall have a nominal thickness of 1/4 in [6.5 mm] and reduced width of 1-1/2 in [38 mm] and a minimum length of 8 in [200 mm]. Other dimensions of the transverse tension test specimen shall be as specified in the Tension Test clause of AWS B4.0.

12.2.1 The specimen shall be tested in the as-welded (unaged) condition in the manner described in the Tension Test clause of AWS B4.0.

12.2.2 The results of the transverse tension test shall meet the requirements specified in Table 4. A test specimen that fractures in the base metal shall be considered to have met those requirements.

13. Bend Test

13.1 For single pass electrode classifications, one longitudinal face bend test specimen, as required in Table 3, shall be machined from the welded test assembly described in 9.4.2 and shown in Figure 3. The dimensions of the specimen shall be as shown in Figure 3. Other dimensions of the longitudinal bend test specimen shall be as specified in the Bend Test clause of AWS B4.0.

13.2 The welded test assembly or bend specimen may be aged at 200 °F to 220 °F [95 °C to 105 °C] for up to 48 hours, then allowed to cool to room temperature. In case of dispute, aging the bend specimen shall be the referee method. Refer to A8.3 for a discussion on the purpose of aging.

13.3 The bend specimen shall be tested in the manner described in the Bend Test clause of AWS B4.0 by bending it uniformly through 180° over a 3/4 in [19 mm] radius, using any suitable jig, as specified in the Bend Test clause of AWS B4.0. Positioning of the face bend specimens shall be such that the face that was welded last is in tension.

13.4 Each specimen, after bending, shall conform to the 3/4 in [19 mm] radius, with appropriate allowance for spring-back, and the weld metal shall not contain openings in excess of 1/8 in [3.2 mm] on the convex surface.

14. Impact Test

14.1 Five Charpy V-notch impact test specimens, as specified in the Fracture Toughness Testing clause of AWS B4.0, shall be machined from the weld test assembly shown in Figure 2, for those classifications for which impact testing is required in Table 3.

The Charpy V-notch specimens shall have the notched surface and the surface to be struck parallel with each other within 0.002 in [0.05 mm]. The other two surfaces shall be square with the notched or struck surface within 10 minutes of a degree. The notch shall be smoothly cut and be square with the longitudinal edge of the specimen within one degree. Test specimens shall not contain metal that has been affected thermally as a result of cutting or preparation.

The geometry of the notch shall be measured on at least one specimen in a set of five specimens. Measurement shall be done at a minimum 10X magnification. The correct location of the notch shall be verified by etching before or after machining.

14.2 The five specimens shall be tested in accordance with the Fracture Toughness Test section of AWS B4.0. The test temperature shall be at or below the temperature specified in Table 4, for the classification under test. The actual temperature used for testing shall be listed on the certification documentation when issued.

14.3 In evaluating the test results, the lowest and the highest values obtained shall be disregarded. Two of the remaining three values shall equal or exceed the specified 20 ft-lbf [27 J] energy level. One of the three may be lower, but not lower than 15 ft-lbf [20 J], and the average of the three shall not be less than the required 20 ft-lbf [27 J] energy level.

14.4 For classifications with the “N” (nuclear) designation, three additional specimens shall be prepared. These specimens shall be tested at a temperature range of 60 °F to 90 °F [15 °C to 32 °C]. Two of the three shall equal or exceed 75 ft-lbf [100 J], and the third shall not be lower than 70 ft-lbf [95 J]. The average of the three shall equal or exceed 75 ft-lbf [100 J].

15. Optional Supplemental Tests and Requirements

Provisions are made in this specification for four tests listed below which are optional and not required for classification. Conformance to these supplemental requirements is indicated by a specific designator (HX, OE H/L, A, or N) which is added to the classification as shown in Figure 1.

15.1 “H” Optional Supplemental Designator (Diffusible Hydrogen)

15.1.1 For each electrode to be designated by an optional supplemental diffusible hydrogen designator, the 0.045 in or 1/16 in [1.2 mm or 1.6 mm] size, (or the size that the manufacturer produces that is closest to one of these sizes if the specified sizes are not produced), shall be tested according to one of the methods given in AWS A4.3-ADD1. Based upon the average value of test results which satisfy the requirements of Table 8, the appropriate diffusible hydrogen designator may be added at the end of the classification.

15.1.2 Testing shall be done with electrodes in the as-received condition, unless the manufacturer recommends otherwise. Conditioning can be considered to be any special preparation or procedure, such as baking the electrode. If the electrodes are conditioned, that fact, along with the method used for conditioning and the time and temperature involved in the conditioning shall be noted on the certificate of conformance.

15.1.3 For purposes of certifying compliance with diffusible hydrogen requirements, the reference atmospheric condition shall be an absolute humidity of ten (10) grains of moisture/lb [1.43 g/kg] of dry air at the time of welding. The actual atmospheric conditions shall be reported along with the average value for the tests, according to AWS A4.3-ADD1.

15.1.4 When the absolute humidity equals or exceeds the reference condition at the time of preparation of the test assemblies, the test shall be acceptable as demonstrating compliance with the requirements of this specification, provided the actual test results satisfy the diffusible hydrogen requirements for the applicable designator. If the actual test results for an electrode meet the requirements for the lower or lowest hydrogen designator specified in Table 8, the electrode also meets the requirements for all higher hydrogen designations in Table 8 without the need to retest.

15.2 Optional Supplemental Shielding Gas Range Designators for GMAW Electrodes. This test is an optional test and is not required for classification. The “OE H/L” designation added to the end of the classification (see Figure 1) does not constitute a part of the electrode classification. Preparation and testing shall be as prescribed in Clauses 9 through 14, using the shielding gases of the appropriate oxygen equivalent as shown in Table 9 based on the optional designators to be applied. Oxygen equivalent shall be calculated as shown in Equation 1, with the percentages in volume percent. Testing shall also be conducted as prescribed in 15.1 if an optional “HX” diffusible hydrogen designation is applied. Test results for all classification tests, including any optional supplemental designators applied, shall meet the requirements for the classification under test.

Equation 1: % Oxygen Equivalent of a shielding gas (OE) = % O₂ in the shielding gas + (0.5 × % CO₂ in the shielding gas)

A minimum of two shielding gases must be tested, but one of the tests may be the test(s) conducted for electrode classification. All the same tests shall be conducted and all the same requirements shall be met with those gases as those for the electrode classification and any optional, supplemental designators. It is not required for the welding conditions to be identical for each of the gases tested, but all the testing results shall meet all the requirements of this specification for the classification including any optional supplemental designators applied to the classification. The designators for the highest and lowest oxygen equivalent shielding gases that were tested and met all requirements may be added to an electrode classification, as shown in Figure 1 and note e of Table 9. See A8.4 in Annex A for more information on this optional supplemental designator.

15.3 Optional Designator for S-6 Electrodes and Rods Meeting 1.60% Manganese and 1.0% Si Maximums. Electrodes classified as ER70S-6 [ER49S-6] or rods classified as R70S-6 [R49S-6] that also meet 1.60% manganese and 1.0% silicon maximum may have an optional supplemental designator “A” added after the “S-6” in their classification indicating conformance to ASME Section IX, A-No.1 weld deposit composition. See Figure 1 and A8.5 for more information on this optional supplemental designator.

15.4 “N” Optional Supplemental Designator for Electrodes and Rods for Nuclear Applications. The addition of the letter “N” as an optional supplemental designator to a classification indicates that the electrode is intended for certain very special welds in nuclear applications. These welds are found in the core belt region of the reactor vessel. This region is subject to intense neutron radiation, and it is necessary, therefore, that the phosphorus and copper contents of the weld metal be limited in order to resist neutron radiation-induced embrittlement. See Table 1, note e. It is also necessary that the weld metal has a high upper shelf energy level in order to withstand some embrittlement, yet remain serviceable over the years.

16. Method of Manufacture

The electrodes and rods classified according to this specification may be manufactured by any method that will produce electrodes and rods that meet the requirements of this specification.

17. Standard Sizes

Standard sizes for electrodes and rods in the different package forms (straight lengths, coils with support, coils without support, spools, and drums) are as specified in AWS A5.02/A5.02M.

18. Finish and Uniformity

Finish and uniformity shall be as specified in AWS A5.02/A5.02M.

19. Standard Package Forms

Standard package forms are straight lengths, coils with support, coils without support, spools, and drums. Standard package dimensions and weights and other requirements for each form shall be as specified in AWS A5.02/A5.02M.

20. Winding Requirements

20.1 Winding requirements shall be as specified in AWS A5.02/A5.02M.

20.2 The cast and helix of filler metal shall be as specified in AWS A5.02/A5.02M.

20.3 The cast and helix of solid filler metal on 4 in [100 mm] spools shall be such that a specimen long enough to produce a single loop, when cut from the spool and laid unrestrained on a flat surface, will:

- (1) form a circle not less than 4 in [100 mm] nor more than 9 in [230 mm] in diameter
- (2) rise above the flat surface no more than 1/2 in [13 mm] at any location

20.4 The cast and helix of solid filler metal on all other package forms shall be such that a specimen long enough to produce a single loop, when cut from the package and laid unrestrained on a flat surface, will:

- (1) form a circle not less than 12 in [300 mm] in diameter for wire diameters of 0.030 in [0.8 mm] and smaller, or form a circle not less than 15 in [380 mm] in diameter for wire diameters 0.035 in [0.9 mm] and larger
- (2) rise above the flat surface no more than 1 in [25 mm] at any location

Certain bulk packages may contain wire that has been elastically twisted or otherwise treated to provide straight wire feed. Wire from these packages will not form a circle when cut. Traditional cast and helix measurements may have no relevance. Any method of wire form inspection shall be as agreed upon between purchaser and supplier.

21. Filler Metal Identification

Filler metal identification (including marking of bare straight lengths of filler rod), product information, and the precautionary information shall be as specified in AWS A5.02/A5.02M.

22. Packaging

Electrodes and rods shall be suitably packaged to ensure against damage during shipment and storage under normal conditions.

23. Marking of Packages

23.1 The product information (as a minimum) that shall be legibly marked so as to be visible from the outside of each unit package shall be as specified in AWS A5.02/A5.02M.

23.2 The appropriate precautionary information given in ANSI Z49.1, latest edition (as a minimum) or its equivalent, shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages within a larger package. Typical examples of "warning labels" and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

Table 1
Chemical Composition Requirements for Solid Electrodes and Rods

AWS Classification ^a A5.18 [A5.18M]	UNS Number ^b	Weight Percent ^{c,d}												
		C	Mn	Si	P ^e	S	Ni	Cr	Mo	V	Cu ^{e,f}	Ti	Zr	Al
ER70S-2 [ER49S-2]	K10726	0.07	0.90 to 1.40	0.40 to 0.70	0.025	0.035	0.15	0.15	0.15	0.03	0.50	0.05 to 0.15	0.02 to 0.12	0.05 to 0.15
ER70S-3 [ER49S-3]	K11022	0.06 to 0.15	0.90 to 1.40	0.45 to 0.75	0.025	0.035	0.15	0.15	0.15	0.03	0.50	—	—	—
ER70S-4 [ER49S-4]	K11132	0.06 to 0.15	1.00 to 1.50	0.65 to 0.85	0.025	0.035	0.15	0.15	0.15	0.03	0.50	—	—	—
ER70S-6 ^g [ER49S-6 ^g]	K11140	0.06 to 0.15	1.40 to 1.85	0.80 to 1.15	0.025	0.035	0.15	0.15	0.15	0.03	0.50	—	—	—
ER70S-7 [ER49S-7]	K11125	0.07 to 0.15	1.50 to 2.00 ^h	0.50 to 0.80	0.025	0.035	0.15	0.15	0.15	0.03	0.50	—	—	—
ER70S-8 [ER49S-8]	—	0.02 to 0.10	1.40 to 1.90	0.55 to 1.10	0.025	0.035	0.15	0.15	0.15	0.03	0.50	Ti + Zr: 0.10 to 0.30		—
ER70S-9 [ER49S-9]	—	0.03 to 0.12	1.25 to 2.20	0.15	0.025	0.035	0.50	0.15	0.15	0.03	0.50	Ti + Zr: 0.05 to 0.25		—
ER70S-G [ER49S-G]	—	Not Specified ⁱ												

^a Refer to Figure 1 for an explanation of the classification system.

^b SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System*.

^c Single values are maximum.

^d Analysis for boron is required to be reported if intentionally added, or if it is known to be present at levels greater than 0.0010%.

^e The letter "N" as an optional suffix to a classification indicates that the weld metal is intended for the core belt region of nuclear reactor vessels, as described in 15.4. This suffix will change the limits on the phosphorus and copper as follows: P = 0.012% maximum, Cu = 0.08% maximum.

^f Copper due to any coating on the electrode or rod plus the copper content of the filler metal itself shall not exceed the stated 0.50% maximum.

^g The letter "A" as an optional suffix (ER70S-6A [ER49S-6A]) designates an electrode or rod of this classification that also meets the A-No. 1 requirement of 1.60% Mn maximum and 1.0% Si maximum. See 15.3 and A8.5.

^h In this classification, the maximum manganese may exceed 2.00%. If it does, the maximum carbon must be reduced 0.01% for each 0.05% increase in manganese or part thereof.

ⁱ Chemical requirements are not specified but there shall be no intentional adding of Ni, Cr, or Mo greater than 0.15% maximum, or V greater than 0.03% maximum. Composition shall be reported. Requirements are those agreed upon between the purchaser and the supplier.

Table 2
Chemical Composition Requirements for Weld Metal from Composite Electrodes

AWS Classification ^{a,b} A5.18 [A5.18M]	UNS Number ^c	Weight Percent ^{d,e,f}									
		C	Mn	Si	P	S	Ni	Cr	Mo	V	Cu
E70C-3X [E49C-3X]	W07703	0.12	1.75	0.90	0.03	0.03	0.50	0.20	0.30	0.08	0.50
E70C-6X [E49C-6X]	W07706	0.12	1.75	0.90	0.03	0.03	0.50	0.20	0.30	0.08	0.50
E70C-8X [E49C-8X]	—	0.12	1.75	0.90	0.03	0.03	0.50	0.20	0.30	0.08	0.50
E70C-12X [E49C-12X]	—	0.12	1.60	0.90	0.03	0.03	0.50	0.20	0.30	0.08	0.35
E70C-GX [E49C-GX]	Not Specified ^g										
E70C-GSX [E49C-GSX]	Not Required ^h										

^a Refer to Figure 1 for an explanation of the designation system.

^b Shielding gas shall be as designated in Figure 1 and Table 4. Electrodes may also be classified with different shielding gases by using the optional supplemental OE H/L designator. See 15.2 and A8.4.

^c SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System*.

^d Single values are maximums.

^e Analysis for boron is required to be reported if intentionally added, or if it is known to be present at levels greater than 0.0010%.

^f The sum of Ni, Cr, Mo, and V shall not exceed 0.50%.

^g The composition shall be reported. The requirements are as agreed upon between purchaser and supplier.

^h For single pass classifications the composition of weld metal is not required. Dilution with the base material in single pass welds is usually quite high.

Table 3
Required Tests

AWS Classification ^a A5.18 [A5.18M]	Chemical Analysis		Radiographic Test	Tension Test	Bend Test	Impact Test	Optional Diffusible Hydrogen and Shielding Gas Range Tests
	Electrode	Weld Metal					
Solid Electrodes							
ER70S-2 [ER49S-2]	Required	Not Required	Required	Required	Not Required	Required	(e, f)
ER70S-3 [ER49S-3]							
ER70S-6 [ER49S-6]							
ER70S-7 [ER49S-7]							
ER70S-8 [ER49S-8]							
ER70S-9 [ER49S-9]							
ER70S-4 [ER49S-4]	Required	Not Required	Required	Required	Not Required	Not Required	(e, f)
ER70S-G [ER49S-G]	Required	Not Required	Required	Required	Not Required	(d)	
Composite Electrodes							
E70C-3X [E49C-3X]	Not Required	Required	Required	Required	Not Required	Required	(e, f)
E70C-6X [E49C-6X]							
E70C-8X [E49C-8X]							
E70C-12X [E49C-12X]							
E70C-GX [E49C-GX]	Not Required	Required	Required	Required	Not Required	(d)	
E70C-GSX ^b [E49C-GSX ^b]	Not Required	Not Required	Not Required	Required ^c	Required	Not Required	

^a Refer to Figure 1 for an explanation of the classification system.

^b Intended for single-pass welding.

^c Transverse tension test. All others are all-weld-metal tension tests.

^d Not specified but as agreed upon between purchaser and supplier.

^e Optional diffusible hydrogen test is required only when specified by the purchaser or when the manufacturer puts the diffusible hydrogen designator on the label. See also A2.2 and A8.2.

^f Optional Shielding Gas Range testing is required only when specified by the purchaser or when the manufacturer puts an optional supplemental shielding gas range designator on the label. See also A8.4.

Table 4
Mechanical Property Requirements for GMAW and GTAW Tests

AWS Classification ^a A5.18 [A5.18M]	Shielding Gas ^{b,c,d}	Tensile Strength ^e ksi [MPa]	Yield Strength ^f (minimum) ksi [MPa]	Elongation ^g Percent (minimum)	Energy Absorbed ^{h,i} (minimum average) A5.18 [A5.18M]
ER70S-2 [ER49S-2]	CO ₂ (C1)	70 [490]	58 [400]	22	20 ft-lbf @ -20 °F [27 J @ -30 °C]
ER70S-3 [ER49S-3]	CO ₂ (C1)	70 [490]	58 [400]	22	20 ft-lbf @ 0 °F [27 J @ -20 °C]
ER70S-4 [ER49S-4]	CO ₂ (C1)	70 [490]	58 [400]	22	Not Required
ER70S-6 [ER49S-6] ER70S-7 [ER49S-7] ER70S-8 [ER49S-8]	CO ₂ (C1)	70 [490]	58 [400]	22	20 ft-lbf @ -20 °F [27 J @ -30 °C]
ER70S-9 [ER49S-9]	85%–95% Ar/ balance CO ₂ (M20)	70 [490]	58 [400]	22	20 ft-lbf @ -20 °F [27 J @ -30 °C]
ER70S-G [ER49S-G]	(j)	70 [490]	58 [400]	22	(j)
Composite Electrodes					
E70C-3C [E49C-3C]	CO ₂ (C1)	70 [490]	58 [400]	22	20 ft-lbf @ 0 °F [27 J @ -20 °C]
E70C-3M [E49C-3M]	75%–80% Ar/ balance CO ₂ (M21)	70 [490]	58 [400]	22	20 ft-lbf @ 0 °F [27 J @ -20 °C]
E70C-6C [E49C-6C] E70C-8C [E49C-8C]	CO ₂ (C1)	70 [490]	58 [400]	22	20 ft-lbf @ -20 °F [27 J @ -30 °C]
E70C-6M [E49C-6M] E70C-8M [E49C-8M]	75%–80% Ar/ balance CO ₂ (M21)	70 [490]	58 [400]	22	20 ft-lbf @ -20 °F [27 J @ -30 °C]
E70C-12C [E49C-12C]	CO ₂ (C1)	70–90 [490–620]	58 [400]	22	20 ft-lbf @ -20 °F [27 J @ -30 °C]
E70C-12M [E49C-12M]	75%–80% Ar/ balance CO ₂ (M21)	70–90 [490–620]	58 [400]	22	20 ft-lbf @ -20 °F [27 J @ -30 °C]
E70C-GX [E49C-GX]	(j)	70 [490]	58 [400]	22	(j)
E70C-GSX [E49C-GSX]	(j)	70 [490]	Not Required	Not Required	Not Required

^a Refer to Figure 1 for an explanation of the classification system.

^b The designations for the shielding gases (in parentheses) are from AWS A5.32M/A5.32.

^c The use of a particular shielding gas for classification purposes shall not be construed to restrict the use of other gas mixtures. A filler metal tested with other gas blends may result in weld metal having different mechanical properties.

^d Testing with 100% Ar shielding is required when classification testing is based upon GTAW only.

^e Tensile strengths are minimum unless specified otherwise.

^f Yield strength measured at 0.2% offset.

^g Percent elongation in 2 in [50 mm] gage length (or 1.4 in [36 mm] gage length for the 0.350 in [9.0 mm] tension specimen required in 12.1).

^h For classifications with the “N” (nuclear) optional supplemental designator, three additional specimens shall be tested at a temperature range of 60 °F to 90 °F [15 °C to 32 °C]. Two of the three shall equal, or exceed, 75 ft-lbf [100 J], and the third shall not be lower than 70 ft-lbf [95 J]. The average of the three shall equal, or exceed, 75 ft-lbf [100 J].

ⁱ Filler metal classification testing to demonstrate conformance to a specified minimum acceptable level for impact testing, i.e., minimum energy at specified temperature, can be met by testing and meeting the minimum energy requirement at any lower temperature. In these cases, the actual temperature used for testing shall be listed on the certification documentation when issued.

^j Not specified (as agreed upon between purchaser and supplier).

Table 5
Base Metal for Test Assemblies

AWS Classifications	ASTM Specification	UNS Number ^a
All except E70C-GSX [E49C-GSX]	A36 A285 Grade C A515 Grade 70, or A516 Grade 70	K02600 K02801 K03101 K02700
E70C-GSX [E49C-GSX]	A515 Grade 70, or A516 Grade 70	K03101 K02700

^a Refer to SAE-HS-1088/ASTM DS-58H, *Metals & Alloys in the Unified Numbering System*.

Table 6
GMAW Groove Weld Assembly Test Conditions^{a, b}

Standard Size ^c	0.045 in [1.2 mm]	1/16 in [1.6 mm]
Heat Input per Pass ^d	25 kJ/in to 60 kJ/in [1.0 kJ/mm to 2.4 kJ/mm]	30 kJ/in to 65 kJ/in [1.2 kJ/mm to 2.6 kJ/mm]
Shielding Gas ^e	as specified in Table 4	
Contact-tip-to-work distance ^f	1/2 in to 1 in [12 mm to 25 mm]	

^a Welding shall use DCEP (Direct Current Electrode Positive) with spray or globular transfer except for E70C-8X [E49C-8X] which shall be welded on DCEN (Direct Current Electrode Negative).

^b A constant voltage (CV) welding process shall be used.

^c If sizes other than 0.045 in and 1/16 in [1.2 mm and 1.6 mm] are tested, the heat input shall be modified as needed. The groove assembly joint configuration is not recommended for electrode sizes smaller than 0.035 in [0.9 mm].

^d The calculation to be used for heat input is:

$$(1) \text{ Heat Input (kJ/in)} = \frac{\text{volts} \times \text{amps} \times 60}{\text{Travel Speed (in/min)} \times 1000} \quad \text{or} \quad \frac{\text{volts} \times \text{amps} \times 60 \times \text{arc time (min)}}{\text{Weld Length (in)} \times 1000}$$

$$(2) \text{ Heat Input (kJ/mm)} = \frac{\text{volts} \times \text{amps} \times 60}{\text{Travel Speed (mm/min)} \times 1000} \quad \text{or} \quad \frac{\text{volts} \times \text{amps} \times 60 \times \text{arc time (min)}}{\text{Weld Length (mm)} \times 1000}$$

^e Gases other than those specified in Table 4 are used when applying an optional supplemental shielding gas range designator. When using shielding gas blends containing Ar, the minimum nominal voltage shall be 24 V.

^f Distance from the contact tip to the work, not from the shielding gas cup to the work.

Notes:

1. Base metal shall be as specified in Table 5. The surfaces to be welded shall be clean.
2. Prior to welding, the groove assembly may be preset so that the welded joint will be sufficiently flat to facilitate test specimen removal. As an alternative, restraint or a combination of restraint and preset may be used.
3. Preheat and interpass temperatures for all electrode classifications shall be as specified in 9.4.1.

Table 7
GTAW Groove Weld Assembly Test Conditions

Standard size ^a	3/32 in	[2.4 mm]	1/8 in	[3.2 mm]
Shielding gas ^b	Ar	Ar	Ar	Ar
Nominal current, DCEN (DCEN = electrode negative)	220 A to 250 A	220 A to 250 A	250 A to 280 A	250 A to 280 A
Approximate arc voltage ^c	13 V to 16 V	13 V to 16 V	16 V to 19 V	16 V to 19 V
Travel speed	4 in/min to 6 in/min	[2.0 mm/sec ± 0.4 mm/sec]	4 in/min to 6 in/min	[2.0 mm/sec ± 0.4 mm/sec]

^a If sizes other than those shown above are tested, nominal current and arc voltage shall be changed as needed.

^b AWS A5.32M/A5.32 (ISO 14175 MOD), Classification II.

^c Arc voltage shall be reported for information only. The voltage range is only a suggested range and may change based on power source characteristics. Typically, the voltage cannot be set independent of the current.

Notes:

1. Base metal shall be as specified in Table 5. The surfaces to be welded shall be clean.
2. Prior to welding, the assembly may be preset so that the welded joint will be sufficiently flat to facilitate test specimen removal. As an alternative, restraint or a combination of restraint and preset may be used.
3. Preheat and interpass temperatures shall be as specified in 9.4.1.
4. The travel speed does not apply to the first layer.
5. The first layer shall contain a maximum of two passes.
6. Test conditions for composite electrodes used as rods shall be as recommended by the manufacturer.

Table 8
Diffusible Hydrogen Limits for Weld Metal^a

Optional, Supplemental Diffusible Hydrogen Designator ^{b, c, d}	Average Diffusible Hydrogen ^e Maximum (mL/100 g Deposited Metal)
H16	16
H8	8
H4	4
H2	2

^a Limits on diffusible hydrogen when tested in accordance with AWS A4.3-ADD1, as specified in 15.1.

^b Refer to Figure 1.

^c The lower diffusible hydrogen limits may not be available in some classifications.

^d Electrodes which satisfy the diffusible hydrogen limits for H2 also satisfy the requirements for H4, H8, and H16. Electrodes which satisfy the diffusible hydrogen limits for H4 also satisfy the requirements for H8 and H16. Electrodes which satisfy the requirement for H8 also satisfy the requirement for H16.

^e These hydrogen limits are based on welding in air containing a maximum of 10 grains of water per pound [1.43 g/kg] of dry air. Testing at any higher atmospheric moisture level is acceptable provided these limits are satisfied.

Table 9
Shielding Gas Requirements for Oxygen Equivalent Gas Range Designator^{a, b}

Calculated Oxygen Equivalent of Shielding Gas used for Testing, OE (%) ^c	Typical Shielding Gas Used for Testing ^d	Optional OE Designator Applied to Classification ^{e, f}
49.5–50.5	100% CO ₂	50
12.0–13.0	75% Ar, balance CO ₂	12
7.0–8.0	85% Ar, balance CO ₂	7
3.5–4.5	92% Ar, balance CO ₂	4
1.5–2.5	98% Ar, balance O ₂	2

^a Testing and results with alternate shielding gases must conform to the requirements of the classification under test, including all optional supplemental designators. See 15.2 for testing details.

^b Only the highest and lowest oxygen equivalent gases must be used for testing. Intermediate oxygen equivalent gases need not be tested, nor should their designators be shown in the classification. See Figure 1 and A8.4.

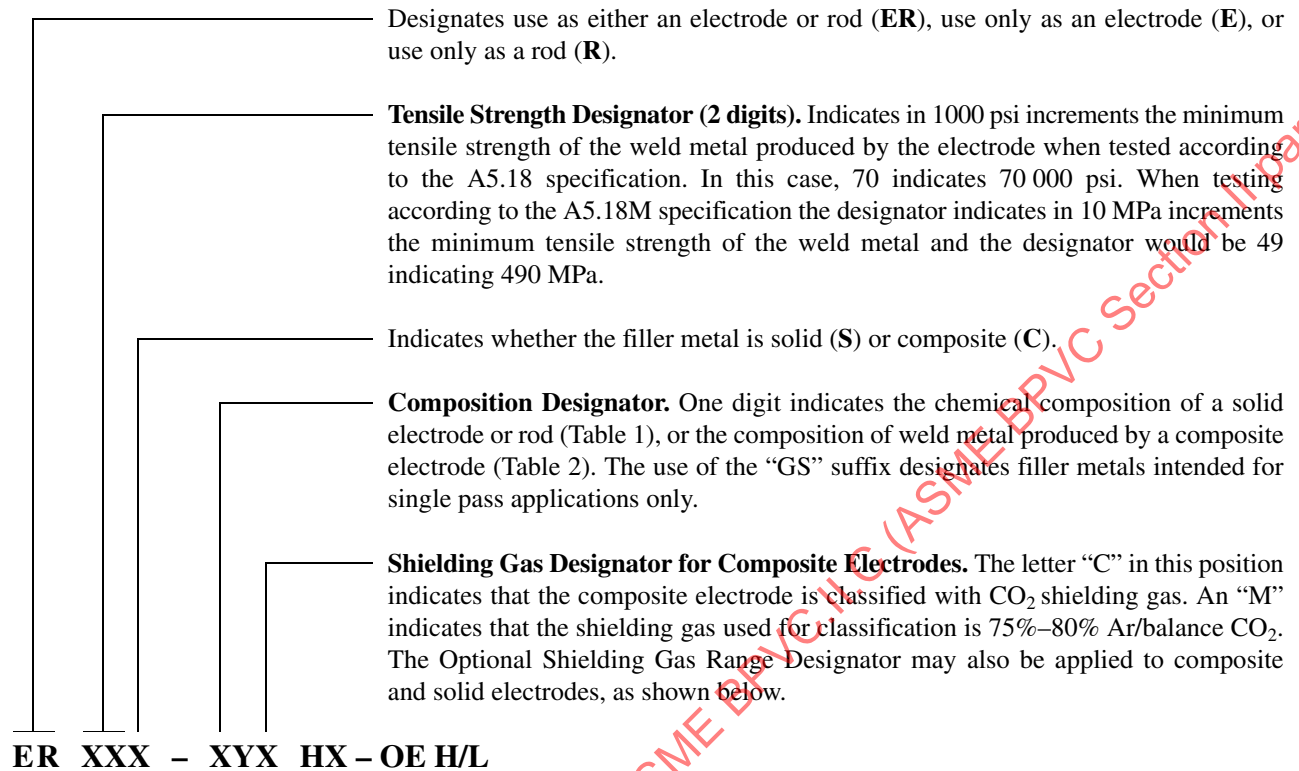
^c Calculated per Equation 1 in 15.2.

^d Another shielding gas of the same oxygen equivalent may be used for testing. For example, 98% Ar, balance O₂ or 96% Ar, balance CO₂ may both be used for testing to apply the “2” designator.

^e The highest and lowest designators may be added to a classification in the format OE H/L with “H” being the OE designator for the highest oxygen equivalent shielding gas that was tested and met all requirements for classification and “L” being the OE designator for the lowest oxygen equivalent shielding gas that was tested and met all requirements for classification. See Figure 1.

^f The listed designators (50, 12, 7, 4, and 2) are the only ones that may be applied.

Mandatory Classification Designators^a



Optional, Supplemental Designators^b

Shielding Gas Range Designator. This designator indicates that the electrode meets the requirements of the classification with shielding gases of different oxygen equivalencies. Refer to 15.2, Table 9, and A8.4 in Annex A.

Diffusible Hydrogen Designator. This designator indicates the diffusible hydrogen content of the weld deposit when tested according to the provisions of this specification. Refer to 15.1 and Table 8. See also A8.2 in Annex A.

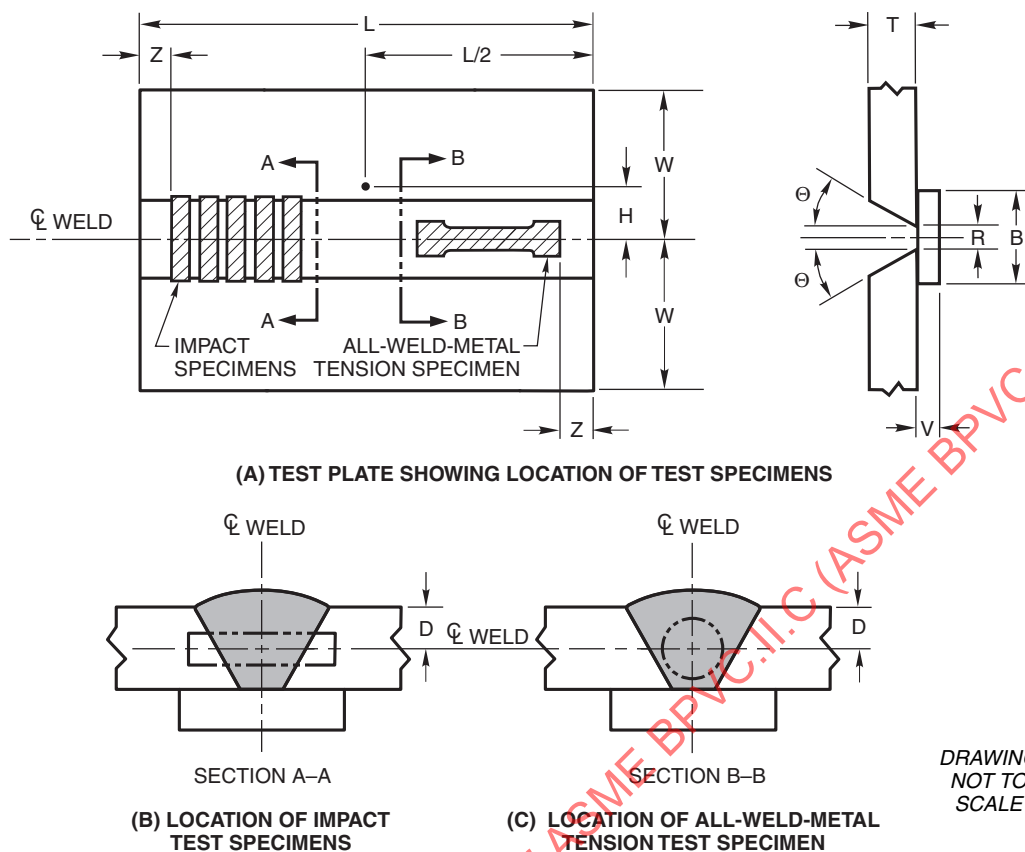
The letter “N” is added after the composition designator for solid electrodes when note e of Table 1 and note h of Table 4 apply. See 15.4.

The letter “A” is added after “S-6” for solid electrodes and rods that also meet chemical composition requirements of ASME Section IX “A-No. 1.” See 15.3 and A8.5.

^a The combination of these designators constitutes the electrode (or rod) classification.

^b These designators are optional and do not constitute a part of the electrode (rod) classification.

Figure 1—A5.18/A5.18M Classification System

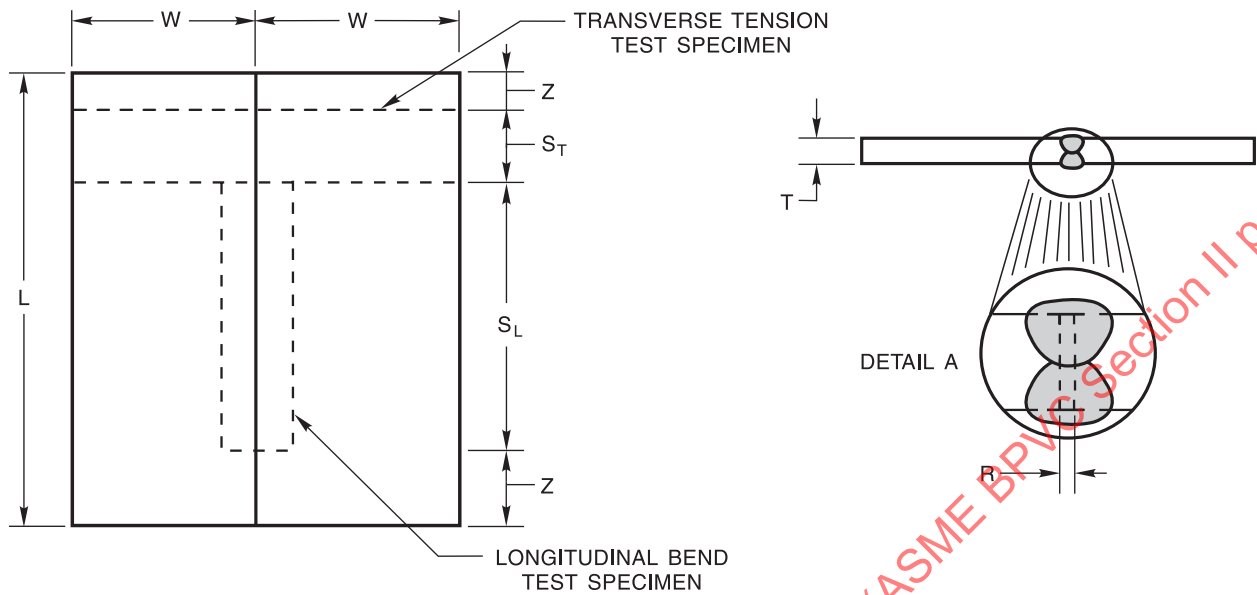


	Description	Primary Assembly for GMAW		Alternate Assembly for GMAW		Assembly for GTAW	
		in	mm	in	mm	in	mm
D	Specimen Center	$3/8 \pm 1/32$	10 ± 1	$3/8 \pm 1/32$	10 ± 1	$1/4 \pm 1/32$	6 ± 1
L	Length, min.	10	250	10	250	10	250
H	Approximate Point of Temperature Measurement	1	25	1	25	1	25
R	Root Opening	$1/2, -0, +1/16$	$13, -0, +1$	$5/8, -0, +1/16$	$16, -0, +1/16$	$1/4, -0, +1/16$	$6, -0, +1$
V	Backup Strip Thickness, min.	$3/8$	10	$3/8$	10	$1/4$	6
B	Backup Strip Width, min.	1	25	$1-1/4$	32	1	25
T	Thickness, nominal	$3/4$	20	$3/4$	20	$1/2$	12
W	Width, min.	5	125	5	125	5	125
Z	Discard, min.	1	25	1	25	1	25
θ	Bevel Angle	$22.5^\circ \pm 2^\circ$	$22.5^\circ \pm 2^\circ$	$10^\circ, +2.5^\circ, -0^\circ$	$10^\circ, +2.5^\circ, -0^\circ$	$22.5^\circ \pm 2^\circ$	$22.5^\circ \pm 2^\circ$

Notes:

1. Base metal shall be as specified in Table 5. Nominal plate thickness tolerance subject to base metal specification.
2. The surfaces to be welded shall be clean.
3. Prior to welding, the assembly may be preset so that the welded joint will be sufficiently flat, within 5° of plane, to facilitate test specimen removal. As an alternative, restraint or a combination of restraint and preset may be used.
4. The alternate GMAW test assembly will also meet the requirements of joint type 1.3 per ISO 15792-1:2020. It is acceptable for classification, but in case of dispute, the Primary Assembly shall be the referee test assembly.

Figure 2—Groove Weld Test Assembly for Mechanical Properties and Soundness of Weld Metal

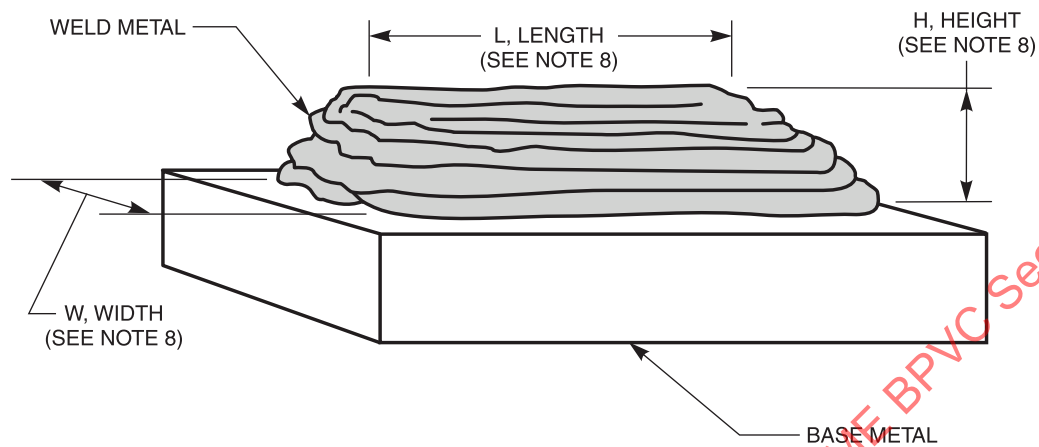


Dimensions			
		in	mm
L	Length, min.	10	250
W	Width, min.	4	100
R	Root Opening, max.	1/16	1.5
S _T	Transverse Specimen	2	50
S _L	Longitudinal Specimen, min.	6	150
T	Thickness, nominal	1/4	6
Z	Discard, min	1	25

Notes:

1. Base metal shall be as specified in Table 5. Nominal plate thickness tolerance subject to base metal specification.
2. The surfaces to be welded shall be clean.
3. Detail A shows the completed joint and approximate weld configuration.
4. Test conditions shall be as recommended by the manufacturer and shall be made available to the purchaser upon request.

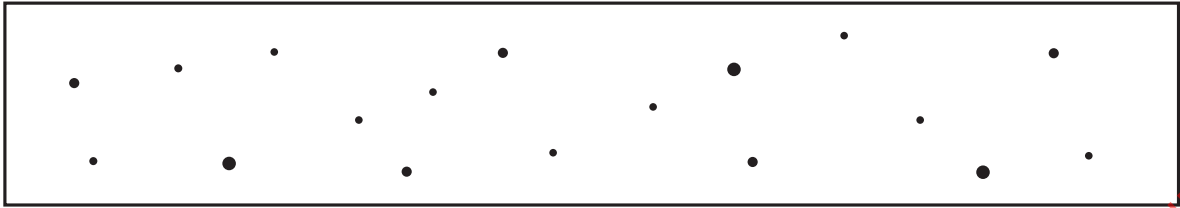
Figure 3—Weld Test Assembly for Transverse Tension and Longitudinal Guided Bend Tests



Notes:

1. Base metal of any convenient size, of any type specified in Table 5 shall be used as the base for the weld pad.
2. The surface of the base metal on which the filler metal is to be deposited shall be clean.
3. The pad shall be welded in the flat position with successive layers to obtain weld metal of sufficient height.
4. Welding conditions shall be as specified in Table 6.
5. The preheat temperature shall not be less than 60 °F [15 °C] and the interpass temperature shall not exceed 325 °F [165 °C].
6. Any slag shall be removed after each pass.
7. The test assembly may be quenched in water between passes to control interpass temperature.
8. The minimum completed pad size shall be at least four layers in height (H), Length (L), after allowance for start and stop areas, and width (W) shall be sufficient to perform analysis. The sample for analysis shall be taken at least 3/8 in [9.5 mm] above the original base metal surface.

Figure 4—Pad for Chemical Analysis of Weld Metal from Composite Electrodes

**(A) ASSORTED ROUNDED INDICATIONS**

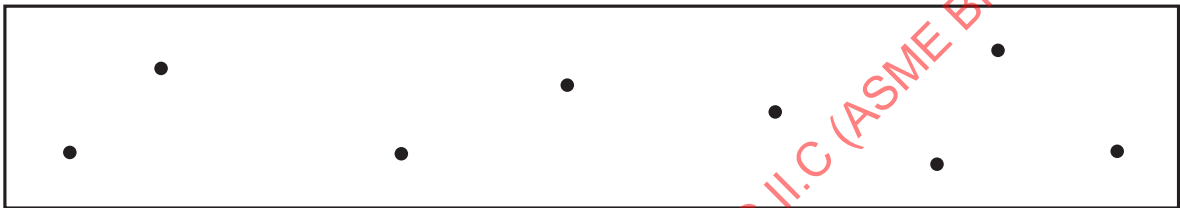
SIZE 1/64 in TO 1/16 in [0.4 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 18, WITH THE FOLLOWING RESTRICTIONS:

MAXIMUM NUMBER OF LARGE 3/64 in TO 1/16 in [1.2 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 3.

MAXIMUM NUMBER OF MEDIUM 1/32 in TO 3/64 in [0.8 mm TO 1.2 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 5.

MAXIMUM NUMBER OF SMALL 1/64 in TO 1/32 in [0.4 mm TO 0.8 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 10.

**(B) LARGE ROUNDED INDICATION**

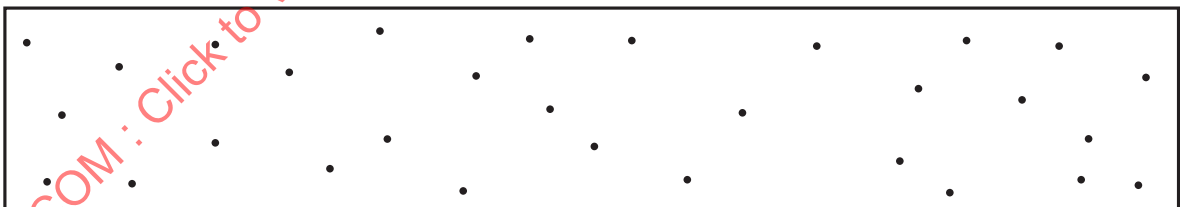
SIZE 3/64 in TO 1/16 in [1.2 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 8.

**(C) MEDIUM ROUNDED INDICATIONS**

SIZE 1/32 in TO 3/64 in [0.8 mm TO 1.2 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 15.

**(D) SMALL ROUNDED INDICATIONS**

SIZE 1/64 in TO 1/32 in [0.4 mm TO 0.8 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 30.

Notes:

1. In using these standards, the chart which is most representative of the size of the rounded indications present in the test specimen radiograph shall be used for determining conformance to these radiographic standards.
2. Since these are test welds specifically made in the laboratory for classification purposes, the radiographic requirements for these test welds are more rigid than those which may be required for general fabrication.
3. Indications whose largest dimension does not exceed 1/64 in [0.4 mm] shall be disregarded.

Figure 5—Radiographic Acceptance Standards

Annex A (Informative)

Guide to AWS Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding

This annex is not part of this standard but is included for informational purposes only.

A1. Introduction

The purpose of this guide is to correlate the electrode and rod classifications with their intended applications, so the specification can be used effectively. Appropriate base metal specifications are referred to whenever that can be done and when it would be helpful. Such references are intended only as examples, rather than complete listings of the materials for which each filler metal is suitable.

A2. Classification System

A2.1 The system for identifying the electrode classifications in this specification follows the standard pattern used in other AWS filler metal specifications, as shown in Figure 1.

A2.2 The prefix “E” designates an electrode as in other specifications. The letters “ER” indicate that the filler metal may be used either as an electrode or a rod. For A5.18, the number 70 indicates the required minimum tensile strength, as a multiple of 1000 psi, of the weld metal in a test weld made in accordance with specification A5.18. Similarly, for A5.18M, the number 49 indicates the required minimum tensile strength, as a multiple of 10 MPa, of the weld metal in a test weld made in accordance with specification A5.18M.

The letter “S” designates a solid electrode or rod. The letter “C” designates a composite electrode or rod. The digit following the hyphen, 2, 3, 4, 6, 7, 8, 9, 12, G, or GS, indicates the chemical composition and/or impact testing requirements specified in Tables 1, 2, and 4.

In the case of some composite stranded and metal cored electrodes, the letter “M” or “C” will follow, indicating the type of shielding gas.

Optional designators are also used in this specification in order to identify electrodes and rods that have met mandatory classification requirements and certain supplementary requirements as agreed to between the supplier and purchaser. An optional supplemental diffusible hydrogen designator (H16, H8, H4, or H2) may follow the classification designation, indicating whether the electrode will meet a maximum hydrogen level of 16, 8, 4, or 2 mL/100g of deposited metal when tested as outlined in AWS A4.3. Electrodes that are designated as meeting the lower or lowest hydrogen limits, as specified in Table 8, are also understood to be able to meet any higher hydrogen limits without necessarily being designated as such.

An optional supplemental designator may be used to indicate that the electrode will meet the requirements for classification with various shielding gases. The gases are categorized by a calculated oxygen equivalent to determine conformance with the optional designators. Also see 15.2 and A8.4.

The addition of the letter “N” as an optional supplemental designator to a classification indicates that the electrode is intended for certain very special welds in nuclear applications. These welds are found in the core belt region of the reactor vessel. This region is subject to intense neutron radiation, and it is necessary, therefore, that the phosphorus and copper contents of the weld metal be limited in order to resist neutron radiation-induced embrittlement. It is also necessary that

the weld metal has a high upper shelf energy level in order to withstand some embrittlement, yet remain serviceable over the years.

The addition of the letter “A” as an optional supplemental designator to an S-6 classification indicates that the electrode or rod meets the additional manganese and silicon requirements for ASME Boiler and Pressure Vessel Code, Section IX A-Number 1. Also see A8.5.

A2.3 “G” Classification

A2.3.1 This specification includes filler metals classified as ER70S-GX [ER49S-GX], E70C-GX [E49C-GX], and E70C-GSX [E49C-GSX]. The “G” (multiple pass) or “GS” (single pass) indicates that the filler metal is of a “general” classification. It is general because not all of the particular requirements specified for each of the other classifications are specified for this classification. The intent in establishing these classifications is to provide a means by which filler metals that differ in one respect or another (chemical composition, for example) from all other classifications (meaning that the composition of the filler metal, in the case of the example, does not meet the composition specified for any of the classifications in the specification) can still be classified according to the specification. The purpose is to allow a useful filler metal, one that otherwise would have to await a revision of the specification, to be classified immediately under the existing specification. This means that two filler metals, each bearing the same “G” classification, may be quite different in some particular respect (chemical composition, again, for example).

A2.3.2 The point of difference between filler metal of a “G” classification and filler metal of a similar classification without the “G” (or even with it, for that matter) may be further clarified from the use of the words “not required” and “not specified” in the specification. The use of these words is as follows:

“Not Required” is used in those areas of the specification that specify the tests that must be conducted in order to classify a filler metal. It indicates that that test is not required because the results for the particular test are not a requirement for that particular classification. When a test is “not required,” it is not necessary to conduct the corresponding test in order to classify a filler metal to that classification. When a purchaser wants the information provided by that test in order to consider a particular product of that classification for a certain application, the purchaser will have to arrange for that information with the supplier of the product. The purchaser will have to establish with that supplier just what the testing procedure and the acceptance requirements are to be for that test. The purchaser may want to incorporate that information (via AWS A5.01M/A5.01) in the purchase order.

“Not Specified” is used in those areas of the specification that refer to the results of some particular test. It indicates that the requirements for that test are not specified for that particular classification. If the required results from a specific test are listed as “not specified” but the test in question is shown as “required” then the test results must be reported.

A2.4 Request for Filler Metal Classification. When a filler metal cannot be classified other than as a “G” classification, a manufacturer may request that a new classification be established. The manufacturer shall do this using the following procedure.

(1) A request to establish a new filler metal classification must be submitted in writing. The request needs to provide sufficient detail to permit the Committee on Filler Metals and Allied Materials and the relevant Subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

- (a) A declaration that the new classification will be offered for sale commercially.
- (b) All classification requirements as given for existing classifications, such as chemical composition ranges, mechanical property requirements, and usability test requirements.
- (c) Any conditions for conducting the tests used to demonstrate that the filler metal meets the classification requirements. (It would be sufficient, for example, to state that welding conditions are the same as for other classifications.)
- (d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the annex).
- (e) Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.

(f) A request for a new classification without the above information will be considered incomplete. The Secretary will return the request to the requester for further information.

(2) In order to comply with the AWS Policy on Patented Items, Trademarks, and Restraint of Trade, if the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester shall disclose this. In these cases, the patent holder must allow the use of this technology, such as by license. The Secretary will provide examples of acceptable wording to the patent holder, as required.

(3) The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters for processing.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01M/A5.01. Any testing a purchaser requires of the supplier for material shipped in accordance with this specification shall be clearly stated in the purchase order according to the provisions of AWS A5.01M/A5.01. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing is normally conducted on material of that classification, as specified in Schedule F, Table 1 of AWS A5.01M/A5.01. Testing in accordance with any other schedule in that table must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations and optional supplemental designators, if applicable, on the packaging enclosing the product, or the classification on the product itself, constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification.

The only testing requirement implicit in this certification is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped, and that the material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation. Certification is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the certification required by the specification is the classification test of representative material, cited above, and the Manufacturer's Quality Assurance Program in AWS A5.01M/A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes in the atmosphere to which welders and welding operators are exposed during welding. They are:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling)
- (2) Number of welders and welding operators working in that space
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes used
- (4) The proximity of the welders or welding operators to the fumes, as the fumes issue from the welding zone, and to the gases and dusts in the space in which they are working
- (5) The ventilation provided to the space in which the welding is done

A5.2 American National Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the clause on Ventilation in that document. See also AWS F3.2M/F3.2, *Ventilation Guide for Weld Fume*, for more detailed descriptions of ventilation options.

A6. Welding Considerations

A6.1 Gas metal arc welding (GMAW) can be divided into three categories based on the mode of metal transfer. These modes are (1) spray (conventional or pulsed), (2) globular, and (3) short circuiting transfer. In the spray, pulsed spray, and globular modes, transfer occurs as distinct droplets that are detached from the electrode, transferring along the arc column into the weld pool. In the short circuiting mode, the metal is deposited during frequent short circuiting of the electrode in the molten pool.

A6.2 Spray Transfer

A6.2.1 The spray transfer mode for carbon steel is most commonly obtained with argon shielding gas mixtures with up to 5% of oxygen [AWS A5.32M/A5.32, Classification M13 or M22] or up to 15% carbon dioxide [AWS A5.32M/A5.32, Classification M12 or M20]. A characteristic of this transfer mode is the smooth arc plasma through which hundreds of very fine droplets are transferred to the weld pool each second.

A6.2.2 Spray transfer with argon-oxygen containing shielding gas is primarily a function of current density, polarity, and resistance heating of the electrode. The high droplet rate, approximately 250 droplets per second, develops suddenly above a critical current level, commonly referred to as the transition current (for each size of electrode). Below this current, the metal is transferred in drops generally larger in diameter than the electrode and at a rate of from 10 drops to 20 drops per second (globular transfer). The transition current is also dependent to some extent on the chemical composition of the electrode. For 1/16 in [1.6 mm] diameter carbon steel electrodes, a transition current of 270 amperes (direct current, electrode positive [dcep]) is common. Alternating current is not recommended for this type of welding because it does not produce a stable arc.

A6.2.3 Pulsed Spray. Metal transfer in pulsed spray welding is similar to that of the spray transfer described above, but it occurs at a lower average current. The lower average current is made possible by rapid pulsing of the welding current between a high level, where metal will transfer rapidly in the spray mode, and a low level, where no transfer will take place. At a typical rate of 60 pulses to 120 pulses per second, a melted drop is formed by the low current arc, which is then “squeezed off” by the high current pulse. This permits all-position welding.

A6.3 Globular Transfer. The mode of transfer that characterizes 100% CO₂ (AWS A5.32M/A5.32 Classification C1) as a shielding gas is globular. Common practice with globular transfer is to use low arc voltage to minimize spatter. This shortens the arc length causing the arc to be “buried” and results in deeper penetration and better containment of spatter within the weld pool. Electrodes of 0.045 in through 1/16 in [1.2 mm through 1.6 mm] diameter normally are used at welding currents in the range of 275 amperes to 400 amperes (dcep), for this type of transfer. The rate at which droplets (globules) are transferred ranges from 20 to 70 per second, depending on the size of the electrode, the amperage, polarity, and arc voltage.

A6.4 Short Circuiting Transfer. This mode of transfer is obtained with small diameter electrodes, (0.030 in to 0.045 in [0.8 mm to 1.2 mm]), using low arc voltages and amperages and a power source designed for short circuiting transfer. The electrode short-circuits to the weld metal, usually at a rate of from 50 to 200 times per second. Metal is transferred with each short circuit, but not across the arc. Short circuiting gas metal arc welding of carbon steel is done most commonly with mixtures of argon and CO₂ as the shielding gas or with CO₂ (AWS A5.32M/A5.32 Classification C1) alone. The penetration of such welds is greater with CO₂ than it is with argon-CO₂ mixtures. Mixtures of 50% to 80% argon with CO₂ remainder can be advantageous for thin materials. They provide low penetration, higher short circuiting rates, and lower minimum currents and voltages than does CO₂ alone.

A7. Description and Intended Use of Electrodes and Rods

A7.1 Shielding Gas Consideration. Solid electrodes in this specification are classified with CO₂ gas shielding. However, this is not to preclude their use with other shielding gases, and optional OE designators indicate conformance to this specification when welded with various shielding gases. See A8.4 for more details on these designators.

A7.2 ER70S-2 [ER49S-2]. Electrodes and rods of the ER70S-2 [ER49S-2] classification are primarily used for single-pass welding of killed, semi-killed, and rimmed steels, but may be used for some multipass applications. Because of the added deoxidants, these filler metals can be used for welding steels that have a rusty or dirty surface, with a possible sacrifice of weld quality depending on the condition of the surface. ER70S-2 [ER49S-2] filler metals are used extensively

to produce high quality, high toughness welds with the GTAW process. These filler metals are also well suited for use in single side, melt through welding without a protective root shielding gas on the backside of the joint. Typical specifications for these steels are ASTM A36, A285-C, A515-70, and A516-70, which have UNS numbers K02600, K02801, K03101, and K02700, respectively.

A7.3 ER70S-3 [ER49S-3]. Electrodes and rods of the ER70S-3 [ER49S-3] classification are intended for welding single-pass and multi-pass welds. Typical base metal specifications are often the same as those for the ER70S-2 [ER49S-2] classification. Electrodes of the ER70S-3 [ER49S-3] classification are the most widely used of the GMAW electrodes classified under this specification.

A7.4 ER70S-4 [ER49S-4]. Electrodes and rods of the ER70S-4 [ER49S-4] classification are intended for welding steel where conditions require more deoxidation than is provided by the ER70S-3 [ER49S-3] filler metal. Typical base metal specifications are often the same as those for the ER70S-2 [ER49S-2] classification. This classification does not require impact testing.

A7.5 ER70S-6 [ER49S-6]. Electrodes and rods of the ER70S-6 [ER49S-6] classification are intended for both single-pass and multiple-pass welding. They are especially suited for sheet metal applications, where smooth weld beads are desired, and structural and plate steels that have moderate amounts of rust or mill scale. These electrodes permit the use of higher current ranges with either CO₂ (AWS A5.32M/A5.32 Classification C1) shielding gas or with mixtures of Ar and O₂ or Ar and CO₂. Typical base metal specifications are often the same as those for the ER70S-2 [ER49S-2] classification. See A8.5 for details on the optional “A” designator for ER70S-6 [ER49S-6] electrodes.

A7.6 ER70S-7 [ER49S-7]. Electrodes and rods of the ER70S-7 [ER49S-7] classification are intended for single-pass and multiple-pass welding. They may permit welding with higher travel speeds compared with ER70S-3 [ER49S-3] filler metals. They also provide somewhat better wetting action and bead appearance, when compared with those filler metals. These electrodes permit the use of higher current ranges with either CO₂ (AWS A5.32M/A5.32 Classification C1) shielding gas or with mixtures of Ar and O₂ or Ar and CO₂. Typical base metal specifications are often the same as those for the ER70S-2 [ER49S-2] classifications.

A7.7 ER70S-8 [ER49S-8]. Electrodes (rods) of this type are intended for both single-pass and multiple-pass welding. They are characterized by a stable globular arc, low spatter, good resistance to porosity, and smooth bead shape when using high current with CO₂ shielding gas. These electrodes can be used either with CO₂ shielding gas or with mixtures of Ar and CO₂. Typical specifications for these steels are ASTM A36, A285-C, A515-70, and A516-70, which have UNS numbers K02600, K02801, K03101, and K02700, respectively. Adopted from ISO 14341 class S11.

A7.8 ER70S-9 [ER49S-9]. *ER70S-9 [ER49S-9] is a maximum 0.15% silicon electrode modified with additional alloying elements to minimize silicate island (also referred to as surface silicate, slag island, and/or oxide) formation on the weld surface. Welding is intended to be performed using 85%–95% argon/balance CO₂ shielding gas, DCEP polarity, and spray transfer. It is not intended for welding with 100% CO₂ shielding gas or welding over millscale/rust. Typical applications for this electrode are high speed, single-pass applications, such as frame welding for the automotive industry.*

A7.9 ER70S-G [ER49S-G]. Electrodes and rods of the ER70S-G [ER49S-G] classification are those filler metals not included in the preceding classes and for which only certain mechanical property requirements are specified. The electrodes and rods are intended for both single-pass and multiple-pass applications. The filler metal supplier should be consulted for the composition, properties, characteristics, and intended use of this classification (see A2.3 for further information).

A7.10 E70C-3X [E49C-3X] and E70C-6X [E49C-6X]. Electrodes of the E70C-3X [E49C-3X] and E70C-6X [E49C-6X] classifications are composite stranded or metal cored electrodes intended for both single-pass and multiple-pass applications. They are characterized by a spray arc and excellent bead wash characteristics. The electrodes may be classified under this specification with either CO₂ or 75%–80% Ar/balance CO₂ shielding gas. E70C-3 [E49C-3] requires impacts at 0 °F [–20 °C] while E70C-6 [E49C-6] requires impacts at –20 °F [–30 °C].

A7.11 E70C-8X [E49C-8X]. Electrodes of the E70C-8X [E49C-8X] classification are composite stranded or metal cored electrodes intended for both single-pass and multiple-pass applications using DCEN polarity. They are characterized by shallow penetration, yet high deposition rates and are most suited for sheet metal applications. They have a spray arc and excellent bead wash characteristics.

A7.12 E70C-12X [E49C-12X]. Electrodes of the E70C-12X [E49C-12X] classification are composite stranded or metal cored electrodes intended for both single- and multiple-pass applications meeting the chemical composition requirements of A-No. 1 per QW-442 in the ASME *Boiler and Pressure Vessel Code*, Section IX. The manganese in the weld deposit is restricted to 1.60% maximum and the tensile strength to 90 ksi [620 MPa]. The user is cautioned that the use of a less oxidizing gas mixture than that used for classification may result in higher manganese or tensile strength of the weld deposit.

A7.13 E70C-GX [E49C-GX]. Electrodes of the E70C-GX [E49C-GX] classification are those filler metals not included in the preceding classes and for which only certain mechanical property requirements are specified. These electrodes are intended for both single-pass and multiple-pass applications. They may be classified with either CO₂ or 75%–80% Ar/balance CO₂ shielding gas, as shown by the “C” or “M” suffix. Absence of the “C” or “M” suffix means that the shielding gas used for testing was not one of the above gases and the electrode manufacturer should be consulted for the recommended shielding gas to be used. The filler metal supplier should be consulted for the composition, properties, characteristics, and intended use of this classification (see A2.3 for further information).

A7.14 E70C-GSX [E49C-GSX]. Electrodes of the E70C-GSX [E49C-GSX] classification are composite stranded or metal cored electrodes intended for only single-pass applications. Absence of the shielding gas designator “C” or “M” suffix means that the shielding gas used for testing was some other shielding gas agreed upon between the purchaser and supplier. The electrode manufacturer should be consulted for the recommended shielding gas to be used. The filler metal supplier should also be consulted for the properties, characteristics, and intended use of these classifications. These electrodes may have higher manganese and silicon contents which improve single pass applications (such as tolerance to mill scale, etc.), but could preclude their use on multiple-pass applications due to higher Mn and Si recovery.

A8. Special Tests

A8.1 It is recognized that supplementary tests may be required for certain applications. In such cases, additional tests to determine specific properties such as hardness, corrosion resistance, or mechanical properties at higher or lower service temperatures, may be required. AWS A5.01M/A5.01 contains provisions for ordering such tests. This clause is included for the guidance of those who desire to specify such special tests. Those tests may be conducted as agreed by supplier and purchaser.

A8.2 Diffusible Hydrogen

A8.2.1 Hydrogen induced cracking of weld metal or the heat-affected zone (HAZ) generally is not a problem with carbon steels containing 0.3% or less carbon, nor with lower strength alloy steels. However, electrodes classified in this specification are sometimes used to join higher carbon steels or low-alloy, high strength steels where hydrogen-induced cracking may be a serious problem.

A8.2.2 Gas metal arc welding (GMAW) and gas tungsten arc welding (GTAW) are generally considered to be low hydrogen welding processes. However, as the weld metal or HAZ strength or hardness increases, the concentration of diffusible hydrogen that will cause cracking under given conditions of restraint and heat input becomes lower. It may be appropriate to evaluate the diffusible hydrogen produced during welding with these processes. This cracking (or its detection) is usually delayed some hours after cooling. It may appear as transverse weld cracks, longitudinal cracks (especially in root beads), and toe or underbead cracks in the HAZ.

A8.2.3 Since the available diffusible hydrogen level strongly influences the tendency towards hydrogen-induced cracking, it may be desirable to measure the diffusible hydrogen content resulting from welding with a particular electrode. This specification has, therefore, included the use of optional designators for diffusible hydrogen to indicate the maximum average value obtained under a clearly defined test condition in AWS A4.3.

Electrodes that are designated as meeting the lower or lowest hydrogen limits, as specified in Table 8, are also understood to meet any higher electrode hydrogen limits, even though these are not necessarily designated along with the electrode classification. Therefore, for example an electrode designated as “H4” also meets the “H8” and “H16” requirements without being designated as such.

A8.2.4 The user of this information is cautioned that actual fabrication conditions may result in different diffusible hydrogen values than those indicated by the designator.

A8.2.5 The use of a reference atmospheric condition during welding is necessary because the arc is always imperfectly shielded. Moisture from the air, distinct from that in the electrode or gas, can enter the arc and subsequently the weld pool, contributing to the resulting observed diffusible hydrogen. This effect can be minimized by maintaining a suitable gas flow rate and as short an arc length as possible, consistent with a steady arc. At times, some air will mix with the gas and add its moisture to the other sources of diffusible hydrogen. It is possible for this extra diffusible hydrogen to significantly affect the outcome of a diffusible hydrogen test. For this reason, it is appropriate to specify a reference atmospheric condition. The reference atmospheric condition of 10 grains of moisture per pound [1.43 grams per kilogram] of dry air is equivalent to 10% relative humidity at 70 °F [18 °C] at 29.92 in Hg [760 mm] barometric pressure. Actual conditions, measured using a calibrated psychrometer, that equal or exceed this reference condition provide assurance that the conditions during welding will not diminish the final results of the test.

A8.2.6 The reader is cautioned that the shielding gas itself can contribute significantly to diffusible hydrogen. Normally, welding grade shielding gases are intended to have very low dew points and very low impurity levels. This, however, is not always the case. Instances have occurred where a contaminated gas cylinder resulted in a significant increase of diffusible hydrogen in the weld metal. In case of doubt, a check of gas dew point is suggested. A dew point of -40 °F [-40 °C] or lower is considered satisfactory for most applications.

A8.3 Aging of Specimens. Weld metals may contain significant quantities of hydrogen for some time after they have been made. Most of this hydrogen gradually escapes over time. This may take several weeks at room temperature or several hours at elevated temperatures. As a result of this eventual change in hydrogen level, ductility of the weld metal increases toward its inherent value, while yield, tensile and impact properties remain relatively unchanged. The A5.18 and A5.18M specifications permit the aging of some test specimens or weld test assemblies at elevated temperatures not exceeding 220 °F [105 °C] for up to 48 hours before cooling them to room temperature and subjecting them to testing. The purpose of this treatment is to facilitate removal of hydrogen from the test specimen in order to minimize variations in test results.

Aging treatments are sometimes used for low hydrogen electrode deposits, especially when testing high strength deposits. Note that aging may involve holding test specimens or weld test assemblies at room temperature for several days or holding at a somewhat higher temperature for a shorter period of time. Consequently, users are cautioned to employ adequate preheat and interpass temperatures to avoid the deleterious effects of hydrogen in production welds. It should be kept in mind that aging test assemblies may not remove as much diffusible hydrogen as aging the individual specimens. The purchaser may, by mutual agreement with the supplier, have the thermal aging of specimens prohibited for all mechanical testing done to schedule I or J of AWS A5.01M/A5.01.

A8.4 Optional Shielding Gas Designators. Electrodes are classified with one shielding gas, but carbon and low-alloy steel electrodes often are used with other shielding gases. It may be important for a user or a referencing code or standard to know the response of an electrode and the resulting weld metal to shielding gases other than the one with which it was classified. The optional shielding gas designators may be applied to an electrode classification to indicate that it meets the same classification requirements when used with various ranges of shielding gases.

Shielding gas range designators have been established in this specification based on the oxidation equivalence of the shielding gas. The oxidation equivalence (oxidation potential) of a shielding gas is represented by the 'oxygen equivalent.' This is expressed as a percentage, and calculated as follows (also shown in Equation 1 of 15.2). This equation has been empirically derived to correlate to the composition and properties of the weld metal. It is not a stoichiometric calculation of the oxygen contained in a shielding gas.

% Oxygen Equivalent of a shielding gas (OE) = % O₂ in the shielding gas + (0.5 × % CO₂ in the shielding gas)

The oxidation equivalence of the shielding gas is important for predicting the weld metal chemical composition and resulting weld metal properties. As an example, for the same electrode and welding conditions, the manganese and silicon in a weld deposit will be higher with a low oxidation equivalence shielding gas than with a high oxidation equivalence shielding gas. The bracketed testing approach used in this specification requires testing at both the high and low ends of an oxidation equivalence range before an optional shielding gas designator can be applied. These ranges encompass shielding gases commonly used to deposit carbon and low-alloy steel weld metals.

Some electrodes may not be able to meet the requirements of their classification with any of the listed shielding gas-oxygen equivalents other than the one used for classification. Some others might be able to meet the requirements of their classification over a wide range of oxygen equivalent shielding gases. The bracketed testing only requires that the

highest oxygen equivalent shielding gas and the lowest oxygen equivalent shielding gas must be tested to apply that optional OE designator. For example, if an ER70S-6 electrode is tested and can meet the ER70S-6 requirements for classification with CO₂ shielding gas and with 92Ar/8CO₂ shielding gas, it may have the “OE 50/4” optional shielding gas range designator applied without testing with 85Ar/15CO₂ or 75Ar/25CO₂ shielding gas.

A8.5 Optional Designator for S-6 Electrodes and Rods Meeting A-No.1 Composition. ER70S-6 [ER49S-6] electrodes and R70S-6 [R49S-6] rods are commonly used in welding applications requiring qualification to ASME *Boiler and Pressure Vessel Code*, Section IX. An A-number is used in Section IX for classification of ferrous weld metal for procedure qualification. “A-number 1” (A-No.1) is commonly specified for welding mild steels, and has a maximum manganese limit of 1.60% and a maximum silicon limit of 1.0%. The optional “A” designator for the S-6 filler metal composition is an alternate way to ensure conformance to A-No.1 weld metal deposit. An electrode with the classification ER70S-6A [ER49S-6A] meets all requirements for classification as ER70S-6, and additionally is supplied with a maximum manganese of 1.60% and a maximum silicon of 1.0%. An ER70S-6A [ER49S-6A] electrode may in all cases be considered as an ER70S-6 [ER49S-6] electrode, but an ER70S-6 electrode may not be considered as an ER70S-6A [ER49S-6A] electrode unless it is tested and labeled in that manner.

A9. Discontinued Classifications

Some classifications have been discontinued from one revision of this specification to another. This results either from changes in commercial practice or from changes in the classification system used in the specification. The following classifications have been discontinued over the life of this specification (along with the year in which they were last included in the specification):

Discontinued Classification	Last Published	Discontinued Classification	Last Published
E-60S-1	1965	E70S-1	1969
E-60S-2	1965	E70S-1B ^b	1969
E-60S-3	1965	E70S-2 ^c	1969
E-70T-1 ^a	1965	E70S-3 ^c	1969
E-70T-2 ^a	1965	E70S-4 ^c	1969
E-70T-3 ^a	1965	E70S-5	1969
E-70T-4 ^a	1965	E70S-6 ^c	1969
E-70T-5 ^a	1965	E70S-G ^c	1969
E-70T-G ^a	1965	E70U-1	1969
—	—	ER70S-5	1993

^a These flux-cored electrode classifications were transferred to AWS A5.20-69 and continue to be included in the revisions to that specification.

^b This electrode classification was transferred to the AWS A5.28 specification where it is classified as ER80S-D2.

^c These electrode classifications were changed to the new classification ER70S-X and remain in the current revision of the specification as such.

A10. General Safety Considerations

A10.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Annex Clause A5. Safety and health information is available from other sources, including, but not limited to Safety and Health Fact Sheets, ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations.

A10.2 Safety and Health Fact Sheets. Safety and Health Fact Sheets are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

B6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

AWS Filler Metal Specifications by Material and Welding Process

	OFW	SMAW	GTAW GMAW PAW	FCAW	SAW	ESW	EGW	Brazing
Carbon Steel	A5.2	A5.1, A5.35	A5.18	A5.20	A5.17	A5.25	A5.26	A5.8, A5.31
Low-Alloy Steel	A5.2	A5.5	A5.28	A5.29	A5.23	A5.25	A5.26	A5.8, A5.31
Stainless Steel		A5.4, A5.35	A5.9, A5.22	A5.22	A5.9, A5.22, A5.39	A5.9, A5.22, A5.39	A5.9	A5.8, A5.31
Cast Iron	A5.15	A5.15	A5.15	A5.15				A5.8, A5.31
Nickel Alloys		A5.11, A5.35	A5.14, A5.34	A5.34	A5.14, A5.34, A5.39	A5.14, A5.34, A5.39		A5.8, A5.31
Aluminum Alloys		A5.3	A5.10					A5.8, A5.31
Copper Alloys		A5.6	A5.7					A5.8, A5.31
Titanium Alloys			A5.16					A5.8, A5.31
Zirconium Alloys			A5.24					A5.8, A5.31
Magnesium Alloys			A5.19					A5.8, A5.31
Tungsten Electrodes			A5.12					
Brazing Alloys and Fluxes								A5.8, A5.31
Surfacing Alloys	A5.21	A5.13	A5.21	A5.21	A5.21			
Consumable Inserts			A5.30					
Shielding Gases			A5.32	A5.32			A5.32	

AWS Filler Metal Specifications and Related Documents

Designation	Title
A4.2M (ISO 8249 MOD)	<i>Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal</i>
A4.3	<i>Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding</i>
A4.4M	<i>Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings</i>
A4.5M/A4.5 (ISO 15792-3 MOD)	<i>Standard Methods for Classification Testing of Positional Capacity and Root Penetration of Welding Consumables in a Fillet Weld</i>
A5.01M/A5.01 (ISO 14344 MOD)	<i>Welding and Brazing Consumables—Procurement of Filler Metals and Fluxes</i>
A5.02/A5.02M	<i>Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes</i>
A5.1/A5.1M	<i>Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding</i>
A5.2/A5.2M	<i>Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding</i>
A5.3/A5.3M	<i>Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.4/A5.4M	<i>Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding</i>
A5.5/A5.5M	<i>Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding</i>
A5.6/A5.6M	<i>Specification for Copper and Copper-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.7/A5.7M	<i>Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes</i>
A5.8M/A5.8	<i>Specification for Filler Metals for Brazing and Braze Welding</i>
A5.9/A5.9M (ISO 14343 MOD)	<i>Specification for Bare Stainless Steel Welding Electrodes and Rods</i>
A5.10/A5.10M (ISO 18273 MOD)	<i>Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods</i>
A5.11/A5.11M	<i>Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding</i>
A5.12M/A5.12 (ISO 6848 MOD)	<i>Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting</i>
A5.13/A5.13M	<i>Specification for Surfacing Electrodes for Shielded Metal Arc Welding</i>
A5.14/A5.14M	<i>Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods</i>
A5.15	<i>Specification for Welding Electrodes and Rods for Cast Iron</i>
A5.16/A5.16M (ISO 24034 MOD)	<i>Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods</i>
A5.17/A5.17M	<i>Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.18/A5.18M	<i>Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.19	<i>Specification for Magnesium-Alloy Welding Electrodes and Rods</i>
A5.20/A5.20M	<i>Specification for Carbon Steel Electrodes for Flux Cored Arc Welding</i>
A5.21/A5.21M	<i>Specification for Bare Electrodes and Rods for Surfacing</i>
A5.22/A5.22M	<i>Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods</i>
A5.23/A5.23M	<i>Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.24/A5.24M	<i>Specification for Zirconium and Zirconium-Alloy Welding Electrodes and Rods</i>
A5.25/A5.25M	<i>Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding</i>
A5.26/A5.26M	<i>Specification for Carbon and Low-Alloy Steel Electrodes for Electrode Gas Welding</i>
A5.28/A5.28M	<i>Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.29/A5.29M	<i>Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding</i>
A5.30/A5.30M	<i>Specification for Consumable Inserts</i>
A5.31M/A5.31	<i>Specification for Fluxes for Brazing and Braze Welding</i>
A5.32M/A5.32 (ISO 14175 MOD)	<i>Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes</i>
A5.34/A5.34M	<i>Specification for Nickel-Alloy Flux Cored and Metal Cored Welding Electrodes</i>
A5.35/A5.35M-AMD1	<i>Specification for Covered Electrodes for Underwater Wet Shielded Metal Arc Welding</i>
A5.39/A5.39M	<i>Specification for Stainless Steel and Nickel-Alloy Electrodes and Fluxes for Submerged Arc and Electroslag Welding</i>

INTENTIONALLY LEFT BLANK

SPECIFICATION FOR CARBON STEEL ELECTRODES FOR FLUX CORED ARC WELDING



SFA-5.20/SFA-5.20M



(Identical with AWS Specification A5.20/A5.20M:2021. In case of dispute, the original AWS text applies.)

Specification for Carbon Steel Electrodes for Flux Cored Arc Welding

1. Scope

1.1 This specification prescribes requirements for the classification of carbon steel electrodes for flux cored arc welding (FCAW), either with or without shielding gas.

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore each system must be used independently of the other without combining in any way when referring to weld metal properties. The specification with the designation A5.20 uses U.S. Customary Units. The specification A5.20M uses SI Units. The SI Units are shown within brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for the sizing of electrodes or packaging or both under the A5.20 and A5.20M specifications.

1.3 Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in Clauses B5 and B9.

Safety and Health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by material manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. Unless otherwise defined in this document, welding terms are as defined in AWS A3.0M/A3.0. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to or revisions of any of these publications do not apply.

American Welding Society (AWS) documents:

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

AWS A4.3-ADD1, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*

AWS A4.5M/A4.5 (ISO 15792-3 MOD), *Standard Methods for Classification Testing of Positional Capacity and Root Penetration of Welding Consumables in a Fillet Weld*

AWS A5.01M/A5.01 (ISO 14344 MOD), *Welding Consumables—Procurement of Filler Metals and Fluxes*

AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*

AWS A5.32M/A5.32 (ISO 14175 MOD), *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes*

AWS B4.0, *Standard Methods for Mechanical Testing of Welds*

American National Standards Institute (ANSI) document:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

ASTM International (ASTM) documents:

ASTM A36/A36M, *Specification for Carbon Structural Steel*

ASTM A285/A285M, *Specification for Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength*

ASTM A515/A515M, *Specification for Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service*

ASTM A516/A516M, *Specification for Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service*

ASTM A572/A572M, *Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel*

ASTM A830/A830M, *Standard Specification for Plates, Carbon Steel, Structural Quality, Furnished to Chemical Composition Requirements*

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

ASTM E350, *Standard Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron and Wrought Iron*

ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*

ASTM E2033, *Standard Practice for Radiographic Examination Using Computed Radiography (Photostimulable Luminescence Method)*

ASTM E2698, *Standard Practice for Radiographic Examination Using Digital Detector Arrays*

International Organization for Standardization (ISO) documents:

ISO 15792-1:2020, *Welding Consumables — Test Methods — Part 1: Test Methods for All-Weld Metal Test Specifications in Steel, Nickel and Nickel-Alloys*

ISO 80000-1:2009, *Quantities and Units — Part 1: General. Corrected by ISO 80000-1:2009/Cor 1:2011*

3. Classification

3.1 The flux cored electrodes covered by this AWS A5.20 specification utilize a classification system based upon the U.S. Customary Units, as specified in Table 1 and as shown in Figure 1. The flux cored electrodes covered by this AWS A5.20M specification utilize a classification system based upon the International System of Units (SI), as specified in Table 1 and as shown in Figure 1.

3.1.1 Flux cored electrodes classified for multiple-pass welding are classified according to the following:

(1) The as-welded mechanical properties of the weld metal obtained with a particular shielding gas, if any, as specified in Table 1 and Figure 1.

(2) The positions of welding for which the electrode is suitable, as shown in Table 2.

(3) Chemical composition, as specified in Table 3.

(4) Certain usability characteristics of the electrode, as specified in Table 2.

3.1.2 Flux cored electrodes classified for single-pass welding are classified in the as-welded condition according to the following:

(1) The minimum tensile properties of the weld metal obtained with a particular shielding gas, if any, as specified in Table 1.

(2) The positions of welding for which the electrode is suitable, as shown in Table 2.

(3) Certain usability characteristics of the electrode as specified in Table 2.

3.2 Electrodes classified under one classification shall not be classified under any other classification in this specification with the exceptions:

(1) an electrode may be classified with 100% CO₂ shielding gas and with a 75%–80% Ar/balance CO₂ shielding gas and

(2) an E7XT-1C, -1M [E49XT-1C, -1M] may also be classified as an E7XT-9C, -9M [E49XT-9C, -9M] and/or E7XT-12C, -12M [E49XT-12C, -12M] providing the electrode meets all the requirements of each classification.

3.3 Electrodes may be classified under A5.20 using U.S. Customary Units or under A5.20M using the International System of Units (SI) or they may be classified under both systems. Electrodes classified under either classification system must meet all requirements for classification under that system. The classification system is shown in Figure 1.

3.4 The electrodes classified under this specification are intended for flux cored arc welding, either with or without an external shielding gas. Electrodes intended for use without external shielding gas or with the shielding gas specified in Table 2 are not prohibited from use with any other process or shielding gas for which they are found suitable. *See Clauses A3 and B8.4 for information on optional shielding gas range designators.*

4. Acceptance

Acceptance of the welding electrodes shall be in accordance with the provisions of AWS A5.01M/A5.01 and the tests and requirements of this specification. See Clause B3 for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

5. Certification

By affixing the AWS specification and classification designations to the packaging or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification. See Clause B4 for further information concerning certification and the testing called for to meet this requirement.

6. Rounding Procedure

For purposes of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest 1000 psi (1 ksi) for tensile and yield strength for A5.20 [to the nearest 10 MPa for tensile and

yield strength for A5.20M] and to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfill the requirements for the classification under test.

7. Summary of Tests

7.1 The tests required for each classification are specified in Table 4. The purpose of these tests is to determine one or more of the following attributes of the weld metal: (1) mechanical properties; (2) soundness; (3) chemical composition. Additionally, tests are used to determine the usability of the electrode. The base metal for the weld test assemblies, the welding and testing procedures to be employed, and the results required are given in Clauses 9 through 15.

7.2 This document provides for *three* supplemental tests which are not required for classification but which are used when the corresponding optional supplemental designator is added to the electrode classification.

7.2.1 The supplemental test for diffusible hydrogen “HX” is described in Clause A1 in Annex A.

7.2.2 The optional supplemental designator “J” may be used to indicate that the electrode being classified meets the requirements for improved toughness and will deposit weld metal with Charpy V-Notch properties of at least 20 ft·lbf at -40°F [27 J at -40°C] when welds are made in a manner prescribed by this specification. See Clause A2 in Annex A.

7.2.3 *The optional tests for an oxygen equivalent gas range supplemental designator “OE H/L” are not required for classification, but may be used to indicate that the electrode being classified meets the same classification requirements, including any optional diffusible hydrogen (“HX”) or low temperature toughness (“J”) supplemental designators when tested with other shielding gases. See Clause A3 in Annex A.*

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Material, specimens, or samples for retest may be taken from the original test assembly or sample or from one or two new test assemblies or samples. For chemical analysis, retest need be only for those specific elements that failed to meet the test requirement. If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that, during preparation or after completion of any test, it is clearly determined that specified or proper procedures were not followed in preparing the weld test assembly or test specimen(s) or in conducting the test, the test shall be considered invalid, without regard to whether the test was actually completed or whether test results met or failed to meet the requirement. That test shall be repeated, following proper specified procedures. In this case, the requirement for doubling the number of test specimens does not apply.

9. Test Assemblies

9.1 One or more of the following four test assemblies are required, depending on the classification of the electrode and the manner in which the tests are conducted:

- (1) For multiple-pass electrodes, the test assembly in Figure 2, for mechanical properties and soundness of the weld metal.
- (2) For single-pass electrodes, the test assembly in Figure 3, for mechanical properties and soundness of the weld metal.
- (3) The weld pad in Figure 4, for chemical analysis of the weld metal.
- (4) The fillet weld test assembly in Figure 5 for usability of the electrode.

The sample for chemical analysis may be taken from the reduced section of the fractured tension test specimen or from a corresponding location (or any location above it) along the centerline of the weld metal in the groove weld in Figure 2, thereby avoiding the need to make the weld pad. In case of dispute, the groove weld sample shall be the referee method.

9.2 Preparation of each test assembly shall be as specified in Clauses 9.3 through 9.6, as applicable. The base metal for each assembly shall be as specified in Table 5 and shall meet the requirements of any one of the appropriate ASTM specifications shown there or a chemically equivalent specification. Electrodes shall be tested without “conditioning.” Conditioning can be considered to be any special preparation or procedure, such as baking the electrode, which the user would not normally practice. Testing of the welded test assemblies shall be as specified in Clauses 10 through 15.

9.3 Weld Pad. A weld pad shall be prepared as specified in Figure 4, except when an alternative in 9.1 (taking the sample from the broken tension test specimen or from a corresponding location or any location above it along the centerline of the weld metal in the groove weld in Figure 2) is selected. Base metal of any convenient size, of the type specified in Table 5, shall be used as the base metal for the weld pad. The surface of the base metal on which the filler metal is deposited shall be clean. The pad shall be welded in the flat position with multiple layers to obtain undiluted weld metal (1/2 in [12 mm] minimum thickness). The welding procedure used for the weld pad shall satisfy the heat input requirements specified in Table 6. The preheat temperature shall not be less than 60°F [15°C] and the interpass temperature shall not exceed 325°F [165°C]. The slag shall be removed after each pass. The pad may be quenched in water between passes, but must be dry before the start of the next pass. The dimensions of the completed pad shall be as shown in Figure 4. Testing of this assembly shall be as specified in Clause 10.

9.4 Test Assembly for Multipass Electrodes. For multipass electrodes (EXXT-1X, EXXT-4, EXXT-5X, EXXT-6, EXXT-7, EXXT-8, EXXT-9X, EXXT-11, EXXT-12X, and EXXT-G) one or two groove weld test assemblies shall be prepared and welded as specified in Figure 2 and Table 6, using the base metal of the appropriate type specified in Table 5. The electrode diameter for one test assembly shall be 3/32 in [2.4 mm] or the largest diameter manufactured. The electrode diameter for the other test assembly shall be 0.045 in [1.2 mm] or the smallest size manufactured. If the maximum diameter manufactured is 1/16 in [1.6 mm] or less only the largest diameter need be tested. The electrode polarity shall be as specified in Table 2. Welding shall be in the flat position and the assembly shall be restrained or preset during welding to prevent warpage in excess of 5°. A completed weld assembly that is more than 5 degrees out of plane shall be discarded. Test assemblies shall not be straightened. Welding shall begin at 60°F [15°C] minimum. Welding shall continue until the assembly has reached a temperature of 300°F ± 25°F [150°C ± 15°C], measured by temperature indicating crayons or surface thermometers at the location shown in Figure 2. This interpass temperature shall be maintained for the remainder of the weld. Should it be necessary to interrupt welding, the assembly shall be allowed to cool in still air. The assembly shall be heated to a temperature of 300°F ± 25°F [150°C ± 15°C] before welding is resumed. Testing of the assemblies shall be in the as-welded condition and as specified in Table 4.

9.5 Test Assembly for Single-Pass Electrodes. For single-pass electrodes (EXXT-2X, EXXT-3, EXXT-10, EXXT-14, and EXXT-GS) a butt joint test assembly using base metal as specified in Table 5 shall be prepared as specified in Figure 3. The welding procedure shall be selected by the manufacturer. After tack welding the plates at each end, the test assembly shall be welded in the flat position with one bead on each side. Welding shall begin with the assembly at 60°F [15°C] minimum. When the weld bead has been completed on the face side, the assembly shall be turned over and the bead deposited on the root side, as shown in Figure 3. This sequence shall not be interrupted. The electrode size shall be either 3/32 in [2.4 mm] diameter or the size the manufacturer produces that is closest to the 3/32 in [2.4 mm] diameter. The welding polarity shall be as shown in Table 2 for the classification being tested. After welding has been completed and the assembly has cooled, the assembly shall be prepared and tested as specified in Clauses 12 and 13 in the as-welded condition (except for the aging of the bend test specimen specified in 13.2).

9.6 Fillet Weld Test Assembly. The fillet weld test, when required in Table 4, shall be made in accordance with the requirements of AWS A4.5M/A4.5 using any of the base metals listed in Table 5. When specified for an EX0T-XX classification, the test assembly shall be welded in the horizontal position. When specified for an EX1T-XX classification, two test assemblies are required, one welded in the vertical position and one welded in the overhead position. The progression for vertical welding shall be either upward or downward depending on the classification (see Table 2).

Before assembly, the standing member (web) shall have one edge prepared throughout its length and the base member (flange) side shall be straight, smooth, and clean. The test plates shall be assembled as shown in Figure 5. When assembled the faying surfaces shall be in intimate contact along the entire length of the joint. The test assembly shall be secured with tack welds deposited at each end of the weld joint.

The welding procedure and the size of the electrode to be tested shall be as selected by the manufacturer. The fillet weld shall be a single-pass weld deposited either semiautomatically or automatically as selected by the manufacturer. Both

pieces to form the test assembly shall have cross sections of 3/8 in [10 mm] to 1/2 in [12 mm] thickness by 3 in [75 mm] minimum width. The length of the weld shall be 12 in [300 mm] minimum.

The fillet weld size shall not be greater than 3/8 in [10 mm]. Weld cleaning shall be limited to chipping, brushing, and needle scaling. Grinding, filing, or other metal cutting of the fillet weld face is prohibited. The testing of the assembly shall be as specified in Clause 15.

10. Chemical Analysis

10.1 When specified in Table 4, the sample for chemical analysis shall be taken from weld metal produced with the flux cored electrode and the shielding gas (if any) with which it is classified. The sample may be taken from the reduced section of the fractured tension test specimen or from a corresponding location or any location above it along the weld centerline in the groove weld in Figure 2. The sample for chemical analysis shall be prepared for analysis by any means that will not affect the chemical composition.

10.2 The weld pad described in 9.3 may also be used to produce the weld metal sample for chemical analysis. The top surface of the pad described in 9.3 and shown in Figure 4 shall be removed and discarded and a sample for analysis shall be obtained from the underlying metal by any means that will not affect the chemical composition. The sample shall be free of slag. The sample shall be taken at least 3/8 in [10 mm] from the nearest surface of the base metal. In case of dispute, the analysis of the sample taken from the groove weld shall be the referee method.

10.3 The sample shall be analyzed by accepted analytical methods. The referee method shall be ASTM E350.

10.4 The results of the analysis shall meet the requirements of Table 3 for the classification of electrode under test.

11. Radiographic Test

11.1 The welded test assembly described in 9.4 and shown in Figure 2 shall be radiographed to evaluate the soundness of the weld metal. In preparation for radiography, the backing shall be removed and both surfaces of the weld shall be machined or ground smooth and flush with the original surfaces of the base metal or with a uniform reinforcement not exceeding 3/32 in [2.5 mm]. It is permitted on both sides of the test assembly to remove base metal to a depth of 1/16 in [1.5 mm] nominal below the original base metal surface in order to facilitate backing and/or buildup removal. The thickness of the weld metal shall not be reduced by more than 1/16 in [1.5 mm], so that the thickness of the prepared radiographic test specimen equals at least the thickness of the base metal minus 1/16 in [1.5 mm].

Both surfaces of the test assembly, in the area of the weld, shall be smooth enough to avoid difficulty in interpreting the radiograph.

11.2 The weld shall be radiographed in accordance with one of the following. The quality level of inspection shall be 2-2T.

(1) Film Radiography: ASTM E1032.

(2) *Computed Radiography (CR): ASTM E2033 and the requirements of ASTM E1032 except where CR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2033, refers to phosphor imaging plate.*

(3) *Digital Radiography (DR): ASTM E2698 and the requirements of ASTM E1032 except where DR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2698, refers to digital detector array (DDA).*

11.3 The soundness of the weld metal meets the requirements of this specification if the radiograph shows:

(1) no cracks, no incomplete fusion, and no incomplete penetration;

(2) no slag inclusions longer than 1/4 in [6 mm] or 1/3 of the thickness of the weld, whichever is greater, or no groups of slag inclusions in line that have an aggregate length greater than the thickness of the weld in a length 12 times the thickness of the weld except when the distance between the successive inclusions exceeds 6 times the length of the longest inclusion in the group; and

- (3) no rounded indications in excess of those permitted by the radiographic standards in Figure 6.

In evaluating the radiograph, 1 in [25 mm] of the weld on each end of the test assembly shall be disregarded.

A rounded indication is an indication on the radiograph whose length is no more than three times its width. Rounded indications may be circular or irregular in shape and may have tails. The size of a rounded indication is the largest dimension of the indication, including any tail that may be present. The indication may be of porosity or slag. Test assemblies with indications larger than the large indications permitted in the radiographic standard (Figure 6) do not meet the requirements of this specification.

12. Tension Test

12.1 For multiple-pass electrode classifications, one all-weld-metal tension test specimen, as specified in the Tension Test clause of AWS B4.0, shall be machined from the welded test assembly described in 9.4 and shown in Figure 2. The all-weld-metal tension specimen shall have a nominal diameter of 0.5 in [12.5 mm] (or 0.25 in [6.5 mm] for some electrodes, as indicated in Note d of Table 1) and a nominal gage length to diameter ratio of 4:1.

12.1.1 The weld test assembly or tension test specimen may be aged at a temperature not to exceed 220°F [105°C] for up to 48 hours then allowed to cool to room temperature. In case of dispute, aging the tension specimen shall be the referee method. No aging shall be performed prior to radiographic examination. Refer to 8.3 for a discussion of the purpose of aging.

12.1.2 The tension test specimen shall be tested in the manner described in the Tension Test clause of AWS B4.0.

12.1.3 The results of the tension test shall meet the requirements specified in Table 1.

12.2 For single-pass electrode classifications, one transverse tension test specimen, as specified in the Tension Test clause of AWS B4.0, shall be machined from the welded test assembly described in 9.5 and shown in Figure 3. The transverse rectangular tensile specimen shall be a full thickness specimen machined transverse to the weld with a nominal reduced section width of 1.5 in [38 mm].

12.2.1 The tension test specimen shall be tested in the manner described in the Tension Test clause of AWS B4.0.

12.2.2 The results of the tension test shall meet the requirements specified in Table 1.

13. Bend Test

13.1 For single-pass electrode classifications, one longitudinal face bend test specimen, as required in Table 4, shall be machined from the welded test assembly described in 9.5 and shown in Figure 3. The dimensions of the specimen shall be as shown in Figure 3. Other dimensions of the bend specimen shall be as specified in the Bend Test clause of AWS B4.0.

13.2 The weld test assembly or bend specimens may be aged at a temperature not to exceed 220°F [105°C] for up to 48 hours, then allowed to cool to room temperature. In case of dispute, aging the bend specimen shall be the referee method. Refer to B8.3 for a discussion on the purpose of aging.

13.3 The bend specimen shall be tested in the manner described in the Bend Test clause of AWS B4.0 by bending it uniformly through 180° over a 3/4 in [19 mm] radius using any suitable jig, as specified in the Bend Test clause of B4.0. Positioning of the longitudinal face bend specimens shall be such that the weld face of the last side welded is in tension.

13.4 Each specimen, after bending, shall conform to the 3/4 in [19 mm] radius, with an appropriate allowance for spring back, and the weld metal shall not show any crack or other open defect exceeding 1/8 in [3.2 mm] in any direction when examined with the unaided eye. Cracks in the base metal shall be disregarded, as long as they do not enter the weld metal. When base metal openings or cracks enter the weld metal, the test shall be considered invalid. Specimens in which this occurs shall be replaced, specimen for specimen, and the test repeated. In this case, the doubling of specimens required in Clause 8 does not apply.

14. Impact Test

14.1 Five full-size Charpy V-Notch impact test specimens, as specified in the Fracture Toughness Test clause of AWS B4.0 shall be machined from the test assembly shown in Figure 2 for those classifications for which impact testing is specified in Table 4 or when the optional supplemental designator “J” is utilized.

The Charpy V-Notch specimens shall have the notched surface and the struck surface parallel with each other within 0.002 in [0.05 mm]. The other two surfaces of the specimen shall be square with the notched or struck surfaces within 10 minutes of a degree. The notch shall be smoothly machined and shall be square with the longitudinal edge of the specimen within one degree.

The geometry of the notch shall be measured on at least one specimen in a set of five specimens. Measurement shall be done at a minimum 10X magnification. The correct location of the notch shall be verified by etching before or after machining.

14.2 The five specimens shall be tested in accordance with the Fracture Toughness Test section of AWS B4.0. The test temperature shall be at or below the temperature specified in Table 1 for the classification under test. For those electrodes to be identified by the optional supplemental impact designator “J,” the test temperature shall be as specified in Figure 1. See also A2 in Annex A. The actual temperature used shall be listed on the certification document.

14.3 In evaluating the test results, the lowest and the highest values obtained shall be disregarded. Two of the remaining three values shall equal or exceed the specified 20 ft-lbf [27 J] energy level. One of the three may be lower, but not lower than 15 ft-lbf [20 J] and the average of the three shall be not less than the required 20 ft-lbf [27 J] energy level.

15. Fillet Weld Test

15.1 The fillet weld test assembly, when required in Table 4, shall be made in accordance with the requirements of 9.6 and Figure 5. The entire face of the completed fillet shall be examined visually. There shall be no indication of cracks, and the weld shall be reasonably free of undercut, overlap, trapped slag, and surface porosity. After the visual examination, the fillet weld size, leg lengths, and convexity shall be measured *using the methods of AWS A4.5M/A4.5*. The measured dimensions shall meet the requirements in Table 7 for fillet size, convexity, and permissible difference in the leg lengths.

15.2 A minimum of 10 in [250 mm] of the test assembly shall be broken longitudinally through the fillet weld by a force exerted *as shown in AWS A4.5M/A4.5*. Cutting of the test assembly into two or more lengths before fracture is permitted, but a sufficient number of segments shall be fractured such that a minimum of 10 in [250 mm] is examined. When necessary, to facilitate fracture through the fillet, one or more of the procedures listed *in AWS A4.5M/A4.5* may be used.

Tests in which the weld metal pulls out of the base metal during bending are invalid. Specimens in which this occurs shall be replaced, specimen for specimen, and the test completed. In this case, the doubling of the specimens required for retest in Clause 8 does not apply.

15.3 The fractured surfaces shall be examined. They shall be free of cracks and shall be reasonably free of porosity and trapped slag. Incomplete fusion at the root of the weld shall not exceed 20% of the total length of the weld. Slag beyond the vertex of an isosceles triangle with the hypotenuse as the face shall not be considered incomplete fusion.

16. Optional Supplemental Tests and Requirements

Provisions are made in this specification for three tests listed below which are optional and not required for classification. Conformance to these supplemental requirements is indicated by a specific designator (HX, J, or *OE H/L*) which is added to the classification as shown in Figure 1.

16.1 “H” Optional Supplemental Designator (Diffusible Hydrogen). An optional supplemental designator is used to indicate the diffusible hydrogen content of the deposited weld metal. Refer to A1 in Annex A.

16.2 “J” Optional Supplemental Designator (Improved Impact Properties). A provision is made to indicate weld-metal toughness properties that exceed those required for classification. A “J” optional supplemental designator is used to indicate the deposited weld metal can produce 20 ft-lbs at -40°F [27 J at -40°C]. Refer to A2 in Annex A.

16.3 “OE” Optional Supplemental Shielding Gas Range Designators. A provision is made to indicate that an electrode meets the requirements for classification with shielding gases other than that with which it was classified, such as 100% CO₂ (“C” designator) or 75%–80% Ar/balance CO₂ (“M” designator). This optional supplemental shielding gas designator indicates the high and low oxygen equivalent gases that were used in testing which met the AWS A5.20 or A5.20M requirements for that classification including all mandatory classification requirements and all optional supplemental requirements (if any). Refer to Clause A3, Table A.2 in Annex A, and Clause B8.4 in Annex B.

17. Method of Manufacture

The electrodes classified according to this specification may be manufactured by any method that will produce electrodes that meet the requirements of this specification.

18. Standard Sizes

Standard sizes for filler metal in the different package forms such as coils with support, coils without support, drums, and spools are as specified in AWS A5.02/A5.02M.

19. Finish and Uniformity

Finish and uniformity shall be as specified in AWS A5.02/A5.02M.

20. Standard Package Forms

Standard package forms are coils with support, coils without support, spools, and drums. Standard package dimensions and weights for each form shall be as specified in AWS A5.02/A5.02M.

21. Winding Requirements

21.1 Winding requirements shall be as specified in AWS A5.02/A5.02M. The outermost layer of electrode on spools shall be at least 1/8 in [3 mm] inside the rim (the OD) of the flanges of the spool.

21.2 The cast and helix of electrode in coils, spools, and drums shall be as specified in AWS A5.02/A5.02M.

22. Filler Metal Identification

22.1 Electrode identification, product information, and precautionary information shall be as specified in AWS A5.02/A5.02M.

23. Packaging

Electrodes shall be suitably packaged to ensure against damage during shipment and storage under normal conditions.

24. Marking of Packages

24.1 The product information specified in AWS A5.02/A5.02M. (as a minimum) shall be legibly marked and visible from the outside of each unit package.

24.2 The appropriate precautionary information as given in ANSI Z49.1, latest edition (as a minimum) or its equivalent, shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages enclosed within a larger package. Typical examples of “warning labels” and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

Table 1
Mechanical Property Requirements (as welded)

AWS Classifications A5.20 [A5.20M]	Tensile Strength ksi [MPa]	Yield Strength ^a ksi [MPa]	Minimum % Elongation ^b	Minimum Charpy V-Notch Energy ft-lbs [Joules]
E7XT-1C, 1M [E49XT-1C, -1M]	70–95 [490–670]	58 [390] min.	22	20 ft-lbf @ 0°F [27 J @ –20°C]
E7XT-2C, -2M ^c [E49XT-2C, -2M ^c]	70 [490] min.	Not Specified	Not Specified	Not Specified
E7XT-3 ^c [E49XT-3 ^c]				
E7XT-10 ^c [E49XT-10 ^c]				
E7XT-14 ^c [E49XT-14 ^c]				
E7XT-GS ^c [E49XT-GS ^c]				
E7XT-4 [E49XT-4]	70–95 [490–670]	58 [390] min.	22 ^d	Not Specified
E7XT-7 [E49XT-7]				
E7XT-11 [E49XT-11]				
E7XT-G [E49XT-G]				
E7XT-5C, -5M [E49XT-5C, -5M]	70–95 [490–670]	58 [390] min.	22	20 ft-lbf @ –20°F [27 J @ –30°C]
E7XT-6 [E49XT-6]				
E7XT-8 [E49XT-8]				
E7XT-9C, -9M [E49XT-9C, -9M]				
E7XT-12C, -12M [E49XT-12C, -12M]	70–90 [490–620]			
E6XT-GS ^c [E43XT-GS ^c]	60 [430] min.	Not Specified	Not Specified	Not Specified
E6XT-G [E43XT-G]	60–80 [430–600]	48 [330] min.	22	Not Specified

^a Yield Strength at 0.2% offset.

^b In 2 in [50 mm] gage length when a 0.500 in [12.5 mm] nominal diameter tensile specimen and nominal gage length to diameter ratio of 4:1 (as specified in the Tension Test clause of AWS B4.0) is used.

^c These classifications are intended for single-pass welding. They are not for multiple-pass welding. Only tensile strength is specified and, for this reason, only transverse tension and longitudinal guided bends are required (see Table 4).

^d The minimum % elongation requirement for E7XT-11 [E49XT-11] is 20%. For 0.045 in [1.2 mm] and smaller sizes of the E7XT-11 [E49XT-11] classification, a nominal 0.250 in [6.5 mm] tensile specimen with a 1 in [25 mm] gage length is permitted.

Table 2
Usability Designators and General Description of Electrode Types^{a, b}

Electrode Classification ^c	Welding Positions ^e	Process	Polarity ^d	General Description
E70T-1X	H & F	FCAW-G	DCEP	Flux cored electrodes of this type are gas shielded and have a rutile base slag. They are characterized by a spray transfer, low spatter loss, and a moderate volume of slag which completely covers the weld bead.
E71T-1X	H, F, VU, & OH			
E70T-2X	H & F	FCAW-G	DCEP	Flux cored electrodes of this type are similar to the “T-1” type electrodes but with higher manganese or silicon, or both. They are designed primarily for single-pass welding in the flat and horizontal positions. The higher levels of deoxidizers in this electrode type allow single-pass welding of heavily oxidized or rimmed steel.
E71T-2X	H, F, VU, & OH			
E70T-3	H & F	FCAW-S	DCEP	Flux cored electrodes of this type are self-shielded and are intended for single-pass welding, and are characterized by a spray type transfer. The titanium-based slag system is designed to make very high welding speeds possible.
E70T-4	H & F	FCAW-S	DCEP	Flux cored electrodes of this type are self-shielded and are characterized by a globular type transfer. Its fluoride-based basic slag system is designed to make very high deposition rates possible and to produce very low sulfur welds for improved resistance to hot cracking.
E70T-5X	H & F	FCAW-G	DCEP or DCEN	Flux cored electrodes of this type are gas shielded and are characterized by a globular transfer, slightly convex bead contour, and a thin slag that may not completely cover the weld bead. They have a lime-fluoride slag system and develop improved impact properties and better cold cracking resistance than typically exhibited by the “T-1” type electrodes.
E71T-5X	H, F, VU, & OH			
E70T-6	H & F	FCAW-S	DCEP	Flux cored electrodes of this type are self-shielded and are characterized by a spray transfer. Its oxide-based slag system is designed to produce good low temperature notch toughness, good penetration into the root of the weld, and excellent slag removal.
E70T-7	H & F	FCAW-S	DCEN	Flux cored electrodes of this type are self-shielded and are characterized by a small droplet to spray type transfer. The fluoride-based slag system is designed to provide high deposition rates in the downhand positions with the larger diameters and out-of-position capabilities with the smaller diameters.
E71T-7	H, F, VU, & OH			
E70T-8	H & F	FCAW-S	DCEN	Flux cored electrodes of this type are self-shielded and are characterized by a small droplet to spray type transfer. The slag system is designed to provide improved out-of-position control. The weld metal produced typically exhibits very good low temperature notch toughness and crack resistance.
E71T-8	H, F, VU, VD, & OH			
E70T-9X	H & F	FCAW-G	DCEP	Flux cored electrodes of this type are similar in design and application to the T-1 types but with improved weld metal notch toughness capabilities.
E71T-9X	H, F, VU, & OH			
E70T-10	H & F	FCAW-S	DCEN	Flux cored electrodes of this type are self-shielded and are characterized by a small droplet transfer. The fluoride-based slag system is designed to make single-pass welds at high travel speeds.
E70T-11	H & F	FCAW-S	DCEN	Flux cored electrodes of this type are self-shielded and are characterized by a smooth spray type transfer, limited slag coverage, and are generally not recommended for the welding of materials over 3/4 in [20 mm] thick.
E71T-11	H, F, VD, & OH			

(Continued)

Table 2 (Continued)
Usability Designators and General Description of Electrode Types^{a, b}

Electrode Classification ^c	Welding Positions ^e	Process	Polarity ^d	General Description
E70T-12X	H & F	FCAW-G	DCEP	Flux cored electrodes of this type are similar in design and application to the T-1 types. However, they have been modified for improved impact toughness and to meet the lower manganese requirements of the A-No. 1 Analysis Group in the <i>ASME Boiler and Pressure Vessel Code</i> , Section IX.
E71T-12X	H, F, VU, & OH			
E71T-14	H, F, VD, & OH	FCAW-S	DCEN	Flux cored electrodes of this type are self-shielded and are characterized by a smooth spray-type transfer. The slag system is designed for single-pass welds in all positions and at high travel speeds.
E60T-G	H & F	Not Specified	Not Specified	As agreed upon between purchaser and supplier.
E70T-G				
E61T-G	H, F, VU or VD, & OH	Not Specified	Not Specified	As agreed upon between purchaser and supplier.
E71T-G				
E60T-GS	H & F	Not Specified	Not Specified	As agreed upon between purchaser and supplier.
E70T-GS				
E61T-GS	H, F, VU or VD, & OH	Not Specified	Not Specified	As agreed upon between purchaser and supplier.
E71T-GS				

^a For more information refer to B6 and B7 (in Annex B).

^b Properties of weld metal from electrodes that are used with external shielding gas will vary according to the shielding gas used. See B8.4.

^c The "X," if present, indicates the shielding gas used (C or M).

^d The term "DCEP" refers to direct current electrode positive (dc, reverse polarity). The term "DCEN" refers to direct current electrode negative (dc, straight polarity).

^e H = horizontal position, F = flat position, OH = overhead position, VU = vertical position with upward progression, VD = vertical position with downward progression

Table 3
Weld Metal Composition Requirements

Electrode Classification A5.20 [A5.20M]	UNS ^a Number	Weight Percent ^{b,c,d}										
		C	Mn	Si	S	P	Cr ^e	Ni ^e	Mo ^e	V ^e	Al ^{e,f}	Cu ^e
E7XT-1C, -1M [E49XT-1C, -1M]	W07601	0.12	1.75	0.90	0.03	0.03	0.20	0.50	0.30	0.08	—	0.35
E7XT-5C, -5M [E49XT-5C, -5M]	W07605											
E7XT-9C, -9M [E49XT-9C, -9M]	W07609											
E7XT-4 [E49XT-4]	W07604	0.30	1.75	0.60	0.03	0.03	0.20	0.50	0.30	0.08	1.8	0.35
E7XT-6 [E49XT-6]	W07606											
E7XT-7 [E49XT-7]	W07607											
E7XT-8 [E49XT-8]	W07608											
E7XT-11 [E49XT-11]	W07611											
E7XT-12C, -12M [E49XT-12C, -12M]	W07612	0.12	1.60	0.90	0.03	0.03	0.20	0.50	0.30	0.08	—	0.35
EXXT-G [EXXT-G]	—	(g)	1.75	0.90	0.03	0.03	0.20	0.50	0.30	0.08	1.8	0.35
E7XT-2C, -2M [E49XT-2C, -2M]	W07602	Not Specified ^h										
E7XT-3 [E49XT-3]	W07603											
E7XT-10 [E49XT-10]	W07610											
E7XT-14 [E49XT-14]	W07614											
EXXT-GS [EXXT-GS]	—											

^a According to SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System*.

^b The weld metal shall be analyzed for the specific elements for which values are shown in this table. The total of all the elements listed in this table shall not exceed 5%.

^c Single values are maximums.

^d Analysis for B is required to be reported if intentionally added, or if it is known to be present at levels greater than 0.0010%.

^e The analysis of these elements shall be reported if intentionally added.

^f Applicable to self-shielded electrodes only. Electrodes for use with gas shielding normally do not have any significant additions of aluminum.

^g The limit for gas-shielded electrodes is 0.18% maximum. The limit for self-shielded electrodes is 0.30% maximum.

^h The composition of weld metal is not particularly meaningful since electrodes of these classifications are intended only for single-pass welds. Dilution from the base metal in such welds is usually quite high. See B6 in the Annex B.

Table 4
Tests Required for Classification^a

AWS Classifications	Chemical Analysis	Radiographic Test	Tension Test	Impact Test	Fillet Weld Test	Bend Test
EXXT-1C, -1M	R	R	R	R	R	NR
EXXT-5C, -5M						
EXXT-6						
EXXT-8						
EXXT-9C, -9M						
EXXT-12C, -12M						
EXXT-4	R	R	R	NR	R	NR
EXXT-7						
EXXT-11						
EXXT-G						
EX0T-3 ^b	NR	NR	R ^c	NR	NR	R
EX0T-10 ^b						
EXXT-2C, -2M ^b	NR	NR	R ^c	NR	R	R
EX1T-14 ^b						
EXXT-GS ^b						

^a The letter "R" indicates the test is required. "NR" indicates the test is not required.

^b Intended for single-pass welding.

^c Transverse tension test. All others require all-weld-metal tension test.

Table 5
Base Metal for Test Assemblies

AWS Classifications	ASTM Specification	UNS Number ^a
EXXT-1C, -1M	A36/A36M A285/A285M Grade C A515/A515M Grade 70 A516/A516M Grade 70 A572/A572M Grade 50 A830/ A830M Grade 1015 A830/ A830M Grade 1018 A830/ A830M Grade 1020	K02303 K02304 K02305 K02306 K02600 K02801 K03101 K02700 G10150 G10180 G10200
EXXT-4		
EXXT-5C, -5M		
EXXT-6		
EXXT-7		
EXXT-8		
EXXT-9C, -9M		
EXXT-11		
EXXT-12C, -12M		
EXXT-G		
EXXT-2C, -2M	A515/A515M Grade 70 or A516/A516M Grade 70	K03101 K02700
EXXT-3		
EXXT-10		
EXXT-14		
EXXT-GS		

^aAccording to ASTM DS-56 (or SAE HS-1086), *Metals & Alloys in the Unified Numbering System*.

Table 6
Heat Input Requirements and Suggested Pass and
Layer Sequence for Multiple-Pass Electrode Classifications

Electrode Diameter		Required Average Heat Input ^{a, b, c, d}	Suggested Passes per Layer		Suggested Number of Layers
in	mm		Layer 1	Layer 2 to Top	
≤ 0.030	≤ 0.8	20–35 [0.8–1.4]	1 or 2	2 or 3	6 to 9
0.035	0.9				
—	1.0	25–50 [1.0–2.0]	1 or 2	2 or 3	6 to 9
0.045	—				
—	1.2				
0.052	—	25–55 [1.0–2.2]	1 or 2	2 or 3	5 to 8
—	1.4				
1/16 (0.062)	1.6				
0.068	—	35–65 [1.4–2.6]	1 or 2	2 or 3	5 to 8
—	1.8				
0.072	—				
5/64 (0.078)	2.0				
3/32 (0.094)	2.4	40–65 [1.6–2.6]	1 or 2	2 or 3	4 to 8
7/64 (0.109)	2.8	50–70 [2.0–2.8]	1 or 2	2 or 3	4 to 7
0.120	—	55–75 [2.2–3.0]	1 or 2	2	4 to 7
1/8 (0.125)	3.2				
5/32 (0.156)	4.0	65–85 [2.6–3.3]	1	2	4 to 7

^a Heat input is calculated using one of the following formulas:

Heat Input (kJ/in)	Formula #1	$\frac{\text{volts} \times \text{amps} \times 60}{\text{travel speed (in/min)} \times 1000}$
	Formula #2	$\frac{\text{volts} \times \text{amps} \times 60 \times \text{arc time (minutes)}}{\text{weld length (in)} \times 1000}$
Heat Input (kJ/mm)	Formula #1	$\frac{\text{volts} \times \text{amps} \times 60}{\text{travel speed (mm/min)} \times 1000}$
	Formula #2	$\frac{\text{volts} \times \text{amps} \times 60 \times \text{arc time (minutes)}}{\text{weld length (mm)} \times 1000}$

^b Does not apply to the first layer. The first layer shall have a maximum of two passes.

^c The average heat input is the calculated average for all passes excluding the first layer.

^d A nonpulsed constant voltage (CV) welding mode shall be used.

Table 7
Dimensional Requirements for Fillet Weld Usability Test Specimens

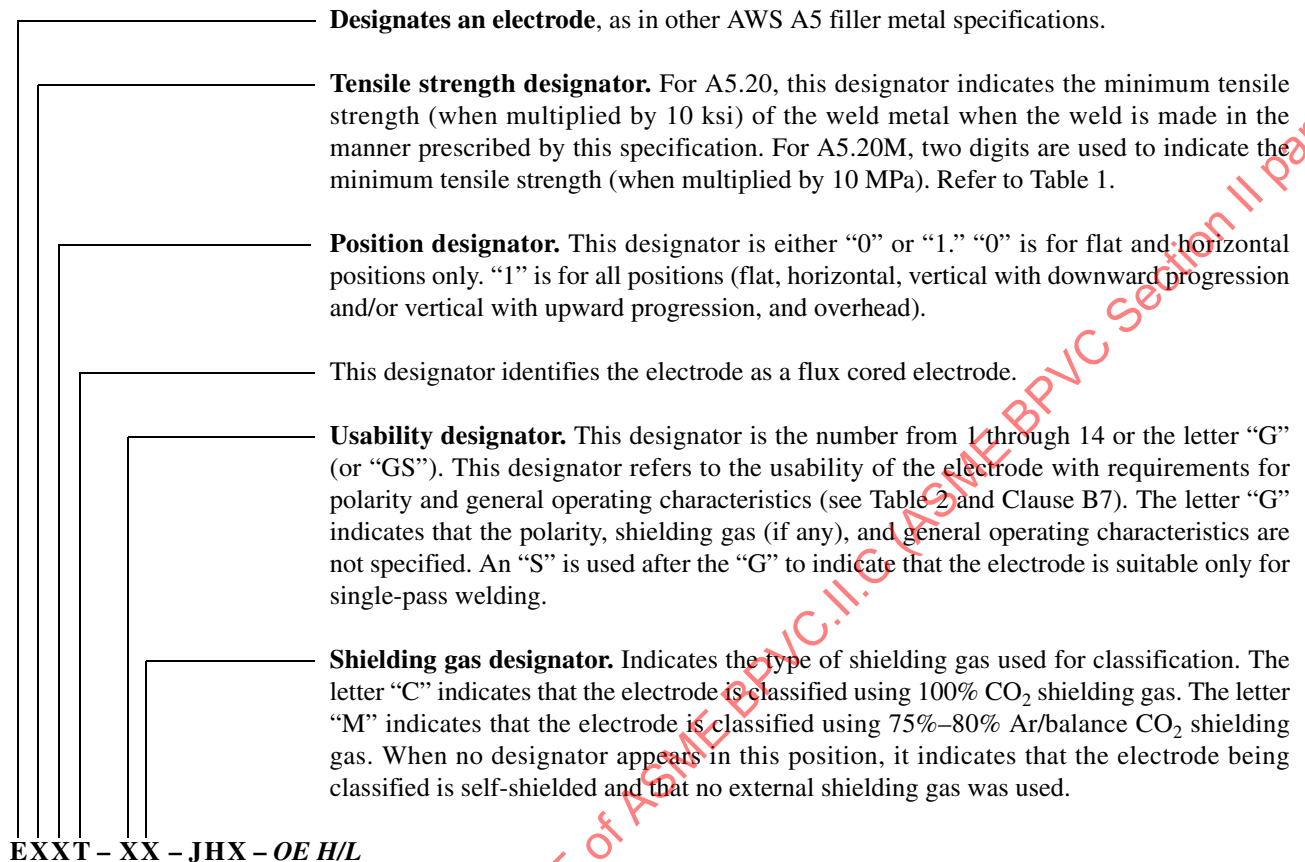
Measured Fillet Weld Size ^a		Maximum Convexity ^b		Maximum Difference Between Fillet Weld Legs ^c	
in	mm	in	mm	in	mm
1/8	3	1/16	2	1/32	1
5/32	4	1/16	2	1/16	2
3/16	—	1/16	—	1/16	—
—	5	—	2	—	2
7/32	—	1/8	—	3/32	—
1/4	6	1/8	3	3/32	2
9/32	7	1/8	3	1/8	3
5/16	8	1/8	3	1/8	3
11/32	9	1/8	3	5/32	4
3/8	10	1/8	3	5/32	4

^a Maximum permitted fillet weld size is 3/8 in [10 mm].

^b Convexity measurements shall be made to the nearest 1/16 in [2 mm].

^c Fillet weld leg length measurements shall be made to the nearest 1/32 in [1 mm].

Mandatory Classification Designators^a



Optional Supplemental Designators^b

*Optional **shielding gas range designator.** This designator indicates that the electrode meets all mandatory and applied optional requirements of the classification with shielding gases of different oxygen equivalencies. Refer to Clause A3, Table A.2, and Clause B8.4.*

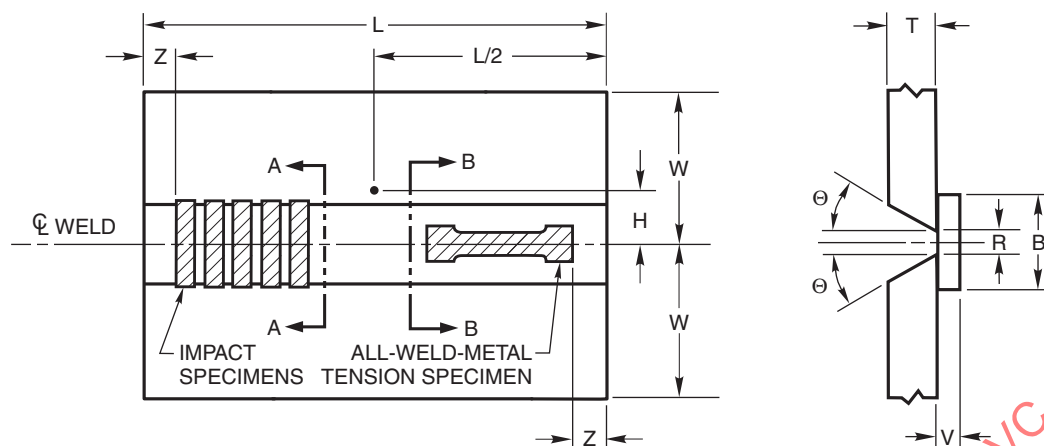
Optional supplemental diffusible hydrogen designator. Refer to Clause A1.

The letter “J” designates that the electrode will deposit weld metal with Charpy V-Notch properties of at least 20 ft-lbf at –40°F [27 J at –40°C] when the welds are made in a manner prescribed by this specification. Refer Clause A2.

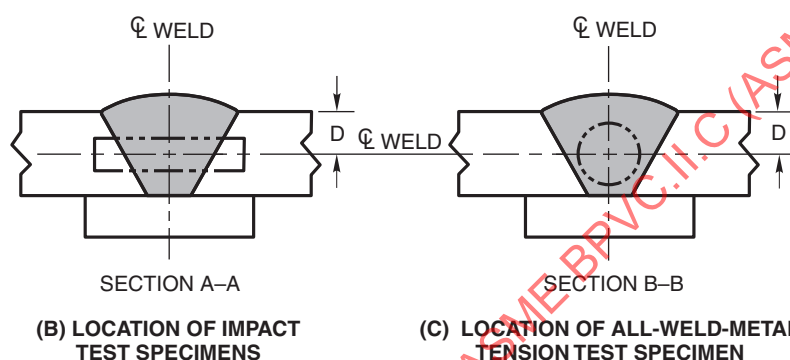
^a The combination of these designators constitutes the flux cored electrode classification.

^b These designators are optional and do not constitute a part of the flux cored electrode classification.

Figure 1—A5.20/A5.20M Classification System



(A) TEST PLATE SHOWING LOCATION OF TEST SPECIMENS

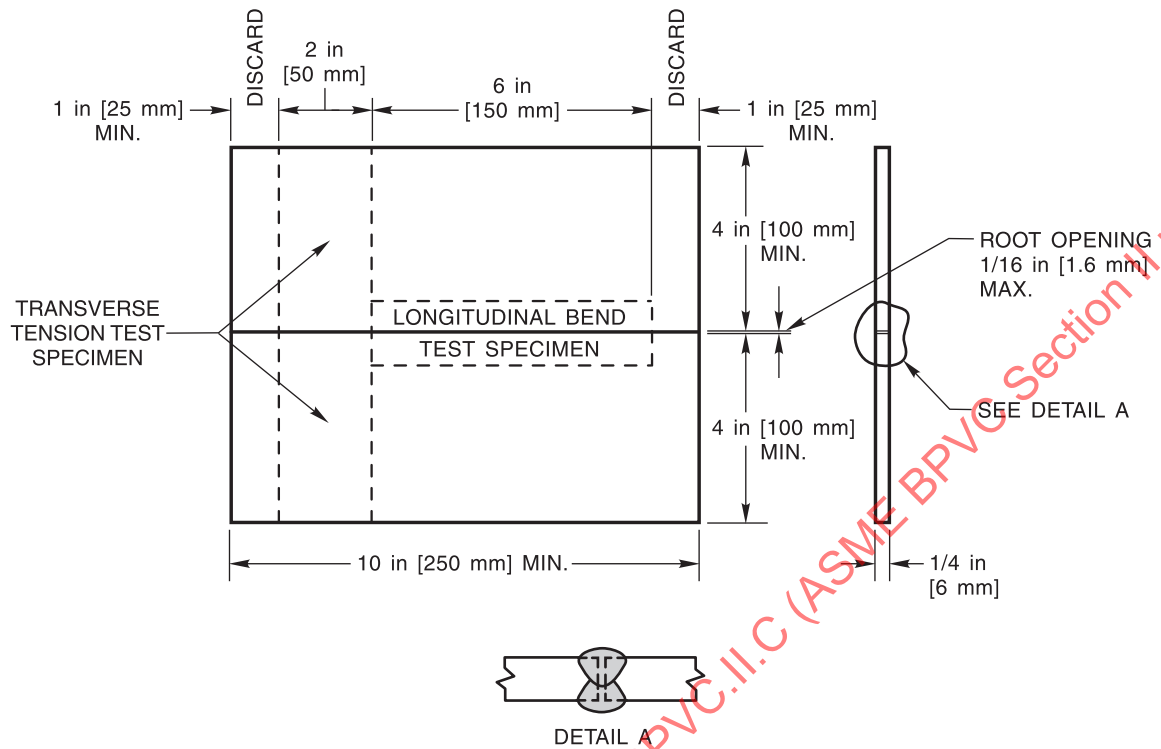


*DRAWING
NOT TO
SCALE*

Dimension	Description	Test Assembly 1		Test Assembly 2	
		A5.20, in	A5.20M, mm	A5.20, in	A5.20M, mm
L	Length, min.	10	250	10	250
T	Nominal Thickness	3/4	20	3/4	20
W	Width, min.	5	125	5	125
V	Backing Thickness, min.	1/4	6	1/4	6
D	Specimen Center	3/8±1/32	10 ± 1	3/8 ± 1/32	10 ± 1
B	Backing Width, min.	2 × R	2 × R	2 × R	2 × R
R	Root Opening	1/2, −0, +1/16	12, −0, +1	5/8, −0, +1/16	16, −0, +1
Z	Discard, min.	1	25	1	25
θ	Bevel Angle	22.5° ± 2°	22.5° ± 2°	10°, −0, +2.5°	10°, −0, +2.5°
H	Approximate Point of Temperature Measurement	1	25	1	25

1. Either test assembly is acceptable for classification. In case of dispute, Test Assembly 1 shall be the referee test assembly.
2. For 0.045 in [1.2 mm] and smaller diameters of the EXXT11-X electrode classifications, the test [plate thickness shall be 1/2 in [12 mm] nominal and the maximum root opening shall be 1/4 in -0 in $+1/16$ in [6 mm -0 mm $+1$ mm]. The all-weld-metal tension specimen shall be reduced to a nominal diameter of 0.250 in [6.5 mm] with a nominal gage length to diameter ratio of 4:1. See Note d in Table 1.
3. Base metal shall be as specified in Table 5.

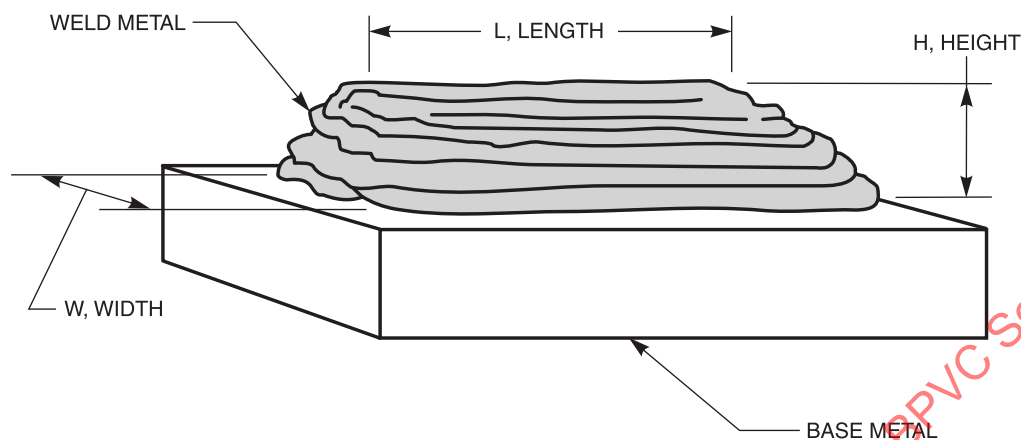
Figure 2—Test Assembly for Mechanical Properties and Soundness of Weld Metal from Multiple-Pass Electrodes



Notes:

1. Detail A shows the completed joint and approximate weld configuration.
2. Plate thickness may be reduced to 3/16 in [5 mm] for an electrode of 0.068 in [1.7 mm] diameter or smaller.

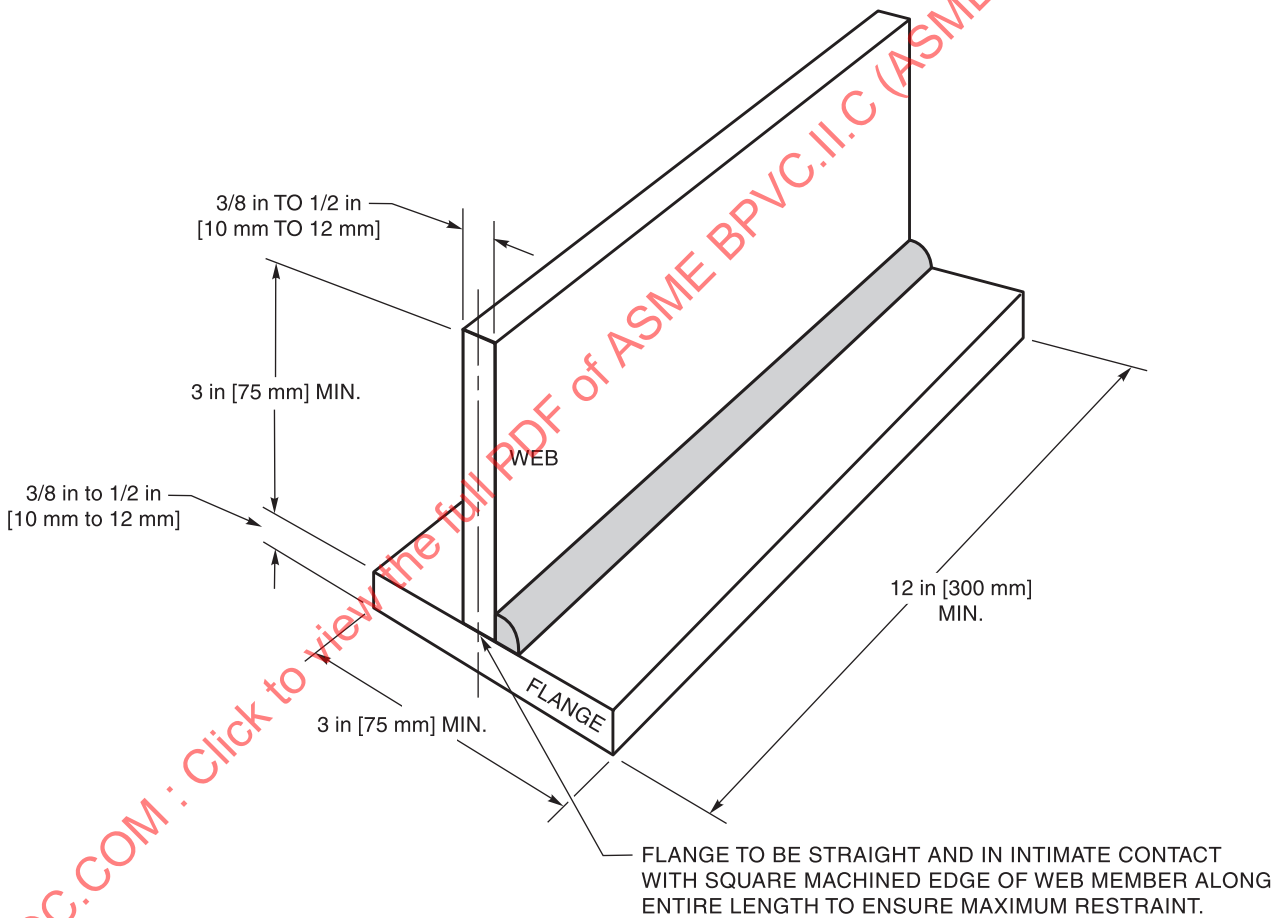
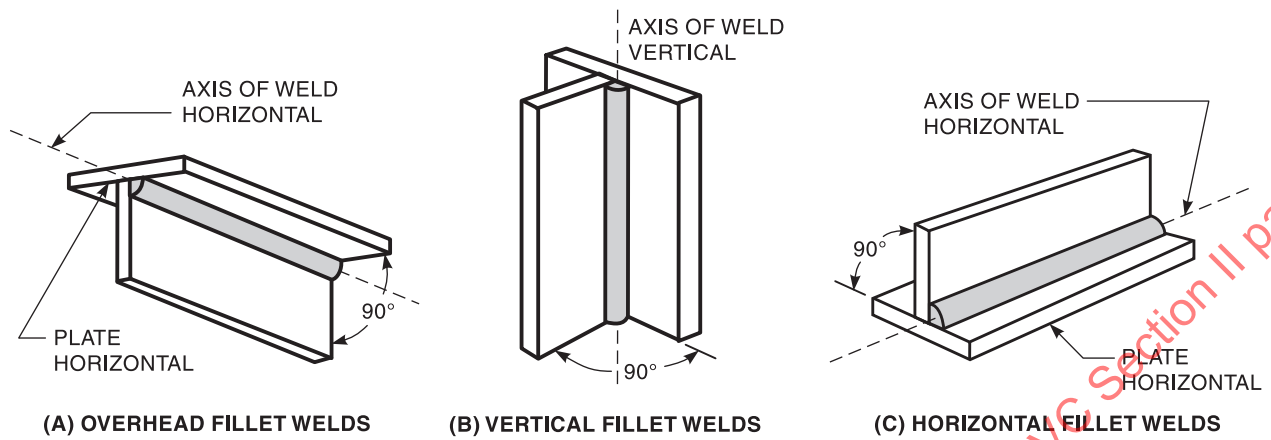
Figure 3—Test Assembly for Transverse Tension and Longitudinal Guided Bend Tests for Welds Made with Single-Pass Electrodes



Weld Pad Size (all minimums)					
Length, L		Width, W		Height, H	
in	mm	in	mm	in	mm
1-1/2	38	1/2	12	1/2	12

- Notes:
1. Base metal of any convenient size, of the type specified in Table 5, shall be used as the base for the weld pad.
 2. The surface of the base metal on which the filler metal is to be deposited shall be clean.
 3. The pad shall be welded in the flat position with successive layers to obtain undiluted weld metal, using the specified shielding gas (if any) based on the shielding gas designator of the classification using the polarity as specified in Table 2 and following the heat input requirements specified in Table 6.
 4. The number and size of the beads will vary according to the size of the electrode and the width of the weave, as well as with the amperage employed. The weave width shall be limited to a maximum of 6 times the electrode diameter.
 5. The preheat temperature shall not be less than 60°F [15°C] and the interpass temperature shall not exceed 325°F [165°C].
 6. The test assembly may be quenched in water (temperature unimportant) between passes to control interpass temperature. The weld pad assembly shall be dry before the start of each pass.
 7. The minimum completed pad size shall be that shown above. The sample to be tested in Clause 10 shall be taken from weld metal that is at least 3/8 in [10 mm] above the original base metal surface.

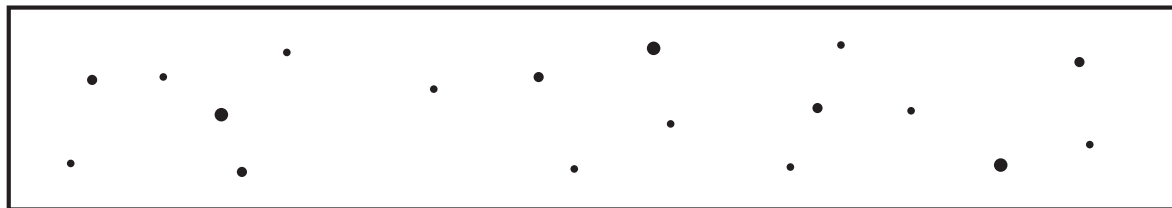
Figure 4—Pad for Chemical Analysis of Deposited Weld Metal



Notes:

1. Base metal shall be any of the types specified in Table 5.
2. Welding positions shall be as specified in 9.6.
3. The surfaces to be welded shall be clean.
4. A single-pass fillet weld shall be made on one side of the joint.
5. Weld cleaning shall be limited to slag chipping, brushing, and needle scaling. Grinding or filing of the final weld surface is prohibited.
6. The tests shall be conducted without postweld heat treatment.

Figure 5—Fillet Weld Test Assembly and Positions

**(A) ASSORTED ROUNDED INDICATIONS**

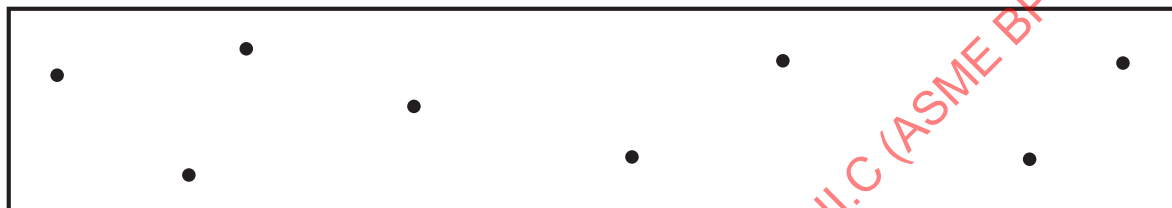
SIZE 1/64 in TO 1/16 in [0.4 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 18, WITH THE FOLLOWING RESTRICTIONS:

MAXIMUM NUMBER OF LARGE 3/64 in TO 1/16 in [1.2 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 3.

MAXIMUM NUMBER OF MEDIUM 1/32 in TO 3/64 in [0.8 mm TO 1.2 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 5.

MAXIMUM NUMBER OF SMALL 1/64 in TO 1/32 in [0.4 mm TO 0.8 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 10.

**(B) LARGE ROUNDED INDICATION**

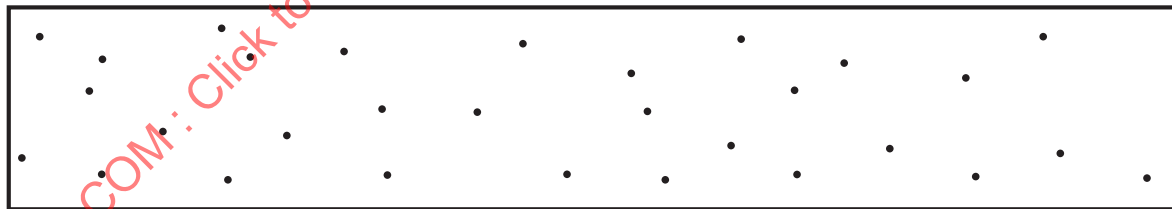
SIZE 3/64 in TO 1/16 in [1.2 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 8.

**(C) MEDIUM ROUNDED INDICATIONS**

SIZE 1/32 in TO 3/64 in [0.8 mm TO 1.2 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 15.

**(D) SMALL ROUNDED INDICATIONS**

SIZE 1/64 in TO 1/32 in [0.4 mm TO 0.8 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 30.

Notes:

1. In using these standards, the chart which is most representative of the size of the rounded indications present in the test specimen radiograph shall be used for determining conformance to these radiographic standards.
2. Since these are test welds specifically made in the laboratory for classification purposes, the radiographic requirements for these test welds are more rigid than those which may be required for general fabrication.
3. Indications whose largest dimension does not exceed 1/64 in [0.4 mm] shall be disregarded.

Figure 6—Radiographic Standards for Test Assemblies in Figure 2

Annex A (Normative)

Requirements for Optional Supplemental Tests

This annex is part of this standard and includes mandatory elements for use with this standard.

This annex contains requirements for optional supplemental designators which, at the option of the manufacturer, may be added to the electrode classification to indicate conformance to certain requirements which are supplemental to those required for classification under this specification.

A1. “H” Optional Supplemental Designator (Diffusible Hydrogen)

This diffusible hydrogen test is an optional test and is not required for classification. The “HX” designation added to the end of the classification (see Figure 1) does not constitute a part of the electrode classification.

A1.1 The 3/32 in [2.4 mm] or the largest diameter and the 0.045 in [1.2 mm] or the smallest diameter of an electrode to be identified by an optional supplemental diffusible hydrogen designator shall be tested according to one of the methods given in AWS A4.3. If the maximum diameter manufactured is 1/16 in [1.6 mm] or less, only the largest diameter needs to be tested. A mechanized welding system shall be used for the diffusible hydrogen test. Based upon the average value of test results which satisfy the requirements of Table A.1, the appropriate diffusible hydrogen designator may be added at the end of the classification.

A1.2 Testing shall be done with electrode from a previously unopened container. Conditioning of the electrode prior to testing is not permitted. Conditioning can be construed to be any special preparation or procedure, such as baking the electrode. The shielding gas, if any, used for classification purposes shall also be used for the diffusible hydrogen test. Welds for hydrogen determination shall be made at a wire feed rate (or welding current) which is based upon the manufacturer’s recommended operating range for the electrode size and type being tested. When using wire feed rate, the minimum wire feed rate to be used for the diffusible hydrogen test is given by the equation shown below. When using welding current, the equation shown is modified by substituting “welding current” wherever “WFR” appears.

$$WFR_{min.} = WFR_{mfg. min.} + 0.75 (WFR_{mfg. max.} - WFR_{mfg. min.})$$

where:

$WFR_{min.}$ is the minimum wire feed rate to be used for the diffusible hydrogen test.

$WFR_{mfg. min.}$ is the minimum wire feed rate recommended by the manufacturer.

$WFR_{mfg. max.}$ is the maximum wire feed rate recommended by the manufacturer.

The voltage shall be as recommended by the manufacturer for the wire feed rate (or welding current) used for the test. The contact tip-to-work distance (CTWD) shall be at the minimum recommended by the manufacturer for the wire feed rate (or welding current) used for the test. The travel speed used shall be as required to establish a weld bead width that is appropriate for the specimen, typically 50% to 75% of the specimen width.

A1.3 For purposes of certifying compliance with diffusible hydrogen requirements, the reference atmospheric condition shall be an absolute humidity of ten (10) grains of moisture/lb [1.43 g/kg] of dry air at the time of welding. The actual atmospheric conditions shall be reported along with the average value for the tests according to AWS A4.3 (see B8.2.5 in Annex B).

A1.4 When the absolute humidity equals or exceeds the reference condition at the time of preparation of the test assembly, the test shall be acceptable as demonstrating compliance with the requirements of this specification provided the actual test results satisfy the diffusible hydrogen requirements for the applicable designator. If the actual test results for an electrode meet the requirements for the lower or lowest hydrogen designator, as specified in Table A.1, the electrode also meets the requirements for all higher designators in Table A.1 without need to retest.

A1.5 Electrodes that are designated as meeting a lower or the lowest hydrogen limits as specified in Table A.1 also are understood to be able to meet any higher hydrogen limits. See Note d of Table A.1.

A2. “J” Optional Supplemental Designator (Improved Impact Properties)

This test is an optional test and is not required for classification. The “J” designation added to the end of the classification (see Figure 1) does not constitute a part of the electrode classification. The “J” is used to indicate that the electrode will deposit weld metal with Charpy V-Notch impact properties of at least 20 ft-lbf at -40°F [27J at -40°C] when the welds are made in the manner prescribed by this specification.

A3. “OE” Optional Supplemental Shielding Gas Range Designator

This test is an optional test and is not required for classification. The “OE H/L” designation added to the end of the classification (see Figure 1) does not constitute a part of the electrode classification. Preparation and testing shall be as prescribed in Clauses 9 through 15, using the shielding gases of the appropriate oxygen equivalent as shown in Table A.2 based on the optional designators to be applied. Oxygen equivalent shall be calculated as shown in Equation A.1, with the percentages in volume percent. Testing shall also be conducted as prescribed in Clause A1 if an optional “HX” diffusible hydrogen designation is applied. Testing shall also be conducted as prescribed in Clause A2 if an optional “J” designator is applied. Test results for all classification tests, including any optional supplemental designators applied, shall meet the requirements for the classification under test.

Equation A.1: % Oxygen Equivalent of a shielding gas (OE) = % O_2 in the shielding gas + $(0.5 \times \% \text{CO}_2 \text{ in the shielding gas})$

A minimum of two shielding gases must be tested, but one or both of the tests may be the test(s) conducted for electrode classification. All the same tests shall be conducted and all the same requirements shall be met with those gases as those for the electrode classification and any optional supplemental designators. It is not required for the welding conditions to be identical for each of the gases tested, but all the testing results shall meet all the requirements of this specification for the classification including any optional supplemental designators applied to the classification. The designators for the highest and lowest oxygen equivalent shielding gases that were tested and met all requirements may be added to an electrode classification, as shown in Figure 1 and note e of Table A.2. See Clause B8.4 in Annex B for more information on this optional supplemental designator.

Table A.1
Optional Diffusible Hydrogen Requirements^a

AWS A5.20/A5.20M Classifications	Optional Supplemental Diffusible Hydrogen Designator ^{c, d}	Average Diffusible Hydrogen, Maximum (mL/100g Deposited Metal)
(b)	H16	16
	H8	8
	H4	4
	H2	2

^a Limits on diffusible hydrogen when tested in accordance with AWS A4.3.

^b The appropriate designator is added to the end of a complete electrode classification. See Figure 1.

^c The lower diffusible hydrogen levels (H8, H4, and H2) may not be available in some classifications. Refer to B8.2.7.

^d Electrodes which satisfy the diffusible hydrogen limit for the H2 designator also satisfy the limits for the H4, H8, and H16 designators. Electrodes which satisfy the diffusible hydrogen limit for the H4 designator also satisfy the limits for the H8 and H16 designators. Electrodes which satisfy the limit for the H8 designator also satisfy the limit for the H16 designator.

Table A.2
Shielding Gas Requirements for Oxygen Equivalent Gas Range Designator^{a, b}

Calculated Oxygen Equivalent of Shielding Gas used for Testing, OE (%) ^c	Typical Shielding Gas Used for Testing ^d	Optional OE Designator Applied to Classification ^{e, f}
49.5–50.5	100% CO ₂	50
12.0–13.0	75% Ar, balance CO ₂	12
7.0–8.0	85% Ar, balance CO ₂	7
3.5–4.5	92% Ar, balance CO ₂	4

^a Testing and results with alternate shielding gases must conform to the requirements of the classification under test, including all optional supplemental designators. See Clause A3 for testing details.

^b Only the highest and lowest oxygen equivalent gases must be used for testing. Intermediate oxygen equivalent gases need not be tested, nor should their designators be shown in the classification. See Figure 1 and B8.4.

^c Calculated per Equation A.1.

^d Another shielding gas of the same oxygen equivalent may be used for testing. For example, 96% Ar, balance O₂ or 92% Ar, balance CO₂ may both be used for testing to apply the “4” designator.

^e The highest and lowest designators may be added to a classification in the format OE H/L with “H” being the OE designator for the highest oxygen equivalent shielding gas that was tested and met all requirements for classification and “L” being the OE designator for the lowest oxygen equivalent shielding gas that was tested and met all requirements for classification. See Figure 1.

^f The listed designators (50, 12, 7, and 4) are the only ones that may be applied.

Annex B (Informative)

Guide to AWS Specification for Carbon Steel Electrodes for Flux Cored Arc Welding

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The purpose of this guide is to correlate the electrode classifications with their intended applications so the specification can be used effectively. This guide provides examples rather than complete listings of the materials and applications for which each filler metal is suitable.

B2. Classification System

B2.1 Classification of Electrodes. The system for identifying the electrode classifications in this specification follows the standard pattern used in other AWS filler metal specifications. An illustration of this system is given in Figure 1. The prefix letter E at the beginning of each classification designation stands for electrode. The letter “X” (or series of X’s) represents each of the (nonfixed) designators used in the classification or for optional supplemental designators.

B2.2 Some of the classifications are intended to weld only in the flat and horizontal positions (EX0T-5C, -5M, for example). Others are intended for welding in all positions (EX1T-1C, -1M, for example). As in the case of covered electrodes, the smaller sizes of flux cored electrodes are the ones used for out-of-position work. Flux cored electrodes larger than 5/64 in [2.0 mm] in diameter are usually used for horizontal fillets and flat position welding.

B2.3 Optional supplemental designators are also used in this specification in order to identify electrode classifications that have met certain supplemental requirements as agreed to between the supplier and the purchaser. The optional supplemental designators are not part of the electrode classification.

B2.3.1 This specification has included the use of optional designators for diffusible hydrogen (see Clause A1 in Annex A) to indicate the maximum average value obtained under a clearly defined test condition in AWS A4.3. Electrodes that are designated as meeting the lower or lowest hydrogen limits as specified in Table A.1 are understood to be able to meet any higher hydrogen limits when tested in accordance with Clause A1. See Note d of Table A.1.

B2.3.2 The A5.20/A5.20M specification has established multiple-pass classification requirements using a test assembly as shown in Figure 2 using downhand welding procedures with heat inputs as shown in Table 6. In addition, this specification has included the optional supplemental designator “J” to indicate conformance to optional supplemental mechanical property requirements. In order to include product with improved toughness at lower temperature an optional supplemental designator, “J,” has been added to identify electrodes which, when tested, produce weld metal which exhibits 20 ft-lbf at -40°F [27 J at -40°C]. The user is cautioned that although improved weld metal toughness will be evidenced when welding is performed under conditions specified in this specification, other applications of the electrode, such as long-term postweld heat treatment or vertical up welding with higher heat input, may produce results markedly different from the improved toughness levels given. The users should always perform their own mechanical properties verification testing.

B2.3.3 The A5.20/A5.20M specification includes an optional supplemental designator indicating that the electrode will meet the requirements for classification with various shielding gases. The gases are categorized by a calculated oxygen equivalent to determine conformance with the optional designators. More information can be found in Clauses A3 and B8.4.

B2.4 “G” Classification

B2.4.1 These specifications include electrodes classified as E6XT-G, E6XT-GS, E7XT-G, and E7XT-GS. The “G” or “GS” indicates that the electrode is of a “general” classification. It is “general” because not all of the particular requirements specified for each of the other classifications are specified for this classification. The intent in establishing this classification is to provide a means by which electrodes that differ in one respect or another (description of usability and/or operating polarity, for example) from all other classifications can still be classified according to the specification. The purpose is to allow a useful electrode—one that otherwise would have to await a revision of the specification—to be classified immediately, under the existing specification. This means that two electrodes—each bearing the same “G” classification—may be quite different in some certain respect (usability characteristics and polarity, again, for example).

B2.4.2 The point of difference between an electrode of a “G” classification and an electrode of a similar classification without the “G” (or even with it, for that matter) may be further clarified from the use of the words “not required” and “not specified” in the specification. The use of these words is as follows:

Not Required is used in those areas of the specification that specify the tests that must be conducted in order to classify an electrode. It indicates that that test is not required because the results for the particular test are not a requirement for that particular classification. When a test is “not required,” it is not necessary to conduct the corresponding test in order to classify an electrode to that classification. When a purchaser wants the information provided by that test in order to consider a particular product of that classification for a certain application, the purchaser will have to arrange for that information with the supplier of the product. The purchaser will have to establish with that supplier just what the testing procedure and the acceptance requirements are to be for that test. The purchaser may want to incorporate that information (via AWS A5.01M/A5.01) in the purchase order.

Not Specified is used in those areas of the specification that refer to the results of some particular test. It indicates that the requirements for that test are not specified for that particular classification. If the required results from a specific test are listed as “not specified” but the test in question is shown as “required” then the test results must be reported.

B2.5 Request for Filler Metal Classification

(1) When a filler metal cannot be classified other than as a “G” classification, a manufacturer may request that a new classification be established. The manufacturer shall do this using the following procedure.

(2) A request to establish a new filler metal classification must be submitted in writing. The request needs to provide sufficient detail to permit the Committee on Filler Metals and Allied Materials and the relevant Subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

- (a) A declaration that the new classification will be offered for sale commercially.
- (b) All classification requirements as given for existing classifications, such as chemical composition ranges, mechanical property requirements, and usability test requirements.
- (c) Any conditions for conducting the tests used to demonstrate that the filler metal meets the classification requirements. (It would be sufficient, for example, to state that welding conditions are the same as for other classifications).
- (d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the annex).
- (e) Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.
- (f) A request for a new classification without the above information will be considered incomplete. The Secretary will return the request to the requester for further information.

(3) In order to comply with the AWS Policy on Patented Items, Trademarks, and Restraint of Trade, if the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester shall disclose this. In these cases, the patent holder must allow the use of this technology, such as by license. The Secretary will provide examples of acceptable wording to the patent holder, as required.

(4) The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters for processing.

B2.6 An international system for designating welding filler metals has been adopted in many ISO specifications. Table B.1 shows those used in ISO 17632.

B3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01M/A5.01. Any testing a purchaser requires of the supplier for material shipped in accordance with this specification shall be clearly stated in the purchase order. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing the supplier normally conducts on material of that classification, as specified in Schedule F of AWS A5.01M/A5.01. Testing in accordance with any other schedule in that table must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

B4. Certification

The act of placing the AWS specification and classification designations and optional supplemental designators, if applicable, on the packaging enclosing the product or the classification on the product itself constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification. The only testing requirement implicit in this certification is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that the material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation. Certification is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the certification required by the specification is the classification test of representative material, cited above, and the Manufacturer's Quality Assurance Program in AWS A5.01M/A5.01.

B5. Ventilation During Welding

B5.1 Five major factors govern the quantity of fumes in the atmosphere to which welders and welding operators can be exposed during welding. They are:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling)
- (2) Number of welders and welding operators working in that space
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes used
- (4) The proximity of the welders or welding operators to the fumes as the fumes issue from the welding zone, and to the gases and dusts in the space in which they are working
- (5) The ventilation provided to the space in which the welding is done

B5.2 American National Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the clause on Ventilation in that document. See also AWS F3.2M/F3.2, *Ventilation Guide for Weld Fume*, for more detailed descriptions of ventilation options.

B6. Welding Considerations

B6.1 When examining the properties required of weld metal as a result of the tests made according to this specification, it should be recognized that in production, where the conditions and procedures may differ from those in this specification (electrode size, amperage, voltage, type and amount of shielding gas, position of welding, contact tip to work distance (CTWD), plate thickness, joint geometry, preheat and interpass temperatures, travel speed, surface condition, base metal composition and dilution, for example), the properties of the weld metal may also differ. Moreover, the difference may be large or small.

B6.2 Since it has not been possible to specify one single, detailed welding procedure for all products classified under any given classification in this specification, details of the welding procedure used in classifying each product should be recorded by the manufacturer and made available to the user, upon request. The information should include each of the welding parameters referred to in B6.1 above, as well as the actual number of passes and layers required to complete the weld test assembly.

B6.3 The toughness requirements for the different classifications in this specification can be used as a guide in the selection of electrodes for applications requiring low temperature notch toughness. For an electrode of any given classification, there can be a considerable difference between the impact test results from one assembly to another, or even from one impact specimen to another, unless particular attention is given to the manner in which the weld is made and prepared (even the location and orientation of the specimen within the weld), the temperature of testing, and the operation of the testing machine.

B6.4 Hardenability. There are inherent differences in the effect of the carbon content of the weld deposit on hardenability, depending on whether the electrode was gas-shielded or self-shielded. Gas-shielded electrodes generally employ a Mn-Si deoxidation system. The carbon and alloy content affects hardenability in a manner which is typical of many carbon equivalent formulas published for carbon steel. Most self-shielded electrodes utilize an aluminum-based deoxidation system to provide for protection and deoxidation. One of the effects of the aluminum is to modify the effect of carbon equivalent on hardenability, which will, therefore, be lower than the carbon content would indicate based on typical carbon equivalent formulas.

B7. Description and Intended Use of Flux Cored Electrodes

This specification contains many different classifications of flux cored electrodes. The usability designation (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, or the letter “G” or the letters “GS”) in each classification indicates a general grouping of electrodes that contain similar flux or core components and which have similar usability characteristics, except for the “G” and “GS” classifications where usability characteristics may differ between similarly classified electrodes.

B7.1 EXXT-1C and EXXT-1M Classifications. Both the EXXT-1C and EXXT-1M electrodes have similar type slags and are designed for single- and multiple-pass welding using DCEP. The larger diameters (usually 5/64 in [2.0 mm] and larger) are typically used for welding in the flat position and for welding fillet welds in the horizontal position. The smaller diameters (usually 1/16 in [1.6 mm] and smaller) are typically used for welding in all positions. These electrodes are characterized by a spray transfer, low spatter loss, flat to slightly convex bead contour, and a moderate volume of slag, which completely covers the weld bead. Electrodes of this classification have a rutile base slag and have the ability to produce high deposition rates.

Electrodes in the EXXT-1C group are classified with CO₂ shielding gas [AWS A5.32M/A5.32, Symbol C1]. However, other gas mixtures such as Ar-CO₂ [AWS A5.32M/A5.32 Symbol M21] may be used to improve usability, especially for out-of-position applications, when recommended by the manufacturer. Increasing the amount of Ar in the Ar-CO₂ mixture will increase the manganese and silicon contents in the weld metal. The increase in manganese, silicon, or other alloys will increase the yield and tensile strengths and may affect impact properties.

Electrodes in the EXXT-1M group are classified with 75% to 80% Ar/balance CO₂ shielding gas. Increasing the amount of Ar in the Ar-CO₂ mixture will reduce the manganese and silicon losses that occur in the welding arc. The resulting increase of manganese, silicon, or other elements will increase the yield and tensile strengths and may affect impact properties.

B7.2 EXXT-2C and EXXT-2M Classification. Electrodes of these classifications are essentially EXXT-1C and EXXT-1M with higher manganese or silicon, or both, and are designed primarily for single-pass welding in the flat position and for welding fillet welds in the horizontal position. The higher levels of deoxidizers in these classifications allow single-pass welding of heavily oxidized or rimmed steel.

Weld metal composition requirements are not specified for single-pass electrodes, since checking the composition of the undiluted weld metal will not provide an indication of the composition of a single-pass weld. These electrodes give good mechanical properties in single-pass welds.

The manganese content and the tensile strength of the weld metal of multiple-pass welds made with EXXT-2C and EXXT-2M electrodes will be high. These electrodes can be used for welding base metals which have heavier mill scale, rust, or other foreign matter that cannot be tolerated by some electrodes of the EXXT-1C or EXXT-1M classifications. The arc transfer, welding characteristics and deposition rates of these electrodes, however, are similar.

B7.3 EXXT-3 Classification. Electrodes of this classification are self-shielded, used on DCEP and have a spray-type transfer. The slag system is designed to make very high welding speeds possible. The electrodes are used for single-pass welds in the flat, horizontal, and vertical (up to 20° incline) positions (downward progression) on sheet metal. Since these electrodes are sensitive to the effects of base metal quenching, they are not generally recommended for the following:

- (1) T- or lap joints in materials thicker than 3/16 in [5 mm]
- (2) Groove, edge, or corner joints in materials thicker than 1/4 in [6 mm]

The electrode manufacturer should be consulted for specific recommendations.

B7.4 EXXT-4 Classification. Electrodes of this classification are self-shielded, operate on DCEP, and have a globular type transfer. The basic slag system is designed to make very high deposition rates possible and to produce a weld that is very low in sulfur for improved resistance to hot cracking. These electrodes produce welds with low penetration enabling them to be used on joints with varying gaps and for single- and multiple-pass welding.

B7.5 EXXT-5C and EXXT-5M Classifications. Electrodes of the EXXT-5C and EXXT-5M classifications are used primarily for single- and multiple-pass welds in the flat position and for welding fillet welds in the horizontal position using DCEP or DCEN, depending on the manufacturer's recommendation. These electrodes are characterized by a globular transfer, slightly convex bead contour, and a thin slag that may not completely cover the weld bead. These electrodes have lime-fluoride base slag. Weld deposits produced by these electrodes typically have impact properties and hot and cold crack resistance that are superior to those obtained with rutile base slags. Some of these electrodes, using DCEN, can be used for welding in all positions. However, the operator appeal of these electrodes is not as good as that of those with rutile base slags.

Electrodes of the EXXT-5C classifications are designed to be used with CO₂ shielding gas [AWS A5.32M/A5.32, Symbol C1]; however, as with the EXXT-1C classification, Ar-CO₂ mixtures may be used to reduce spatter, when recommended by the manufacturer. Increasing the amount of Ar in the Ar-CO₂ mixture will increase the manganese and silicon contents which will increase the yield and tensile strengths and may affect impact properties.

Electrodes of the EXXT-5M classification are designed for use with 75% to 80% Ar/balance CO₂ shielding. Their use with gas mixtures having reduced amounts of Ar with CO₂ shielding gas will result in some deterioration in arc characteristics, an increase in spatter, and a reduction in manganese and silicon in the weld metal. This reduction in manganese, silicon, or other alloys will decrease the yield and tensile strengths and may affect impact properties.

B7.6 EXXT-6 Classification. Electrodes of this classification are self-shielded, operate on DCEP, and have a spray-type transfer. The slag system is designed to give good low temperature impact properties, good penetration into the root of the weld, and excellent slag removal, even in a deep groove. These electrodes are used for single- and multiple-pass welding in flat and horizontal positions.

B7.7 EXXT-7 Classification. Electrodes of this classification are self-shielded, operate on DCEN and have a small droplet to spray type transfer. The slag system is designed to allow the larger sizes to be used for high deposition rates in the horizontal and flat positions, and to allow the smaller sizes to be used for all welding positions. The electrodes are used for single- and multiple-pass welding and produce very low sulfur weld metal which is very resistant to hot cracking.

B7.8 EXXT-8 Classification. Electrodes of this classification are self-shielded, operate on DCEN, and have a small droplet to spray type transfer. These electrodes are suitable for all welding positions, and the weld metal has very good low temperature notch toughness and crack resistance. These electrodes are used for single- and multiple-pass welds.

B7.9 EXXT-9C and EXXT-9M Classifications. Electrodes of the EXXT-9C group are classified with CO₂ shielding gas [AWS A5.32/A5.32M, Symbol C1]. However, gas mixtures of Ar-CO₂ are sometimes used to improve usability, especially for out-of-position applications. Increasing the amount of Ar in the Ar-CO₂ mixture will affect the weld metal analysis and mechanical properties of weld metal deposited by these electrodes, just as it will for weld metal deposited by EXXT-1C and EXXT-1M electrodes (see B7.1).

Electrodes of the EXXT-9M group are classified with a 75%–80% Ar/balance CO₂ shielding gas [AWS A5.32M/A5.32, Symbol M21]. Their use with Ar/CO₂ shielding gas mixtures having reduced amounts of Ar, or with CO₂ shielding gas, may result in some deterioration of arc characteristics and out-of-position welding characteristics. In addition, a reduction of the manganese and silicon contents in the weld will result, which will have some effect on properties of weld metal from these electrodes, just as it will on properties of weld metal deposited by EXXT-1C and EXXT-1M electrodes (see B7.1).

Both the EXXT-9C and EXXT-9M electrodes are designed for single- and multiple-pass welding. The larger diameters (usually 5/64 in [2.0 mm] and larger) are used for welding in the flat position and for welding fillet welds in the horizontal position. The smaller diameters (usually 1/16 in [1.6 mm] and smaller) are often used for welding in all positions.

The arc transfer, welding characteristics, and deposition rates of the EXXT-9C and EXXT-9M electrodes are similar to those of the EXXT-1C or EXXT-1M classifications (see B7.1). EXXT-9C and EXXT-9M electrodes are essentially EXXT-1C and EXXT-1M electrodes that deposit weld metal with improved impact properties. Some electrodes in this classification require that joints be relatively clean and free of oil, excessive oxide, and scale in order that welds of radiographic quality can be obtained.

B7.10 EXXT-10 Classification. Electrodes of this classification are self-shielded, operate on DCEN, and have a small droplet transfer. The electrodes are used for single-pass welds at high travel speeds on material of any thickness in the flat, horizontal, and vertical (up to 20° incline) positions.

B7.11 EXXT-11 Classification. Electrodes of this classification are self-shielded, operate on DCEN, and have a smooth spray-type transfer. They are general purpose electrodes for single- and multiple-pass welding in all positions. Their use is generally not recommended on thicknesses greater than 3/4 in [19 mm]. The electrode manufacturer should be consulted for specific recommendations.

B7.12 EXXT-12C and EXXT-12M Classifications. Electrodes of these classifications are essentially EXXT-1C and EXXT-1M electrodes and are similar in arc transfer, welding characteristics, and deposition rates; however, they have been modified to improve impact toughness and to meet the lower manganese requirements of the A-No. 1 Analysis Group in the ASME *Boiler and Pressure Vessel Code*, Section IX. Therefore, they have an accompanying decrease in tensile strength and hardness. Since welding procedures influence all-weld-metal properties, users are urged to check hardness on any application where a maximum hardness level is a requirement.

B7.13 EXXT-14 Classification. Electrodes of this classification are self-shielded, operate on DCEN, and have a smooth spray-type transfer. They are intended for single-pass welding. The slag system is designed with characteristics so that these electrodes can be used to weld in all positions and also to make welds at high speed. They are used to make welds on sheet metal up to 3/16 in [5 mm] thick, and often are specifically designed for galvanized, aluminized, or other coated steels. Since these welding electrodes are sensitive to the effects of base metal quenching, they are not generally recommended for the following:

- (1) T- or lap joints in materials thicker than 3/16 in [5 mm]
- (2) Groove, edge, or corner joints in materials thicker than 1/4 in [6 mm]

The electrode manufacturer should be consulted for specific recommendations.

B7.14 EXXT-G Classification. This classification is for multiple-pass electrodes that have usability characteristics not covered by any presently defined classification. Except for chemical composition requirements to assure a carbon steel deposit and the tensile strength, yield strength, and percent elongation which are specified, the requirements for this classification are not specified. They are those that are agreed to by the purchaser and the supplier.

B7.15 EXXT-GS Classification. This classification is for single-pass electrodes that have usability characteristics not covered by any presently defined classification. Except for the tensile strength, which is specified, the requirements for this classification are not specified. They are agreed upon by the purchaser and supplier.

B8. Special Tests

B8.1 It is recognized that supplementary tests may be required for certain applications. In such cases, tests to determine specific properties such as hardness, corrosion resistance, or strength at elevated or cryogenic temperatures may be

required. AWS A5.01M/A5.01 contains provisions for ordering such tests. This clause is included for the guidance of those who desire to specify such special tests. Those tests may be conducted as agreed upon between the purchaser and supplier.

B8.2 Diffusible Hydrogen Test

B8.2.1 Hydrogen-induced cracking of weld metal or the heat-affected zone (HAZ) generally is not a problem with carbon steels containing 0.3% or less carbon, nor with lower-strength alloy steels. However, electrodes classified in this specification are sometimes used to join higher carbon steels or low-alloy, high-strength steels where hydrogen-induced cracking may be a serious problem.

B8.2.2 Most flux cored electrodes deposit weld metal having diffusible hydrogen levels of less than 16 mL/100 g of deposited metal. For that reason, flux cored electrodes are generally considered to be low hydrogen. However, some commercially available products will, under certain conditions, produce weld metal with diffusible hydrogen levels in excess of 16 mL/100 g of deposited metal. Therefore it may be appropriate for certain applications to utilize the optional supplemental designators for diffusible hydrogen when specifying the flux cored electrodes to be used.

B8.2.3 As the weld metal or HAZ strength or hardness increases, the concentration of diffusible hydrogen that will cause cracking under given conditions of restraint and heat input becomes lower. This cracking (or its detection) is usually delayed some hours after cooling. It may appear as transverse weld cracks, longitudinal cracks (especially in the root beads), and toe or underbead cracks in the HAZ.

B8.2.4 Since the available diffusible hydrogen level strongly influences the tendency toward hydrogen-induced cracking, it may be desirable to measure the diffusible hydrogen content resulting from welding with a particular electrode. This specification has, therefore, included the use of optional designators for diffusible hydrogen to indicate the maximum average value obtained under a clearly defined test condition in AWS A4.3.

B8.2.5 The user of this information is cautioned that actual fabrication conditions may result in different diffusible hydrogen values than those indicated by the designator. The welding consumable is not the only source of diffusible hydrogen in the welding process. In actual practice, the following may contribute to the hydrogen content of the finished weldment.

(1) **Surface Contamination.** Rust, primer coating, anti-spatter compounds, dirt, and grease can all contribute to diffusible hydrogen levels in practice. Consequently, standard diffusible hydrogen tests for classification of welding consumable require test material to be free of contamination. AWS A4.3 is specific as to the cleaning procedure for test material.

(2) **Atmospheric Humidity.** The welding arc is subject to atmospheric contamination when using either a self-shielded or gas-shielded welding consumable. Moisture from the air, distinct from that in the welding consumable, can enter the arc and subsequently the weld pool, contributing to the resulting observed diffusible hydrogen. AWS A4.3 has established a reference atmospheric condition at which the contribution to diffusible hydrogen from atmospheric humidity is considered to be negligible. This influence of atmospheric humidity also can be minimized by maintaining as short an arc length as possible consistent with a steady arc. For flux cored electrodes, arc length is controlled primarily by arc voltage. Experience has shown that the effect of arc length is minor at the H16 level, but can be very significant at the H4 level. An electrode meeting the H4 requirements under the reference atmospheric conditions may not do so under conditions of high humidity at the time of welding, especially if a long arc length is maintained.

(3) **Shielding Gas.** The reader is cautioned that the shielding gas itself can contribute significantly to diffusible hydrogen. Normally, welding grade shielding gases are intended to have very low dew points and very low impurity levels. This, however, is not always the case. Instances have occurred where a contaminated gas cylinder resulted in a significant increase of diffusible hydrogen in the weld metal. Further, moisture permeation through some hoses and moisture condensation in unused gas lines can become a source of diffusible hydrogen during welding. In case of doubt, a check of gas dew point is suggested. A dew point of 40°F [40°C] or lower is considered satisfactory for most applications.

(4) **Absorbed/Adsorbed Moisture.** Flux cored electrodes can absorb/adsorb moisture over time which contributes to diffusible hydrogen levels. This behavior is well documented for shielded metal arc electrode coverings exposed to the atmosphere. Hydration of oxide films and lubricants on solid electrode surfaces under what may be considered "normal" storage conditions has also been reported to influence diffusible hydrogen. Moisture absorption/adsorption can be particularly significant if material is stored in a humid environment in damaged or open packages, or if unprotected for long periods of time. In the worst case of high humidity, even overnight exposure of unprotected electrodes can lead to a significant increase of diffusible hydrogen. For these reasons, indefinite periods of storage should be avoided. The

storage and handling practices necessary to safeguard the condition of a welding consumable will vary from one product to another even within a given classification. Therefore, the consumable manufacturer should always be consulted for recommendations on storage and handling practice. In the event the electrode has been exposed, the manufacturer should be consulted regarding probable damage to its controlled hydrogen characteristics and possible reconditioning of the electrode.

(5) **Effect of Welding Process Variables.** Variations in welding process variables (e.g., amperage, voltage, CTWD, type of shielding gas, current type/polarity, single electrode vs. multiple electrode welding, etc.) are all reported to influence diffusible hydrogen test results in various ways. For example, with respect to CTWD, a longer contact tip-to-work distance will promote more preheating of the electrode, causing some removal of hydrogen-bearing compounds (e.g., moisture, lubricants, etc.) before they reach the arc. Consequently, the result of longer CTWD can be to reduce diffusible hydrogen. However, excessive CTWDs with external gas-shielded welding processes may cause some loss of shielding if the contact tip is not adequately recessed in the gas cup. If shielding is disturbed, more air may enter the arc and increase the diffusible hydrogen. This may also cause porosity due to nitrogen pickup.

Since welding process variables can have a significant effect on diffusible hydrogen test results, it should be noted that an electrode meeting the H4 requirements, for example, under the classification test conditions should not be expected to do so consistently under all welding conditions. Some variation should be expected and accounted for when making welding consumable selections and establishing operating ranges in practice.

B8.2.6 As indicated in B8.2.5 (5), the welding procedures used with flux cored electrodes will influence the values obtained on a diffusible hydrogen test. To address this, the AWS A5M Subcommittee on Carbon and Low-Alloy Steel Electrodes for Flux Cored Arc Welding has incorporated into its specification test procedure requirements for conducting the diffusible hydrogen test when determining conformance to the hydrogen optional supplemental designator requirements shown in Table A.1. See Clause A1 in Annex A. The following is provided as an example.

EXAMPLE: Manufacturer ABC, an electrode manufacturer, recommends and/or publishes the following procedure range for its EX1T-1C electrode.

Electrode Diameter	Shielding Gas	Wire Feed Rate in/min [cm/min]	Arc Voltage (volts)	CTWD in [mm]	Deposition Rate lbs/hr [kg/hr]
0.045 in [1.2 mm]	CO ₂	175–300 [445–760]	22–26	1/2–3/4 [12–20]	3.3–5.8 [1.5–2.6]
		300–425 [760–1080]	25–29	5/8–7/8 [16–22]	5.8–8.1 [2.6–3.7]
		425–550 [1080–1400]	28–31	3/4–1 [20–25]	8.1–10.5 [3.7–4.8]
1/16 in [1.6 mm]	CO ₂	150–225 [380–570]	23–26	3/4–1 [20–25]	5.4–8.0 [2.5–3.6]
		225–300 [570–760]	25–28	7/8–1-1/8 [22–29]	8.0–10.8 [3.6–4.9]
		300–375 [760–950]	27–32	1–1-1/4 [25–32]	10.8–12.2 [4.9–5.5]

Based upon the manufacturer's recommended operating range, the minimum wire feed rate and the CTWD to be used for hydrogen testing are determined as follows:

- For 0.045 in [1.2 mm] diameter the minimum wire feed rate ($WFR_{min.}$) to be used for the hydrogen test, as specified in 16.2, is $WFR_{min.} = 175 \text{ in/min.} + 0.75 (550 \text{ in/min.} - 175 \text{ in/min.}) = 456 \text{ in/min.}$ [$WFR_{min.} = 445 \text{ cm/min.} + 0.75 (1400 \text{ cm/min.} - 445 \text{ cm/min.}) = 1160 \text{ cm/min.}$].
The CTWD to be used for the hydrogen test is 3/4 in [20 mm], the minimum CTWD recommended by the manufacturer for the test wire feed rate of 456 in/min. [1160 cm/min.].
- For 1/16 in [1.6 mm] diameter the minimum wire feed rate ($WFR_{min.}$) to be used for the hydrogen test, as specified in 16.2, is $WFR_{min.} = 150 \text{ in/min.} + 0.75 (375 \text{ in/min.} - 150 \text{ in/min.}) = 319 \text{ in/min.}$ [$WFR_{min.} = 380 \text{ cm/min.} + 0.75 (950 \text{ cm/min.} - 380 \text{ cm/min.}) = 808 \text{ cm/min.}$].
The CTWD to be used for the hydrogen test is 1 in [25 mm], the minimum CTWD recommended by the manufacturer for the test wire feed rate of 319 in/min. [808 cm/min.].

B8.2.7 Not all classifications may be available in the H16, H8, H4, or H2 diffusible hydrogen levels. The manufacturer of a given electrode should be consulted for availability of products meeting these limits.

B8.3 Aging of Specimens. Weld metals may contain significant quantities of hydrogen for some time after they have been made. Most of this hydrogen gradually escapes over time. This may take several weeks at room temperature or several hours at elevated temperatures. As a result of this eventual change in hydrogen level, ductility of the weld metal increases toward its inherent value, while yield, tensile, and impact properties remain relatively unchanged. The A5.20 and A5.20M specifications permit the aging of the test specimens or weld test assemblies at elevated temperatures not exceeding 220°F [105°C] for up to 48 hours before cooling them to room temperature and subjecting them to testing. The purpose of this treatment is to facilitate removal of hydrogen from the test specimen in order to reduce scatter in test results.

Aging treatments are sometimes used for low hydrogen electrode deposits, especially when testing high strength deposits. Note that aging may involve holding test specimens or weld test assemblies at room temperature for several days or holding at a somewhat higher temperature for a shorter period of time. Consequently, users are cautioned to employ adequate preheat and interpass temperatures to avoid the deleterious effects of hydrogen in production welds. It should be kept in mind that aging test assemblies may not remove as much diffusible hydrogen as aging the individual specimens. The purchaser may, by mutual agreement with the supplier, have the thermal aging of specimens prohibited for all mechanical testing done to schedule I or J of AWS A5.01M/A5.01.

B8.4 Optional Shielding Gas Designators. *Electrodes are classified with one shielding gas, but carbon and low-alloy steel electrodes often are used with other shielding gases. It may be important for a user or a referencing code or standard to know the response of an electrode and the resulting weld metal to shielding gases other than the one with which it was classified. The optional shielding gas designators may be applied to an electrode classification to indicate that it meets the same classification requirements when used with various ranges of shielding gases.*

Shielding gas range designators have been established in this specification based on the oxygen equivalence of the shielding gas. The oxygen equivalence (oxidation potential) of a shielding gas is represented by the “oxygen equivalent.” This is expressed as a percentage, and calculated as follows (also shown in Equation A.1 of Clause A3). This equation has been empirically derived to correlate to the composition and properties of the weld metal. It is not a stoichiometric calculation of the oxygen contained in a shielding gas.

% Oxygen Equivalent of a shielding gas (OE) = % O₂ in the shielding gas + (0.5 × % CO₂ in the shielding gas)

The oxygen equivalence of the shielding gas is important for predicting the weld metal chemical composition and resulting weld metal properties. As an example, for the same electrode and welding conditions, the manganese and silicon in a weld deposit will be higher with a low oxygen equivalence shielding gas than with a high oxygen equivalence shielding gas. The bracketed testing approach used in this specification requires testing at both the high and low ends of an oxygen equivalence range before an optional shielding gas designator can be applied. These ranges encompass shielding gases commonly used to deposit carbon and low-alloy steel weld metals.

Some electrodes may not be able to meet the requirements of their classification with any of the listed shielding gas oxygen equivalents other than the one used for classification. Some others might be able to meet the requirements of their classification over a wide range of oxygen equivalent shielding gases. The bracketed testing only requires that the highest oxygen equivalent shielding gas and the lowest oxygen equivalent shielding gas must be tested to apply that optional OE designator. For example, if an E71T-12C electrode is tested and can meet the E71T-12C requirements for classification with CO₂ shielding gas and with 92Ar/8CO₂ shielding gas, it may have the “OE 50/4” optional shielding gas range designator applied without testing with 85Ar/15CO₂ or 75Ar/25CO₂ shielding gas. An electrode that is classified with CO₂ shielding gas (for example E71T-1C) and the same electrode that is also classified with 75%Ar/25%CO₂ shielding gas (for example E71T-1M) has already been tested with both gases required for the OE 50/12 shielding gas designator. The OE 50/12 designator can be applied to both of those classifications with no further testing, as long as any optional supplemental designators have been included in the classification testing for both shielding gases.

B9. General Safety Considerations

B9.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Annex Clause A5. Safety and health information is available from other sources, including, but not limited to Safety and Health Fact Sheets, ANSI Z49.1 *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations.

B9.2 Safety and Health Fact Sheets. Safety and Health Fact Sheets are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

B10. Discontinued Classifications

The EXXT-13 electrode classification has been discontinued with this revision of the document.

Table B.1
Comparison of Classifications^a

AWS A5.20 [A5.20M]	ISO 17632-A	ISO 17632-B
E7XT-1-X [E49XT-1X]	T38 2 R X	T49 2 T1-X X
E7XT-2X [E49XT-2X]	T3T Z R X	T49 Z T2-X X S
E7XT-3 [E49XT-3]	T3T Z V NO	T49 Z T3-X NO S
E7XT-4 [E49XT-4]	T38 Z W NO	T49 Z T4-X NO
E7XT-5X [E49T-5X]	T38 3 B X	T49 3 T5-X X
E7XT-6 [E49XT-6]	T38 3 Y NO	T49 3 T6-X NO
E7XT-7 [E49XT-7]	T38 Z W NO	T49 Z T7-X NO
E7XT-8 [E49XT-8]	T38 3 Y NO	T49 3 T8-X NO
E7XT-9X [E49XT-9X]	T38 3 R X	T49 3 T9-X X
E7XT-10 [E49XT-10]	T3T Z V NO	T49 Z T10-X NO S
E7XT-11 [E49XT-11]	T38 Z W NO	T49 Z T11-X NO
E7XT-12X [E49XT-12X]	T38 Z R X	T49 3 T12-X X
E7XT-14 [E49XT-14]	T3T Z V NO	T49 Z T14-X NO S

^aThe requirements for the similar classifications shown are not necessarily identical in every respect.

Annex C (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

C1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

C2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

C3. General Procedure for all Requests

C3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

C3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

C3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

C3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

C3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

C3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

C4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

C5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

C6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

INTENTIONALLY LEFT BLANK

SPECIFICATION FOR BARE ELECTRODES AND RODS FOR SURFACING



SFA-5.21/SFA-5.21M



(25)

(Identical with AWS Specification A5.21/A5.21M:2024. In case of dispute, the original AWS text applies.)

Specification for Bare Electrodes and Rods for Surfacing

1. Scope

1.1 This specification prescribes the requirements for the classification of bare (*uncoated*) *solid* electrodes and rods *as well as tubular electrodes and rods* for *weld* surfacing. The specification does not provide for classification of electrode-flux combinations for submerged arc welding.

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to material. The specification with the designation A5.21 uses U.S. Customary Units. The specification A5.21M uses SI Units. The latter are shown within brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing of filler metal or packaging or both under A5.21 or A5.21M specifications.

1.3 Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in the *non-mandatory* annex, Clauses A5 and A10.

Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

American Welding Society (AWS) documents:

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

AWS A5.01M/A5.01 (ISO 14344 MOD), *Welding and Brazing Consumables—Procurement of Filler Metals and Fluxes*

AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*

American National Standards Institute (ANSI) document:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

ASTM International (ASTM) documents:

ASTM A36/A36M, *Standard Specification for Carbon Structural Steel*

ASTM A285/A285M, *Standard Specification for Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength*

ASTM B214, *Standard Test Method for Sieve Analysis of Metal Powders*

ASTM E18, *Standard Test Methods for Rockwell Hardness of Metallic Materials*

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

ASTM E384, *Standard Test Method for Knoop and Vickers Hardness of Materials*

International Organization for Standardization (ISO) document:

ISO 80000-1, *Quantities and units — Part 1: General*

3. Classification

3.1 The surfacing electrodes and rods covered by this specification are classified according to the following:

3.1.1 Solid surfacing electrodes and rods are classified on the basis of the composition of the material as manufactured (or the stock from which it was made) (see Tables 1, 2, and 4).

3.1.2 Metal cored and flux cored composite (tubular) surfacing electrodes and rods, except for tungsten carbide rods, are classified on the basis of the composition of an undiluted weld deposit, as shown in Tables 1, 3, and 4.

3.1.3 Tubular tungsten carbide surfacing rods are classified on the basis of the mesh range, quantity, and composition of the tungsten carbide granules, as shown in Tables 5 and 6.

3.2 Material classified under one classification shall not be classified under any other classification in this specification, with the exception of the *ERFe-RBU* and *ERFeMn-RBU* classifications related to railway weld procedures described in the AWS D15.2 specification.

4. Acceptance

Acceptance of the welding electrodes and rods shall be in accordance with the provisions of AWS A5.01M/A5.01 and the tests and requirements of this specification. See A3 (in Annex A) for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

5. Certification

By affixing the AWS specification and classification designations to the packaging, or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification. See A4 (in Annex A) for further information concerning certification and the testing called for to meet this requirement.

Table 1
Solid and Cored Iron Base Electrodes and Rods—Chemical Composition Requirements^a

AWS Classification ^g	Annex A Reference	UNS Numbers ^b		Composition, Weight Percent ^{c, d, e, f}														Other Elements, Total ^h
		UNS (Solid)	UNS (Cored)	C	Mn	Si	Cr	Ni	Mo	V	W	Ti	Nb	Al	B	Fe		
ERFe-1	A7.1.1	T74000	W74030	0.03–0.20	0.2–3.0	1.5	4.0	3.0	1.5	—	—	1.5	—	2.0	—	Rem	1.0	
ERFe-1A	A7.1.1	T74001	W74031	0.04–0.25	1.5–3.5	1.0	0.5–3.5	—	—	—	—	—	—	2.0	—	Rem	1.0	
ERFe-2	A7.1.1	T74002	W74032	0.10–0.40	0.5–4.0	2.5	4.0	2.0	2.0	0.35	—	1.5	—	2.0	—	Rem	1.0	
ERFe-3	A7.1.2	T74003	W74033	0.40–0.80	0.5–2.0	1.0	4.0–9.0	—	1.5	—	—	—	—	2.0	—	Rem	1.0	
ERFe-5	A7.1.3	T74005	W74035	0.50–0.80	1.5–2.5	0.9	1.5–3.0	—	—	—	—	—	—	—	—	Rem	1.0	
ERFe-6	A7.1.4	T75006	W77530	0.6–1.3	0.4–1.0	1.5	3.0–5.0	—	7.0–9.5	0.5–2.5	0.5–2.5	—	—	—	—	Rem	1.0	
ERFe-8	A7.1.5	T75008	W77538	0.25–0.70	0.5–2.5	1.5	3.0–9.0	—	0.5–4.0	2.0	2.0	1.5	4.0	—	—	Rem	1.0	
ERFe-9	A7.1.6	—	—	1.0–2.5	1.0–2.5	2.0	5.0–10.0	—	2.0	1.5	2.0	7.0	9.0	—	—	Rem	1.0	
ERFe-10	A7.1.7	—	—	0.04–0.30	0.5–3.0	1.0	11.0–18.0	6.0	2.5	1.0	1.5	—	1.0	—	—	Rem	3.5	
ERFe-RBU	A7.1.8	—	—	0.03–0.40	0.2–4.0	2.5	4.0	4.0	2.0	0.35	—	1.5	—	2.0	—	Rem	1.0	
ERFeMn-C	A7.1.9	—	W79230	0.5–1.0	12–16	1.3	2.5–5.0	2.5–5.0	—	—	—	—	—	—	—	Rem	1.0	
ERFeMn-D	A7.1.9	—	—	0.5–1.0	15–20	1.5	7.5	—	1.5	1.2	—	—	—	2.0	—	Rem	1.0	
ERFeMn-F	A7.1.9	—	W79630	0.5–1.5	16–27	1.5	2.0–7.0	3.0	1.5	—	—	—	—	2.0	—	Rem	1.0	
ERFeMn-G	A7.1.9	—	W79231	0.5–1.5	12–18	1.5	2.0–7.0	1.0	1.5	—	—	—	—	2.0	—	Rem	1.0	
ERFeMn-H	A7.1.9	—	W79232	0.30–0.80	12–16	1.3	4.5–7.5	2.0	—	—	—	—	—	—	—	Rem	1.0	
ERFeMnCr	A7.1.10	—	W79730	0.25–0.75	12–18	1.5	11–18	2.0	2.0	1.0	—	—	—	2.0	—	Rem	1.0	
ERFeMn-RBU	A7.1.11	—	—	0.3–1.5	12–27	1.5	18.0	5.0	2.0	1.2	—	0.5	—	2.0	—	Rem	1.0	
ERFeCr-A	A7.1.12	—	W74531	1.5–3.5	0.5–1.5	2.0	8–15	—	3	—	—	—	—	—	—	Rem	1.0	

(Continued)

Table 1 (Continued)
Solid and Cored Iron Base Electrodes and Rods—Chemical Composition Requirements^a

AWS Classification ^g	Annex A Reference	UNS Numbers ^b		Composition, Weight Percent ^{c, d, e, f}														Other Elements, Total ^h
		UNS (Solid)	UNS (Cored)	C	Mn	Si	Cr	Ni	Mo	V	W	Ti	Nb	Al	B	Fe		
ERFeCr-A1A	A7.1.13	—	W74530	3.5–5.5	4.0–6.0	0.5–2.0	20–25	—	0.50	—	—	—	—	—	—	Rem	1.0	
ERFeCr-A3A	A7.1.14	—	W74533	2.5–4.0	0.5–3.5	0.5–2.0	14–20	—	1	—	—	—	—	—	—	Rem	1.0	
ERFeCr-A4	A7.1.13	—	W74534	3.5–5.0	0.5–3.5	2.0	20–29	—	0.5–3.0	—	—	—	—	—	1	Rem	1.0	
ERFeCr-A5	A7.1.15	—	W74535	1.5–3.0	0.3–2.5	2.5	23–32	4	4	—	—	—	—	—	—	Rem	1.0	
ERFeCr-A9	A7.1.16	—	W74539	3.0–7.5	4.5	2.5	24–40	—	2	—	—	—	—	—	2	Rem	1.0	
ERFeCr-A10	A7.1.17	—	W74540	4.0–7.0	0.5–2.5	1.5	17–25	—	—	—	—	—	—	—	1	Rem	1.0	
ERFeCr-E3	A7.1.18	—		5.0–7.0	2.0	2.0	18–28	—	4.0–7.0	—	3.0–5.0	—	—	—	—	Rem	1.0	
ERFeCr-E4	A7.1.18	—		4.0–7.0	2.0	2.0	18–30	—	2–8	3	4	—	8	—	—	Rem	1.0	
ERFeCr-E5	A7.1.19	—		4.0–7.0	1.5	1.5	18–30	—	—	—	—	—	5–8	—	1	Rem	1.0	
ERFeV	A7.1.20	—		2.5–6.0	2.5	2.5	7	1.5	1.5	12–24	5–12	0.1	—	—	1.0	Rem	3.0	
ERFeB	A7.1.21	—		0.3–3.0	3.0	1.5	8	3	4	—	—	—	6	—	1–5	Rem	1.0	

^a Covered composite iron base electrodes that were included in AWS A5.21:80, *Specification for Bare Surfacing Electrodes and Rods*, were deleted from A5.21:2001. They have since appeared in AWS A5.13/A5.13M, *Specification for Surfacing Electrodes for Shielded Metal Arc Welding*.

^b ASTM DS-56/SAE HS-1086, *Metals & Alloys in the Unified Numbering System*.

^c Single values are maximum. Rem = Remainder.

^d Electrodes and rods shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for "Other Elements, Total" in the last column of the table.

^e Sulfur and phosphorus contents shall not exceed 0.035% each.

^f For solid electrodes and rods, composition is that of the electrode itself or the stock from which it was made. For metal cored or flux cored electrodes, the composition is that of a weld deposit prepared in accordance with 9.3.

^g For metal cored and flux cored composite (tubular) electrodes and rods, insert "C" in the classification designation immediately following the "R."

^h Aluminum and magnesium contents of weld metal deposited by self-shielding electrodes shall not be included in the value of "Other Elements, Total."

Table 2
Solid Cobalt and Nickel Base Bare Electrodes and Rods—Chemical Composition Requirements

Composition, Weight Percent ^{a, b, c}														
AWS Classification	Annex A Reference	UNS Number ^d	C	Mn	Si	Cr	Ni	Mo	Fe	W	Co	B	V	Other Elements, Total
ERCoCr-A	A7.2.1	R30006	0.9–1.4	1.0	2.0	26–32	3.0	1.0	3.0	3.0–6.0	Rem	—	—	0.50
ERCoCr-B	A7.2.2	R30012	1.2–1.7	1.0	2.0	26–32	3.0	1.0	3.0	7.0–9.5	Rem	—	—	0.50
ERCoCr-C	A7.2.3	R30001	2.0–3.0	1.0	2.0	26–33	3.0	1.0	3.0	11.0–14.0	Rem	—	—	0.50
ERCoCr-E	A7.2.4	R30021	0.15–0.45	1.5	1.5	25–30	1.5–4.0	4.5–7.0	3.0	0.50	Rem	—	—	0.50
ERCoCr-F	A7.2.5	R30002	1.5–2.0	1.0	1.5	24–27	21–24	1.0	3.0	11–13	Rem	—	—	0.50
ERCoCr-G	A7.2.6	R30014	3.0–4.0	1.0	2.0	24–30	4.0	1.0	3.0	12–16	Rem	—	—	0.50
ERCoCr-H	A7.2.7	R31233	0.02–0.10	1.5	1.0	23.5–27.5	7.0–11.0	4.0–6.0	1.0–5.0	1.0–3.0	Rem	0.02	—	N = 0.03–0.12 Others = 0.50
ERNiCr-A	A7.3.1	N99644	0.20–0.60	—	1.2–4.0	6.5–14.0	Rem ^e	—	1.0–3.5	—	—	1.5–3.0	—	0.50
ERNiCr-B	A7.3.1	N99645	0.30–0.80	—	3.0–5.0	9.5–16.0	Rem ^e	—	2.0–5.0	—	—	2.0–4.0	—	0.50
ERNiCr-C	A7.3.1	N99646	0.50–1.00	—	3.5–5.5	12–18	Rem ^e	—	3.0–5.5	—	—	2.5–4.5	—	0.50
ERNiCr-D	A7.3.4	N99647	0.6–1.1	—	4.0–6.6	8.0–12.0	Rem	—	1.0–5.0	1.0–3.0	0.10	0.35–0.60	—	0.50
ERNiCr-E	A7.3.4	N99648	0.1–0.5	—	5.5–8.0	15–20	Rem	—	3.5–7.5	0.5–1.5	0.10	0.7–1.4	—	Sn = 0.5–0.9 Others = 0.50
ERNiCrMo-5A	A7.3.2	N10006	0.12	1.0	1.0	14–18	Rem ^e	14–18	4.0–7.0	3.0–5.0	—	—	0.40	0.50
ERNiCrFeCo	A7.3.3	F46100	2.5–3.0	1.0	0.6–1.5	25–30	10–33	7–10	20–25	2.0–4.0	10–15	—	—	0.50

^a Single values are maximum. Rem = Remainder.

^b Electrodes and rods shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for “Other Elements, Total” in the last column of the table.

^c Sulfur and phosphorus content shall not exceed 0.03% each.

^d ASTM DS-56/SAE HS-1086, *Metals & Alloys in the Unified Numbering System*.

^e Includes incidental cobalt.

Table 3
Metal Cored and Flux Cored Composite Cobalt and
Nickel-Bare Electrodes and Rods-Chemical Composition Requirements

AWS Classification ^d	Annex A Reference	UNS Number ^e	Composition, Weight Percent ^{a, b, c}											Other Elements, Total
			C	Mn	Si	Cr	Ni	Mo	Fe	W	Co	B	V	
ERCCoCr-A	A7.2.1	W73036	0.7–1.4	2.0	2.0	25–32	3.0	1.0	5.0	3.0–6.0	Rem	—	—	1.0
ERCCoCr-B	A7.2.2	W73042	1.2–2.0	2.0	2.0	25–32	3.0	1.0	5.0	7–10	Rem	—	—	1.0
ERCCoCr-C	A7.2.3	W73031	2.0–3.0	2.0	2.0	25–33	3.0	1.0	5.0	11–14	Rem	—	—	1.0
ERCCoCr-E	A7.2.4	W73041	0.15–0.40	2.0	1.5	25–30	1.5–4.0	4.5–7.0	5.0	0.50	Rem	—	—	1.0
ERCCoCr-G	A7.2.6	W73032	3.0–4.0	1.0	2.0	24–30	4.0	1.0	5.0	12–16	Rem	—	—	1.0
ERCNiCr-A	A7.3.1	W89634	0.20–0.60	—	1.2–4.0	6.5–14.0	Rem ^f	—	1.0–3.5	—	—	1.5–3.0	—	1.0
ERCNiCr-B	A7.3.1	W89635	0.30–0.80	—	3.0–5.0	9.5–16.0	Rem ^f	—	2.0–5.0	—	—	2.0–4.0	—	1.0
ERCNiCr-C	A7.3.1	W89636	0.50–1.00	—	3.0–5.5	12–18	Rem ^f	—	3.0–5.5	—	—	2.5–4.5	—	1.0
ERCNiCrMo-5A	A7.3.2	W80036	0.12	1.0	2.0	14–18	Rem ^f	14–18	4.0–7.0	3.0–5.0	—	—	0.40	1.0
ERCNiCrFeCo	A7.3.3	W83032	2.2–3.0	1.0	2.0	25–30	10–33	7–10	20–25	2.0–4.0	10–15	—	—	1.0

^a Single values are maximum. Rem = Remainder.

^b Electrodes and rods shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for “Other Elements, Total” in the last column of the table.

^c Sulphur and phosphorus contents shall not exceed 0.03% each.

^d The designator “C” following ER indicates that the electrode or rod is a metal cored or flux cored composite (tubular) product.

^e ASTM DS-56/SAE HS-1086, *Metals & Alloys in the Unified Numbering System*.

^f Includes incidental cobalt.

Table 4
Solid and Cored Copper Base Electrodes and Rods—Chemical Composition Requirements

AWS Classification ^e	Annex A Reference	UNS Numbers ^a		Composition, Weight Percent ^{b,c,d}									
		Solid	Cored	Fe	Cu	Al	Zn	Si	Pb	Sn	P	Mn	Other Elements, Total ^f
ERCuAl-A2 ^g	A7.4.1.1	C61800	W60618	0.5–1.5	Rem	8.5–11.0	0.02	0.10	0.02	—	—	—	0.50
ERCuAl-A3 ^g	A7.4.1.2	C62400	W60624	2.0–4.5	Rem	10.0–11.5	0.10	0.10	0.02	—	—	—	0.50
ERCuAl-C	A7.4.1.3	C62580	W60626	3.0–5.0	Rem	12–13	0.02	0.04	0.02	—	—	—	0.50
ERCuAl-D	A7.4.1.3	C62581	W61626	3.0–5.0	Rem	13–14	0.02	0.04	0.02	—	—	—	0.50
ERCuAl-E	A7.4.1.3	C62582	W62626	3.0–5.0	Rem	14–15	0.02	0.04	0.02	—	—	—	0.50
ERCuSi-A ^g	A7.4.1.4	C65600	W60657	0.50	Rem	0.01	1.0	2.8–4.0	0.02	1.0	—	1.5	0.50
ERCuSn-A ^g	A7.4.1.5	C51800	W60518	—	Rem	0.01	—	—	0.02	4.0–6.0	0.10–0.35	—	0.50
ERCuSn-D	A7.4.1.5	C52400	W60524	—	88.5 min.	0.01	—	—	0.05	9.0–11.0	0.10–0.35	—	0.50

^a ASTM DS-56/SAE HS-1086, *Metals & Alloys in the Unified Numbering System*.

^b Single values are maximum, except where otherwise specified. Rem = Remainder.

^c Electrodes and rods shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for “Other Elements, Total” in the last column of the table.

^d For solid electrodes and rods, composition is that of the electrode itself or the stock from which it was made. For metal cored or flux cored electrodes, the composition is that of a weld deposit prepared in accordance with 9.3 or 9.4.

^e For metal cored and flux cored composite (tubular) electrodes and wires, insert “C” in the classification designation immediately following the “R.”

^f Sulfur content shall not exceed 0.015%.

^g These AWS classifications are intended to correspond to the same classification that appears in AWS A5.7/A5.7M, *Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes*. Due to possible ongoing revisions, the composition ranges may not be identical.

Table 5
Mesh Size and Quantity of Tungsten Carbide (WC) Granules
in the Core of Tungsten Carbide Bare Rods and Electrodes

AWS Classification ^{a,b}	Annex A Reference	U.S. Standard Mesh Size of Tungsten Carbide Granules ^c	Quantity of Tungsten Carbide (WC1 + WC2) Granules, Weight Percent	SI Equivalents	
				U.S. Standard Mesh Size	Opening, mm
RWCX-10/30	A7.5.1	thru 12–on 30	60 ± 3	10	2.00
RWCX-20/30	A7.5.1	thru 20–on 30	60 ± 3	20	0.85
RWCX-30/40	A7.5.1	thru 30–on 40	60 ± 3	30	0.60
RWCX-40	A7.5.1	thru 40	60 ± 3	40	0.43
RWCX-40/120	A7.5.1	thru 40–on 120	60 ± 3	120	0.13
ERFeWCX-30/230 ^d	A7.5.2	thru 30–on 230	40–60 ± 3	230	0.06
ErNiWCX-30/230 ^e	A7.5.3	thru 30–on 230	40–60 ± 3	230	0.06

^a “X” designates the type of tungsten carbide granules; X = 1 for WC1 granules, X = 2 for WC2 granules, X = 3 for a blend of WC1 and WC2 granules.

^b The “C” normally present in composite designations can be deleted in these classifications, as tungsten carbide electrodes and rods are only composite.

^c The mesh size of the tungsten carbide granules may vary from that specified above, provided that no more than 5.0% of the granules is retained on the “thru” sieve and that no more than 20.0% passes the “on” sieve.

^d This is constructed with an iron-based sheath.

^e This is constructed with a nickel-based sheath.

Table 6
Chemical Composition Requirements for Tungsten Carbide Granules

Element	Composition, Weight Percent ^a		
	WC1	WC2	WC3
C	3.6–4.2	6.0–6.2	As agreed upon between the purchaser and supplier
Si	0.3	0.3	
Ni	0.3	0.3	
Mo	0.6	0.6	
Co	0.3	0.3	
W	94.0 min.	91.5 min.	
Fe	1.0	1.0	
Th	0.01	0.01	

^a Single values are maximum, unless noted otherwise.

6. Rounding Procedure

For purposes of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or ISO 80000-1, Annex B, Rule A (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfill the requirements for the classification under test.

7. Summary of Tests

7.1 Solid Electrodes or Rods. Chemical analysis of the filler metal itself (or the stock from which it is made) is the only test required for classification of a product under this specification.

7.2 Metal Cored and Flux Cored Composite (Tubular) Electrodes and Rods

7.2.1 Chemical analysis of a pad of undiluted weld metal, as shown in Figure 1, or a fused sample as agreed upon by the supplier and purchaser, is the only test required for classification. In case of dispute, the weld pad described in 9.3 shall be the referee method.

7.3 Tungsten Carbide Rods

7.3.1 The amount and mesh size distribution of the tungsten carbide granules shall be determined (see Table 5). Sieve analysis shall be in accordance with ASTM B214.

7.3.2 Chemical analysis of the tungsten carbide granules shall be determined (see Table 6).

8. Retests

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Material, specimens, or samples for retest may be taken from the original test assembly or sample, or from one or two new test assemblies or samples. For chemical analysis, retest need be only for those specific elements that failed to meet the test requirement. If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

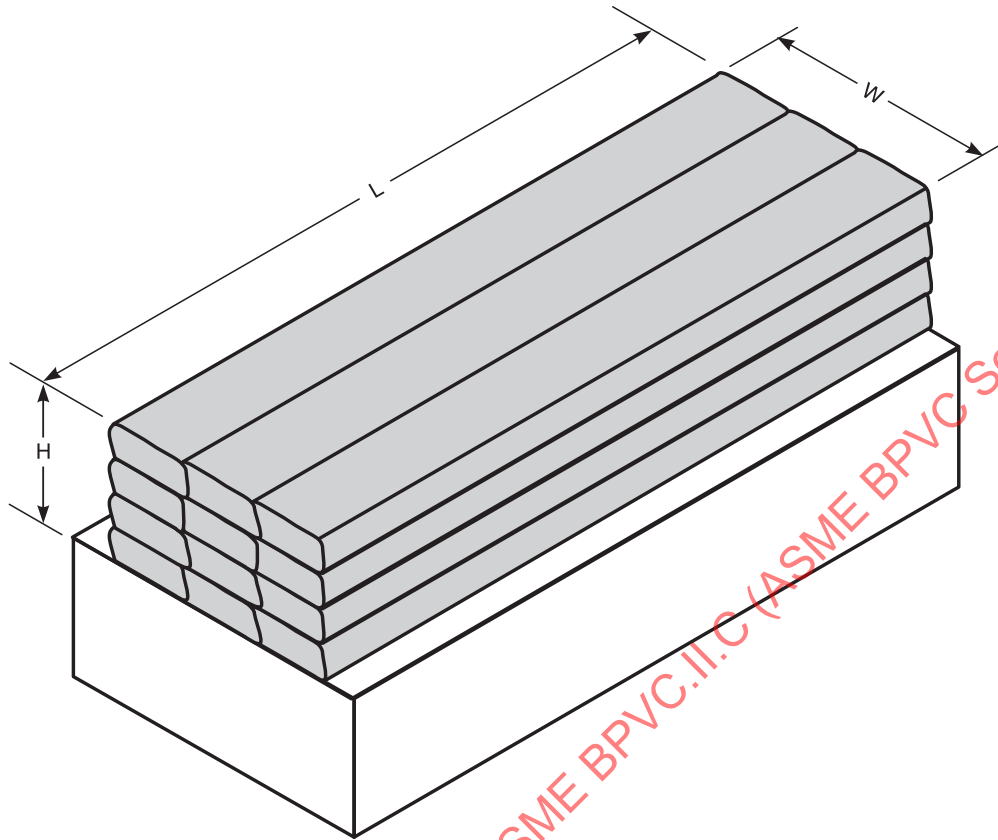
In the event that, during preparation or after completion of any test, it is clearly determined that prescribed or proper procedures were not followed in preparing the weld test assembly or test specimen(s) or in conducting the test, the test shall be considered invalid, without regard to whether the test was actually completed or whether test results met, or failed to meet, the requirement. That test shall be repeated, following proper prescribed procedures. In this case, the requirement for doubling the number of test specimens does not apply.

9. Chemical Composition Requirements

9.1 For solid drawn bare surfacing electrodes or rods, a sample of the filler metal or the stock from which it is made shall be prepared for chemical analysis. Solid filler metal, when analyzed for elements that are present in a coating (copper flashing for example), shall be analyzed without removing the coating. When the filler metal is analyzed for elements other than those in the coating, the coating shall be removed if its presence affects the results of the analysis for other elements. Rod stock may be analyzed prior to coating for those elements not added in the coating.

9.2 For cast bare surfacing electrodes or rods, the chemical analysis sample shall be prepared from the as-manufactured material only.

9.3 For composite metal cored electrodes or rods other than tungsten carbide rods (see 9.5), samples for chemical analysis may be obtained by any method producing undiluted weld metal or ingot as agreed upon between the purchaser and supplier. A weld pad may be prepared using the welding process for which it was designed to operate (Figure 1). In case of a dispute, the weld pad shall be the referee method.



Electrode Size		Weld Pad Size, minimum	
in	mm	in	mm
0.045	1.2	L = 2	50
0.052	1.3	W = 1/2	13
1/16 (0.062)	1.6	H = 1/2	13
5/64 (0.078)	2.0	L = 3	75
3/32 (0.094)	2.4	W = 1/2	13
—	2.5	H = 5/8	16
7/64 (0.109)	2.8		
0.120	3.0		
1/8 (0.125)	3.2		
5/32 (0.156)	4.0		
3/16 (0.187)	4.8	L = 3	75
0.197	5.0	W = 1/2	13
0.238	6.0	H = 3/4	19
1/4 (0.250)	6.4		
5/16 (0.312)	8.0		

Note: Number of weld passes and layers is for illustration purpose only.

Figure 1—Pad for Chemical Analysis of Undiluted Weld Metal

9.3.1 For flux cored composite electrodes and rods, including self-shielded electrodes, the sample for chemical analysis shall be obtained from an undiluted weld pad (see Figure 1) deposited with the welding process for which it was designed.

9.3.2 The dimensions of the completed pad shall be as shown in Figure 1 for each size of electrode. Testing shall be as specified in 9.3.5.

9.3.3 The weld pad test assembly shall be welded in the flat position using welding conditions specified by the manufacturer.

9.3.4 The base metal shall conform to one of the following specifications or its equivalent:

9.3.4.1 ASTM A285/A285M.

9.3.4.2 ASTM A36/A36M.

9.3.5 The top surface of the pad or ingot shall be removed and discarded, and a sample for analysis shall be obtained from the underlying metal by any appropriate means. Postweld heat treatment may be used to facilitate this removal procedure. Chemical analysis may be made by any suitable method as agreed upon between the purchaser and supplier. The referee method shall be the appropriate ASTM method for the element being determined.

9.4 The results of the analysis shall meet the requirements in either Table 1, 2, 3, or 4, for the classification of bare surfacing electrode or rod under test.

9.5 Tungsten Carbide Electrodes and Rods

9.5.1 Weight-percentage of the tungsten carbide particles, as specified in Table 5, shall be determined as follows:

(1) Record the weight of the tungsten carbide welding electrode or rod sample to the nearest tenth of a gram.

(2) Remove the tungsten carbide from the tube and clean it by washing with water and treating with 1-1 hydrochloric acid, as required, to remove any flux, powdered iron, graphite, etc. Heating of the acid may be required. Hot or cold 1-1 hydrochloric acid will not appreciably attack cast tungsten carbide in less than an hour. When handling any acids, appropriate safety precautions should be followed.

(3) Wash and rinse the tungsten carbide particles thoroughly with tap water.

(4) Dry the tungsten carbide particles by holding in an oven at $250^{\circ}\text{F} \pm 25^{\circ}\text{F}$ [$120^{\circ}\text{C} \pm 15^{\circ}\text{C}$] for a minimum period of one hour.

(5) Weigh the cleaned and dried tungsten carbide particles, and calculate the percentage of tungsten carbide from the initial weight of the tube, using the formula:

$$\% \text{ of tungsten carbide particles} = \frac{\text{weight of clean and dried tungsten carbide particles}}{\text{weight of bare electrode or rod sample}} \times 100$$

9.5.2 Chemical composition of tungsten carbide particles shall conform to the requirements of Table 6. Chemical analysis may be made by any suitable method as agreed upon between the purchaser and supplier. Tungsten carbide particles for chemical analysis shall be free of any surface contaminants.

10. Method of Manufacture

The electrodes and rods classified according to this specification may be manufactured by any method that will produce material that meets the requirements of this specification. For tungsten carbide rods, any carbon steel sheath material that will not significantly alter the matrix of the deposit may be used.

11. Standard Sizes and Lengths

Standard sizes and lengths of electrodes and rods shall be as shown in Tables 7, 8, and 9.

Table 7
Standard Sizes for Bare Electrodes and Rods
Using Solid Drawn or Composite (Tubular) Wire^{a, b}

Diameter		Tolerance	
in	mm	in	mm
0.045	—	±0.002	—
—	1.2	—	+0.02, -0.05
0.052	1.3	±0.002	—
—	1.4	—	+0.02, -0.05
1/16 (0.062)	1.6	±0.002	+0.02, -0.06
5/64 (0.078)	2.0	±0.003	+0.02, -0.06
3/32 (0.094)	2.4	±0.003	+0.02, -0.06
—	2.5	—	+0.02, -0.06
7/64 (0.109)	2.8	±0.003	+0.02, -0.06
0.120	3.0	±0.003	+0.02, -0.07
1/8 (0.125)	3.2	±0.003	+0.02, -0.07
5/32 (0.156)	4.0	±0.004	+0.02, -0.07
3/16 (0.188)	4.8	±0.004	—
—	5.0	—	+0.02, -0.08
—	6.0	—	+0.02, -0.08
1/4 (0.250)	6.4	±0.004	—
5/16 (0.312)	8.0	±0.004	+0.02, -0.08

^a Other diameter electrodes may be supplied as agreed upon between the manufacturer and purchaser.

^b Electrode and rod length may be supplied as agreed upon between the manufacturer and purchaser.

Table 8
Standard Sizes for Cast Electrodes and Rods^{a, b}

Nominal Diameter		Tolerance	
in	mm	in	mm
3/32 (0.094)	2.4	±0.02	±0.5
1/8 (0.125)	3.2	±0.02	±0.5
5/32 (0.156)	4.0	±0.02	±0.5
3/16 (0.188)	—	±0.02	—
—	5.0	—	±0.5
1/4 (0.250)	6.4	±0.03	±0.8
5/16 (0.312)	8.0	±0.03	±0.8

^a Other diameter electrodes or rods may be supplied as agreed upon between the manufacturer and purchaser.

^b Electrode and rod length may be supplied as agreed upon between the manufacturer and purchaser.

Table 9
Standard Sizes for Tungsten Carbide (WC) Rods

Nominal Diameter ^a		Length
in	mm	
1/8 (0.125)	3.2	See Note b
5/32 (0.156)	4.0	
3/16 (0.188)	—	
—	5.0	
1/4 (0.250)	6.4	
5/16 (0.312)	8.0	
3/8 (0.375)	9.5	

^a Diameter tolerance is $\pm 1/16$ (0.063) in [± 1.6 mm] from the nominal diameter.

^b Rod length may be supplied as agreed upon between the purchaser and supplier.

12. Finish and Uniformity

Finish and uniformity shall be as specified in AWS A5.02/A5.02M.

13. Standard Package Forms

Standard package dimensions and weights and other requirements for each form shall be as specified in AWS A5.02/A5.02M.

14. Winding Requirements

14.1 Winding requirements shall be as specified in AWS A5.02/A5.02M.

14.2 The cast and helix of filler metal shall be as specified in AWS A5.02/A5.02M.

15. Filler Metal Identification

15.1 Filler metal identification, product information and the precautionary information shall be as specified in AWS A5.02/A5.02M.

15.2 Coils without support shall have a tag containing this information securely attached to the filler metal at the inside end of the coil.

15.3 Coils with support shall have the information securely affixed in a prominent location on the support.

15.4 Spools shall have the information securely affixed in a prominent location on the outside of at least one flange of the spool.

15.5 Drums shall have the information securely affixed in a prominent location on the side of the drum.

16. Packaging

16.1 Filler metal in all product forms, excepting welding rods in straight lengths, shall be packaged in accordance with AWS A5.02/A5.02M.

16.2 Packaging of straight lengths of bare welding rods shall be as agreed upon between the purchaser and supplier.

17. Marking of Packages

17.1 The product information (as a minimum) that shall be legibly marked and visible from the outside of each unit package shall be as specified in AWS A5.02/A5.02M.

17.2 The appropriate precautionary information as given in ANSI Z49.1 (as a minimum), or its equivalent, shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages enclosed within a larger package. Typical examples of “warning labels” and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

ASME BPVC Section II part C) 2025
Click to view the full PDF of ASME BPVC.II.C (ASME BPVC Section II part C) 2025
ASMENORMDOC.COM

Annex A (Informative)

Guide to AWS Specification for Bare Electrodes and Rods for Surfacing

This annex is not part of this standard but is included for informational purposes only.

A1. Introduction

This guide has been prepared as an aid to prospective users of the electrodes and rods covered by the specification in determining the classification of filler metal best suited for a particular application, with due consideration to the particular requirements for that application.

A2. Classification System

A2.1 The system for identifying the electrode classifications in this specification follows the standard pattern used in other AWS filler metal specifications. The letters ER at the beginning of each classification designation stand for electrode and rod, indicating that the filler metal may be used either way. The letter R alone means the electrode may be used only as a welding rod. The designator C, when it appears after ER or R, indicates that the electrode or rod is either a metal cored or flux cored composite (tubular) electrode or rod.

A2.2 The letters immediately after the R, RC, ER, or ERC are the chemical symbols for the principal elements in the classification. Thus, CoCr is a cobalt-chromium alloy; CuAl is a copper-aluminum alloy, etc. Where more than one classification is included in a basic group, the individual classifications in the group are identified by the letters, A, B, C, etc., as in ERCuSn-A. Further subdivision is done by using a 1, 2, etc., after the last letter, as the “2” in ERCuAl-A2. An additional letter or number has been added to some designations if the composition requirements in this specification differ somewhat from those of the earlier versions for electrodes of the same basic classification.

A2.3 Many classifications in this specification have a corresponding SMAW classification in A5.13/A5.13M, *Specification for Surfacing Electrodes for Shielded Metal Arc Welding*.

A2.4 Request for Filler Metal Classification

(1) When a surfacing electrode or rod cannot be classified as given in this specification, the manufacturer may request that a classification be established for that welding electrode *or rod*. The manufacturer may do this by following the procedure given here.

(2) A request to establish a new electrode or rod classification must be a written request, and must provide sufficient detail to permit the AWS A5 Committee on Filler Metals and Allied Materials or the subcommittee to determine whether the new classification or the modification of an existing classification is more appropriate, and whether either is necessary to satisfy the need. The request needs to state the variables and their limits, for such a classification or modification. The request should contain some indication of the time by which completion of the new classification or modification is needed. In particular, the request needs to include:

- (a) A declaration that the new classification will be offered for sale commercially.
- (b) All classification requirements as given for existing classifications, such as chemical composition ranges, mechanical property requirements, and usability test requirements.

(c) Any conditions for conducting the tests used to demonstrate that the product meets the classification requirements. It would be sufficient, for example, to state that welding conditions are the same as for other classifications.

(d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the Annex).

(e) Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.

(f) A request for a new classification without the above information will be considered incomplete. The secretary will return the request to the requester for further information.

(3) The request should be sent to the secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01M/A5.01 as the specification states. Any testing a purchaser requires of the supplier, for material shipped in accordance with this specification, needs to be clearly stated in the purchase order, according to the provisions of AWS A5.01M/A5.01. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing they normally conduct on material of that classification, as specified in Schedule F, Table 1, of AWS A5.01M/A5.01. Testing in accordance with any other Schedule in that table must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product, or the classification on the product itself, constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification.

The only testing requirement implicit in this "certification" is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that the material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation. "Certification" is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been made. The basis for the "certification" required by the specification is the classification test of "*representative material*" cited above, and the "Manufacturer's Quality Assurance System" in AWS A5.01M/A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fume to which welders and welding operators are exposed during welding. These are as follows:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling)
- (2) Number of welders and welding operators working in that space
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes involved
- (4) The proximity of the welder or welding operator to the fumes as they issue from the welding zone, and to the gases and dusts in the space in which he is working
- (5) The ventilation provided to the space in which the welding is done

A5.2 American National Standard ANSI Z49.1 discusses the ventilation that is required during welding and should be referred to for details. Attention is particularly drawn to the section entitled “Ventilation.” See also AWS F3.2, *Ventilation Guide for Weld Fumes*, for more detailed description of ventilation options.

A6. Surfacing Considerations

A6.1 Role of Hydrogen in Surfacing. Hydrogen can be detrimental to surfacing deposits. The effect varies widely from one alloy type to another. In general, hydrogen’s detrimental effect on microstructure is most pronounced for martensitic types, with austenitic types being the least affected. Other factors influencing hydrogen’s effect include carbon and alloy contents plus in-service welding variables.

In welding there are many sources for hydrogen contamination with moisture being one of the most important. Most electrodes and welding rods are manufactured and packaged to control moisture. When received, consideration must be given to proper storage to prevent moisture pick-up. During use, improper regard to welding procedure and environment variables can result in spalling or “hydrogen-induced” underbead cracking. In austenitic materials, excessive hydrogen can manifest itself as porosity in the deposit.

A6.2 For additional surfacing considerations refer to the appropriate volume of the AWS *Welding Handbook*.

A7. Description and Intended Use of Electrodes and Rods for Surfacing

A7.1 Iron Base Electrodes and Rods

A7.1.1 ERFe-1, ERFe-1A, and ERFe-2 Electrodes

A7.1.1.1 Characteristics. Deposits made with these electrodes and rods are a machinery-grade steel suitable for application on carbon and alloy steels. With care, they can be applied crack-free. Deposits are machinable with carbide tipped tools. Deposit hardness generally is in the range of 20 HRC–50 HRC with ERFe-2 filler metal providing weld metal with the higher hardness. These deposits contain sufficient alloy to attain full hardness without the need of heat treatment. Abrasion resistance is comparable to heat treated steels of equal hardness.

A7.1.1.2 Applications. These electrodes and rods are used to restore worn machinery parts to their original dimensions. Deposit surfaces are suitable for metal-to-metal rolling and sliding contact such as occurs on large low speed gear teeth, shafts, etc. High compressive strength makes these materials suitable as a base for more abrasion resistant materials.

A7.1.2 ERFe-3 Electrodes and Rods

A7.1.2.1 Characteristics. Weld metal deposited by these electrodes and rods is an air-hardening tool steel type with high room-temperature hardness (55 HRC–60 HRC). Deposits can be applied crack-free with careful procedures. The deposits cannot be easily machined and are generally ground when finishing is required.

A7.1.2.2 Applications. ERFe-3 electrodes and rods are used to overlay surfaces and edges requiring high hardness and crack-free deposits such as the edges of tools and dies. Deposits are suitable for subsequent surfacing with high-nickel alloys and many tool steels. Although generally used for metal-to-metal applications, the weld metal performs well in earth-abrasion applications where high impact is encountered.

A7.1.3 ERFe-5 Electrodes and Rods

A7.1.3.1 Characteristics. These electrodes and rods deposit a cold work tool steel weld metal. Hardness as deposited should be in the range of 50 HRC–55 HRC. Weld metal deposited by ERFe-5 electrodes is air hardening and machinable only after annealing. Typical deposit characteristics include high compressive strength with moderate abrasion resistance.

A7.1.3.2 Applications. These electrodes are used for metal-to-metal wear applications such as machine components, shafts, brake drums, and knife edges.

A7.1.4 ERF_e-6 Electrodes and Rods

A7.1.4.1 Characteristics. Weld metal deposited by ERF_e-6 electrodes and rods is a high-speed tool steel with a hardness in the range of 60 HRC or higher. The deposit maintains a high degree of hardness up to 1100 °F [600 °C]. Weld metal deposited by ERF_e-6 electrodes is air hardening and is machinable only after annealing.

A7.1.4.2 Applications. Weld deposits may be used for metal-to-metal wear applications at temperatures to 1100 °F [600 °C]. Typical applications, *which* combine high temperature service with *severe* abrasion and metal-to-metal wear, include *shear blades, trimming dies, and punching dies.*

A7.1.5 ERF_e-8 Electrodes and Rods

A7.1.5.1 Characteristics. Weld metal deposited by ERF_e-8 electrodes and rods is a hot work tool steel with a hardness in the range of 50 HRC–60 HRC. The microstructure consists of martensite plus alloy carbides to produce a tough, hard deposit on either carbon or low-alloy steel base metal. Proper preheating is essential to ensure crack-free deposits (consult the manufacturer). The deposit may be finished by grinding.

A7.1.5.2 Applications. This composition is used for overlaying surfaces subjected to moderate abrasive wear with high impact. Applications typically include machine tools and components subject to sliding metal-to-metal wear *in hot forming processes.*

A7.1.6 ERF_e-9 Electrodes and Rods

A7.1.6.1 Characteristics. Weld metal deposited by ERF_e-9 electrodes and rods is a composite overlay with a hardness in the range of 55 HRC–65 HRC. The microstructure consists of a martensite matrix strengthened with titanium or niobium carbide precipitates for high-stress abrasion resistance on either carbon or low-alloy steel base metal. Stress-relief micro-cracking can occur upon cooling. The deposit is not machinable and may be finished by grinding.

A7.1.6.2 Applications. This composition is used for overlaying surfaces subjected to high-stress abrasive wear, like in mineral grinding situations, with possibly some high impact, like on certain quarrying ground-engaging tools. Applications typically include cement clinker crusher rolls. Multi-layer deposits are possible in certain applications.

A7.1.7 ERF_e-10 Electrodes and Rods

A7.1.7.1 Characteristics. Weld metal deposited by ERF_e-10 electrodes and rods results in a martensitic stainless steel with a hardness in the range of 35 HRC–55 HRC, the latter to be adjusted and homogenized by a postweld heat treatment. The martensitic microstructure also includes refractory alloy carbides to better resist fire-cracking and to produce a hard and corrosion-resistant deposit on either carbon or low-alloy steel base metal. Proper preheating is essential to ensure crack-free multi-layer deposits. The deposit may be machined.

A7.1.7.2 Applications. This composition is used for overlaying surfaces subjected to moderate abrasive wear combined with heavy rolling loads, bending stresses, thermal cycles, and corrosive cooling waters. Applications typically include cladding of continuous caster rolls in steel making.

A7.1.8 ERF_e-RBU Electrodes and Rods

A7.1.8.1 Characteristics. This is a general classification introduced to facilitate the description of railway weld repair processes. Specific welding procedures may call on more restrictive A5.21 classifications like ERF_e-1 or ERF_e-2. Deposits made by ERF_e-RBU electrodes and rods tend to be mixtures of ferritic, bainitic, or martensitic microstructures depending on actual composition and welding process parameters. They contain sufficient alloy to attain full hardness without the need for heat treatment. Hardness is usually in the 25 HRC–50 HRC range. These filler metals provide good resistance to rolling, sliding and metal-to-metal wear. With care, the deposits can be applied crack-free. They can be machined with carbide-tipped tools.

A7.1.8.2 Applications. These electrodes and rods are used for the rebuilding and repair of worn track rails, rail ends and rail crossing points. They exhibit low material deformation on impact and the ability to provide some work hardening without cracking. The related applications are described in the AWS D15.2 specification.

A7.1.9 ERF_eMn Series Electrodes and Rods (except ERF_eMnCr and ERF_eMn-RBU)

A7.1.9.1 Characteristics. Deposits made with these electrodes and rods nominally contain 14% manganese, although they may vary from 12% to 27%. This is an amount sufficient to yield austenitic weld deposits. Austenite is a

nonmagnetic tough form of steel. To preserve the toughness, excessive heat must be avoided during welding, *keeping a maximum interpass temperature of 500 °F [260 °C]*. Stringer beads and skip welding are thus recommended. Additions of other *elements*, such as 4% nickel, give more stability to the austenite. Chromium and molybdenum can also be added to increase the yield strength. Abrasion resistance is only a little better than that of low-carbon steel unless there has been sufficient impact to cause work hardening. As deposited, surfaces generally are no harder than 20 HRC, but can work harden in service up to 55 HRC. Deposits are difficult to machine; grinding is preferred for finishing to dimensions.

Weld metal deposited by ERFEMn-F electrodes and rods differ from the other austenitic manganese classifications in that a single-layer deposit will be fully austenitic when deposited on carbon steel or low-alloy steel base metal. This is the direct result of the higher carbon and manganese contents of the filler metal.

A7.1.9.2 Applications. These electrodes *and rods* are used for the rebuilding, repair, and joining of austenitic manganese steels. Ability to absorb high impact makes such deposits ideal for rebuilding of worn rock-crushing equipment *and other wear components* subject to *heavy impact loads* such as railroad frogs.

A7.1.10 ERFEMnCr Electrodes and Rods

A7.1.10.1 Characteristics. Weld metal deposited by ERFEMnCr electrodes have similar characteristics to those of the austenitic manganese steel deposits. *However*, the high-chromium content improves the stability of austenite when compared to ERFEMn deposits. These deposits cannot be flame cut due to their high chromium content, and care must be taken in application to avoid heat build-up *beyond a maximum interpass temperature of 500 °F [260 °C]*.

A7.1.10.2 Applications. Like ERFEMn-type electrodes and rods, ERFEMnCr electrodes and rods are used for rebuilding, repair, and joining of equipment made from austenitic manganese steels. ERFEMnCr electrodes and rods offer the added advantage of being usable for joining austenitic manganese steel to itself and to carbon steel. ERFEMnCr weld metals are often used as a base layer for *subsequent* surfacing with ERFECr-AX(X) *hardfacing filler metals* on parts subject to both abrasion and impact.

A7.1.11 ERFEMn-RBU Electrodes and Rods

A7.1.11.1 Characteristics. *This is a general classification introduced to facilitate the description of railway weld repair processes. Specific welding procedures may call on more restrictive A5.21 classifications like ERFEMn-F, ERFEMn-G or ERFEMnCr. Deposits made by ERFEMn-RBU electrodes and rods nominally contain 14% manganese, although they may vary from 12% to 27%. This is an amount sufficient to yield austenitic weld deposits. To preserve the toughness, excessive heat must be avoided during welding, keeping a maximum interpass temperature of 500 °F [260 °C]. Stringer beads and skip welding are thus recommended. As deposited, surfaces generally are no harder than 20 HRC, but can work harden in service up to 55 HRC. Deposits are difficult to machine; grinding is preferred for finishing to dimensions.*

A7.1.11.2 Applications. *These electrodes and rods are used for the rebuilding and repair of high manganese steel railroad frogs and crossing diamonds. The related applications are described in the AWS D15.2 specification. Such deposits can absorb high impact and heavy rolling loads.*

A7.1.12 ERFECr-A Electrodes and Rods

A7.1.12.1 Characteristics. Weld metal deposited by these electrodes and rods will contain moderate amounts of chromium carbides in a high-carbon austenitic matrix. Two layers are recommended to achieve uniform hardness and deposit composition. Additional layers may be prone to spalling and should be applied with caution *per manufacturer instructions*. The deposit *can work-harden up to 55 HRC–60 HRC* and provides greater impact resistance, but lesser abrasion resistance than other ERFECr-X(X) classifications. The deposits should be ground if finishing is required as they are not readily machined or flame cut. Weld metal deposited by ERFECr-A electrodes may be applied to carbon, low-alloy, austenitic manganese, and austenitic stainless steel base metals.

A7.1.12.2 Applications. ERFECr-A is a general purpose hardfacing alloy which can be used where limited stress-relief cracking (cross-check) is acceptable but severe abrasion is not encountered. *Typical applications have been found with gyratory and primary cone crushers as well as dredge pump shells.*

A7.1.13 ERFECr-A1A and ERFECr-A4 Electrodes and Rods

A7.1.13.1 Characteristics. Weld metal deposited by these electrodes and rods will contain *hyper-eutectic coarse primary hexagonal* chromium carbides in an austenitic matrix providing great wear resistance and fair toughness. *The*

typical hardness range is 50 HRC–60 HRC. Surface cross-checks are normal and provide a degree of stress-relief. To achieve the desired composition, a minimum of two layers is usually recommended. Additional layers may be prone to spalling and must be applied with caution per manufacturer instructions. These electrodes are suitable for welding on carbon, low-alloy, and austenitic manganese steels. The weld metal deposited by ERFecr-A1A electrodes generally provides greater impact resistance than ERFecr-A4. Deposits cannot be flame-cut and must be ground when finishing is required.

A7.1.13.2 Applications. Typical applications include bucket lips and teeth, coal pulverizer rolls, impact hammers, and conveyor screws used for handling rock, ore, coal, etc. Very low coefficients of friction develop as a result of the wear surface polishing to a slick finish under mineral abrasion.

A7.1.14 ERFecr-A3A Electrodes and Rods

A7.1.14.1 Characteristics. The microstructure of weld metal deposited by ERFecr-A3A electrodes and rods resembles that of white cast iron with hypo- or near-eutectic chromium carbides with a hardness in the range of 45 HRC–55 HRC. The deposit has higher toughness than weld metal deposited by ERFecr-A1A, ERFecr-A4, ERFecr-A9, or ERFecr-A10 electrodes and rods, but implies a reduction in abrasion resistance. Surface cross-checks are normal and provide a degree of stress-relief. The deposit cannot be flame-cut. Finishing is by grinding only.

A7.1.14.2 Applications. This weld metal is a general-purpose hardfacing alloy typically used as a final overlay on roll crushers, mill hammers, cone crushers, and road work ground-engaging tools, often applied over a prior austenitic manganese steel build-up.

A7.1.15 ERFecr-A5 Electrodes and Rods

A7.1.15.1 Characteristics. The weld deposit contains fine secondary chromium carbides evenly dispersed in an austenitic matrix. The typical hardness range is 35 HRC–50 HRC. The nonmagnetic weld metal has fair machinability. Some free chromium provides fair corrosion resistance. Build-up should be restricted to three layers to minimize relief checking. Some grades can be applied crack-free.

A7.1.15.2 Applications. Components surfaced with these electrodes and rods are frequently used for applications involving metal-to-metal friction wear or low-stress metal-to-earth abrasion. The corrosion resistance makes this deposit a good choice for process equipment like pulping screws.

A7.1.16 ERFecr-A9 Electrodes and Rods

A7.1.16.1 Characteristics. The deposit contains a high volume of hyper-eutectic coarse primary hexagonal chromium carbides in an austenitic matrix with a typical hardness of 55 HRC to 65 HRC. Such deposits develop dense stress-relief cracking patterns (cross-checks). To achieve the desired composition, a minimum of two layers is usually recommended. Additional layers may be prone to spalling and must be applied with caution per manufacturer instructions. The weld metal may be applied on carbon or low-alloy steel, austenitic manganese steel, or austenitic stainless steel base metal. The deposit cannot be flame-cut. Finishing is by grinding only.

A7.1.16.2 Applications. These electrodes are frequently used for applications involving severe abrasive wear combined with moderate impact. They count high-volume applications such as bimetallic wear plates, oil sands slurry lines, vertical roller mills, coal pulverizers, mixer components, sugar mills, etc.

A7.1.17 ERFecr-A10 Electrodes and Rods

A7.1.17.1 Characteristics. Weld metal deposited by these electrodes and rods contains massive hyper-eutectic primary hexagonal carbides in a matrix strengthened with finer eutectic carbides. The deposit has a hardness of 55 HRC–65 HRC, which decreases progressively up to a temperature of 1400 °F [760 °C]. Such deposits develop dense stress-relief cracking (cross-check) patterns. The composition provides the ultimate in low-stress abrasion resistance, but with reduced impact resistance. Deposit thickness should not exceed two layers. The deposit cannot be flame cut. Finishing is by grinding only.

A7.1.17.2 Applications. Deposits of this type may be used in severe abrasive applications that involve minimal impact. Typical applications include bulk handling equipment, glass and sand mixers, agricultural implements, civil works, and certain high-temperature applications.

A7.1.18 ERF_{Cr}-E3 and ERF_{Cr}-E4 Electrodes and Rods

A7.1.18.1 Characteristics. Weld metal deposited by these electrodes and rods will show a dense microstructure containing coarse primary hexagonal chromium carbides interlocked with finer refractory metal carbides (Mo, W, V, Nb/Cb, Ti) in an austenitic matrix. Such deposit provides excellent abrasive wear resistance under little to no impact. The typical undiluted metal hardness range is 60 HRC–65 HRC, which decreases progressively up to a temperature of 1400 °F [760 °C]. Surface cross-checks are normal and provide a degree of stress-relief. A maximum of two layers is usually recommended. Additional layers may be prone to fracture and/or spalling and must be applied with caution per manufacturer instructions. Deposits cannot be flame-cut and must be ground when finishing is required.

A7.1.18.2 Applications. This weld metal is generally the most appropriate for severe wear involving very fine and high-velocity abrading particles as well as for higher temperature service with little to no impact. Typical applications include coke pusher shoes, iron sinter breakers, exhaust fan liners, pug mills, brick extruders, etc.

A7.1.19 ERF_{Cr}-E5 Electrodes and Rods

A7.1.19.1 Characteristics. Weld metal deposited by these electrodes and rods will show a dense microstructure containing coarse primary hexagonal chromium carbides in addition to niobium carbides (5–8% Nb/Cb) in an austenitic matrix. Such deposit provides excellent abrasive wear resistance under little to no impact. The typical undiluted metal hardness range is 60 HRC–65 HRC. Surface cross-checks are normal and provide a degree of stress-relief. A maximum of three layers is usually recommended. Additional layers may be prone to fracture and/or spalling. Deposits cannot be flame-cut and must be ground when finishing is required.

A7.1.19.2 Applications. This weld metal is generally appropriate for severe wear involving fine abrading particles with little to no impact. Typical applications include bucket wheel reclaimer lips and teeth, exhaust fan liners, mixer components, conveyor screws, coal crusher segments, dry cement pumps, etc.

A7.1.20 ERF_V Electrodes and Rods

A7.1.20.1 Characteristics. Weld metal deposited by these electrodes and rods will contain a large amount of evenly distributed vanadium carbides, as the primary wear resistance factor, along with secondary tungsten carbides. The deposit provides severe abrasion resistance against medium-size and coarse mineral particles under moderate impact. The typical hardness range is 55 HRC–65 HRC. Stress-relief micro-cracking can occur upon cooling. A maximum of three layers is usually recommended. The deposit can easily be repaired without compromising the microstructure. These electrodes and rods are suitable for welding on carbon and low-alloy steels. Finishing is by grinding only.

A7.1.20.2 Applications. The deposit provides enhanced metal-to-earth abrasion resistance over the ERF_{Cr}-AX series. Typical applications include ground-engaging tools, cultivator chisels, sweeps and plows, ammonia injectors, dry cement pump screws, pug mills, construction residues shredder hammers, sugar cane harvesters, civil works auger tips, etc.

A7.1.21 ERF_B Electrodes and Rods

A7.1.21.1 Characteristics. Weld metal deposited by these electrodes and rods will contain very fine evenly distributed boron carbide precipitates (1%–5% B), as the primary wear resistance factor, sometimes along with secondary metal carbides (Cr, Mo, Nb/Cb). The deposit is often chromium-free and niobium is often the secondary alloying element of choice. Nickel can be added to improve on toughness. The deposit provides abrasion resistance against fine mineral particles under moderate to high impact. The typical hardness range is 65 HRC–70 HRC. Stress-relief micro-cracking can occur upon cooling. A maximum of two layers is recommended. Finishing is by grinding only.

A7.1.21.2 Applications. The deposit provides metal-to-earth abrasion resistance comparable to the ERF_{Cr}-AX series. It can offer a chromium-free and mostly crack-free hardfacing alternative. It reaches a high hardness in a single layer. Typical applications include cultivator sweeps, cutter blades, augers, conveyor screws, continuous mining wheels, etc.

A7.2 Cobalt Base Electrodes and Rods

A7.2.1 ERCoCr-A Electrodes and Rods

A7.2.1.1 Characteristics. Weld metals deposited by ERCoCr-A electrodes and rods are characterized by a hypoeutectic structure, consisting of a network of about 13% eutectic chromium carbides distributed in a cobalt-chromium-

tungsten solid solution matrix. The result is a material with a combination of overall resistance to low stress abrasive wear, with the necessary toughness to resist some degree of impact. Cobalt alloys also are inherently good for resisting metal-to-metal wear, particularly in high load situations that are prone to galling. The high-alloy content of the matrix also affords excellent resistance to corrosion, oxidation, and elevated temperature retention of hot hardness up to a maximum of 1200 °F [650 °C]. These alloys are not subject to allotropic transformation and therefore do not lose their properties if the base metal is subsequently heat treated.

A7.2.1.2 Applications. The alloy is recommended for cases where wear is accompanied by elevated temperatures and where corrosion is involved, or both. Some typical applications are automotive and fluid flow valves, chain saw guides, hot punches, shear blades, and extruder screws.

A7.2.2 ERCoCr-B Electrodes and Rods

A7.2.2.1 Characteristics. Weld metal deposited by ERCoCr-B electrodes and rods is similar in composition to deposits made using ERCoCr-A electrodes and rods except for a slightly higher percentage (approximately 16%) of carbides. The alloy also has a slightly higher hardness and better abrasive and metal-to-metal wear resistance. Impact and corrosion resistance are lowered slightly. Deposits can be machined with carbide tools.

A7.2.2.2 Applications. ERCoCr-B electrodes and rods are used interchangeably with ERCoCr-A electrodes and rods. Choice will depend on the specific application.

A7.2.3 ERCoCr-C Electrodes and Rods

A7.2.3.1 Characteristics. This alloy has a higher percentage (approximately 19%) of carbides than deposits made using either ERCoCr-A or ERCoCr-B class. In fact, the composition is such that primary hyper-eutectic carbides are found in the microstructure. This characteristic gives the alloy higher wear resistance accompanied by reductions in the impact and corrosion resistance. The higher hardness also means a greater tendency to check during cooling. The checking tendency may be minimized by closely monitoring preheating, interpass temperature, and post heating techniques. *While the cobalt-chromium deposits soften somewhat at elevated temperatures, they normally are considered immune to tempering.*

A7.2.3.2 Applications. Weld metal deposited by ERCoCr-C electrodes and rods is used to build-up items such as mixers, rotors, or wherever harsh abrasion and low impact are encountered.

A7.2.4 ERCoCr-E Electrodes and Rods

A7.2.4.1 Characteristics. Welds made using ERCoCr-E electrodes and rods have very good strength and ductility in temperatures up to 2100 °F [1150 °C]. Deposits are resistant to thermal shock as well as oxidizing and reducing atmospheres. Early applications of these types of alloys were found in jet engine components such as turbine blades and vanes. The deposit is a solid solution strengthened alloy with a relatively low weight-percent carbide phase in the microstructure. Hence, the alloy is very tough and will work harden. Deposits possess excellent self-mated galling resistance and also are very resistant to cavitation erosion.

A7.2.4.2 Applications. Welds made using ERCoCr-E electrodes and rods are used where the resistance to thermal shock is important. Typical applications, similar to those of deposits made using ERCoCr-A electrodes and rods, include idle rolls, hot extrusion and forging dies, hot shear blades, tong bits, valve trim, etc.

A7.2.5 ERCoCr-F Electrodes and Rods

A7.2.5.1 Characteristics. ERCoCr-F differs from the other cobalt chrome tungsten alloys due to the addition of over 20% nickel. This alloy was developed to impart additional oxidation and corrosion resistance, especially where lead additives are made to automotive engine fuels. Other properties, such as hot hardness, metal-to-metal wear resistance, and thermal fatigue, are similar to type ERCoCr-A type deposits.

A7.2.5.2 Applications. ERCoCr-F is used almost exclusively on automotive (gasoline) exhaust valves, especially on air-cooled (higher operating temperature) engines. Most surfacing is done with automatic equipment by the original equipment manufacturer, and very little by the maintenance market. Both oxyfuel gas welding (OFW) and gas tungsten arc welding (GTAW) are used.

A7.2.6 ERCoCr-G Electrodes and Rods

A7.2.6.1 Characteristics. ERCoCr-G is a higher carbon and tungsten version of ERCoCr-C that imparts excellent abrasion resistance under high loads. The increase in the volume fraction of primary carbides also increases the average hardness and adhesive wear resistance. This type of material is sensitive to cracking in the weld deposits and therefore, preheat and interpass temperatures as well as cooling rate must be closely controlled.

A7.2.6.2 Applications. ERCoCr-G is used extensively on bearing areas of tri-cone type drilling tools. Application is typically by manual or automated gas tungsten arc welding (GTAW) and oxyfuel gas welding (OFW).

A7.2.7 ERCoCr-H Electrodes and Rods

A7.2.7.1 Characteristics. ERCoCr-H electrodes and rods produce weld deposits with a balanced combination of wear and corrosion resistance. Excellent resistance to weld cracking allows weld deposition without the need for a butter layer or preheating. Weld deposit surfaces work harden very rapidly and can achieve up to 50 HRC after cold working. Final machining, peening, or burnishing operations can be used to increase surface hardness and enhance wear resistance.

A7.2.7.2 Applications. ERCoCr-H weld metal is widely used for the overlay of carbon, low alloy, and stainless steels. The deposited weld metal excels where aqueous corrosion resistance is required in conjunction with wear resistance. Applications have included oil and gas valve components; marine riser tensioners, shafts, and larger hydraulic system pistons; U-bends, piping, and valves used in conveying sour crudes containing abrasives; slurry, rock, and acid tumblers and mixers; and impellers.

A7.2.8 In the as-welded condition, the typical hardness values for multilayer welds made using cobalt base electrodes and rods are as follows:

CoCr-A	23 HRC–47 HRC
CoCr-B	34 HRC–47 HRC
CoCr-C	43 HRC–58 HRC
CoCr-E	20 HRC–35 HRC
CoCr-F	32 HRC–46 HRC
CoCr-G	52 HRC–60 HRC
CoCr-H	20 HRC–30 HRC

A7.3 Nickel Base Electrodes and Rods

A7.3.1 ERNiCr-A, -B, and -C Electrodes and Rods

A7.3.1.1 Characteristics. Undiluted weld metals of these compositions exhibit a structure consisting of borides and chromium carbides in a nickel-rich matrix. The nickel-base and high-chromium content gives these deposits good heat and corrosion resistance. Care should be taken when cooling these deposits because of a tendency to stress crack. These alloys possess excellent resistance to low-stress abrasion which increases with increasing boron content in the deposit.

Weld metal deposited by these electrodes and rods flows very easily, has very high abrasion resistance, and normally takes on a high polish.

The deposits have high corrosion resistance and normally require grinding for finishing. Single-layer deposits typically have hardness between 35 HRC and 45 HRC. Multilayer deposits typically have hardness between 49 HRC and 56 HRC.

A7.3.1.2 Applications. Typical applications include cultivator sweeps, plow shares, extrusion screws, pump sleeves, pistons, impellers, capstan rings, glass mold faces, centrifuge filters, and sucker pump rods.

A7.3.2 ERNiCrMo-5A Electrodes and Rods

A7.3.2.1 Characteristics. Weld metal of this composition is a solid solution strengthened alloy with a relatively low weight-percent carbide phase. The resultant deposit is tough and work hardening.

Deposits have the ability to retain hardness to 1400 °F [760 °C]. Deposits are machinable with high-speed tool bits and have excellent resistance to high-temperature wear and impact.

A7.3.2.2 Applications. These electrodes are used to rebuild and repair hot extrusion and forging dies, sizing punches, hot shear blades, guide rolls, tong bits, blast furnace bells, etc.

A7.3.3 ERNiCrFeCo Electrodes and Rods

A7.3.3.1 Characteristics. Filler metal deposited by these electrodes is a nickel-chromium-iron-cobalt base alloy containing a fairly large volume fraction of hypereutectic chromium carbides distributed throughout the microstructure. The alloy offers many of the same high performance characteristics of deposits made using ERCoCr-C or ERNiCr-C electrodes or rods in terms of abrasive wear resistance. The reduced content of nickel or cobalt, or both, lowers corrosion properties and galling resistance. The high volume fraction of carbides makes this alloy sensitive to cracking during cooling.

Hardness values for single layer deposits will be lower because of dilution from the base metal.

A7.3.3.2 Applications. Welds made using ERNiCrFeCo electrodes or rods are preferred where high abrasion with low impact is a major factor. Typical applications are feed screws, slurry pumps, and mixer components.

A7.3.4 ERNiCr-D and E Electrodes and Rods

A7.3.4.1 Characteristics. Undiluted weld metals of these compositions with Si/B greater than 3.3 exhibit a structure consisting of a nickel solid solution, a binary eutectic of nickel solid solution and nickel silicide; and a ternary eutectic of nickel solid solution, nickel silicide, and nickel boride. There are also carbide and boride particles dispersed in the matrix. The microstructures differ from those of ERNiCr-A, B, and C in that the brittle binary eutectic of nickel solid solution and nickel boride does not form, thus improving the cracking resistance during welding.

A7.3.4.2 Applications. Welds of these compositions are used for hardfacing the trims of fluid control valves. In the nuclear industry, they are used to replace cobalt-containing weld overlays in order to reduce the cobalt content in the process stream.

A7.4 Copper Base Electrodes and Rods

A7.4.1 Introduction. The copper base solid welding materials classified by this specification are used to deposit overlays for bearings and wear-resistant surfaces and to resist corrosion.

A7.4.1.1 ERCuAl-A2 filler metal is used for building up bearing surfaces between the hardness range of 130–150 HB. It is also used for wear-resistant surfaces as well as for corrosion-resistant surfaces subject to saltwater and many commonly used acids.

A7.4.1.2 ERCuAl-A3 filler metal deposits produce a deposit of high strength and good ductility with a nominal hardness of 166 HB. This alloy is ideal for bearing surfaces requiring high strength and good ductility such as for a forge press piston.

A7.4.1.3 ERCuAl-C, ERCuAl-D, and ERCuAl-E filler metals have excellent wear-resisting characteristics and are used where extreme wear and high pressure are encountered in service. ERCuAl-D and ERCuAl-E are also used for fabricating new or rebuilding worn ferrous dies used for forming or drawing titanium, and low-carbon and stainless steel. These alloys are not recommended for corrosion. Typical hardness levels for ERCuAl-C, ERCuAl-D and ERCuAl-E are 250 HB–290 HB, 310 HB–350 HB, and 340 HB–380 HB, respectively.

A7.4.1.4 ERCuSi-A (copper-silicon) filler metal is used primarily for corrosion-resistant surfaces. Copper silicon deposits are generally not suited for bearing service applications.

A7.4.1.5 ERCuSn-A, ERCuSn-D (copper-tin) filler metal is primarily used to build-up bearing surfaces where lower hardness is required. This alloy is used for corrosion-resistant surfaces, and occasionally, for wear-resistance applications. The higher tin content of ERCuSn-D weld deposits has improved wear resistance but also has increased hot shortness of the alloys.

A7.4.2 Applications

A7.4.2.1 Hot Hardness. The copper base filler metals are not recommended for use at elevated temperatures. Mechanical properties will generally degrade as the temperature increases above 400 °F [200 °C]

A7.4.2.2 Abrasion. Copper-base weld deposits are not recommended for use where severe abrasion is encountered in service.

A7.4.2.3 Metal to Metal Wear. Bearing surface overlays are often designed with preferential wear requirements. To do this with copper-base alloys, select a material that will result in a weld deposit of 50 points–75 points Brinell softer than the mating surface. This will assure a preferential wear system.

A7.4.2.4 Machinability. All of the copper-base weld deposits are machinable.

A7.4.2.5 Preparation and Welding Characteristics. The base metal should be machined or ground prior to application of the first pass. The weld deposits should be wire brushed or ground between passes. The first pass should be applied at the low end of amperage to minimize dilution. Excessive base metal dilution can result in reduced machinability and service performance. The manufacturer should be consulted for specific welding parameters.

A7.4.2.6 Preheat. Preheating may be desirable depending on the base metal to be overlaid. Generally, no preheat is necessary on low carbon steel. Medium-to-high carbon steel may require 300 °F–600 °F [150 °C–315 °C] preheat, depending on the carbon content. On subsequent layers, an interpass temperature of 500 °F [260 °C] should not be exceeded. The manufacturer should be consulted for complicated overlays.

A7.5 Tungsten Carbide Electrodes and Rods

A7.5.1 RWCX Series Rods

A7.5.1.1 Characteristics. Tungsten carbide tubular rods in this classification contain 60% by weight of tungsten carbide particles in an iron base matrix. The WC1 carbide is an eutectic mixture of WC and W₂C. The WC2 carbide is macrocrystalline WC. Hardness of the deposit matrix varies from 30 HRC to 60 HRC depending on welding technique. Hardness of individual carbide particles is typically between 2200 HV100 and 2600 HV100 for the eutectic tungsten carbide and between 1800 HV100 and 2200 HV100 for the macrocrystalline tungsten carbide. Abrasion resistance of tungsten carbide deposits is outstanding.

A7.5.1.2 Applications. Iron base tungsten carbide composite deposits are applied on surfaces subject to extreme sliding abrasion combined with a limited amount of impact. Such applications are encountered in earth drilling, earthmoving, brick making, and farming. Specific components that may require this type of a surfacing overlay include oil drill bits and tool joints, drilling augers, excavator teeth, ammonia injectors, cultivator chisels, shares and plows, pug knives, woodyard tools, grain mill hammers, etc.

A7.5.2 ERFWCX-30/230 Electrodes

A7.5.2.1 Characteristics. Tungsten carbide tubular electrodes under this specification are metal cored or flux cored wires containing between 40% and 60% by weight of tungsten carbide particles in an iron base matrix. The WC1 carbide is an eutectic mixture of WC and W₂C. The WC2 carbide is macrocrystalline WC. Hardness of the deposit matrix is generally between 50 HRC and 60 HRC depending on tungsten carbide dissolution. Hardness of individual carbide particles is typically between 2200 HV100 and 2600 HV100 for the eutectic tungsten carbide and between 1800 HV100 and 2200 HV100 for the macrocrystalline tungsten carbide. Abrasion resistance of tungsten carbide deposits is outstanding. A maximum of two layers is recommended to avoid fracture and spalling. Micro-cracking is very likely to occur upon cooling. Repairs and touch-ups are difficult. Finishing is by grinding only.

A7.5.2.2 Applications. Iron base tungsten carbide composite deposits are applied on surfaces subject to extreme sliding abrasion combined with little to no impact. Such applications are encountered in oil and gas drilling, earthmoving, mining, brick making, and farming. Specific components that may require this type of a surfacing overlay include drill bits, drilling augers, excavator teeth, muller plows, pug knives, brick extruders, pigment cyclones, tillage tools, etc.

A7.5.3 ERNiWCX-30/230 Electrodes and Rods

A7.5.3.1 Characteristics. Tungsten carbide tubular electrodes and rods under this specification are metal cored or flux cored wires containing between 40% and 60% by weight of tungsten carbide particles in a nickel base matrix, generally a self-fluxing nickel alloy (NiSiB or NiCrSiB). The WC1 carbide is an eutectic mixture of WC and W₂C. The WC2 carbide is macrocrystalline WC. Hardness of the deposit matrix is generally between 40 HRC and 50 HRC depending on its composition and tungsten carbide dissolution. Hardness of individual carbide particles is typically 2200 HV100–2600 HV100 for the eutectic tungsten carbide and 1800 HV100–2200 HV100 for the macrocrystalline tungsten carbide. Abrasion resistance of tungsten carbide deposits is outstanding. A maximum of two layers is recommended to avoid fracture and spalling. Micro-cracking is very likely to occur upon cooling. Repairs and touch-ups are feasible. Finishing is by grinding only.

A7.5.3.2 Applications. *Nickel base tungsten carbide composite deposits are applied on surfaces subject to extreme sliding abrasion combined with little to no impact. Such applications are encountered in oil and gas drilling, earthmoving, mining, iron ore pellet plants, oil sands processes, brick making, cement plants, pigment refineries, pulp and paper, etc. Specific components that may require this type of a surfacing overlay include drill bits, drill string stabilizers, ground-engaging tools, oil sands crusher and sizer teeth, slurry lines, muller plows, pug knives, brick extruders, pigment cyclones and micronizers, anode paste mixers, drilling augers, screw conveyors, pump rotors, iron ore pellet crusher rolls, iron sinter breakers, dredge cutter teeth, press screws, etc.*

A8. Suggested Methods for Preparation of Fused Samples for Analysis

A8.1 The determination of the chemical composition of the as-manufactured solid bare electrodes and rods presents no technical difficulties. The filler metal, in the form of a solid wire, may be subdivided for analysis by any convenient method, and all samples or chips will be representative of the lot of filler metal. Difficulties are encountered in obtaining a representative sample of metal cored and flux cored composite (tubular) electrodes and rods. Some filler metal of the composite type is in the form of a tubular wire, the core of which is filled with a mixture of particles, often unbonded. Samples obtained by merely cutting or subdividing the composite type of filler metal may not prove representative of the filler metal due to the possible loss of some of the core material at the ends of the sample. Therefore, the sheath and core of composite-type welding electrodes and welding rods must be combined before a sample representative of the filler metal can be obtained. To accomplish this, the specification requires the preparation of an essentially homogeneous fused sample of the metal cored electrode or rod and a weld metal pad of the flux cored composite (tubular) electrode or rod. These samples can then be subdivided by routine methods.

A8.2 Preparation of a fused sample by gas tungsten arc welding using argon or helium shielding gas will transfer essentially all of the components of the composite-type welding rods through the arc. Some slight loss in carbon will occur, but such loss will never be greater than would be encountered in an actual welding operation, regardless of process. Nonmetallic ingredients, if present in the core, will form a slag on the top of the deposit which must be removed and discarded. The specification classifies the filler metals only on the basis of metallic chemical composition. Gas tungsten arc welded fused samples should not be prepared using composite tubular electrodes of the self-shielded type as the formation of reactive gases will cause instabilities in the arc.

A8.3 The sample of fused filler metal must be large enough to provide the amount of undiluted material required by the chemist for analysis. No size or shape of deposited pads has been specified because these are immaterial if the deposit is truly undiluted.

A8.4 A sample made using the composite type filler metal which has been fused in a copper mold will be undiluted since there will be essentially no admixture with base metal.

A8.5 A sample made using the composite type filler metal deposited on a steel base plate, Figure 1, will become diluted and contaminated by admixture with the base metal. Such a deposit will have to be multilayered to overcome this dilution. To ensure an undiluted sample, the pad will need to be 1/2 in [13 mm] minimum height for electrode diameters 0.045 in–1/16 in [1.2 mm–1.6 mm], 5/8 in [16 mm] minimum height for electrode diameters 5/64 in–0.120 in [2.0 mm–3.0 mm], and 3/4 in [19 mm] minimum height for larger electrode sizes.

A8.6 Assurance that an undiluted sample is being obtained from the chosen size of pad at the selected distance above the base can be obtained by analyzing chips removed from successively lower layers of the pad. Layers which are undiluted will all have the same chemical composition. Therefore, the determination of identical compositions for two successive layers of deposited filler metal will provide evidence that the last layer is undiluted.

A9. Discontinued Classifications

Some classifications have been discontinued from one revision of this specification to another. This results either from changes in commercial practice or changes in the classification used in the specification. The classifications that have been discontinued are listed in Table A.1, along with the year they were last included in the specification.

Table A.1
Discontinued and Transferred Electrode and Rod Classifications^a

AWS Classification	Last A5.21 Publication Date
RFe5-A	1980
RFe5-B	1980
RFeCr-A1	1980
EFe5-A	1980
EFe5-B	1980
EFe5-C	1980
EFeMn-A ^b	1980
EFeMn-B ^b	1980
EFeCr-A1	1980
RWC-5/8	1980
RWC-8/12	1980
RWC-12/20	1980
RWC-30	1980
EWC-12/30 ^c	1980
EWC-20/30 ^c	1980
EWC-30/40 ^c	1980
EWC-40 ^c	1980
EWC-40/120 ^c	1980

^a See Clause A9, Discontinued Classifications (in Annex A), for information on discontinued classifications.

^b These AWS classifications have been transferred to AWS A5.13 without a change in classification designation.

^c These AWS classifications have been transferred to AWS A5.13 with a change in classification to EWCX-X/X.

A10. General Safety Considerations

A10.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in annex clause A5. Safety and health information is available from other sources, including, but not limited to *Safety and Health Fact Sheets*, ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations.

A10.2 Safety and Health Fact Sheets. Safety and Health Fact Sheets are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

B6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

AWS Filler Metal Specifications by Material and Welding Process

	OFW	SMAW	GTAW GMAW PAW	FCAW	SAW	ESW	EGW	Brazing
Carbon Steel	A5.2	A5.1, A5.35	A5.18	A5.20	A5.17	A5.25	A5.26	A5.8, A5.31
Low-Alloy Steel	A5.2	A5.5	A5.28	A5.29	A5.23	A5.25	A5.26	A5.8, A5.31
Stainless Steel		A5.4, A5.35	A5.9, A5.22	A5.22	A5.9, A5.22, A5.39	A5.9, A5.22, A5.39	A5.9	A5.8, A5.31
Cast Iron	A5.15	A5.15	A5.15	A5.15				A5.8, A5.31
Nickel Alloys		A5.11, A5.35	A5.14, A5.34	A5.34	A5.14, A5.34, A5.39	A5.14, A5.34, A5.39		A5.8, A5.31
Aluminum Alloys		A5.3	A5.10					A5.8, A5.31
Copper Alloys		A5.6	A5.7					A5.8, A5.31
Titanium Alloys			A5.16					A5.8, A5.31
Zirconium Alloys			A5.24					A5.8, A5.31
Magnesium Alloys			A5.19					A5.8, A5.31
Tungsten Electrodes			A5.12					
Brazing Alloys and Fluxes								A5.8, A5.31
Surfacing Alloys	A5.21	A5.13	A5.21	A5.21	A5.21			
Consumable Inserts			A5.30					
Shielding Gases			A5.32	A5.32			A5.32	

AWS Filler Metal Specifications and Related Documents

Designation	Title
A4.2M (ISO 8249 MOD)	<i>Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal</i>
A4.3-ADD1	<i>Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding</i>
A4.4M	<i>Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings</i>
A4.5M/A4.5 (ISO 15792-3 MOD)	<i>Standard Methods for Classification Testing of Positional Capacity and Root Penetration of Welding Consumables in a Fillet Weld</i>
A5.01M/A5.01 (ISO 14344 MOD)	<i>Welding and Brazing Consumables—Procurement of Filler Metals and Fluxes</i>
A5.02/A5.02M	<i>Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes</i>
A5.1/A5.1M	<i>Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding</i>
A5.2/A5.2M	<i>Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding</i>
A5.3/A5.3M	<i>Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.4/A5.4M	<i>Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding</i>
A5.5/A5.5M	<i>Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding</i>
A5.6/A5.6M	<i>Specification for Copper and Copper-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.7/A5.7M	<i>Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes</i>
A5.8M/A5.8	<i>Specification for Filler Metals for Brazing and Braze Welding</i>
A5.9/A5.9M (ISO 14343 MOD)	<i>Specification for Bare Stainless Steel Welding Electrodes and Rods</i>
A5.10/A5.10M (ISO 18273 MOD)	<i>Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods</i>
A5.11/A5.11M	<i>Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding</i>
A5.12M/A5.12 (ISO 6848 MOD)	<i>Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting</i>
A5.13/A5.13M	<i>Specification for Surfacing Electrodes for Shielded Metal Arc Welding</i>
A5.14/A5.14M	<i>Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods</i>
A5.15	<i>Specification for Welding Electrodes and Rods for Cast Iron</i>
A5.16/A5.16M (ISO 24034 MOD)	<i>Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods</i>
A5.17/A5.17M	<i>Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.18/A5.18M	<i>Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.19	<i>Specification for Magnesium-Alloy Welding Electrodes and Rods</i>
A5.20/A5.20M	<i>Specification for Carbon Steel Electrodes for Flux Cored Arc Welding</i>
A5.21/A5.21M	<i>Specification for Bare Electrodes and Rods for Surfacing</i>
A5.22/A5.22M	<i>Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods</i>
A5.23/A5.23M	<i>Specification for Low-Alloy and High Manganese Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.24/A5.24M	<i>Specification for Zirconium and Zirconium-Alloy Welding Electrodes and Rods</i>
A5.25/A5.25M	<i>Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding</i>
A5.26/A5.26M	<i>Specification for Carbon and Low-Alloy Steel Electrodes for Electrode Gas Welding</i>
A5.28/A5.28M	<i>Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.29/A5.29M	<i>Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding</i>
A5.30/A5.30M	<i>Specification for Consumable Inserts</i>
A5.31M/A5.31	<i>Specification for Fluxes for Brazing and Braze Welding</i>
A5.32M/A5.32 (ISO 14175 MOD)	<i>Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes</i>
A5.34/A5.34M	<i>Specification for Nickel-Alloy Flux Cored and Metal Cored Welding Electrodes</i>
A5.35/A5.35M-AMD1	<i>Specification for Covered Electrodes for Underwater Wet Shielded Metal Arc Welding</i>
A5.39/A5.39M	<i>Specification for Stainless Steel and Nickel-Alloy Electrodes and Fluxes for Submerged Arc and Electroslag Welding</i>

SPECIFICATION FOR STAINLESS STEEL FLUX CORED AND METAL CORED WELDING ELECTRODES AND RODS



SFA-5.22/SFA-5.22M



(25)

(Identical with AWS Specification A5.22/A5.22M:2024. In case of dispute, the original AWS text applies.)

Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods

1. Scope

1.1 This specification prescribes requirements for the classification of flux cored stainless steel electrodes for flux cored arc welding, flux cored stainless steel rods for root pass welding with the gas tungsten arc process, and metal cored stainless steel electrodes for gas metal arc welding, gas tungsten arc welding, plasma arc welding, submerged arc welding, and any other process to which they may be applied.

The chromium content of undiluted weld metal from these electrodes and rods is not less than 10.5% nominal and the iron content exceeds that of any other element. For purposes of classification, the iron content shall be derived as the balance element when all other elements are considered to be set at their specified minimum values.

1.2 This specification uses both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to material properties. The specification with the designation A5.22 uses U.S. Customary Units. The specification A5.22M uses SI Units. The latter are shown within brackets ([]) or in appropriate columns in tables. Standard dimensions based on either system may be used for sizing of filler metals or packaging or both under A5.22 or A5.22M specifications.

1.3 Safety and health issues are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in Annex Clauses A5 and A11.

Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets*
- (3) Other safety and health information on the AWS website*

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers*
- (2) Operating Manuals supplied by equipment manufacturers*

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. Unless otherwise defined in this document, welding terms are as defined in AWS A3.0M/A3.0. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to or revisions of any of these publications do not apply.

American Welding Society (AWS) documents:

AWS A4.5M/A4.5 (ISO 15792-3:2011 MOD), *Standard Methods for Classification Testing of Positional Capacity and Root Penetration of Welding Consumables in a Fillet Weld*

AWS A5.01M/A5.01 (ISO 14344 MOD), *Procurement Guidelines for Consumables—Welding and Allied Processes—Flux and Gas Shielded Electrical Welding Processes*

AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*

AWS A5.32M/A5.32 (ISO 14175:2008 MOD), *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes*

AWS B4.0, *Standard Methods for Mechanical Testing of Welds*

American National Standards Institute (ANSI) document:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

ASTM International (ASTM) documents:

ASTM A36/A36M, *Standard Specification for Carbon Structural Steel*

ASTM A240, *Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and General Applications*

ASTM A285, *Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength*

ASTM A515, *Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service*

ASTM E23, *Standard Test Methods for Notched Bar Impact Testing of Metallic Materials*

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specification*

ASTM E353, *Chemical Analysis of Stainless, Heat-Resisting, Maraging and Other Similar Chromium-Nickel-Iron Alloys*

ASTM E1019, *Standard Test Methods for the Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel, Iron, Nickel, and Cobalt Alloys by Various Combustion and Inert Gas Fusion Techniques*

ASTM E1032, *Standard Test Methods for Radiographic Examination of Weldments*

ASTM E2033, *Standard Practice for Computed Radiology (Photostimulable Luminescence Method)*

ASTM E2698, *Standard Practice for Radiological Examination Using Digital Detector Arrays*

International Organization for Standardization (ISO) document:

ISO 80000-1, *Quantities and units*

3. Classification

3.1 The welding electrodes and rods covered by this A5.22/A5.22M specification are classified using a system that is independent of U.S. Customary Units and the International System of Units (SI). *Classification for the flux cored electrodes and rods is according to the chemical composition of the undiluted weld metal, as specified in Table 1FC, the position of welding, and the external shielding gas required (for those classifications for which one is required), as specified in Table 2. Classifications for the metal cored electrodes indicate the chemical composition of the undiluted weld metal only, as specified in Table 1MC.*

3.2 Electrodes and rods classified under one classification *shall not be classified under any other classification in this specification*, except on the basis of carbon content and shielding gas used provided they meet all the requirements of those classifications as specified in Table 1FC or Table 1MC. More than one classification based upon any element other than carbon is not permitted. Table 3 lists a number of examples of possible dual classification.

3.3 *Electrodes and rods may be classified under A5.22 using U.S. Customary Units or under A5.22M using the International System of Units (SI) or they may be classified under both systems. Electrodes and rods classified under either classification system must meet all requirements for classification under that system. The classification system is shown in Figure A.1.*

Table 1FC
Chemical Composition Requirements for Flux Cored Electrodes and Rods for Undiluted Weld Metal

AWS Classification ^c	Weight Percent ^{a,b}												Other Required Elements ^e
	C	Cr	Ni	Mo	Nb Plus Ta	Mn	Si	P	S	N	Cu	Co ^d	
E307TX-X	0.13	18.0–20.5	9.0–10.5	0.5–1.5	—	3.30–4.75	1.0	0.04	0.03	—	0.75	0.50	—
E308TX-X	0.08	18.0–21.0	9.0–11.0	0.75	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E308HTX-X	0.04–0.08	18.0–21.0	9.0–11.0	0.75	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E308LTX-X	0.04	18.0–21.0	9.0–11.0	0.75	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E308MoTX-X	0.08	18.0–21.0	9.0–11.0	2.0–3.0	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E308LMoTX-X	0.04	18.0–21.0	9.0–12.0	2.0–3.0	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E309TX-X	0.10	22.0–25.0	12.0–14.0	0.75	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E309HTX-X	0.04–0.10	22.0–25.0	12.0–14.0	0.75	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E309LTX-X	0.04	22.0–25.0	12.0–14.0	0.75	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E309MoTX-X	0.12	21.0–25.0	12.0–16.0	2.0–3.0	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E309LMoTX-X	0.04	21.0–25.0	12.0–16.0	2.0–3.0	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E309LNiMoTX-X	0.04	20.5–23.5	15.0–17.0	2.5–3.5	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E309LNbTX-X	0.04	22.0–25.0	12.0–14.0	0.75	0.70–1.00	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E310TX-X	0.20	25.0–28.0	20.0–22.5	0.75	—	1.0–2.5	1.0	0.03	0.03	—	0.75	0.50	—
E312TX-X	0.15	28.0–32.0	8.0–10.5	0.75	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E316TX-X	0.08	17.0–20.0	11.0–14.0	2.0–3.0	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E316HTX-X	0.04–0.08	17.0–20.0	11.0–14.0	2.0–3.0	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E316LTX-X	0.04	17.0–20.0	11.0–14.0	2.0–3.0	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E317LTX-X	0.04	18.0–21.0	12.0–14.0	3.0–4.0	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E347TX-X	0.08	18.0–21.0	9.0–11.0	0.75	8 × C min., 0.2 min. –1.0 max.	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E347HTX-X	0.04–0.08	18.0–21.0	9.0–11.0	0.75	8 × C min. –1.0 max.	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E409TX-X	0.10	10.5–13.5	0.60	0.75	—	0.80	1.0	0.04	0.03	—	0.75	0.50	Ti = 10 × C min. –1.5 max.
E409NbTX-X	0.10	10.5–13.5	0.6	0.5	8 × C min. –1.5 max.	1.2	1.0	0.04	0.03	—	0.5	0.50	—

(Continued)

Table 1FC (Continued)
Chemical Composition Requirements for Flux Cored Electrodes and Rods for Undiluted Weld Metal

AWS Classification ^c	Weight Percent ^{a,b}												Other Required Elements ^e
	C	Cr	Ni	Mo	Nb Plus Ta	Mn	Si	P	S	N	Cu	Co ^d	
E410TX-X	0.12	11.0–13.5	0.60	0.75	—	1.2	1.0	0.04	0.03	—	0.75	0.50	—
E410NiMoTX-X	0.06	11.0–12.5	4.0–5.0	0.40–0.70	—	1.0	1.0	0.04	0.03	—	0.75	0.50	—
E430TX-X	0.10	15.0–18.0	0.60	0.75	—	1.2	1.0	0.04	0.03	—	0.75	0.50	—
E430NbTX-X	0.10	15.0–18.0	0.6	0.5	0.5–1.5	1.2	1.0	0.04	0.03	—	0.5	0.50	—
E2209TX-X	0.04	21.0–24.0	7.5–10.0	2.5–4.0	—	0.5–2.0	1.0	0.04	0.03	0.08–0.20	0.75	0.50	—
E2307TX-X	0.04	22.5–25.5	6.5–10.0	0.8	—	2.0	1.0	0.03	0.02	0.10–0.20	0.50	0.50	—
E2553TX-X	0.04	24.0–27.0	8.5–10.5	2.9–3.9	—	0.5–1.5	0.75	0.04	0.03	0.10–0.25	1.5–2.5	0.50	—
E2594TX-X	0.04	24.0–27.0	8.0–10.5	2.5–4.5	—	0.5–2.5	1.0	0.04	0.03	0.20–0.30	1.5	0.50	W=1.0
EGTX-X ^g	Not Specified												
E307T0-3	0.13	19.5–22.0	9.0–10.5	0.5–1.5	—	3.30–4.75	1.0	0.04	0.03	—	0.75	0.50	—
E308T0-3	0.08	19.5–22.0	9.0–11.0	0.75	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E308HT0-3	0.04–0.08	19.5–22.0	9.0–11.0	0.75	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E308LT0-3	0.04	19.5–22.0	9.0–11.0	0.75	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E308MoT0-3	0.08	18.0–21.0	9.0–11.0	2.0–3.0	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E308HMoT0-3	0.07–0.12	19.0–21.5	9.0–10.7	1.8–2.4	—	1.25–2.25	0.25–0.80	0.04	0.03	—	0.75	0.50	—
E308LMoT0-3	0.04	18.0–21.0	9.0–12.0	2.0–3.0	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E309T0-3	0.10	23.0–25.5	12.0–14.0	0.75	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E309LT0-3	0.04	23.0–25.5	12.0–14.0	0.75	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E309MoT0-3	0.12	21.0–25.0	12.0–16.0	2.0–3.0	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E309LMoT0-3	0.04	21.0–25.0	12.0–16.0	2.0–3.0	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E309LNbT0-3	0.04	23.0–25.5	12.0–14.0	0.75	0.70–1.00	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E310T0-3	0.20	25.0–28.0	20.0–22.5	0.75	—	1.0–2.5	1.0	0.03	0.03	—	0.75	0.50	—
E312T0-3	0.15	28.0–32.0	8.0–10.5	0.75	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E316T0-3	0.08	18.0–20.5	11.0–14.0	2.0–3.0	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E316LT0-3	0.04	18.0–20.5	11.0–14.0	2.0–3.0	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E316LKT0-3 ^f	0.04	17.0–20.0	11.0–14.0	2.0–3.0	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—

(Continued)

Table 1FC (Continued)
Chemical Composition Requirements for Flux Cored Electrodes and Rods for Undiluted Weld Metal

AWS Classification ^c	Weight Percent ^{a,b}												Other Required Elements ^e
	C	Cr	Ni	Mo	Nb Plus Ta	Mn	Si	P	S	N	Cu	Co ^d	
E317LT0-3	0.04	18.5–21.0	13.0–15.0	3.0–4.0	—	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E347T0-3	0.08	19.0–21.5	9.0–11.0	0.75	8 × C min., 0.2 min. –1.0 Max.	0.5–2.5	1.0	0.04	0.03	—	0.75	0.50	—
E409T0-3	0.10	10.5–13.5	0.60	0.75	—	0.80	1.0	0.04	0.03	—	0.75	0.50	Ti = 10 × C min. –1.5 max.
E410T0-3	0.12	11.0–13.5	0.60	0.75	—	1.0	1.0	0.04	0.03	—	0.75	0.50	—
E410NiMoT0-3	0.06	11.0–12.5	4.0–5.0	0.40–0.70	—	1.0	1.0	0.04	0.03	—	0.75	0.50	—
E430T0-3	0.10	15.0–18.0	0.60	0.75	—	1.0	1.0	0.04	0.03	—	0.75	0.50	—
E2209T0-3	0.04	21.0–24.0	7.5–10.0	2.5–4.0	—	0.5–2.0	1.0	0.04	0.03	0.08–0.20	0.75	0.50	—
E2307T0-3	0.04	22.5–25.5	6.5–10.0	0.8	—	2.0	1.0	0.03	0.02	0.10–0.20	0.50	0.50	—
E2553T0-3	0.04	24.0–27.0	8.5–10.5	2.9–3.9	—	0.5–1.5	0.75	0.04	0.03	0.10–0.25	1.5–2.5	0.50	—
E2594T0-3	0.04	24.0–27.0	8.0–10.5	2.5–4.5	—	0.5–2.5	1.0	0.04	0.03	0.20–0.30	1.5	0.50	W = 1.0
EGTX-3 ^g	Not Specified												
R308LT1-5	0.03	18.0–21.0	9.0–11.0	0.75	—	0.5–2.5	1.2	0.04	0.03	—	0.75	0.50	—
R309LT1-5	0.03	22.0–25.0	12.0–14.0	0.75	—	0.5–2.5	1.2	0.04	0.03	—	0.75	0.50	—
R316LT1-5	0.03	17.0–20.0	11.0–14.0	2.0–3.0	—	0.5–2.5	1.2	0.04	0.03	—	0.75	0.50	—
R347T1-5	0.08	18.0–21.0	9.0–11.0	0.75	8 × C min., 0.2 min. –1.0 max.	0.5–2.5	1.2	0.04	0.03	—	0.75	0.50	—
RGT1-5 ^g	Not Specified												

^a The weld metal shall be analyzed for the specific elements in this table. If the presence of *unspecified* elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total (excluding iron) does not exceed 0.50%.

^b Single values shown are maximum.

^c In this table, the “X” following the “T” refers to the position of welding (1 for all-position operation or 0 for flat or horizontal operation) and the “X” following the dash refers to the shielding medium (–1 or –4) as shown in the AWS Classification column in Table 2).

^d For certain specialized applications, including but not limited to medical and nuclear power applications, a significantly lower Co limit than 0.50% may be necessary. A lower limit should be specified in the purchase order following the guidance in AWS A5.01M/A5.01.

^e Analysis for Bi is required to be reported if intentionally added, or if it is known to be present at levels greater than 0.002%. See A8.1.4 for more information.

^f This alloy is designed for cryogenic applications.

^g See A2.2.7 and A2.2.8.

Note:

1. Cb has been changed to Nb.

Table 1MC
Chemical Composition Requirements for Metal Cored Electrodes for Undiluted Weld Metal

AWS Classification	Weight Percent ^{a,b}												Other Required Elements ^c
	C	Cr	Ni	Mo	Nb Plus Ta	Mn	Si ^c	P	S	N	Cu	Co ^d	
EC209	0.05	20.5–24.0	9.5–12.0	1.5–3.0	—	4.0–7.0	0.90	0.03	0.03	0.10–0.30	0.75	0.50	V = 0.10–0.30
EC218	0.10	16.0–18.0	8.0–9.0	0.75	—	7.0–9.0	3.5–4.5	0.03	0.03	0.08–0.18	0.75	0.50	—
EC219	0.05	19.0–21.5	5.5–7.0	0.75	—	8.0–10.0	1.00	0.03	0.03	0.10–0.30	0.75	0.50	—
EC240	0.05	17.0–19.0	4.0–6.0	0.75	—	10.5–13.5	1.00	0.03	0.03	0.10–0.30	0.75	0.50	—
EC307	0.04–0.14	19.5–22.0	8.0–10.7	0.5–1.5	—	3.30–4.75	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC308	0.08	19.5–22.0	9.0–11.0	0.75	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC308Si	0.08	19.5–22.0	9.0–11.0	0.75	—	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	0.50	—
EC308H	0.04–0.08	19.5–22.0	9.0–11.0	0.50	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC308L	0.03	19.5–22.0	9.0–11.0	0.75	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC308LSi	0.03	19.5–22.0	9.0–11.0	0.75	—	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	0.50	—
EC308Mo	0.08	18.0–21.0	9.0–12.0	2.0–3.0	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC308LMo	0.04	18.0–21.0	9.0–12.0	2.0–3.0	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC309	0.12	23.0–25.0	12.0–14.0	0.75	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC309Si	0.12	23.0–25.0	12.0–14.0	0.75	—	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	0.50	—
EC309L	0.03	23.0–25.0	12.0–14.0	0.75	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC309LSi	0.03	23.0–25.0	12.0–14.0	0.75	—	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	0.50	—
EC309Mo	0.12	23.0–25.0	12.0–14.0	2.0–3.0	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC309LMo	0.03	23.0–25.0	12.0–14.0	2.0–3.0	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC310	0.08–0.15	25.0–28.0	20.0–22.5	0.75	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC312	0.15	28.0–32.0	8.0–10.5	0.75	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC316	0.08	18.0–20.0	11.0–14.0	2.0–3.0	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC316Si	0.08	18.0–20.0	11.0–14.0	2.0–3.0	—	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	0.50	—
EC316H	0.04–0.08	18.0–20.0	11.0–14.0	2.0–3.0	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC316L	0.03	18.0–20.0	11.0–14.0	2.0–3.0	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC316LSi	0.03	18.0–20.0	11.0–14.0	2.0–3.0	—	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	0.50	—

(Continued)

Table 1MC (Continued)
Chemical Composition Requirements for Metal Cored Electrodes for Undiluted Weld Metal

AWS Classification	Weight Percent ^{a,b}												Other Required Elements ^e
	C	Cr	Ni	Mo	Nb Plus Ta	Mn	Si ^c	P	S	N	Cu	Co ^d	
EC316LMn	0.03	19.0–22.0	15.0–18.0	2.5–3.5	—	5.0–9.0	0.30–0.65	0.03	0.03	0.10–0.20	0.75	0.50	—
EC317	0.08	18.5–20.5	13.0–15.0	3.0–4.0	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC317L	0.03	18.5–20.5	13.0–15.0	3.0–4.0	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC318	0.08	18.0–20.0	11.0–14.0	2.0–3.0	8 × C min., 0.2 min. –1.0 max.	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC320	0.07	19.0–21.0	32.0–36.0	2.0–3.0	8 × C min. –1.0 max.	2.5	0.60	0.03	0.03	—	3.0–4.0	0.50	—
EC320LR	0.025	19.0–21.0	32.0–36.0	2.0–3.0	8 × C min. –1.0 max.	1.5–2.0	0.15	0.015	0.02	—	3.0–4.0	0.50	—
EC321	0.08	18.5–20.5	9.0–10.5	0.75	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	Ti = 9 × C min. –1.0 max.
EC330	0.18–0.25	15.0–17.0	34.0–37.0	0.75	—	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC347	0.08	19.0–21.5	9.0–11.0	0.75	10 × C min., 0.2 min. –1.0 max.	1.0–2.5	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC347Si	0.08	19.0–21.5	9.0–11.0	0.75	10 × C min., 0.2 min. –1.0 max.	1.0–2.5	0.65–1.00	0.03	0.03	—	0.75	0.50	—
EC383	0.025	26.5–28.5	30.0–33.0	3.2–4.2	—	1.0–2.5	0.50	0.02	0.03	—	0.70–1.50	0.50	—
EC385	0.025	19.5–21.5	24.0–26.0	4.2–5.2	—	1.0–2.5	0.50	0.02	0.03	—	1.2–2.0	0.50	—
EC409	0.08	10.5–13.5	0.6	0.50	—	0.8	0.8	0.03	0.03	—	0.75	0.50	Ti = 10 × C min. –1.5 max.
EC409Nb	0.08	10.5–13.5	0.6	0.50	10 × C min., 0.75 max.	0.8	1.0	0.04	0.03	—	0.75	0.50	—
EC410	0.12	11.5–13.5	0.6	0.75	—	0.6	0.5	0.03	0.03	—	0.75	0.50	—
EC410NiMo	0.06	11.0–12.5	4.0–5.0	0.4–0.7	—	0.6	0.5	0.03	0.03	—	0.75	0.50	—
EC420	0.25–0.40	12.0–14.0	0.6	0.75	—	0.6	0.5	0.03	0.03	—	0.75	0.50	—
EC430	0.10	15.5–17.0	0.6	0.75	—	0.6	0.5	0.03	0.03	—	0.75	0.50	—

(Continued)

Table 1MC (Continued)
Chemical Composition Requirements for Metal Cored Electrodes for Undiluted Weld Metal

AWS Classification	Weight Percent ^{a,b}												Other Required Elements ^e
	C	Cr	Ni	Mo	Nb Plus Ta	Mn	Si ^c	P	S	N	Cu	Co ^d	
EC439	0.04	17.0–19.0	0.6	0.5	—	0.8	0.8	0.03	0.03	—	0.75	0.50	Ti = 10 × C min. –1.1 max.
EC439Nb	0.04	17.0–20.0	0.6	0.5	8 × C min. –0.75 max.	0.8	0.8	0.03	0.03	—	0.75	0.50	Ti = 0.10–0.75
EC446LMo	0.015	25.0–27.5	f	0.75–1.50	—	0.4	0.4	0.02	0.02	0.015	f	0.50	—
EC630	0.05	16.00–16.75	4.5–5.0	0.75	0.15–0.30	0.25–0.75	0.75	0.03	0.03	—	3.25–4.00	0.50	—
EC19–10H	0.04–0.08	18.5–20.0	9.0–11.0	0.25	0.05	1.0–2.0	0.30–0.65	0.03	0.03	—	0.75	0.50	Ti = 0.05
EC16-8-2	0.10	14.5–16.5	7.5–9.5	1.0–2.0	—	1.0–2.0	0.30–0.65	0.03	0.03	—	0.75	0.50	—
EC2209	0.03	21.5–23.5	7.5–9.5	2.5–3.5	—	0.50–2.00	0.90	0.03	0.03	0.08–0.20	0.75	0.50	—
EC2553	0.04	24.0–27.0	4.5–6.5	2.9–3.9	—	1.5	1.0	0.04	0.03	0.10–0.25	1.5–2.5	0.50	—
EC2594	0.03	24.0–27.0	8.0–10.5	2.5–4.5	—	2.5	1.0	0.03	0.02	0.20–0.30	1.5	0.50	W = 1.0
EC33-31	0.015	31.0–35.0	30.0–33.0	0.5–2.0	—	2.00	0.50	0.02	0.01	0.35–0.60	0.3–1.2	0.50	—
EC3556	0.05–0.15	21.0–23.0	19.0–22.5	2.5–4.0	—	0.50–2.00	0.20–0.80	0.04	0.015	0.10–0.30	—	16.0–21.0	W = 2.0–3.5 Nb = 0.30 Ta = 0.30–1.25 Al = 0.10–0.50 Zr = 0.001–0.100 La = 0.005–0.100 B = 0.02
ECG ^g	Not Specified												

^a Analysis shall be made for the elements for which specific values are shown in this table. If the presence of *unspecified* elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total, excluding iron, does not exceed 0.50%.

^b Single values shown are maximum percentages.

^c For special applications, electrodes may be purchased with less than the specified silicon content.

^d For certain specialized applications, including but not limited to medical and nuclear power applications, a significantly lower Co limit than 0.50% may be necessary. A lower limit should be specified in the purchase order following the guidance in AWS A5.01M/A5.01.

^e Analysis for Bi is required to be reported if intentionally added, or if it is known to be present at levels greater than 0.002%. See A8.1.4 for more information.

^f Total of Ni + Cu is 0.5 wt % maximum.

^g See A2.2.7 and A2.2.8.

Table 2
Required Shielding Medium, Polarity, and Welding Process

AWS Classification ^a	External Shielding Gas ^b	Welding Polarity	Welding Process
EXXXTX-1 EXXXTX-3 EXXXTX-4 RXXXT1-5	CO ₂ ^d none (self-shielded) 75%–80% Argon/remainder CO ₂ ^e 100% Argon ^f	DCEP DCEP DCEP DCEN	FCAW FCAW FCAW GTAW
EXXXTX-G RXXXT1-G	Not Specified ^c Not Specified ^c	Not Specified ^c Not Specified ^c	FCAW GTAW
ECXXX	Argon with up to 2% O ₂ ^g 100% Argon ^f	DCEP DCEN	GMAW GTAW

^a The letters “XXX” stand for the designation of the chemical composition (see Table 1). The “X” after the “T” designates the position of operation. A “0” indicates flat or horizontal operation; a “1” indicates all position operation. Refer to Figure A.1 and Clause A2 for a complete description of this classification system.

^b The requirement for the use of a specified external shielding gas shall not be construed to restrict the use of any other medium for which the electrodes are found suitable, for any application other than the classification tests.

^c See A2.2.7 to A2.2.9 for additional information.

^d AWS A5.32/A5.32M Class C1.

^e AWS A5.32/A5.32M Class M21.

^f AWS A5.32/A5.32M Class I1.

^g AWS A5.32/A5.32M Class I1 or M13.

Table 3
Examples of Potentially Occurring Dual Classified Electrodes

Primary Classification	Alternate Classification
E308HT1-1	E308T1-1
E308LT0-1	E308T0-1
E308LT0-3	E308T0-3
E308LT1-1	E308LT1-4
EC308L	EC308

3.4 The flux cored electrodes and rods classified under this specification are intended for flux cored arc welding and for root pass welding with the gas tungsten arc process, but this is not to prohibit their use with any other process for which they are found suitable. The metal cored electrodes and rods classified under this specification are intended for gas metal arc welding, gas tungsten arc welding, plasma arc welding, and submerged arc welding, but this does not prohibit their use with any other process for which they are found suitable.

4. Acceptance

Acceptance of the material shall be in accordance with the provisions of AWS A5.01M/A5.01 and the tests and requirements of this specification. See A3 (in Annex A) for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

5. Certification

By affixing the AWS specification and classification designations to the packaging or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification. See A4 (in Annex A) for further information concerning certification and the testing called for to meet this requirement.

6. Rounding Procedure

For the purpose of determining conformance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest 1 000 psi (1 ksi) for tensile strength for U.S. Customary Unit standard [to the nearest 10 MPa for tensile strength for S.I. Unit standard] and to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfill the requirements for the classification under test.

7. Summary of Tests

7.1 The tests required for each classification are specified in Table 4. The purpose of these tests is to determine the chemical composition, the mechanical properties, the usability, and the soundness of the weld metal. The base metal for the weld test assemblies, the welding and testing procedures to be employed and the results required are given in Clauses 9 through 15.

7.2 Chemical analysis is required for each size of electrode and rod. The tests for mechanical properties and soundness are conducted on weld metal from the 1/16 in [1.6 mm] size of electrode and rod. In any case in which that size is not manufactured, the size closest to it that is manufactured shall be used for the classification tests. The bend tests are conducted on the largest size manufactured. When required by Table 4, the fillet weld tests shall be conducted on the largest size and smallest size manufactured.

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Specimens for retest may be taken from the original test assembly or a new test assembly. For chemical analysis, *if the retest specimens are taken from the original test assembly, retest need be only for those specific elements that failed to meet the test requirement.* If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

**Table 4
Required Tests**

Classification ^a	Chemical Analysis	Radiographic Test	Tension Test	Face Bend Test	Root Bend Test	Impact Test	Fillet Weld Test
E2XXXT0-X	Required	Required	Required	NR ^b	NR ^b	NR ^b	NR ^b
E3XXXT0-X	Required	Required	Required	Required	NR ^b	NR ^{b,c}	NR ^b
E316LKT0-3	Required	Required	Required	Required	NR ^b	Required	NR ^b
E4XXXT0-X	Required	Required	Required	NR ^b	NR ^b	NR ^b	NR ^b
E2XXXT1-X	Required	Required	Required	NR ^b	NR ^b	NR ^b	Required
E3XXXT1-X	Required	Required	Required	Required	NR ^b	NR ^{b,c}	Required
E4XXXT1-X	Required	Required	Required	NR ^b	NR ^b	NR ^b	Required
R3XXXT1-5	Required	Required	Required	NR ^b	Required	NR ^b	NR ^b
ECXXX	Required	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
EGTX-X, RGT1-5, and ECG	<i>d</i>	<i>d</i>	<i>d</i>	<i>d</i>	<i>d</i>	<i>d</i>	<i>d</i>

^a In the table, the “X” at the end of the “EXXXT0-X” classifications refers to the shielding medium (-1, -3, -4, or -G) the “X” at the end of the “EXXXT1-X” classifications refers to the shielding medium (-1, -4, or -G).

^b NR = not required (see A2.2.8).

^c Impact testing is required when the optional supplemental designator “J” is added to the classification. See Figure A.1.

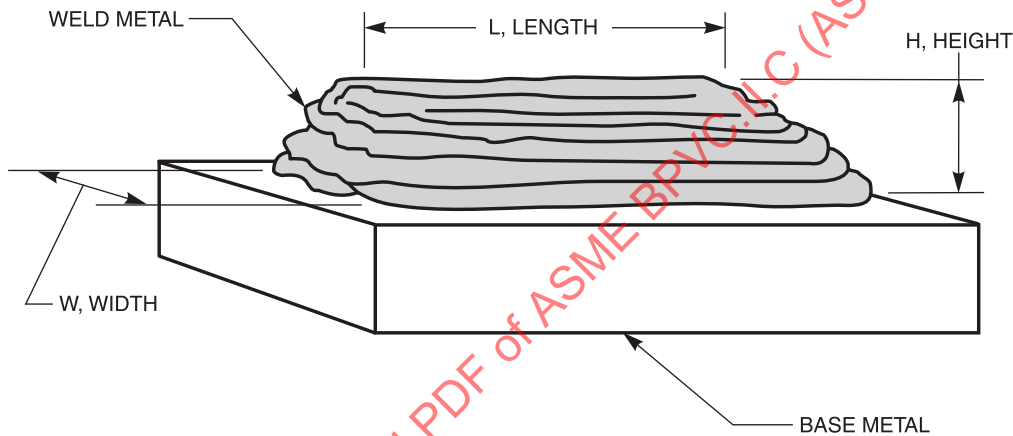
^d The G classification requirements are by agreement between the supplier and purchaser.

If it is clearly determined that the specified or proper procedures were not followed in the preparation or testing of the weld test assembly or test specimen(s), the test shall be considered invalid, without regard to whether the test was completed or whether the test results met or failed to meet the requirement. That test shall be repeated, following proper specified procedures. In this case, the requirement for doubling the number of test specimens does not apply.

9. Weld Test Assemblies

9.1 Between one and four test assemblies are required (according to the classification under test) for the tests specified in Table 4. They are:

- (1) The weld pad in Figure 1 for chemical analysis of undiluted weld metal, or a fused sample of a metal cored electrode.
- (2) The groove weld in Figure 2 for tension, impact, and radiographic testing of the weld metal.
- (3) The groove weld in Figure 3A for the face bend test, or Figure 3B for the root bend test.
- (4) The fillet weld in Figure 4 for usability of the electrode.



AWS Classification	Weld Pad Size, Minimum								Minimum Distance of Sample from Surface of Base Plate	
	Diameter		L	W		H				
	in	mm	in	mm	in	mm	in	mm	in	mm
E3XXTX-X	0.035	0.9								
E316LKT0-3	0.045	1.2	3	75	3/4	19	1/2	13	3/8	10
E4XXTX-X	0.052	1.4								
E2XXXTX-X	1/16	1.6	3	75	3/4	19	5/8	16	1/2	13
ECXXX ^a	5/64	2.0								
EGTX-X and ECG	3/32	2.4	3-1/2	88	1	25	3/4	19	5/8	16
	7/64	2.8								
R3XXT1-5	5/64	2.0								
RGT1-5	0.087	2.2	3	75	3/4	19	3/8	10	1/4	7
	3/32	2.4								

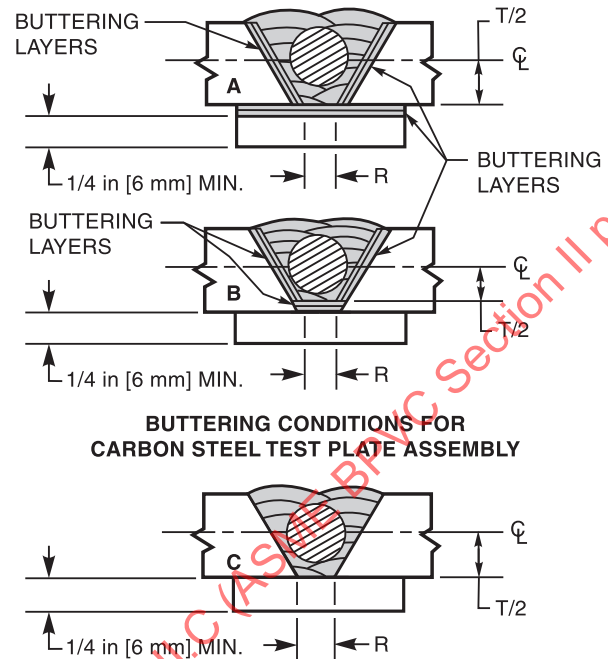
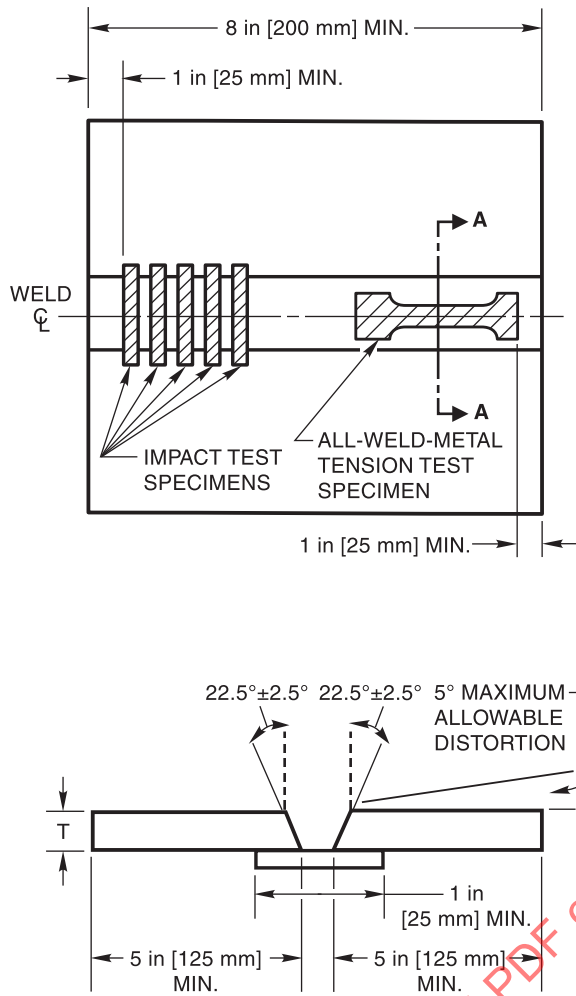
^a Refer to 10.2 for alternative to the pad for chemical analysis.

Notes:

1. Number of passes per layer is optional.
2. Width and thickness of the base plate may be any dimension suitable for the electrode diameter and current in use.
3. The first and last inch (25 mm) of the weld length shall be disregarded. The top surface shall be removed and chemical analysis samples shall be taken from the underlying metal of the top layer of the remaining deposited metal.
4. The use of copper chill bars is optional.

Source: Adapted from AWS A5.22-95 (R2005).

Figure 1—Pad for Chemical Analysis of Undiluted Weld Metal



**BUTTERING CONDITIONS FOR
CARBON STEEL TEST PLATE ASSEMBLY**

**MATCHING COMPOSITION FOR
STAINLESS STEEL TEST PLATE ASSEMBLY**

**BUTTERING CONDITIONS AND
TENSION SPECIMEN LOCATION**

SECTION A-A

DIAGRAM A AND DIAGRAM B FOR CARBON STEEL TEST PLATES. DIAGRAM C FOR TEST PLATES OF MATCHING COMPOSITION OF TYPE 410, 430A, OR 430B FOR THE E4XXTX-X CLASSIFICATIONS ONLY AND TYPES 304 OR 304L FOR THE REMAINDER.

AWS Classification	Diameter		(T) Plate Thickness		(R) Root Openings		Recommended Passes per Layer		Recommended Number of Layers
	in	mm	in	mm	in	mm	Layer 1 and 2	Layer 3 to Top	
	0.035	0.9	1/2	12	3/8	10	1 or 2	2, 3, or 4	6 to 9
E3XXTX-X	0.045	1.2							
E316LKT0-3	0.052	1.4							
E4XXTX-X	1/16	1.6	3/4	20	3/8	10	1 or 2	2 or 3 ^a	5 to 8
E2XXTX-X	5/64	2.0							
EGTX-X and ECG	3/32	2.4							
	7/64	2.8							
	1/8	3.2	3/4	20	3/8	10	1 or 2	2 or 3 ^a	4 to 6
	5/32	4.0							
R3XXT1-5	5/64	2.0							
RG7T1-5	0.087	2.2	1/2	12	1/4	6	1 or 2	2 or 3 ^a	5 to 8
	3/32	2.4							

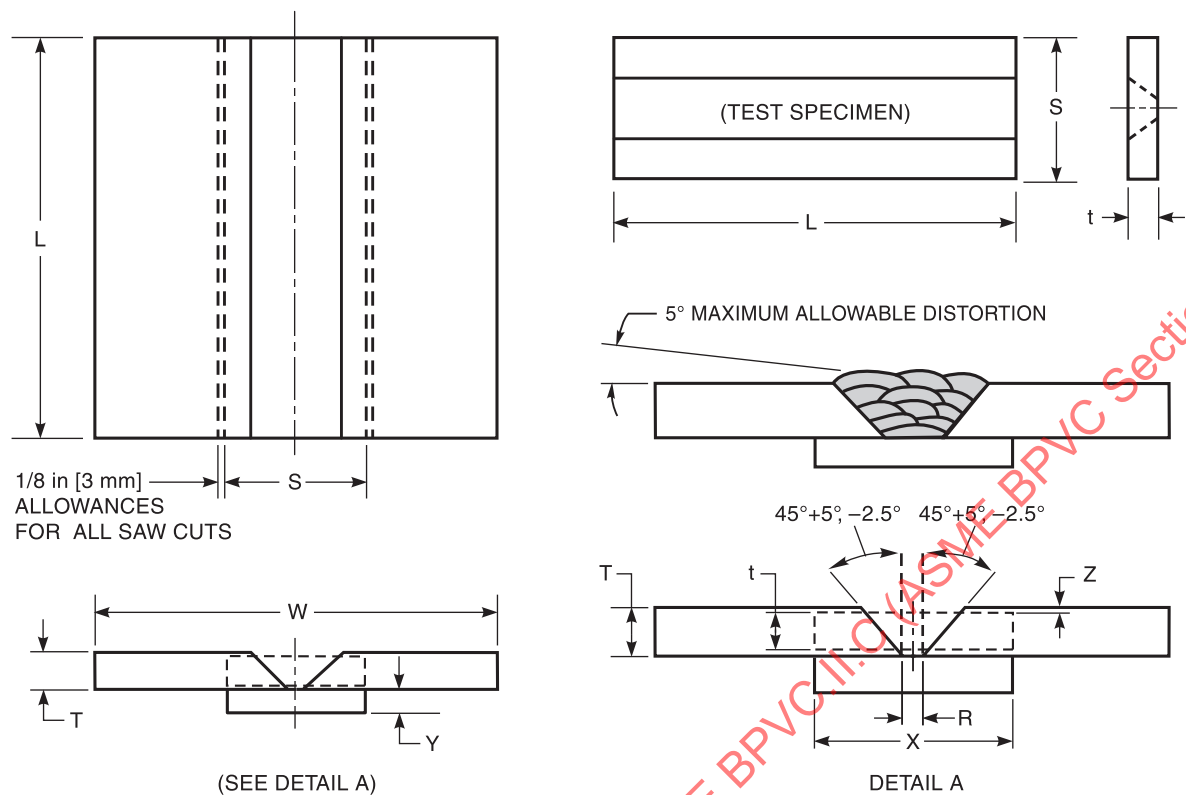
^aFinal layer may be 4 passes.

Notes:

1. The tensile test specimen shall be located such that its centerline to be T/2 above any buttering, if used, otherwise on the centerline of the plate. Its dimensions shall be as specified in 12.1, and AWS B4.0.
2. For test assemblies requiring impact testing, the length shall be extended as needed for Charpy V-notch impact specimens, which shall be located as shown in Figure 6.

Source: Modified adoption of Figure 2 from AWS A5.1/A5.1M:2004, and Figure 2 from AWS A5.4/A5.4M:2006.

Figure 2—Groove Weld Test Assembly for Tension, Impact, and Radiographic Tests



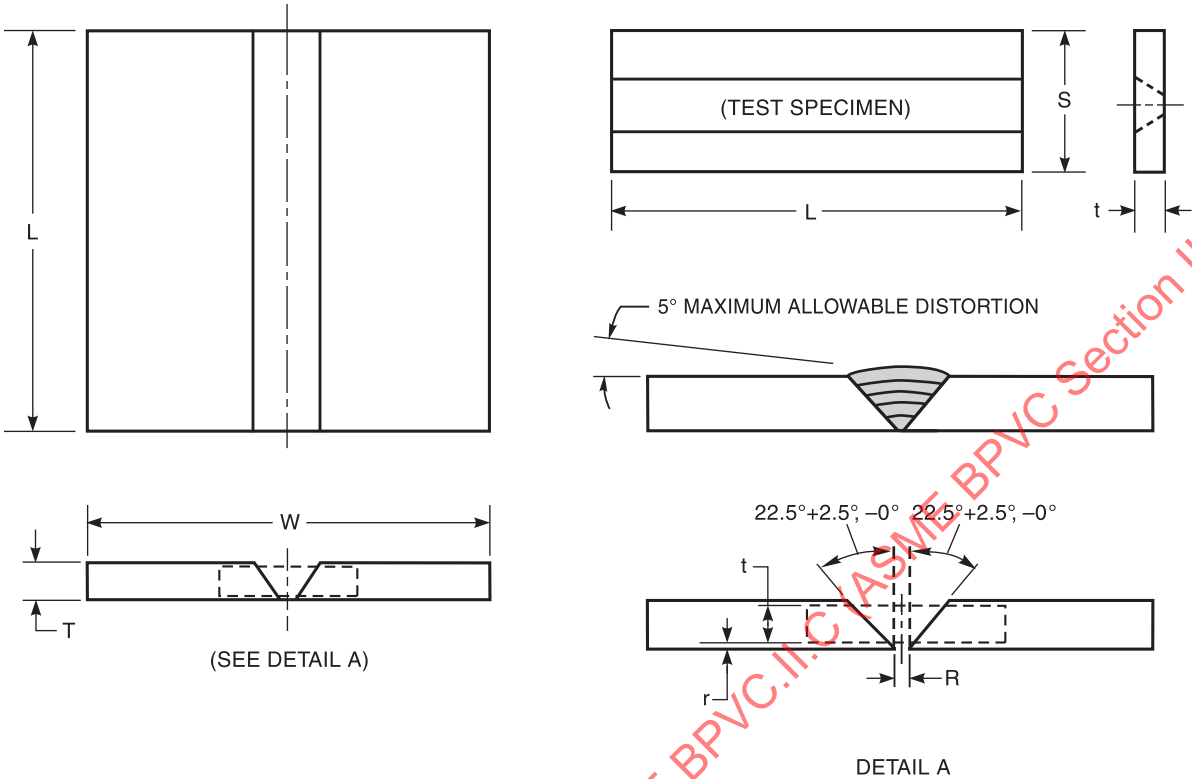
DIMENSIONS			
		in	mm
L	Length	6 min.	150 min.
R	Root opening	1/4 min.	6 min.
S	Specimen Width	2 ± 1/8	50 ± 3
T	Thickness	1/2	12
t	Specimen Thickness	3/8 min.	10 min.
W	Width	6 min.	150 min.
X	Backing Bar Width	2 max.	50 max.
Y	Backing Bar Thickness	1/4 min.	6 min.
Z	Specimen Location	1/16 min.	1.5 min.

Electrode Diameter		Recommended Passes Per Layer		Recommended Number of Layers
in	mm	Layer 1	Layers 2 to Top ^a	
0.035	0.9			
0.045	1.2			
0.052	1.4			
1/16	1.6	1	2 to 3	3 to 5
5/64	2.0			
3/32	2.4			
7/64	2.8			
1/8	3.2	1	1 to 2	2 to 4
5/32	4.0			

^a Top layer must be 2 passes minimum.

Source: Modified adoption of Figure 3 from AWS A5.34/A5.34M:2007.

Figure 3A—Groove Weld Test Assembly for Face Bend Test



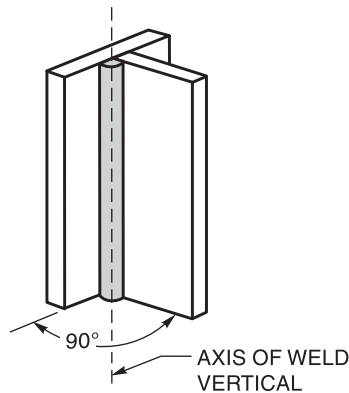
Note: Remove amount of material necessary to clean up root surface. Material removed should not exceed 1/64 in [0.4 mm].

DIMENSIONS					
		in	mm		
L	Length	6 min.	150 min.		
S	Specimen Width	2 ± 1/8	50 ± 3		
R	Root Opening	3/32 to 1/8	2.4 to 3.2		
r	Root Land	1/32 to 1/16	0.8 to 1.6		
T	Thickness	1/2	12		
t	Specimen Thickness	3/8 min.	10 min.		
W	Width	6 min.	150 min.		

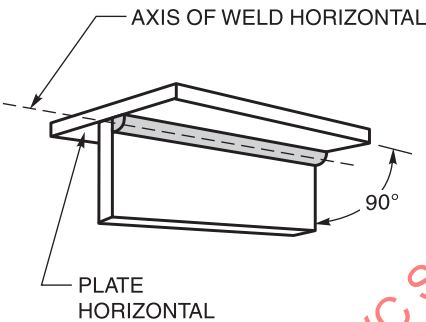
AWS Classification	Diameter		Passes per Layer		
	in	mm	Layer 1	Layer 2	Layer 3 to Completion
R3XXT1-5	5/64	2.0	1	1	As required
	0.087	2.2			
	3/32	2.4			

Source: Modified adoption of Figure 3 from AWS A5.34/A5.34M:2007.

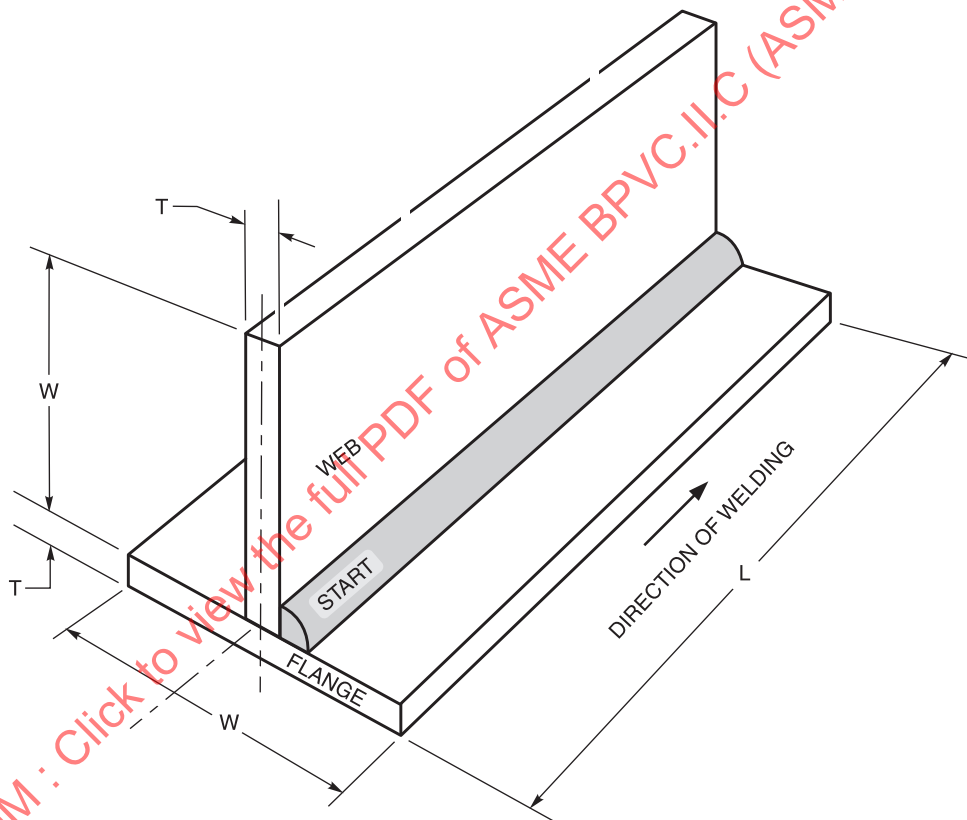
Figure 3B—Groove Weld Test Assembly for Root Bend Test



VERTICAL WELDING TEST POSITION – 3F



OVERHEAD WELDING TEST POSITION – 4F



DIMENSION		in	mm
L	Length	8 min.	200 min.
T	Thickness	3/8 max.	10 max.
W	Width	2 min.	50 min.

Flange to be straight and in intimate contact with square machined edge of web member along entire length to insure maximum restraint.

Source: Modified adoption of Figure 4 from AWS A5.34/A5.34M:2007.

Figure 4—Preparation of Fillet Weld Test Specimen

The sample for chemical analysis may be taken from the reduced section of the fractured tension test specimen or from a corresponding location (or any location above it) *along the centerline of the weld metal in the groove weld* in Figure 2, thereby avoiding the need to make the weld pad. In case of dispute, the weld pad shall be the referee method.

9.2 Preparation of each weld test assembly shall be as specified in 9.3, 9.4, and 9.5. The base metal for each assembly shall conform to the following or an equivalent:

9.2.1 For the chemical analysis pad, the base metal to be used shall be carbon steel, low-alloy steel, or stainless steel of 0.25% carbon maximum for all classifications of electrodes and rods except for classifications with up to 0.04% carbon maximum. For chemical analysis of these low carbon classifications, the base metal shall be steel of 0.03% carbon maximum. Other steels having a carbon content of 0.25% maximum may be used with the further restrictions in 9.3.2 and 10.1.2.

9.2.2 For all-weld-metal tension and radiographic tests, the steel to be used shall be of a matching type or either of the following:

- (1) For E4XXTX-X and E4XXT0-3 classifications—ASTM A240, Types 410, 430A, or 430B
- (2) For all other classifications—ASTM A240, Types 304 or 304L

Optionally, the steel may conform to one of the following specifications or their equivalents, provided two buttering layers of the filler metal, as shown in Figure 2, are deposited in stringer beads using electrodes of the same classification, or an equivalent classification of AWS A5.4/A5.4M, as that being classified:

ASTM A36, ASTM A285, or ASTM A515

9.2.3 For the bend test, if required, and for the fillet weld test, if required, the steel to be used shall be of a matching type or either of the following:

- (1) For E4XXTX-X classifications—ASTM A240, Types 410, 430A, or 430B
- (2) For all other electrode/rod classifications—ASTM A240, Types 304 or 304L

9.3 Weld Pad

9.3.1 A weld pad shall be prepared as specified in Figure 1 (except when one of the alternatives to a weld pad in 9.1 or one of the methods given in 10.2 is selected). Base metal of any convenient size, of the type specified in 9.2 shall be used as the base for the weld pad. The surface of the base metal on which the filler metal is deposited shall be clean. The pad shall be welded in the flat position with multiple beads and multiple layers to obtain undiluted weld metal. The preheat temperature shall be not less than 60 °F [15 °C]. The slag shall be removed after each pass. The amperage or wire feed speed and the arc voltage shall be as recommended by the manufacturer. The shielding medium and polarity shall be as specified in Table 2. The pad may be quenched in water between passes *but must be dry before the start of the next pass* (if the pad is to be used for ferrite determination, see A6.9). The dimensions of the completed pad shall be as shown in Figure 1, for each size of electrode or rod. Testing of this assembly shall be as specified in Clause 10.

9.3.2 The pad shall be at least four layers high. At least nine layers shall be required to obtain undiluted weld metal when base metal containing more than 0.03% carbon is used with the low carbon classifications.

9.4 Groove Weld

9.4.1 For Mechanical Properties and Soundness

9.4.1.1 As required by Table 4, a test assembly shall be prepared and welded as specified in Figure 2 and in 9.4.1.2 and 9.4.1.3 using base metal of the appropriate type specified in 9.2.

9.4.1.2 The test assembly shall be welded in the flat position using the process, shielding medium, and polarity shown in Table 2, and the amperage or wire feed speed and arc voltage recommended by the manufacturer. The test assembly shall be preset or sufficiently restrained during welding to prevent warpage in excess of 5°. A welded test assembly that has warped more than 5° shall be discarded. Welded test assemblies shall not be straightened.

9.4.1.3 The preheat and interpass temperatures shall be as specified in Table 5. These temperatures are measured mid-length of the assembly at a distance of 1 in [25 mm] from the centerline of the weld. These temperatures are also required for all buttering passes. After each pass, the assembly shall be allowed to cool in air (not quenched in water) to a temperature within the range specified in Table 5.

Table 5
Preheat and Interpass Temperature Requirements for Groove Weld Test Assemblies

AWS Classification ^a	Temperature			
	Minimum		Maximum	
	°F	°C	°F	°C
E2XXTX-X	60	15	300	150
E3XXTX-X	60	15	300	150
R3XXT1-5	60	15	300	150
E4XXTX-X ^b	300	150	500	260
EXXTX-G ^c	Not Specified			

^a In this table, the “X” following the “T” refers to the position of welding (1 for all-position or 0 for flat or horizontal operation) and the “X” following the dash refers to the shielding medium (-1, -3, or -4) as shown in the AWS Classification.

^b Except for E410TX-X, which shall be 400 °F [205 °C] minimum preheat and 600 °F [315 °C] maximum interpass temperature.

^c The G classification requirements are by agreement between the supplier and purchaser.

9.4.1.4 The assembly shall be tested as specified in Clauses 11, 12, and 14 with or without a postweld heat treatment as specified in Table 6, for the classification under test.

9.4.2 Bend Test

9.4.2.1 As required by Table 4, a test assembly shall be prepared and welded as shown in Figure 3A or 3B, as applicable, and specified in 9.4.2.2 through 9.4.2.4 using base metal of the appropriate type specified in 9.2.

9.4.2.2 The test assembly shall be welded in the flat position using the shielding medium, polarity, and welding process specified in Table 2, and the amperage or wire feed speed and arc voltage recommended by the manufacturer. The test assembly shall be preset or sufficiently restrained to prevent warpage in excess of 5°. A welded test assembly that has warped more than 5° shall be discarded. Weld test assemblies shall not be straightened.

9.4.2.3 The preheat and interpass temperatures shall be as specified in Table 5. Those temperatures are measured mid-length of the assembly at a distance of 1 in [25 mm] from the centerline of the weld. After each pass, the assembly shall be allowed to cool in air (not quenched in water) to a temperature within the range specified in Table 5.

9.4.2.4 The third and subsequent layers of the test assembly for R3XXT1-5 rods may be welded with a similar classification of shielded metal arc welding electrodes, flux cored electrodes or rods, metal cored electrodes, or solid wire electrodes.

9.4.2.5 The assembly shall be tested as specified in Clause 13, in the as-welded condition.

9.5 Fillet Weld

9.5.1 Fillet weld tests, when required by Table 4, shall be performed in the vertical and overhead positions. A test assembly shall be prepared and welded as shown in Figure 4 using base metal of the appropriate type specified in 9.2, and using the shielding medium and polarity shown in Table 2 and the amperage or wire feed speed and arc voltage recommended by the manufacturer. Testing of the assembly shall be as specified in Clause 15.

9.5.2 In preparing the two plates forming the test assembly, the standing member (web) shall have one edge prepared so that when the web is set upon the base plate (flange), which shall be straight and smooth, there will be intimate contact along the entire length of the joint.

9.5.3 A single-pass fillet weld shall be deposited on one side of the joint. When welding in the vertical position, the welding shall progress upwards.

Table 6
Tension Test Requirements

AWS Classification ^a	Tensile Strength, min.		Elongation, min.	Postweld Heat Treatment
	ksi	MPa	Percent	
E307TX-X	85	590	30	None
E308TX-X	80	550	30	None
E308HTX-X	80	550	30	None
E308LTX-X	75	520	30	None
E308MoTX-X	80	550	30	None
E308LMoTX-X	75	520	30	None
E309TX-X	80	550	30	None
E309HTX-X	80	550	30	None
E309LNbTX-X	75	520	30	None
E309LTX-X	75	520	30	None
E309MoTX-X	80	550	25	None
E309LMoTX-X	75	520	25	None
E309LNiMoTX-X	75	520	25	None
E310TX-X	80	550	30	None
E312TX-X	95	660	22	None
E316TX-X	75	520	30	None
E316HTX-X	75	520	30	None
E316LTX-X	70	485	30	None
E317LTX-X	75	520	20	None
E347TX-X	75	520	30	None
E347HTX-X	75	520	30	None
E409TX-X	65	450	15	None
E409NbTX-X	65	450	15	(d)
E410TX-X	75	520	20	(b)
E410NiMoTX-X	110	760	15	(c)
E430TX-X	65	450	20	(d)
E430NbTX-X	65	450	13	(d)
E2209TX-X	100	690	20	None
E2307TX-X	100	690	20	None
E2553TX-X	110	760	15	None
E2594TX-X	110	760	15	None
E316LKT0-3	70	485	30	None
E308HMoT0-3	80	550	30	None
EGTX-X	Not Specified ^e			
R308LT1-5	75	520	30	None
R309LT1-5	75	520	30	None
R316LT1-5	70	485	30	None
R347T1-5	75	520	30	None
RGT1-5	Not Specified ^e			

^a In this table, the "X" following the "T" refers to the position of welding (1 for all-position or 0 for flat or horizontal operation) and the "X" following the dash refers to the shielding medium (-1, -3, or -4) as shown in the AWS Classification.

^b Heat to 1350 °F to 1400 °F [730 °C to 760 °C], hold for one hour (–0, +15 minutes), furnace cool at a rate not exceeding 200 °F [110 °C] per hour to 600 °F [315 °C] and air cool to ambient.

^c Heat to 1100 °F to 1150 °F [595 °C to 620 °C], hold for one hour (–0, +15 minutes), and air cool to ambient.

^d Heat to 1400 °F to 1450 °F [760 °C to 790 °C], hold for two hours (–0, +15 minutes), furnace cool at a rate not exceeding 100 °F [55 °C] per hour to 1100 °F [595 °C] and air cool to ambient.

^e The G classification requirements are by agreement between the supplier and purchaser.

10. Chemical Analysis

10.1 Flux cored electrodes and rods shall be analyzed in the form of weld metal, not filler metal.

10.1.1 The sample for analysis shall be taken from weld metal obtained from either the weld pad prepared according to 9.3 or one of the alternatives in 9.1 produced with the filler metal and shielding medium with which they are classified.

10.1.1 The sample for analysis of weld metal from the pad shall be taken from material above the third layer of weld metal and at least the minimum height above the base metal as specified in Figure 1. The sample shall be free of slag and all other foreign materials. The sample shall come from above the eighth layer for weld metal from the low carbon classifications when base metals containing more than 0.03% carbon are used for the pad.

10.1.3 The sample of weld metal from the reduced section of the fractured tension test specimen, or from a corresponding location (or any location above it) in the groove weld in Figure 2, shall be prepared for analysis by any suitable mechanical means.

10.2 Metal cored electrodes may be sampled for chemical analysis by the following methods:

(1) Gas tungsten arc welding may be used to melt a sample to result in a button (or slug) of sufficient size for analytical use.

(2) Other processes that melt a sample under a vacuum or inert atmosphere that result in a cast button (slug) may be used to produce a specimen for analysis.

(3) Gas metal arc welding with argon and up to 2% oxygen gas shielding may also be used to produce a homogeneous deposit for analysis. In this case, the weld pad shall be produced to the requirements for producing a flux core weld pad deposit.

These methods must be utilized in such a manner that no dilution of the base metal or mold occurs to contaminate the fused sample. Copper molds often are used to minimize the effects of dilution by the base metal or mold.

Special care must be exercised to minimize such dilution effects when testing low carbon filler metals.

10.3 The sample shall be analyzed by accepted analytical methods. The referee method shall be that found in ASTM E353.

10.4 The results of the analysis shall meet the requirements of Table 1FC or Table 1MC for the classification of electrode or rod under test.

11. Radiographic Test

11.1 When required in Table 4, the groove weld described in 9.4.1 and shown in Figure 2 shall be radiographed to evaluate the soundness of the weld metal. In preparation for radiography, the backing shall be removed and both surfaces of the weld shall be machined or ground smooth and flush with the original surfaces of the base metal or with a uniform reinforcement not exceeding 3/32 in [2.4 mm]. It is permitted on both sides of the test assembly to remove base metal to a depth of *up to* 1/16 in [1.5 mm] nominal below the original base metal surface in order to facilitate backing and/or buildup removal. The thickness of the weld metal shall not be reduced by more than 1/16 in [1.5 mm], *so that the thickness of the prepared radiographic test specimen equals at least the thickness of the base metal minus 1/16 in [1.5 mm]*.

Both surfaces of the test assembly in the area of the weld shall be smooth enough to avoid difficulty in interpreting the radiograph.

11.2 *The weld shall be radiographed in accordance with one of the following. The quality level of inspection shall be 2-2T.*

(1) *Film Radiology: ASTM E1032.*

(2) *Computed Radiology (CR): ASTM E2033 and the requirements of ASTM E1032 except where CR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2033, refers to phosphor imaging plate.*

(3) *Digital Radiology (DR): ASTM E2698 and the requirements of ASTM E1032 except where DR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2698, refers to digital detector array (DDA).*

11.3 The soundness of the weld metal meets the requirements of this specification if the radiograph shows:

- (1) no cracks, no incomplete fusion, and no incomplete penetration
- (2) no rounded indications in excess of those permitted by the radiographic standards in Figure 5A or 5B, as applicable
- (3)(a) in any 6 in [150 mm] length of the 1/2 in [13 mm] thick test assembly: no individual slag inclusion longer than 7/32 in [5.6 mm] and a maximum total length of 7/16 in [11 mm] for all slag inclusions.
- (3)(b) in any 6 in [150 mm] length of the 3/4 in [20 mm] thick test assembly: no individual slag inclusion in excess of 9/32 in [7.1 mm] and a maximum total length of 15/32 in [12 mm] for all slag inclusions.

In evaluating the radiograph, 1 in [25 mm] of the weld on each end of the test assembly shall be disregarded.

11.3.1 A rounded indication is an indication on the radiograph whose length is no more than three times its width. Rounded indications may be circular or irregular in shape and they may have tails. The size of a rounded indication is the largest dimension of the indication, including any tail that may be present. The indications may be of porosity.

11.3.2 Indications whose largest dimension does not exceed 1/64 in [0.4 mm] shall be disregarded. Test assemblies with indications larger than the large indications permitted in the radiographic standards do not meet the requirements of this specification.

12. Tension Test

12.1 One all-weld-metal tension test specimen, as specified in the Tension Test clause of AWS B4.0, shall be machined from the groove weld described in 9.4.1 and shown in Figure 2. The all-weld-metal tension test specimen shall have a gage length-to-diameter ratio of 4:1.

12.2 The *tension test* specimen shall be tested in the manner described in the Tension Test clause of AWS B4.0. The 1/2 in [12 mm] plate uses a 0.250 in [6.5 mm] tension specimen, while the 3/4 in [20 mm] plate uses a 0.500 in [12.5 mm] specimen.

12.3 The results of the tension test shall meet the requirements specified in Table 6.

13. Bend Test

13.1 Electrodes

13.1.1 One longitudinal face bend specimen, as required in Table 4, shall be machined from the groove weld test assembly described in 9.4.2 and shown in Figure 3A.

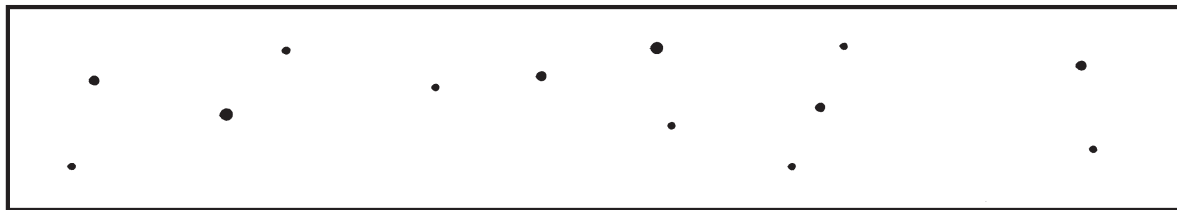
13.1.2 Backing strip and weld reinforcement shall be removed by machining. Grinding of the face surface of the specimen shall follow. The corners on the face side of the specimen shall be slightly rounded by filing or grinding. The longitudinal face bend test specimen shall be uniformly bent through 180° over a radius of 3/4 in [20 mm]. Typical bending jigs are shown in AWS B4.0. The specimen shall be positioned so that the face of the weld is in tension.

13.1.3 After bending, the bend test specimen shall conform to the designated radius, with appropriate allowance for spring back, and the weld metal shall show no defects on the tension face greater than 1/8 in [3.2 mm].

13.2 Rods

13.2.1 One longitudinal root bend specimen, as required in Table 4, shall be machined from the groove weld assembly described in 9.4.2 and shown in Figure 3B.

13.2.2 Weld reinforcement shall be removed by machining. Grinding of both faces of the specimen shall follow. All corners on the root side of the specimen shall be slightly rounded by filing or grinding. The longitudinal root bend

**(A) ASSORTED ROUNDED INDICATIONS**

SIZE $1/64$ in TO $1/16$ in [0.4 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 13 WITH THE FOLLOWING RESTRICTIONS:

MAXIMUM NUMBER OF LARGE $3/64$ in TO $1/16$ in [1.2 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 2.

MAXIMUM NUMBER OF MEDIUM $1/32$ in TO $3/64$ in [0.8 mm TO 1.2 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 4.

MAXIMUM NUMBER OF SMALL $1/64$ in TO $1/32$ in [0.4 mm TO 0.8 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 7.

**(B) LARGE ROUNDED INDICATIONS**

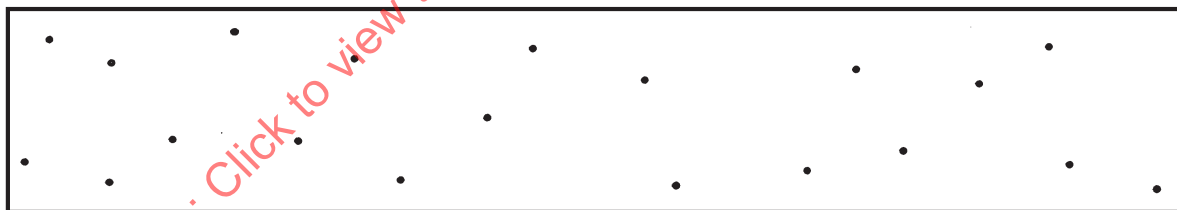
SIZE $3/64$ in TO $1/16$ in [1.2 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 6.

**(C) MEDIUM ROUNDED INDICATIONS**

SIZE $1/32$ in TO $3/64$ in [0.8 mm TO 1.2 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 10.

**(D) SMALL ROUNDED INDICATIONS**

SIZE $1/64$ in TO $1/32$ in [0.4 mm TO 0.8 mm] IN DIAMETER OR IN LENGTH.

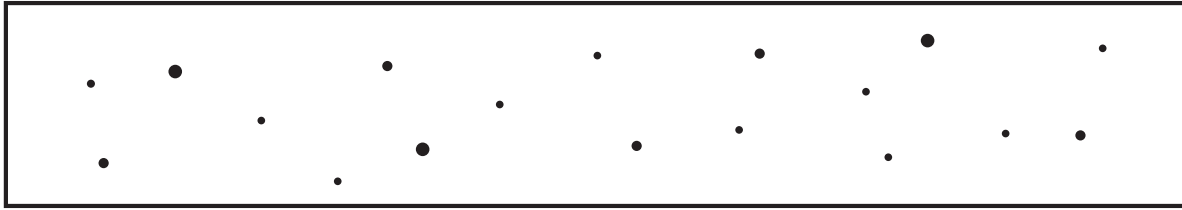
MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 20.

Notes:

1. In using these standards, the chart which is most representative of the size of the rounded indications present in the test specimen radiograph shall be used for determining conformance to these radiographic standards.
2. Since these are test welds specifically made in the laboratory for classification purposes, the radiographic requirements for these test welds are more rigid than those which may be required for general fabrication.

Source: AWS A5.4/A5.4M:2006, Figure 5A.

Figure 5A—Rounded Indication Standards for Radiographic Test— $1/2$ in [12 mm] Plate

**(A) ASSORTED ROUNDED INDICATIONS**

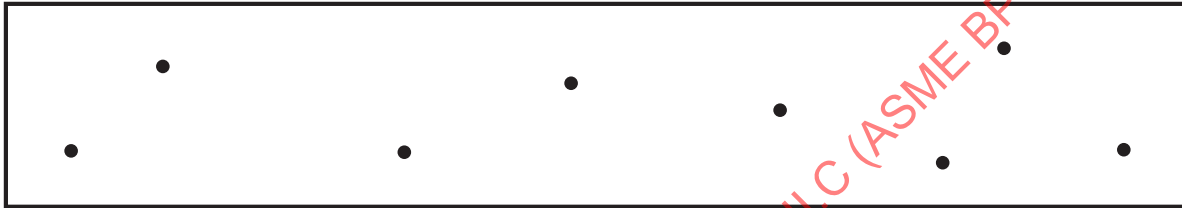
SIZE 1/64 in TO 1/16 in [0.4 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 18 WITH THE FOLLOWING RESTRICTIONS:

MAXIMUM NUMBER OF LARGE 3/64 in TO 1/16 in [1.2 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 3.

MAXIMUM NUMBER OF MEDIUM 1/32 in TO 3/64 in [0.8 mm TO 1.2 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 5.

MAXIMUM NUMBER OF SMALL 1/64 in TO 1/32 in [0.4 mm TO 0.8 mm] IN DIAMETER OR IN LENGTH INDICATIONS = 10.

**(B) LARGE ROUNDED INDICATIONS**

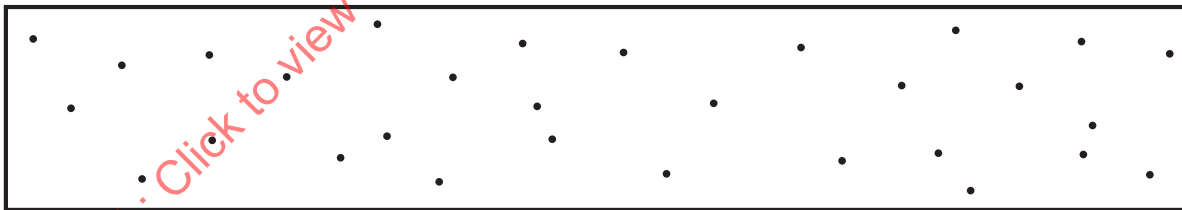
SIZE 3/64 in TO 1/16 in [1.2 mm TO 1.6 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 8.

**(C) MEDIUM ROUNDED INDICATIONS**

SIZE 1/32 in TO 3/64 in [0.8 mm TO 1.2 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 15.

**(D) SMALL ROUNDED INDICATIONS**

SIZE 1/64 in TO 1/32 in [0.4 mm TO 0.8 mm] IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 30.

Notes:

1. In using these standards, the chart which is most representative of the size of the rounded indications present in the test specimen radiograph shall be used for determining conformance to these radiographic standards.
2. Since these are test welds specifically made in the laboratory for classification purposes, the radiographic requirements for these test welds are more rigid than those which may be required for general fabrication.

Source: AWS A5.4/A5.4M:2006, Figure 5B.

Figure 5B—Rounded Indication Standards for Radiographic Test—3/4 in [20 mm] Plate

specimen shall be bent uniformly through 180° over a radius of 3/4 in [20 mm]. Typical bending jigs are shown in AWS B4.0. The specimen shall be positioned so that the root of the weld is in tension.

13.2.3 After bending, the bend test specimen shall conform to the designated radius, with appropriate allowance for spring back, and the weld metal shall show no defects on the tension face greater than 1/8 in [3.2 mm].

14. Impact Test

14.1 Five full-size Charpy V-notch impact test specimens, as specified in the Fracture and Notch Toughness Test clause of AWS B4.0, shall be machined from the test assembly shown in Figure 2 for those classifications for which impact testing is required in Table 4 (see Figure 6 for orientation and location). The Charpy V-notch specimens shall have the notched surface and the struck surface parallel with each other within 0.002 in [0.05 mm]. The other two surfaces of the specimen shall be square with the notched or struck surfaces within 10 minutes of a degree. The notch shall be smoothly machined and shall be square with the longitudinal edge of the specimen within one degree.

The geometry of the notch shall be measured on at least one specimen in a set of five specimens. Measurement shall be done at a minimum 10X magnification. The correct location of the notch shall be verified by etching before or after machining.

14.2 The five specimens shall be tested at a temperature of -320 °F [-196 °C] in accordance with the impact test section of AWS B4.0.

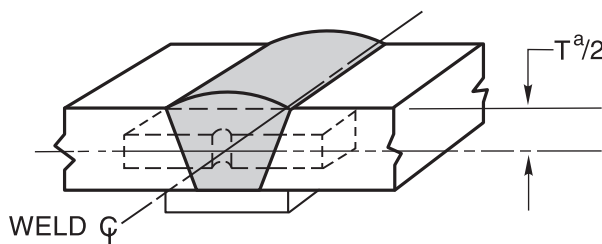
14.3 Lateral expansion shall be measured in accordance with ASTM E23. In evaluating the test results, the highest and lowest lateral expansion values shall be disregarded. The remaining three impact specimens shall each exhibit lateral expansion of 0.015 in [0.38 mm] minimum.

15. Fillet Weld Test

15.1 The fillet weld test, when required in Table 4, shall be made in accordance with the requirements of 9.5, Figure 4, and AWS A4.5M/A4.5. The entire face of the completed fillet weld shall be examined visually. There shall be no indication of cracks and the weld shall be reasonably free of undercut, overlap, trapped slag, and surface porosity. After the visual examination, the fillet weld size and convexity shall be measured using the methods of AWS A4.5M/A4.5.

15.2 Fillet weld size and convexity shall meet the requirements of Table 7.

15.3 The root penetration shall be verified using the cross-section method of AWS A4.5M/A4.5, and the macro shall show penetration to or beyond the junction of the edges of the plates.



^a If buttering is used in preparation of the test plate (see Figure 2) the T/2 dimension may need to be reduced to assure that none of the buttering becomes part of the notch area of the impact specimen.

Note: Specimen size to be in accordance with AWS B4.0, *Standard Methods for Mechanical Testing of Welds*.

Source: Figure A.4 of AWS A5.4/A5.4M:2006.

Figure 6—Orientation and Location of Impact Test Specimen

Table 7
Dimensional Requirements for Fillet Weld Usability Test Specimens

Measured Fillet Weld Size ^a		Maximum Convexity ^b		Maximum Difference Between Fillet Weld Legs ^c	
in	mm	in	mm	in	mm
1/8	3	1/16	2	1/32	1
5/32	4	1/16	2	1/16	2
3/16	—	1/16	—	1/16	—
—	5	—	2	—	2
7/32	—	1/8	—	3/32	—
1/4	6	1/8	3	3/32	2
9/32	7	1/8	3	1/8	3
5/16	8	1/8	3	1/8	3
11/32	9	1/8	3	5/32	4
3/8	10	1/8	3	5/32	4

^aMaximum permitted fillet weld size is 3/8 in [10 mm].

^bConvexity measurements shall be made to the nearest 1/16 in [2 mm].

^cFillet weld leg length measurements shall be made to the nearest 1/32 in [1 mm].

16. Method of Manufacture

The electrodes and rods classified according to this specification may be manufactured by any method that will produce material that meets the requirements of this specification.

17. Electrode and Rod Requirements

17.1 Standard Sizes. Standard sizes for filler metal in the different package forms (straight lengths, coils with support, coils without support, spools, and drums) are as specified in AWS A5.02/A5.02M.

17.2 Finish and Uniformity

17.2.1 Finish and uniformity shall be as specified in AWS A5.02/A5.02M.

17.2.2 A suitable protective coating may be applied to any filler metal in this specification.

17.3 Standard Package Forms

17.3.1 Standard package forms are straight lengths, coils with support, coils without support, spools, and drums. Standard package dimensions and weights and other requirements for each form shall be as specified in AWS A5.02/A5.02M.

17.4 Winding Requirements

17.4.1 Winding requirements shall be as specified in AWS A5.02/A5.02M.

17.4.2 The cast and helix of filler metal shall be as specified in AWS A5.02/A5.02M.

17.5 Electrode and Rod Identification

17.5.1 Filler metal identification, including marking of bare straight lengths of filler rod, product information, and the precautionary information, shall be as specified in AWS A5.02/A5.02M.

17.5.2 Coils without support shall have a tag containing this information securely attached to the filler metal at the inside end of the coil.

17.6 Packaging. Filler metal shall be suitably packaged to ensure against damage during shipment and storage under normal conditions.

17.7 Marking of Packages

17.7.1 The product information (as a minimum) shall be legibly marked so as to be visible from the outside of each unit package shall be as specified in AWS A5.02/A5.02M.

17.7.2 The appropriate precautionary information as given in ANSI Z49.1 (as a minimum) or its equivalent, shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages enclosed within a larger package.

Annex A (Informative)

Guide to AWS Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods

This annex is not part of this standard but is included for informational purposes only.

A1. Introduction

The purpose of this guide is to correlate the electrode and rod classifications with their intended applications so the specification can be used effectively. Appropriate base metal specifications are referenced whenever that can be done and when it would be helpful. Such references are intended only as examples rather than complete listings of the materials for which each filler metal is suitable. This specification includes welding rods classified as R3XXT1-5. These are flux cored welding rods which can be used for GTAW of the root pass of stainless steel pipe without the use of a back shielding gas.

The metal cored electrodes previously classified according to AWS A5.9/A5.9M have been included in this specification, in agreement with worldwide classification of metal cored electrodes in the same specifications as flux cored electrodes. By far the most popular metal cored electrodes are the EC409 type and similar ferritic stainless steel alloys. These are commonly used for single pass welding on thin wall tubing, as in automobile exhaust systems. Since these are mainly used in single pass welding, mechanical properties are not specified for such electrodes.

A2. Classification System

A2.1 The system for identifying the electrode and rod classifications in this specification follows the standard pattern used in other AWS filler metal specifications.

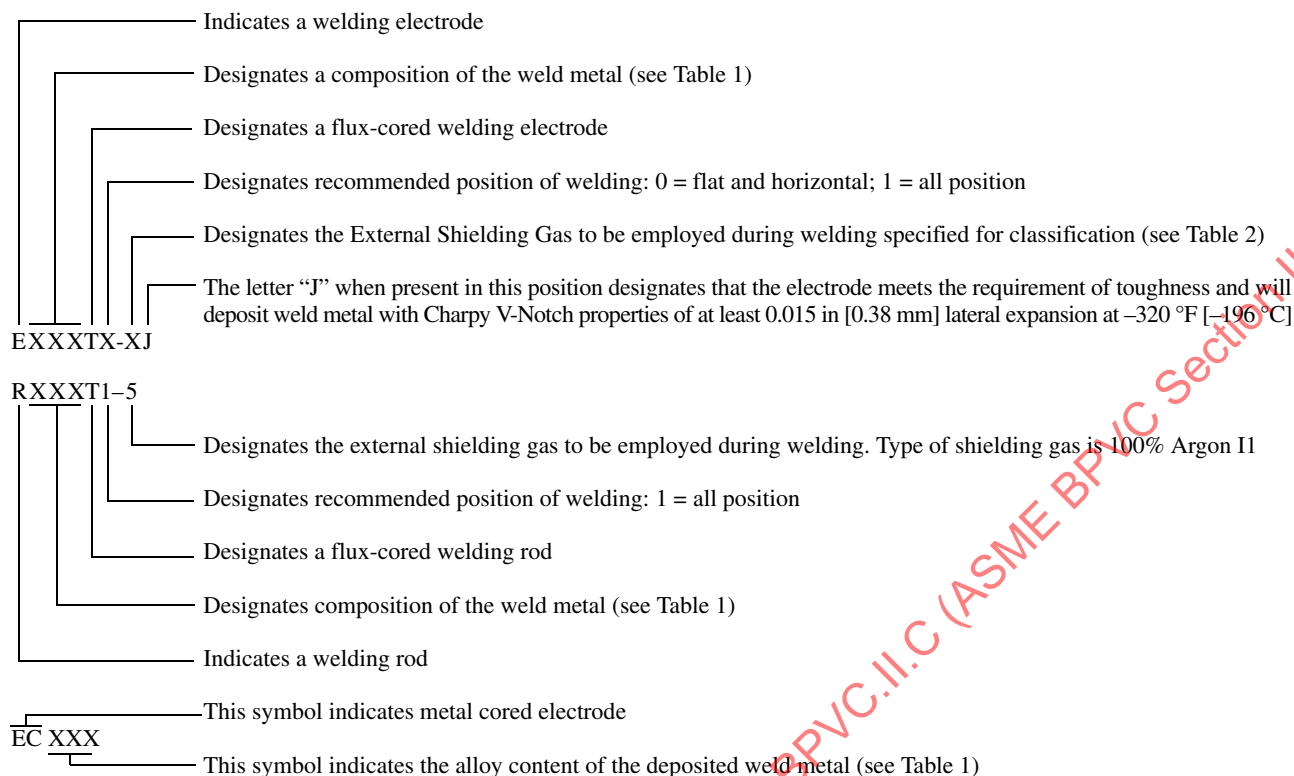
A2.2 The letter “E” at the beginning of each classification designation stands for electrode, and the letter “R” indicates a welding rod. The letters “EC” indicate a metal cored electrode. Figure A.1 is a graphical explanation of the system.

A2.2.1 The chemical composition is identified by a three-digit or four-digit number, and, in some cases, additional chemical symbols and the letters “L” or “H.” The numbers generally follow the pattern of the AISI numbering system for heat- and corrosion-resisting steels; however, there are exceptions. In some classifications additional chemical symbols are used to signify modifications of basic alloy types. The letter “L” denotes low carbon content in the deposit. The letter “H” denotes carbon content in the upper part of the range that is specified for the corresponding standard alloy type.

If a “G” is used for the chemical composition designator, it signifies that the chemical composition and mechanical properties are not specified and are as agreed upon between supplier and purchaser. Refer to A2.2.7 for a further explanation of the “G” classification and its implications.

A2.2.2 The letter “K” in the E316LKT0-3 classification, or the optional supplemental designator “J” for other classifications, signifies that weld metal deposited by these electrodes is designed for cryogenic applications.

A2.2.3 Following the chemical composition designation comes the letter “T,” which signifies that the product is a flux cored electrode or rod. Following the “T” is a 1 or 0 indicating the recommended position of welding. Following the position indicator and a dash, are the numerals “1,” “3,” “4,” or “5” or the letter “G.” The numerals “1,” “4,” and “5” identify the shielding gas required for classification of the electrode or rod. The numeral “3” signifies that an external shielding gas is not employed and that the weld puddle is shielded by the atmosphere and slag generated by the flux core.



Source: AWS A5.22-95 (R2005): Figure A.1.

Figure A.1—Classification Systems

The letter "G" signifies that the shielding medium is not specified and is agreed upon between the purchaser and supplier. Refer to A2.2.7 for a further explanation of the "G" classification and its implications.

A2.2.4 Significance of the position indicators is summarized as follows:

- (1) E XXXT0-X Designates a welding electrode designed for welding in the flat or horizontal positions.
- (2) E XXXT1-X Designates a welding electrode designed for welding in all positions.
- (3) R3 XXXT1-5 Designates a welding rod designed for welding in all positions.

A2.2.5 As shown in Table 2, the shielding designation for a particular classification indicates the external shielding gas to be employed for classification of the electrode/rod. This does not exclude the use of alternate gas mixtures as agreed upon between the purchaser and supplier. The use of alternate gas mixtures may have an effect on welding characteristics, deposit composition, and mechanical properties of the weld, such that classification requirements may not be met.

A2.2.6 While mechanical property tests are required for classification of the electrodes or rods in this specification (see Table 4), the classification designation does not identify the mechanical property test requirements. Refer to Table 6 for mechanical property requirements. Also note that mechanical properties are not a requirement for the EC classifications.

A2.2.7 "G" Classification. This specification includes filler metals classified EGTX-X, RGT1-5, and ECG. The "G" indicates that the filler metal is of a "general" classification. It is general because the filler metal may not meet all requirements for any other classification. The purpose is to allow a useful filler metal to receive a classification before the specification is revised.

One filler metal of a “G” classification is not interchangeable with another filler metal of the same classification.

A2.2.8 The point of difference between a particular filler metal of a “G” classification and all other filler metals with or without the “G” may be seen from the use of the words “not required” and “not specified” in the specification. The use of these words is as follows:

“Not Required” is used in those areas that specify the tests that must be conducted in order to classify a filler metal (or a welding material). The words indicate that there is no requirement for that test for that particular classification. When a purchaser wants the information provided by that test in order to consider a particular product of that classification for a certain application, the purchaser will have to arrange for that information with the supplier of the product. The purchaser will have to establish with that supplier just what the testing procedure and the acceptance requirements are to be for that test. The purchaser may want to incorporate that information (via AWS A5.01M/A5.01) in the purchase order.

“Not Specified” is used in those areas of the specification that refer to the results of some particular test. It indicates that the requirements for that test are not specified for that particular classification. If the results from a specific test are listed as “not specified” but the test in question is shown as “required” then the test results must be reported.

A2.2.9 Request for Filler Metal Classification. When a filler metal cannot be classified other than as a “G” classification, a manufacturer may request that a classification be established. The manufacturer shall do this using the following procedure:

(1) A request to establish a new filler metal classification must be submitted in writing. The request needs to provide sufficient detail to permit the AWS A5 Committee on Filler Metals and Allied Materials and the relevant Subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

- (a) A declaration that the new classification will be offered for sale commercially.
- (b) All classification requirements as given for existing classifications, such as chemical composition ranges, mechanical property requirements, and usability test requirements. Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.
- (c) Any conditions for conducting the tests used to demonstrate that the filler metal meets the classification requirements. (It would be sufficient, for example, to state that welding conditions are the same as for other classifications.)
- (d) Information on Descriptions and Intended Use, which parallels that for existing classifications, for that clause of the Annex.

A request for a new classification without the above information will be considered incomplete. The Secretary will return the request for further information.

(2) In order to comply with the AWS Policy on Patented Items, Trademarks, and Restraint of Trade, if the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester shall disclose this. In these cases, the patent holder must allow the use of this technology, such as by license. The Secretary will provide examples of acceptable wording to the patent holder, as required.

(3) The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters for processing.

A2.3 An international system for designating welding filler metals developed by the International Institute of Welding (IIW) is being adopted in many ISO specifications. Table A.1 shows those in comparable classifications in ISO 17633, *Welding consumables — Tubular cored electrodes and rods for gas shielded and non-gas shielded metal arc welding of stainless and heat-resisting steels — Classification*, along with classification for similar covered electrode classifications in AWS A5.4/A5.4M and similar bare wire classifications in AWS A5.9/A5.9M.

A2.4 ISO 17633 was first published in 2004. The latest revision was published in 2017. It is a cohabitation standard, providing for classification according to the system preferred in Europe or according to the system used by AWS and countries around the Pacific Rim. The “A-side” of the ISO standard indicates chemical composition directly in the designation, as in the “T 19 12 3L R M21 3” classification where the T indicates a tubular cored electrode, the 19

Table A.1
Comparison of A5.22/A5.22M Classifications with AWS A5.4/A5.4M, AWS A5.9/A5.9M, and ISO 17633

AWS A5.22/A5.22M	UNS Number	AWS A5.4/A5.4M ^a	AWS A5.9/A5.9M	ISO 17633-A ^b	ISO 17633-B ^c
E307TX-X	W30731	E307-XX	ER307	—	TS307 F X X
E308TX-X	W30831	E308-XX	ER308, ER308Si	—	TS308 F X X
E308HTX-X	W30831	E308H-XX	ER308H, ER19-10H	—	TS308H F X X
E308LTX-X	W30835	E308L-XX	ER308L, ER308LSi	T 19 9 L X X X	TS308L F X X
E308MoTX-X	W30832	E308Mo-XX	ER308Mo	—	TS308Mo F X X
E308LMoTX-X	W30838	E308LMo-XX	ER308LMo	—	TS308LMo F X X
E309TX-X	W30931	E309-XX	ER309, ER309Si	—	TS309 F X X
E309HTX-X	W30931	E309H-XX	—	—	—
E309LTX-X	W30935	E309L-XX	ER309L, ER309LSi	T 23 12 L X X X	TS309L F X X
E309MoTX-X	W30939	E309Mo-XX	ER309Mo	—	TS309Mo F X X
E309LMoTX-X	W30938	E309LMo-XX	ER309LMo	T 23 12 2 L X X X	TS309LMo F X X
E309LNiMoTX-X	W30936	—	—	—	—
E309LNbTX-X	W30932	—	ER309LNb	—	TS309LNb F X X
E310TX-X	W31031	E310-XX	ER310	T 25 20 X X X	TS310 F X X
E312TX-X	W31331	E312-XX	ER312	T 29 9 X X X	TS312 F X X
E316TX-X	W31631	E316-XX	ER316, ER316Si	—	TS316 F X X
E316HTX-X	W31631	E316H-XX	ER316H	—	TS316H F X X
E316LTX-X, E316LKT0-3	W31635, W31630	E316L-XX	ER316L, ER316LSi	T 19 12 3 L X X X	TS316L F X X
E317LTX-X	W31735	E317L-XX	ER317L	T 19 13 4 N L X X X	TS317L F X X
E347TX-X	W34731	E347-XX	ER347, ER347Si	T 19 9 Nb X X X	TS347 F X X
E347HTX-X	W34731	—	—	—	—
E409TX-X	W40931	—	ER409	T 13 Ti X X X	TS409 F X X
E409NbTX-X	W40957	E409Nb-XX	ER409Nb	—	TS409Nb F X X
E410TX-X	W41031	E410-XX	ER410	T 13 X X X	TS410 F X X
E410NiMoTX-X	W41036	E410NiMo-XX	ER410NiMo	T 13 4 X X X	TS410NiMo F X X
E430TX-X	W43031	E430-XX	ER430	T 17 X X X	TS430 F X X
E430NbTX-X	W43057	E430Nb-XX	—	—	TS430Nb F X X
E2209TX-X	W39239	E2209-XX	ER2209	T 22 9 3 N L X X X	TS2209 F X X
E2307TX-X	S82371	E2307-XX	ER2307	T 23 7 N L	—
E2553TX-X	W39533	E2553-XX	ER2553	—	—
E2594TX-X	W39594	E2594-XX, E2595-XX	ER2594	—	—
EGTX-X	—	—	—	T Z X X X	—
R308LT1-5	W30835	E308L-XX	ER308L	—	TS308L R I I

(Continued)

Table A.1 (Continued)
Comparison of A5.22/A5.22M Classifications with AWS A5.4/A5.4M, AWS A5.9/A5.9M, and ISO 17633

AWS A5.22/A5.22M	UNS Number	AWS A5.4/A5.4M ^a	AWS A5.9/A5.9M	ISO 17633-A ^b	ISO 17633-B ^c
R309LT1-5	W30935	E309L-XX	ER309L	—	TS309L R I I
R316LT1-5	W31635	E316L-XX	ER316L	—	TS316L R I I
R347T1-5	W34731	E347-XX	ER347	—	TS347 R I I
RGT1-5	—	—	—	—	TSZ R I I
EC209	S20980	E209-XX	—	—	TS209 M X X
EC218	S21880	—	—	—	TS218 M X X
EC219	S21980	E219-XX	—	—	TS219 M X X
EC240	S24080	E240-XX	—	—	TS240 M X X
EC307	S30780	E307-XX	—	—	TS307 M X X
EC308	S30880	E308-XX	—	—	TS308 M X X
EC308Si	S30881	E308-XX	—	—	TS308Si M X X
EC308H	S30880	E308H-XX	—	—	TS308H M X X
EC308L	S30883	E308L-XX	—	T 19 9 L M X X	TS308L M X X
EC308LSi	S30888	E308L-XX	—	T 19 9 L M X X	TS308LSi M X X
EC308Mo	S30882	E308Mo-XX	—	—	TS308Mo M X X
EC308LMo	S30886	E308LMo-XX	—	—	TS308LMo M X X
EC309	S30980	E309-XX	—	—	TS309 M X X
EC309Si	S30981	E309-XX	—	—	TS309Si M X X
EC309L	S30983	E309L-XX	—	T 23 12 L M X X	TS309L M X X
EC309LSi	S30988	E309L-XX	—	T 23 12 L M X X	TS309LSi M X X
EC309Mo	S30982	E309Mo-XX	—	—	TS309Mo M X X
EC309LMo	S30986	E309LMo-XX	—	T 23 12 2 L M X X	TS309LMo M X X
EC310	S31080	E310-XX	—	T 25 20 M X X	TS310 M X X
EC312	S31380	E312-XX	—	T 29 9 M X X	TS312 M X X
EC316	S31680	E316-XX	—	—	TS316 M X X
EC316Si	S31681	E316-XX	—	—	TS316Si M X X
EC316H	S31680	E316H-XX	—	—	TS316H M X X
EC316L	S31683	E316L-XX	—	T 19 12 3 L M X X	TS316L M X X
EC316LSi	S31688	E316L-XX	—	T 19 12 3 L M X X	TS316LSi M X X
EC316LMn	S31682	E316LMn-XX	—	—	TS316LMn M X X
EC317	S31780	E317-XX	—	—	TS317 M X X
EC317L	S31783	E317L-XX	—	T 19 13 4 N M X X	TS317L M X X
EC318	S31980	E318-XX	—	—	TS318 M X X

(Continued)

Table A.1 (Continued)
Comparison of A5.22/A5.22M Classifications with AWS A5.4/A5.4M, AWS A5.9/A5.9M, and ISO 17633

AWS A5.22/A5.22M	UNS Number	AWS A5.4/A5.4M ^a	AWS A5.9/A5.9M	ISO 17633-A ^b	ISO 17633-B ^c
EC320	N08021	E320-XX	—	—	TS320 M X X
EC320LR	N08022	E320LR-XX	—	—	TS320LR M X X
EC321	S32180	—	—	—	TS321 M X X
EC330	N08331	E330-XX	—	—	TS330 M X X
EC347	S34780	E347-XX	—	T 19 9 Nb M X X	TS347 M X X
EC347Si	S34788	E347-XX	—	T 19 9 Nb M X X	TS347Si M X X
EC383	N08028	E383-XX	—	—	TS383 M X X
EC385	N08904	E385-XX	—	—	TS385 M X X
EC409	S40900	—	—	T 13 Ti M X X	TS409 M X X
EC409Nb	S40940	E409Nb-XX	—	—	TS409Nb M X X
EC410	S41080	E410-XX	—	T 13 M X X	TS410 M X X
EC410NiMo	S41086	E410NiMo-XX	—	T 13 4 M X X	TS410NiMo M X X
EC420	S42080	—	—	—	TS420 M X X
EC430	S43080	E430-XX	—	T 17 M X X	TS430 M X X
EC439	S43035	—	—	—	TS439 M X X
EC439Nb	S43035	—	—	—	TS439Nb M X X
EC446LMo	S44687	—	—	—	TS446LMo M X X
EC630	S17480	E630-XX	—	—	TS630 M X X
EC19-10H	S30480	E308H-XX	—	—	TS19-10H M X X
EC16-8-2	S16880	E16-8-2-XX	—	—	TS16-8-2 M X X
EC2209	S39209	E2209-XX	—	T 22 9 3 N L M X X	TS2209 M X X
EC2553	S39553	E2553-XX	—	—	TS2553 M X X
EC2594	S32750	E2594-XX, E2595-XX	—	—	TS2594 M X X
EC33-31	R20033	E33-31-XX	—	—	TS33-31 M X X
EC3556	R30556	—	—	—	TS3556 M X X
ECG	—	—	—	T Z M X X	TSZ M X X

^aIn the AWS A5.4/A5.4M classification designations, “-XX” stands for the coating type. -15 means DC current only, all-position welding. -16 means AC or DC current, all-position welding. -17 means AC or DC current, all-position welding but allows for a wider weave in the vertical position. -26 means AC or DC current, flat and horizontal positions only.

^bIn the ISO 17633-A classification designations, the last three symbols (where X stands for any symbol) indicate, respectively, the type of electrode core (R means rutile, slow freezing; P means rutile, fast freezing; M means metal core; U means self-shielding; Z means an unspecified type), the shielding gas for classification (M21 means argon plus 15% to 25% CO₂, C means CO₂; M13 means argon plus up to 3% oxygen; and NO means no shielding gas), and position of welding (1 means all positions including vertical down; 2 means all positions except vertical down; 3 means flat and horizontal only; 4 means flat only; and 5 means flat, horizontal and vertical down).

^cIn the ISO 17633-B classification designations, the last three symbols (where X stands for any symbol) indicate, respectively, the type of electrode or rod (F means flux cored; M means metal cored; and R means a rod for GTAW), the shielding gas for classification (M21 means argon plus 20% to 25% CO₂; C means CO₂; M13 means argon plus up to 3% oxygen, I1 means 100% argon; NO means no shielding gas; and G means an unspecified shielding gas), and position of welding (0 means flat and horizontal only, 1 means all positions).

indicates % Cr, 12 indicates % Ni, 3 indicates % Mo, L indicates low carbon, R indicates a rutile slag system, M21 indicates use with argon-carbon dioxide mixed shielding gas and the last 3 indicates flat and horizontal position welding. The same electrode, classified according to the B-side of the ISO standard, would be designated TS316L-F M21 0 where T indicates a tubular cored electrode, S indicates stainless steel, 316L is the traditional AWS alloy designation, F indicates a flux cored electrode, M21 indicates argon-carbon dioxide mixed shielding gas, and 0 indicates flat and horizontal position welding. The same electrode, according to AWS A5.22, would be classified as E316LT0-4. In the future, AWS may adopt the ISO standard.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01M/A5.01. Any testing a purchaser requires of the supplier, for material shipped in accordance with this specification, shall be clearly stated in the purchase order. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing the supplier normally conducts on material of that classification, as specified in Schedule F, of AWS A5.01M/A5.01. Testing in accordance with any other Schedule must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product, or the classification on the product itself, constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification. The only testing requirement implicit in this *certification* is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that the material met the requirements of the specification. (Representative material, in this case, is any production run of that classification using the same formulation.). *Certification* is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may, or may not, have been conducted. The basis for the *certification* required by the specification is the classification test of *representative material* cited above, and the "Manufacturer's Quality Assurance System" in AWS A5.01M/A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes in the atmosphere to which welders and welding operators are exposed during welding. They are:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling)
- (2) Number of welders and welding operators working in that space
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes involved
- (4) The proximity of the welders or welding operators to the fumes as they issue from the welding zone, and to the gases and dusts in the space in which they are working
- (5) The ventilation provided to the space in which the welding is done.

A5.2 American National Standard Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the clause on ventilation in that document. See also AWS F3.2, *Ventilation Guide for Weld Fume*, for more detailed descriptions of ventilation options.

A6. Ferrite in Weld Deposits

A6.1 Ferrite is known to be very beneficial in reducing the tendency for cracking or fissuring in weld metals; however, it is not essential. Millions of pounds of fully austenitic weld metal have been used for years and have provided satisfac-

tory service performance. Generally, ferrite is helpful when the welds are restrained, the joints are large, and when cracks or fissures adversely affect service performance. Ferrite increases the weld strength level. Ferrite may have a detrimental effect on corrosion resistance in some environments. It also is generally regarded as detrimental to toughness in cryogenic service, and in high temperature service where it can transform into the brittle sigma phase.

A6.2 Ferrite can be measured on a relative scale by means of various magnetic instruments. However, work by the Subcommittee for Welding of Stainless Steel of the High Alloys Committee of the Welding Research Council (WRC) established that the lack of a standard calibration procedure resulted in a very wide spread of readings on a given specimen when measured by different laboratories. A specimen averaging 5.0% ferrite based on the data collected from all the laboratories was measured as low as 3.5% by some and as high as 8.0% by others. At an average of 10% the spread was 7.0% to 16.0%. In order to substantially reduce this problem, the WRC Subcommittee published *Calibration Procedure for Instruments to Measure the Delta Ferrite Content of Austenitic Stainless Steel Weld Metal*¹ on July 1, 1972.

In 1974 the AWS extended this procedure and prepared AWS A4.2, *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic Stainless Steel Weld Metal*. All instruments used to measure the ferrite content of AWS classified stainless electrode products are to be traceable to the latest revision of this AWS standard.

A6.3 The WRC Subcommittee also adopted the term *Ferrite Number* (FN) to be used in place of % ferrite, to clearly indicate that the measuring instrument was calibrated to the WRC procedure. The Ferrite Number, up to 10 FN, is to be considered equal to the “% ferrite” term previously used. It represents a good average of commercial U.S. and world practice on the % ferrite. Through the use of standard calibration procedures, differences in readings due to instrument calibration are expected to be reduced to about $\pm 5\%$, or at the most, $\pm 10\%$ of the measured ferrite value.

A6.4 In the opinion of the WRC Subcommittee, it has been impossible, to date, to accurately determine the true absolute ferrite content of stainless steel weld metals.

A6.5 Even on undiluted pads, ferrite variations from pad to pad must be expected due to slight changes in welding and measuring variables. On a large group of pads from one heat or lot and using a standard pad welding and preparation procedure, two sigma values indicate that 95% of the tests are expected to be within a range of approximately ± 2.2 FN to about 8 FN. If different pad welding and preparation procedures are used, these variations will increase.

A6.6 Even larger variations may be encountered if the welding technique allows excessive nitrogen pickup, in which case the ferrite can be much lower than it should be. High nitrogen pickup can cause a typical 8 FN deposit to drop to 0 FN. A nitrogen pickup of 0.10% will typically decrease the FN by about 8.

A6.7 Plate materials tend to be balanced chemically to have an inherently lower ferrite content than matching weld metals. Weld metal diluted with plate metal will usually be somewhat lower in ferrite than the undiluted weld metal, though this does vary depending on the amount of dilution and the composition of the base metal.

A6.8 In the normally austenitic (types 3XX) filler metals, many types, such as filler metals of types 310, 320, 320LR, 330, 383, and 385, are fully austenitic. The filler metals of type E316 group can be made with little or no ferrite when required for improved corrosion resistance in certain media, and in high temperature and cryogenic applications where ferrite can be detrimental. It also can be obtained in a higher ferrite form, usually over 4 FN, if desired. The remaining normally austenitic (types 3XX) filler metals can be made in low-ferrite versions, but commercial practice usually involves ferrite control above 4 FN. Because of chemical composition limits covering these grades and various manufacturing limits, most lots will be under 10 FN and are unlikely to go over 15 FN commercially. Filler metals of types 312, 2209, 2307, 2553, and 2594 generally are quite high in ferrite, usually over 30 FN.

A6.9 When it is desired to measure ferrite content, the following procedure is recommended:

A6.9.1 The same weld pads, as detailed in 9.3, may be used to measure the ferrite level, provided at least the last two layers are prepared as described in A6.9.3 and A6.9.4. Otherwise, the pads shall be made as detailed on Figure 1 and prepared as described in A6.9.2 through A6.9.4. The base plate may be of Type 301, 302, or 304 conforming to ASTM Specification A167 or A240, or carbon steel. If the base plate contains more than 0.03% carbon and is used for the low

¹ Welding Research Council, P.O. Box 201547, Shaker Heights, OH 44120.

carbon classifications (classifications with up to 0.04% carbon maximum), then the pad shall have a minimum of nine layers. This is required to assure a low carbon weld metal deposit.

A6.9.2 The weld pad must be built to a minimum height of 1/2 in [13 mm] when using Type 301, 302, or 304 base plate. When using a carbon steel base, the weld pad must have a minimum height of 5/8 in [16 mm] to eliminate dilution effects.

A6.9.3 The pad must be welded in the flat position using multiple layers, with at least the last 2 layers deposited using stringer beads. The measurable length between start and stop on the last two layers must be 2 in [50 mm] minimum. The weld layers used for the buildup may be deposited with a weave. The amperage or wire feed speed, the arc voltage, and the contact tip to workpiece distance shall be as recommended by the manufacturer of the electrode. The shielding medium, polarity, and welding process shall be as shown in Table 2. Each pass must be cleaned prior to depositing the next pass. The welding direction should be alternated from pass to pass. The weld stops and starts must be located at the ends of the weld buildup. Between passes, the weld pad may be cooled by quenching in water not sooner than 20 seconds after the completion of each pass. The last two layers must have a maximum interpass temperature of 300 °F [150 °C]. The last pass must be air cooled to below 800 °F [425 °C] prior to quenching in water.

The weld deposit can be built up between two copper bars laid parallel on the base plate. The spacing between the copper bars is dependent on the size of the electrode and the type or size of welding gun used. Care must be taken to make sure the arc does not impinge on the copper bars resulting in copper dilution in the weld metal.

A6.9.4 The completed weld pad must have the surface prepared so that it is smooth with all traces of weld ripple removed and must be continuous in length where measurements are to be taken. This can be accomplished by any suitable means providing the surface is not heated in excess during the machining operation (excessive heating may affect the final ferrite reading). The width of the prepared surface shall not be less than 1/8 in [3 mm]. The surface can be prepared by draw filing using a mill bastard file held on both sides of the weld with the long axis of the file perpendicular to the long axis of the weld. Files shall either be new or shall have only been used on austenitic stainless steel. Filing must be accomplished by smooth draw-filing strokes (one direction only) along the length of the weld while applying a firm downward pressure. If the ferrite content is 30 FN or greater, the surface must be ground to a 600 grit [P1200] finish.

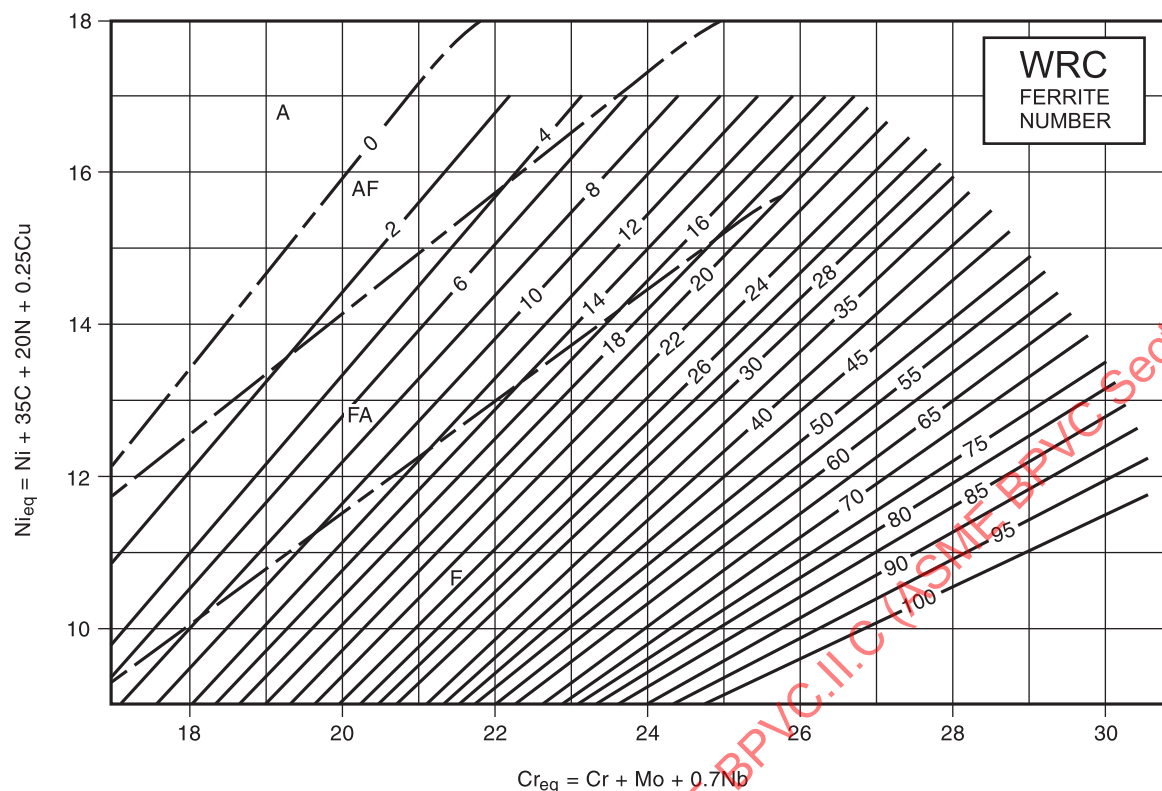
A6.9.5 A minimum of six ferrite readings must be taken on the filed or ground surface along the longitudinal axis of the weld pad with an instrument calibrated in accordance with the procedures specified in AWS A4.2M, *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal* (latest edition). The six or more readings obtained must be averaged to give the final result.

A6.10 The ferrite content of welds may be calculated (predicted) from the chemical composition of the weld deposit. This can be done from the WRC-1992 Diagram² (Figure A.2) which predicts ferrite in Ferrite Number (FN). It is a slight modification of the WRC-1988 Diagram³ to take into account the effect of copper originally proposed by Lake. Studies within the WRC Subcommittee on Welding Stainless Steel and within Commission II of the International Institute of Welding show a closer agreement between measured and predicted ferrite contents using the WRC-1988 Diagram than when using the previously used DeLong Diagram. The WRC-1992 Diagram may not be applicable to compositions greater than 0.3% nitrogen, 1% silicon, or greater than 10% manganese. For stainless steel compositions not alloyed with Cu, the predictions of the 1988 and 1992 diagrams are identical.

The differences between measured and calculated ferrite are somewhat dependent on the ferrite level of the deposit, increasing the ferrite level increases the variance. The agreement between the calculated and measured ferrite values is also strongly dependent on the quality of the chemical analysis. Variations in the results of the chemical analyses encountered from laboratory to laboratory can have significant effects on the calculated ferrite value, changing it as much as 4 FN to 8 FN.

² Kotecki, D. J., and T. A. Siewert, "WRC-1992 Constitution Diagram for Stainless Steel Weld Metals: A Modification of the WRC-1988 Diagram." *Welding Journal* 71(5): 171-s–178-s (1992).

³ McCowan, C. N., T. A. Siewert, and D. L. Olson, 1989. WRC Bulletin 342, Stainless Steel Weld Metal: Prediction of Ferrite Content, Welding Research Council.



Source: AWS A5.4/A5.4M:2006, Figure A.3.

Figure A.2—WRC-1992 Diagram for Stainless Steel Weld Metal

A7. Ferrite and Compositional Concerns for ECXXX Metal Cored Electrodes

A7.1 The welding process used and the welding conditions and technique have a significant influence on the chemical composition and the ferrite content of the weld deposit in many instances. These influences must be considered by the user if the weld deposit must meet specific chemical or Ferrite Number limits. The purpose of A7.2.1 through A7.2.3 is to present some general information on the effect of common arc welding processes on the chemical composition and the ferrite content of weld deposits made with filler metal classified in this specification.

A7.2 The chemical composition of a given weld deposit has the capability of providing an approximately predictable Ferrite Number for the undiluted deposit, as described in A6.10, with the limitations discussed here. However, important changes in the chemical compositions can occur from wire to deposit as described in A7.2.1 through A7.2.3.

A7.2.1 Gas Tungsten Arc Welding. This welding process involves the least change in the chemical composition from wire to deposit, and hence produces the smallest difference between the ferrite content calculated from the wire analysis and that measured on the undiluted deposit. There is some loss of carbon in gas tungsten arc welding—about half of the carbon content above 0.02%. Thus, a wire of 0.06% carbon will typically produce a deposit of 0.04% carbon. There is also some nitrogen pickup—a gain of 0.02%. The change in other elements is not significant in the undiluted weld metal.

A7.2.2 Gas Metal Arc Welding. For this process, typical carbon losses are low, only about one quarter those of the gas tungsten arc welding process. However, the typical nitrogen pick up is much higher than in gas tungsten arc welding, and it should be estimated at about 0.04% (equivalent to about 3 or 4 FN loss) unless specific measurements on welds for a particular application establish other values. Nitrogen pickup in this process is very dependent upon the welding technique and may go as high as 0.15% or more. This may result in little or no ferrite in the weld deposits of filler metals

Table A.2
Variations of Alloying Elements for Submerged Arc Welding

Element	Typical Change from Wire to Deposit
Carbon	Varies. On “L” grades, usually a gain: +0.01% to +0.02%; on non-L grades, usually a loss: up to –0.02%.
Silicon	Usually a gain: +0.3% to +0.6%.
Chromium	Usually a loss, unless a deliberate addition is made to the flux: –0.5% to –3.0%.
Nickel	Little change, unless a deliberate addition is made to the flux.
Manganese	Varies: –0.5% to +0.5%.
Molybdenum	Little change, unless a deliberate addition is made to the flux.
Niobium	Usually a loss, unless a deliberate addition is made to the flux: –0.1% to –0.5%.

such as EC308 and EC309. Some slight oxidation plus volatilization losses may occur in manganese, silicon, and chromium contents.

A7.2.3 Submerged Arc Welding. Submerged arc welds show variable gains or losses of alloying elements, or both depending on the flux used. All fluxes produce some changes in the chemical composition as the electrode is melted and deposited as weld metal. Some fluxes deliberately add alloying elements such as niobium (columbium) and molybdenum; others are very active in the sense that they deplete significant amounts of certain elements that are readily oxidized, such as chromium. Other fluxes are less active and may contain small amounts of alloys to offset any losses and thereby, produce a weld deposit with a chemical composition close to the composition of the electrode. If the flux is active or alloyed, changes in the welding conditions, particularly voltage, will result in significant changes in the chemical composition of the deposit. Higher voltages produce greater flux/metal interactions and, for example, in the case of an alloy flux, greater alloy pickup. When close control of ferrite content is required, the effects of a particular flux/electrode combination should be evaluated before any production welding is undertaken due to the effects as shown in Table A.2.

A7.3 Bare solid filler metal wire, unlike covered electrodes and bare composite cored wires, cannot be adjusted for ferrite content by means of further alloy additions by the electrode producer, except through the use of flux in the submerged arc welding process. Thus, if specific FN ranges are desired, they must be obtained through wire chemical composition selection. This is further complicated by the changes in the ferrite content from wire to deposit caused by the welding process and techniques, as previously discussed.

A7.4 In the 300 series filler metals, the compositions of the bare filler metal wires in general tend to cluster around the midpoints of the available chemical ranges. Thus, the potential ferrite for the 308, 308L, and 347 wires is approximately 10 FN, for the 309 wire approximately 12 FN, and for the 316 and 316L wires approximately 5 FN. Around these midpoints, the ferrite contents may be ± 7 FN or more, but the chemical compositions of these filler metals will still be within the chemical limits specified in this specification.

A7.5 In summary, the ferrite potential of a filler metal afforded by this chemical composition will, except for a few instances in submerged arc welding, be modified downward in the deposit due to changes in the chemical composition which are caused by the welding process and the technique used. Further information can be found in AWS A5.39/A5.39M.

A8. Description and Intended Use of Electrodes and Rods

A8.1 Composition Considerations

A8.1.1 The chemical composition requirements for these electrodes and rods are patterned after those of AWS A5.4/A5.4M, *Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding*, and AWS A5.9/A5.9M, *Specification for Bare Stainless Steel Electrodes and Rods* (see Table A.1).

A8.1.2 The chemical composition requirements of the EXXXTX-1 and EXXXTX-4 classifications are very similar. The requirements of the EXXXT0-3 classifications are different from those of the previous two. The EXXXT0-3 deposits usually have higher nitrogen content. This means that, in order to control the ferrite content of the weld metal, the chemical compositions of the EXXXT0-3 deposits usually have higher Cr/Ni ratios than those of the EXXXTX-1 and EXXXTX-4 deposits.

Since the atmosphere generated by E316LKT0-3 electrodes more efficiently shields the arc from nitrogen pickup than that produced by other EXXXT0-3 electrodes, the Cr/Ni ratio can be the same as for EXXXTX-1 deposits without a loss of ferrite control.

A8.1.3 The chemical composition requirements for metal cored electrodes are identical to those which were previously in the AWS A5.9/A5.9M specification. The most common use of metal cored electrodes is for single pass welds on thin wall tubing used in automotive exhaust systems. These are most commonly the ferritic stainless steel compositions 409, 409Nb, 430, 439, and 439Nb. Because they are used almost exclusively single pass, mechanical properties depend strongly upon the composition of the base metal. Accordingly, mechanical properties are not specified for these compositions.

A8.1.4 Bismuth (Bi) in Flux Cored Stainless Steel Electrodes. For many years, bismuth in one form or another has been added to the core ingredients of many, but by no means all, stainless steel flux cored electrodes for the purpose of improved slag release. In such electrodes, the weld metal typically retains about 0.02% (200 ppm) of bismuth. Bismuth is a surface active element which, under prolonged exposure to temperatures above about 750 °F [400 °C], can segregate to grain boundaries and promote premature failure under sustained tensile loading. Accordingly, stainless steel electrodes containing bismuth additions should not be used for such high temperature service or postweld heat treatment above about 900 °F [500 °C]. Instead, stainless steel flux cored electrodes providing no more than 0.002% (20 ppm) Bi in the weld metal should be specified. For further information, see Welding Research Council Bulletin 460 High Temperature Cracking and Properties of Stainless Steel Flux Cored Welds and Effects of Bismuth⁴ and International Institute of Welding Document IX-1873-97, *Effect of Bismuth on Reheat Cracking Susceptibility in Type 308 FCAW Weld Metal*.

A8.2 Intended Use of Flux Cored Electrodes and Rods. In the following, the final X of the classification refers to -1, -3, or -4.

A8.2.1 E307TX-X. The nominal composition (wt %) of this weld metal is 19 Cr, 9.7 Ni, 1.0 Mo, and 4 Mn. These electrodes are used primarily for moderate strength welds with good crack resistance between dissimilar steels, such as welding austenitic manganese steel to carbon steel forgings or castings.

A8.2.2 E308TX-X. The nominal composition (wt %) of this weld metal is 19.5 Cr and 10 Ni. Electrodes of this classification are most often used to weld base metal of similar composition such as AISI Types 301, 302, 304, 305, and 308.

A8.2.3 E308HTX-X. The composition of this weld metal is the same as that of E308TX-X except for carbon content which is in the high end of the range, 0.04 wt % to 0.08 wt %. Carbon content in this range provides higher tensile and creep strength at elevated temperatures. These electrodes are used primarily for welding type 304H base metal and sometimes type 347H if creep ductility is a concern.

A8.2.4 E308LTX-X. The composition of this weld metal is the same as that of E308TX-X, except for carbon content. By specifying low carbon in this alloy, it is possible to obtain resistance to intergranular corrosion due to carbide precipitation without the use of stabilizers such as niobium or titanium. This low carbon alloy, however, is not as strong at elevated temperature as the E308 and niobium stabilized alloys.

A8.2.5 E308MoTX-X. The composition of this weld metal is the same as that of E308TX-X weld metal, except for the addition of 2 wt %–3 wt % molybdenum. This electrode is recommended for welding CF8M stainless steel castings, as it matches the base metal with regard to chromium, nickel, and molybdenum.⁵ This grade may also be used for welding wrought metals such as Type 316 when ferrite content higher than attainable with E316TX-X electrodes is desired.

⁴ WRC documents are published by Welding Research Council, P.O. Box 201547, Shaker Heights, OH 44120.

⁵ CF8M and CF3M are designations of ASTM A351, Standard Specification for Steel Castings, Austenitic, for Pressure-Containing Parts.

A8.2.6 E308LMoTX-X. The composition of this weld metal is the same as that of E308MoTX-X weld metal, except for the lower carbon content. These electrodes are recommended for welding CF3M stainless steel castings, to match the base metal with regard to chromium, nickel, and molybdenum. This grade may also be used for welding wrought metals such as type 316L stainless when ferrite content higher than attainable with E316LTX-X electrodes is desired.

A8.2.7 E309TX-X. The nominal composition (wt %) of this weld metal is 23.5 Cr and 13 Ni. Electrodes of this classification commonly are used for welding similar alloys in wrought or cast forms. They are used in welding dissimilar metals, such as joining Type 304 to mild steel, welding the stainless steel side of Type 304 clad steels, and applying stainless steel sheet linings to carbon steel sheets. Occasionally, they are used to weld Type 304 base metals where severe corrosion conditions exist that require higher alloy content weld metal.

A8.2.8 E309HTX-X. The composition of this weld metal is the same as that of E309TX-X except for carbon content which is at the high end of the range, 0.04%–0.10%. Carbon content in this range provides higher tensile and creep strength at elevated temperatures. This together with a lower ferrite content makes these electrodes suitable for the welding of 24 Cr 12 Ni wrought and cast grades for corrosion and oxidation resistance. High carbon castings to ACI's HH grade should be welded with an electrode that is similar to the casting composition.

A8.2.9 E309LTX-X. The composition of the weld metal is the same as E309TX-X, except for the carbon content. By specifying low carbon in this alloy, it is possible to obtain resistance to intergranular corrosion due to carbide precipitation without the use of stabilizers such as niobium or titanium. This low carbon alloy, however, is not as strong at elevated temperature as Type 309 or the niobium stabilized modification. A primary application of this alloy is the first layer cladding of carbon steel if no niobium additions are required.

A8.2.10 E309MoTX-X. The composition of this weld metal is the same as that of E309TX-X weld metal, except for the addition of 2 wt %–3 wt % molybdenum. These electrodes are used to join stainless steel to carbon and low-alloy steels for service below 600 °F [315 °C], and for overlaying of carbon and low-alloy steels. The presence of molybdenum provides pitting resistance in a halide environment and helps provide high temperature ductility in dissimilar joints. The ferrite level for this electrode deposit is approximately 18 FN.

A8.2.11 E309LMoTX-X. The composition of this weld metal is the same as E309MoTX-X weld metal, except for the lower carbon content. These electrodes are used to join stainless steel to carbon and low-alloy steels for service below 600 °F [316 °C], and for overlaying of carbon and low-alloy steels. The presence of molybdenum provides pitting resistance in a halide environment and helps provide high temperature ductility in dissimilar joints. The ferrite level for this electrode deposit is approximately 20 FN.

A8.2.12 E309LNiMoTX-X. The composition of this weld metal is essentially the same as E309LMoTX-X except for the lower chromium and higher nickel content. The purpose of this modification is to achieve a lower deposit ferrite content (typically 8 FN–12 FN) when compared to E309LMoTX-X (approximately 20 FN). This composition is required by the pulp and paper industry for joining applications.

A8.2.13 E309LNbTX-X. The composition of this weld metal is the same as E309LTX-X weld metal, except for the addition of 0.7 wt % to 1.0 wt % Nb. These electrodes are used to overlay carbon and low-alloy steels and produce a niobium stabilized first layer on such overlays.

A8.2.14 E310TX-X. The nominal composition (wt %) of this weld metal is 26.5 Cr and 21 Ni. These electrodes are most often used to weld base metals of similar compositions.

A8.2.15 E312TX-X. The nominal composition (wt %) of this weld metal is 30 Cr and 9 Ni. These electrodes most often are used to weld dissimilar metal compositions of which one component is high in nickel. This alloy gives a two-phase weld deposit with substantial amounts of ferrite in an austenitic matrix. Even with considerable dilution by austenite-promoting elements, such as nickel, the microstructure remains two-phase and thus highly resistant to weld metal cracks and fissures.

A8.2.16 E316TX-X. The nominal composition (wt %) of this weld metal is 18.5 Cr, 12.5 Ni, and 2.5 Mo. Electrodes of this classification usually are used for welding similar alloys (about 2 wt % molybdenum). These electrodes have been used successfully in applications involving special alloys for high-temperature service. The presence of molybdenum provides increased creep resistance at elevated temperatures and pitting resistance in a halide environment.

A8.2.17 E316HTX-X. The composition of this weld metal is the same as that of E316TX-X except for carbon content which is in the high end of the range, 0.04 wt % to 0.08 wt %. Carbon content in this range provides higher

tensile and creep strength at elevated temperatures. These electrodes are used primarily for welding type 316H base metal.

A8.2.18 E316LTX-X. The composition of this weld metal is the same as E316TX-X electrodes, except for the lower carbon content. By specifying low carbon in this alloy, it is possible to obtain resistance to intergranular corrosion due to carbide precipitation without the use of stabilizers such as niobium or titanium. This low carbon alloy, however, is not as strong at elevated temperatures as the niobium stabilized alloys.

A8.2.19 E317LTX-X. The nominal composition (wt %) of this weld metal is 19.5 Cr, 13 Ni, and 3.5 Mo. These electrodes usually are used for welding alloys of similar composition and are usually limited to severe corrosion applications. Low carbon (0.04 wt % maximum) in this filler metal reduces the possibility of intergranular carbide precipitation and thereby increases the resistance to intergranular corrosion without the use of stabilizers such as niobium or titanium. This low carbon alloy, however, may not be so strong at elevated temperatures as the niobium stabilized alloys or Type 317.

A8.2.20 E347TX-X. The nominal composition (wt %) of this weld metal is 19.5 Cr and 10 Ni with Nb added as a stabilizer. The alloy is often referred to as a stabilized Type 308 alloy, indicating that it normally is not subject to intergranular corrosion from carbide precipitation. Electrodes of this classification usually are used for welding chromium-nickel stainless steel base metals of similar composition stabilized either with niobium or titanium.

Although niobium is the stabilizing element usually specified in 347 alloys, it should be recognized that tantalum may also be present. Tantalum and niobium are almost equally effective in stabilizing carbon and in providing high-temperature strength. The usual commercial practice is to report niobium as the sum of the niobium plus tantalum. Crack sensitivity of the weld may increase substantially, if dilution by the base metal produces a low ferrite or fully austenitic weld metal deposit.

A8.2.21 E347HTX-X. The composition of this weld metal is the same as that of E347TX-X, except for carbon content which is at the high end of the range, 0.04 wt % to 0.08 wt %. Carbon content in this range provides higher tensile and creep strength at elevated temperatures. These electrodes are used primarily for welding Type 347H base metal but care must be exercised if low creep ductility is a concern.

A8.2.22 E409TX-X. The nominal composition (wt %) of this weld metal is 12 Cr with Ti added as a stabilizer. These electrodes, which produce a ferritic microstructure, often are used to weld base metal of similar composition.

A8.2.23 E409NbTX-X. This classification is the same as E409TX-X, except that niobium is used instead of titanium to achieve similar results. Applications are the same as for E409TX-X filler metals.

A8.2.24 E410TX-X. This 12 Cr (wt %) alloy is an air-hardening steel, and therefore, requires preheat and postheat treatments in order to achieve welds of adequate ductility for most engineering purposes. The most common application of electrodes of this classification is for welding alloys of similar composition. They also are used for surfacing of carbon steels to resist corrosion, erosion, or abrasion, such as occurs in valve seats and other valve parts.

A8.2.25 E410NiMoTX-X. The nominal composition (wt %) of this weld metal is 11.5 Cr, 4.5 Ni, and 0.55 Mo. This electrode generally is used to weld CA6NM castings or similar materials.⁶ These electrodes are modified to contain less chromium and more nickel to eliminate ferrite in the microstructure, as ferrite has a deleterious effect on mechanical properties. Postweld heat treatment in excess of 1150 °F [620 °C] may result in rehardening due to untempered martensite in the microstructure after cooling to room temperature.

A8.2.26 E430TX-X. This is a nominal 16.5 (wt %) Cr alloy. The composition is balanced by providing sufficient chromium to give adequate corrosion resistance for the usual applications and yet retain sufficient ductility in the heat-treated condition. (Excessive chromium will result in lower ductility.)

Welding with E430TX-X electrodes may produce a partially hardened microstructure that requires preheating and a postweld heat treatment. Optimum mechanical properties and corrosion resistance are obtained only when the weldment is heat treated following the welding operation.

⁶ CA6NM is a designation of ASTM A352, *Standard Specification for Steel Castings, Ferritic and Martensitic, for Pressure-Containing Parts, Suitable for Low-Temperature Service*.

A8.2.27 E430NbTX-X. The composition of this weld metal is very similar to that deposited by E430 electrodes, except for the addition of niobium. The weld deposit is a ferritic microstructure with fine grains. Preheat and postweld heat treatment are required to achieve welds of adequate ductility for many engineering purposes. These electrodes are used for the welding of Type 430 stainless steel. They are also used for the first layer in the welding of Type 405 and 410 clad steels.

A8.2.28 E2209TX-X. The nominal composition (wt %) of this weld metal is 22 Cr, 8.5 Ni, 3.5 Mo, and 0.15 N. This electrode is used to join duplex stainless steel base metals containing approximately 22 wt % chromium. The microstructure of the weld deposit consists of a mixture of austenite and ferrite. Because of the two-phase structure, the alloy is one of the family of duplex stainless steel alloys. The alloy has good resistance to stress corrosion cracking and pitting corrosion attack. If post weld annealing is required, this weld metal will require a higher annealing temperature than that required by the duplex base metal.

A8.2.29 E2307TX-X. The nominal composition (wt %) of this weld metal is 24 Cr, 8.5 Ni, and 0.15 N. Electrodes of this classification are used for welding lean duplex stainless steel such as UNS S32101 and S32304. Weld metal deposited by these electrodes has a “duplex” microstructure consisting of an austenite-ferrite matrix. Weld metal deposited with E2307 filler metal combines increased tensile strength and improved resistance to stress corrosion cracking as compared to those properties in 308L weld metal.

A8.2.30 E2553TX-X. The nominal composition (wt %) of this weld metal is 25.5 Cr, 9.5 Ni, 3.4 Mo, 2 Cu, and 0.18 N. This electrode is used to join duplex stainless steel base metals containing approximately 25 wt % chromium. The microstructure of the weld deposit consists of a mixture of austenite and ferrite. Because of the two-phase microstructure, this alloy is one of the family of duplex stainless steel alloys. Duplex stainless steels combine high tensile and yield strengths with improved resistance to pitting corrosion and stress corrosion cracking. If postweld annealing is required, this weld metal will require a higher annealing temperature than that required by the duplex base metal.

A8.2.31 E2594TX-X. The nominal composition (wt %) of this classification is 25.5 Cr, 9.3 Ni, 3.5 Mo, and 0.25 N. The sum of the $\text{Cr} + 3.3 (\text{Mo} + 0.5 \text{W}) + 16 \text{N}$, known as the Pitting Resistance Equivalent Number (PRE_N), is at least 40, thereby allowing the weld metal to be called a “superduplex stainless steel.” This number is a semi-quantitative indicator of resistance to pitting in aqueous chloride containing environments. It is designed for the welding of superduplex stainless steels UNS S32750 and S32760 (wrought) and for UNS J93380 and J93404 (cast). It can also be used for the welding of UNS S32550, J93370, and J93372 when not subject to sulfurous or sulfuric acids in service. It can also be used for the welding of low alloy steels to duplex stainless steels as well as to weld ‘standard’ duplex stainless steels such as UNS S32205 and J92205 although the weld metal impact toughness may be inferior to that from E2209TX-X electrodes. If postweld annealing is required, this weld metal will require a higher annealing temperature than that required by the duplex base metal.

A8.2.32 E308HMoT0-3. The composition of this weld metal is the same as that of E308MoTX-X, except that the carbon content is higher than the E308MoT0-3 range. The higher carbon content provides higher strength at elevated temperatures. The primary use of this electrode is for the welding of armor steel.

A8.2.33 E316LKT0-3. The composition of this weld metal is the same as E316LTX-X. These electrodes, however, are “self-shielding” and are used primarily for welding stainless steels for cryogenic service. Although the nominal chromium, nickel, and molybdenum content of E316LKT0-3 filler metal is essentially the same as the other E316 grades, special attention is given to it in order to maximize low-temperature toughness. Minimizing the content of carbon and nitrogen improves the toughness. Low nitrogen content is achieved by providing a more efficient slag system than is employed with EXXXT0-3 self-shielding electrodes. Delta ferrite in the weld metal has an adverse effect on toughness; therefore, the chemical composition of the weld metal is balanced to provide low maximum ferrite content (3 FN or less). Fully austenitic weld metal is preferred from a toughness standpoint; however, it is recognized that the tendency for weld metal fissuring is greater in fully austenitic weld metals.

A8.2.34 R308LT1-5. The nominal composition (wt %) of this weld metal is 18.5 Cr and 10 Ni with carbon held to 0.03% maximum. This flux cored rod is used primarily for root pass welding of Type 304 or 304L stainless steel joints when an inert gas backing purge is either not possible or not desirable. This rod can only be used with the GTAW process, but caution is advised as it will produce a slag cover which must be removed before additional weld layers can be deposited. It is recommended that the manufacturer’s instructions and guidelines be followed when using this rod.

A8.2.35 R309LT1-5. The nominal composition (wt %) of this weld metal is 23.5 Cr and 13 Ni with carbon held to 0.03% maximum. This flux cored filler rod is used primarily for the root pass welding of carbon steel to austenitic stainless steel when inert gas backing purge is either not possible or not desirable. The high Cr and Ni content allow dilution with carbon steel while still producing a weld metal with sufficient alloy to provide stable austenite with a little ferrite despite normal dilution from the carbon steel side of the joint. This rod can only be used with the GTAW process, but caution is advised as it will produce a slag cover which must be removed before additional weld layers can be deposited. It is recommended that the manufacturer's instructions and guidelines be followed when using this rod.

A8.2.36 R316LT1-5. The nominal composition (wt %) of this weld metal is 18.5 Cr, 13 Ni, and 2.5 Mo with C held to 0.03% maximum. This flux cored filler rod is used primarily for the root pass welding of Type 316 or 316L stainless steel joints when inert gas backing purge is either not possible or not desirable. This rod can only be used with the GTAW process but caution is advised as it will produce a slag cover which must be removed before additional weld layers can be deposited. It is recommended that the manufacturer's instructions and guidelines be followed when using this rod.

A8.2.37 R347T1-5. The nominal composition (wt %) of this weld metal is 19.5 Cr and 10 Ni with Nb added as a stabilizer. This flux cored filler rod is used primarily for the root pass welding of Types 321 and 347 stainless steel joints when inert gas backing purge is either not possible or not desirable. This rod can only be used with the GTAW process, but caution is advised as it will produce a slag cover which must be removed before additional weld layers can be deposited. It is recommended that the manufacturer's instructions and guidelines be followed when using this rod.

A8.3 Intended Use of Metal Cored Electrodes

A8.3.1 EC209. The nominal composition (wt %) of this classification is 22 Cr, 11 Ni, 5.5 Mn, 2 Mo, and 0.20 N. Filler metals of this classification are most often used to weld UNS S20910 base metal. This alloy is a nitrogen-strengthened, austenitic stainless steel exhibiting high strength and good toughness over a wide range of temperatures. Weldments in the as-welded condition made using this filler metal are not subject to carbide precipitation. Nitrogen alloying reduces the tendency for carbon diffusion and thereby increases resistance to intergranular corrosion.

The EC209 filler metal has sufficient total alloy content for use in welding dissimilar alloys like mild steel and the stainless steels, and also for direct overlay on mild steel for corrosion applications when used with the gas metal arc welding process.

The gas tungsten arc, plasma arc, and electron beam processes are not suggested for direct application of this filler metal on mild steel.

A8.3.2 EC218. The nominal composition (wt %) of this classification is 17 Cr, 8.5 Ni, 8 Mn, 4 Si, and 0.13 N. Filler metals of this classification are most often used to weld UNS S21800 base metals. This alloy is a nitrogen-strengthened austenitic stainless steel exhibiting high strength and good toughness over a wide range of temperature. Nitrogen alloying in this base composition results in significant improvement in wear resistance in particle-to-metal and metal-to-metal (galling) applications when compared to the more conventional austenitic stainless steels such as Type 304. The EC218 filler metal has sufficient total alloy content for use in welding dissimilar alloys like mild steel and the stainless steels, and also for direct overlay on mild steel for corrosion and wear applications when used with the gas metal arc process. The gas tungsten arc, plasma arc, and electron beam processes are not suggested for direct application of this filler metal on mild steel.

A8.3.3 EC219. The nominal composition (wt %) of this classification is 20 Cr, 6 Ni, 9 Mn, and 0.20 N. Filler metals of this classification are most often used to weld UNS S21900 base metals. This alloy is a nitrogen-strengthened austenitic stainless steel exhibiting high strength and good toughness over a wide range of temperatures.

Weldments made using this filler metal are not subject to carbide precipitation in the as-welded condition. Nitrogen alloying reduces the tendency for intergranular carbide precipitation in the weld area by inhibiting carbon diffusion and thereby increases resistance to intergranular corrosion.

The EC219 filler metal has sufficient total alloy content for use in joining dissimilar alloys like mild steel and the stainless steels, and also for direct overlay on mild steel for corrosive applications when used with the gas metal arc welding process. The gas tungsten arc, plasma arc, and electron beam processes are not suggested for direct application of this filler metal on mild steel.

A8.3.4 EC240. The nominal composition (wt %) of this classification is 18 Cr, 5 Ni, 12 Mn, and 0.20 N. Filler metal of this classification is most often used to weld UNS S24000 and UNS S24100 base metals. These alloys are nitrogen-strengthened austenitic stainless steels exhibiting high strength and good toughness over a wide range of temperatures. Significant improvement of wear resistance in particle-to-metal and metal-to-metal (galling) applications is a valuable characteristic when compared to the more conventional austenitic stainless steels such as Type 304. Nitrogen alloying reduces the tendency toward intergranular carbide precipitation in the weld area by inhibiting carbon diffusion thereby reducing the possibility for intergranular corrosion. Nitrogen alloying also improves resistance to pitting and crevice corrosion in aqueous chloride-containing media. In addition, weldments in Type 240 exhibit improved resistance to transgranular stress corrosion cracking in hot aqueous chloride-containing media. The EC240 filler metal has sufficient total alloy content for use in joining dissimilar alloys like mild steel and the stainless steels and also for direct overlay on mild steel for corrosion and wear applications when used with the gas metal arc process. The gas tungsten arc, plasma arc, and electron beam processes are not suggested for direct application of this filler metal on mild steel.

A8.3.5 EC307. The nominal composition (wt %) of this classification is 21 Cr, 9.5 Ni, 4 Mn, and 1 Mo. Filler metals of this classification are used primarily for moderate-strength welds with good crack resistance between dissimilar steels such as austenitic manganese steel and carbon steel forgings or castings.

A8.3.6 EC308. The nominal composition (wt %) of this classification is 21 Cr and 10 Ni. Commercial specifications for filler and base metals vary in the minimum alloy requirements; consequently, the names 18-8, 19-9, and 20-10 are often associated with filler metals of this classification. This classification is most often used to weld base metals of similar composition, in particular, Type 304.

A8.3.7 EC308Si. This classification is the same as EC308, except for the higher silicon content. This improves the usability of the filler metal in the gas metal arc welding process (see A9.2). If the dilution by the base metal produces low ferrite or fully austenitic weld metal, the crack sensitivity of the weld is somewhat higher than that of lower silicon content weld metal.

A8.3.8 EC308H. This classification is the same as EC308, except that the allowable carbon content has been restricted to the higher portion of the 308 range. Carbon content in the range of 0.04%–0.08% provides higher strength at elevated temperatures. This filler metal is used for welding 304H base metal.

A8.3.9 EC308L. This classification is the same as EC308, except for the carbon content. Low carbon (0.03% maximum) in this filler metal reduces the possibility of intergranular carbide precipitation. This increases the resistance to intergranular corrosion without the use of stabilizers such as niobium or titanium. Strength of this low carbon alloy, however, is less than that of the niobium-stabilized alloys or Type 308H at elevated temperatures.

A8.3.10 EC308LSi. This classification is the same as EC308L, except for the higher silicon content. This improves the usability of the filler metal in the gas metal arc welding process (see A9.2). If the dilution by the base metal produces a low ferrite or fully austenitic weld, the crack sensitivity of the weld is somewhat higher than that of lower silicon content weld metal.

A8.3.11 EC308Mo. This classification is the same as EC308, except for the addition of molybdenum. It is used for welding ASTM CF8M stainless steel castings and matches the base metal with regard to chromium, nickel, and molybdenum contents. It may be used for welding wrought materials such as Type 316 (UNS31600) stainless when ferrite content in excess of that attainable with the EC316 classification is desired.

A8.3.12 EC308LMo. This classification is used for welding ASTM CF3M stainless steel castings and matches the base metal with regard to chromium, nickel, and molybdenum contents. It may be used for welding wrought materials such as Type 316L stainless when a ferrite in excess of that attainable with EC316L is desired.

A8.3.13 EC309. The nominal composition (wt %) of this classification is 24 Cr and 13 Ni. Filler metals of this classification are commonly used for welding similar alloys in wrought or cast form. Occasionally, they are used to weld Type 304 and similar base metals where severe corrosion conditions exist requiring higher alloy weld metal. They are also used in dissimilar metal welds, such as joining Type 304 to carbon steel, welding the clad side of Type 304 clad steels, and applying stainless steel sheet linings to carbon steel shells.

A8.3.14 EC309Si. This classification is the same as EC309, except for higher silicon content. This improves the usability of the filler metal in the gas metal arc welding process (see A9.2). If the dilution by the base metal produces a

low ferrite or fully austenitic weld metal deposit, the crack sensitivity of the weld is somewhat higher than that of a lower silicon content weld metal.

A8.3.15 EC309L. This classification is the same as EC309, except for the carbon content. Low carbon (0.03% max.) in this filler metal reduces the possibility of intergranular carbide precipitation. This increases the resistance to intergranular corrosion without the use of stabilizers such as niobium or titanium. Strength of this low carbon alloy, however, may not be as great at elevated temperatures as that of the niobium-stabilized alloys or EC309.

A8.3.16 EC309LSi. This classification is the same as EC309L, except for higher silicon content. This improves the usability of the filler metal in the gas metal arc welding process (see A9.2). If the dilution by the base metal produces a low ferrite or fully austenitic weld, the crack sensitivity of the weld is somewhat higher than that of lower silicon content weld metal.

A8.3.17 EC309Mo. This classification is the same as EC309, except for the addition of 2.0% to 3.0% molybdenum to increase its pitting corrosion resistance in halide-containing environments. The primary application for this filler metal is surfacing of base metals to improve their corrosion resistance. The EC309Mo is used to achieve a single-layer overlay with a chemical composition similar to that of a 316 stainless steel. It is also used for the first layer of multilayer overlays with filler metals such as EC316 or EC317 stainless steels. Without the first layer of 309Mo, elements such as chromium and molybdenum might be reduced to unacceptable levels in successive layers by dilution from the base metal. Other applications include the welding of molybdenum-containing stainless steel linings to carbon steel shells, the joining of carbon steel base metals which had been clad with a molybdenum-containing stainless steel, and the joining of dissimilar base metals such as carbon steel to Type 304 stainless steel, for service below 600 °F [315 °C].

A8.3.18 EC309LMo. This classification is the same as an EC309Mo, except for lower maximum carbon content (0.03%). Low carbon contents in stainless steels reduce the possibility of chromium carbide precipitation and thereby increase weld metal resistance to intergranular corrosion. The EC309LMo is used in the same type of applications as the EC309Mo, but where excessive pickup of carbon from dilution by the base metal, where intergranular corrosion from carbide precipitation, or both are factors to be considered in the selection of the filler metal. In multilayer overlays, the low carbon EC309LMo is usually needed for the first layer in order to achieve low carbon contents in successive layers with filler metals such as EC316L or EC317L.

A8.3.19 EC310. The nominal composition (wt %) of this classification is 26.5 Cr and 21 Ni. Filler metal of this classification is most often used to weld base metals of similar composition.

A8.3.20 EC312. The nominal composition (wt %) of this classification is 30 Cr and 9 Ni. Filler metal of this classification was originally designed to weld cast alloys of similar composition. It also has been found to be valuable in welding dissimilar metals such as carbon steel to stainless steel, particularly those grades high in nickel. This alloy gives a two-phase weld deposit with substantial percentages of ferrite in an austenite matrix. Even with considerable dilution by austenite-promoting elements such as nickel, the microstructure remains two-phase and thus highly resistant to weld metal cracks and fissures.

A8.3.21 EC316. The nominal composition (wt %) of this classification is 19 Cr, 12.5 Ni, and 2.5 Mo. This filler metal is used for welding Type 316 and similar alloys. It has been used successfully in certain applications involving special base metals for high-temperature service. The presence of molybdenum provides creep resistance at elevated temperatures and pitting resistance in a halide atmosphere.

A8.3.22 EC316Si. This classification is the same as EC316, except for the higher silicon content. This improves the usability of the filler metal in the gas metal arc welding process (see A9.2). If the dilution by the base metal produces a low ferrite or fully austenitic weld, the crack sensitivity of the weld is somewhat higher than that of lower silicon content weld metal.

A8.3.23 EC316H. This filler metal is the same as EC316, except that the allowable carbon content has been restricted to the higher portion of the 316 range. Carbon content in the range of 0.04 wt % to 0.08 wt % provides higher strength at elevated temperatures. This filler metal is used for welding 316H base metal.

A8.3.24 EC316L. This classification is the same as EC316, except for the carbon content. Low carbon (0.03% maximum) in this filler metal reduces the possibility of intergranular chromium carbide precipitation and thereby increases the resistance to intergranular corrosion without the use of stabilizers such as niobium or titanium. This filler metal is primarily

used for welding low carbon molybdenum-bearing austenitic alloys. This low carbon alloy, however, is not as strong at elevated temperature as the niobium-stabilized alloys or Type EC316H.

A8.3.25 EC316LSi. This classification is the same as EC316L, except for the higher silicon content. This improves the usability of the filler metal in the gas metal arc welding process (see A9.2). If the dilution by the base metal produces a low ferrite or fully austenitic weld, the crack sensitivity is somewhat higher than that of lower silicon content weld metal.

A8.3.26 EC316LMn. The nominal composition (wt %) of this classification is 19 Cr, 15 Ni, 7 Mn, 3 Mo, and 0.2 N. This is a fully austenitic alloy with a typical ferrite content of 0.5 FN maximum. One of the primary uses of this filler metal is for joining similar and dissimilar cryogenic steels for applications down to -452°F (-269°C). This filler metal also exhibits good corrosion resistance in acids and seawater, and is particularly suited for corrosion conditions found in urea synthesis plants. It is also nonmagnetic. The high Mn content of the alloy helps to stabilize the austenitic microstructure and aids in hot cracking resistance.

A8.3.27 EC317. The nominal composition (wt %) of this classification is 19.5 Cr, 14 Ni, and 3.5 Mo, somewhat higher than EC316. It is usually used for welding alloys of similar composition. EC317 filler metal is utilized in severely corrosive environments where crevice and pitting corrosion are of concern.

A8.3.28 EC317L. This classification is the same as EC317, except for the carbon content. Low carbon (0.03% maximum) in this filler metal reduces the possibility of intergranular carbide precipitation. This increases the resistance to intergranular corrosion without the use of stabilizers such as niobium or titanium. This low carbon alloy, however, may not be as strong at elevated temperature as the niobium-stabilized alloys or Type 317.

A8.3.29 EC318. This composition is identical to EC316, except for the addition of niobium. Niobium provides resistance to intergranular chromium carbide precipitation and thus increased resistance to intergranular corrosion. Filler metal of this classification is used primarily for welding base metals of similar composition.

A8.3.30 EC320. The nominal composition (wt %) of this classification is 20 Cr, 34 Ni, 2.5 Mo, and 3.5 Cu, with Nb added to provide resistance to intergranular corrosion. Filler metal of this classification is primarily used to weld base metals of similar composition for applications where resistance to severe corrosion involving a wide range of chemicals, including sulfuric and sulfurous acids and their salts, is required. This filler metal can be used to weld both castings and wrought alloys of similar composition without postweld heat treatment. A modification of this classification without niobium is available for repairing castings which do not contain niobium, but with this modified composition, solution annealing is required after welding.

A8.3.31 EC320LR (Low Residuals). This classification has the same basic composition as EC320; however, the elements C, Si, P, and S are specified at lower maximum levels and the Nb and Mn are controlled within narrower ranges. These changes reduce the weld metal hot cracking and fissuring (while maintaining the corrosion resistance) frequently encountered in fully austenitic stainless steel weld metals. Consequently, welding practices typically used for austenitic stainless steel weld metals containing ferrite can be used in bare filler metal welding processes such as gas tungsten arc and gas metal arc welding. EC320LR filler metal has been used successfully in submerged arc overlay welding, but it may be prone to cracking when used for joining base metal by the submerged arc process. EC320LR weld metal has a lower minimum tensile strength than EC320 weld metal.

A8.3.32 EC321. The nominal composition (wt %) of this classification is 19.5 Cr and 9.5 Ni, with titanium added. The titanium acts in the same way as niobium in Type 347 in reducing intergranular chromium carbide precipitation and thus increasing resistance to intergranular corrosion. The filler metal of this classification is used for welding chromium-nickel stainless steel base metals of similar composition, using an inert gas shielded process. It is not suitable for use with the submerged arc process because only a small portion of the titanium will be recovered in the weld metal.

A8.3.33 EC330. The nominal composition (wt %) of this classification is 35.5 Ni and 16 Cr. Filler metal of this type is commonly used where heat and scale resisting properties above 1800°F (980°C) are required, except in high-sulfur environments, as these environments may adversely affect elevated temperature performance. Repairs of defects in alloy castings and the welding of castings and wrought alloys of similar composition are the most common applications.

A8.3.34 EC347. The nominal composition (wt %) of this classification is 20 Cr and 10 Ni, with Nb added as a stabilizer. The addition of niobium reduces the possibility of intergranular chromium carbide precipitation and thus susceptibility to intergranular corrosion. The filler metal of this classification is usually used for welding chromium-

nickel stainless steel base metals of similar composition stabilized with either Nb or Ti. Although Nb is the stabilizing element usually specified in Type 347 alloys, it should be recognized that tantalum (Ta) is also present. Ta and Nb are almost equally effective in stabilizing carbon and in providing high-temperature strength. If dilution by the base metal produces a low ferrite or fully austenitic weld metal, the crack sensitivity of the weld may increase substantially.

A8.3.35 EC347Si. This classification is the same as EC347, except for the higher silicon content. This improves the usability of the filler metal in the gas metal arc welding process (see A9.2). If the dilution by the base metal produces a low ferrite or fully austenitic weld, the crack sensitivity of the weld is somewhat higher than that of lower silicon content weld metal.

A8.3.36 EC383. The nominal composition (wt %) of this classification is 27.5 Cr, 31.5 Ni, 3.7 Mo, and 1 Cu. Filler metal of this classification is used to weld UNS N08028 base metal to itself, or to other grades of stainless steel. EC383 filler metal is recommended for sulfuric and phosphoric acid environments. The elements C, Si, P, and S are specified at low maximum levels to minimize weld metal hot cracking and fissuring (while maintaining the corrosion resistance) frequently encountered in fully austenitic stainless steel weld metals.

A8.3.37 EC385. The nominal composition (wt %) of this classification is 20.5 Cr, 25 Ni, 4.7 Mo, and 1.5 Cu. ER385 filler metal is used primarily for welding of ASTM B625, B673, B674, and B677 (UNS N08904) materials for the handling of sulfuric acid and many chloride containing media. EC385 filler metal may also be used to join Type 317L material where improved corrosion resistance in specific media is needed. EC385 filler metal may be used for joining UNS N08904 base metals to other grades of stainless steel. The elements C, S, P, and Si are specified at lower maximum levels to minimize weld metal hot cracking and fissuring (while maintaining corrosion resistance) frequently encountered in fully austenitic weld metals.

A8.3.38 EC409. This 12 Cr alloy (wt %) differs from Type 410 material because it has a ferritic microstructure. The titanium addition forms carbides to improve corrosion resistance, increase strength at high temperature, and promote the ferritic microstructure. EC409 filler metals may be used to join matching or dissimilar base metals. The greatest usage is for applications where thin stock is fabricated into exhaust system components.

A8.3.39 EC409Nb. This classification is the same as EC409, except that niobium is used instead of titanium to achieve similar results. Oxidation losses across the arc generally are lower. Applications are the same as those of EC409 filler metals.

A8.3.40 EC410. This 12 Cr alloy (wt %) is an air-hardening steel. Preheat and postweld heat treatments are required to achieve welds of adequate ductility for many engineering purposes. The most common application of filler metal of this type is for welding alloys of similar composition. It is also used for deposition of overlays on carbon steels to resist corrosion, erosion, or abrasion.

A8.3.41 EC410NiMo. The nominal composition (wt %) of this classification is 12 Cr, 4.5 Ni, and 0.55 Mo. It is primarily designed for welding ASTM CA6NM castings or similar material, as well as light-gauge 405, 410, and 410S base metals. Filler metal of this classification is modified to contain less chromium and more nickel to eliminate ferrite in the microstructure as it has a deleterious effect on mechanical properties. Final postweld heat treatment should not exceed 1150 °F [620 °C], as higher temperatures may result in rehardening due to untempered martensite in the microstructure after cooling to room temperature.

A8.3.42 EC420. This classification is similar to EC410, except for slightly higher chromium and carbon contents. EC420 is used for many surfacing operations requiring corrosion resistance provided by 12% chromium along with somewhat higher hardness than weld metal deposited by EC410 electrodes. This increases wear resistance.

A8.3.43 EC430. This is a 16 wt % Cr alloy. The composition is balanced by providing sufficient chromium to give adequate corrosion resistance for the usual applications, and yet retain sufficient ductility in the heat-treated condition (excessive chromium will result in lower ductility). Welding with filler metal of the EC430 classification usually requires preheating and postweld heat treatment.

Optimum mechanical properties and corrosion resistance are obtained only when the weldment is heat treated following the welding operation.

A8.3.44 EC439. This is an 18 wt % Cr alloy that is stabilized with titanium. EC439 provides improved oxidation and corrosion resistance over EC409 in similar applications. Applications are the same as those of EC409 filler metals where thin stock is fabricated into exhaust system components.

A8.3.45 EC439Nb. This classification is the same as EC439, except that niobium is used instead of titanium to achieve similar results. Oxidation loss across the arc for Nb is generally lower than Ti loss in EC439. Applications for EC439Nb filler metal are generally similar to EC439. Its major use is in automotive exhaust systems components.

A8.3.46 EC446LMo. The nominal composition (wt %) of this classification (formerly listed as EC26-1) is 26 Cr and 1 Mo. It is used for welding base metal of the same composition with inert gas shielded welding processes. Due to the high purity of both base metal and filler metal, cleaning of the parts before welding is most important. Complete coverage by shielding gas during welding is extremely important to prevent contamination by oxygen and nitrogen. Nonconventional gas shielding methods (leading, trailing, and back shielding) often are employed.

A8.3.47 EC630. The nominal composition (wt %) of this classification is 16.4 Cr, 4.7 Ni, and 3.6 Cu. The composition is designed primarily for welding ASTM A564 Type 630 and some other precipitation-hardening stainless steels. The composition is modified to prevent the formation of ferrite networks in the martensitic microstructure which have a deleterious effect on mechanical properties. Dependent on the application and weld size, the weld metal may be used as- welded; welded and precipitation hardened; or welded, solution treated, and precipitation hardened.

A8.3.48 EC19-10H. The nominal composition (wt %) of this classification is 19 Cr and 10 Ni and is similar to ER308H, except that the chromium content is lower and there are additional limits on Mo, Nb, and Ti. This lower limit of Cr and additional limits on other Cr equivalent elements allows a lower ferrite range to be attained. A lower ferrite level in the weld metal decreases the chance of sigma embrittlement after long-term exposure at temperatures in excess of 1000 °F [540 °C]. This filler metal should be used in conjunction with welding processes and other welding consumables which do not deplete or otherwise significantly change the amount of chromium in the weld metal. If used with submerged arc welding, a flux that neither removes nor adds chromium to the weld metal is highly recommended.

This filler metal also has the higher carbon level required for improved creep properties in high-temperature service. The user is cautioned that actual weld application qualification testing is recommended in order to be sure that an acceptable weld metal carbon level is obtained. If corrosion or scaling is a concern, special testing, as outlined in Clause A10, Special Tests, should be included in application testing.

A8.3.49 EC16-8-2. The nominal composition (wt %) of this classification is 15.5 Cr, 8.5 Ni, and 1.5 Mo. Filler metal of this classification is used primarily for welding stainless steel such as types 16-8-2, 316, and 347 for high-pressure, high-temperature piping systems. The weld deposit usually has a Ferrite Number no higher than 5 FN. The deposit also has good hot-ductility properties which offer greater freedom from weld or crater cracking even under restraint conditions. The weld metal is usable in either the as-welded condition or solution-treated condition. This filler metal depends on a very carefully balanced chemical composition to develop its fullest properties. Corrosion tests indicate that the 16-8-2 weld metal may have less corrosion resistance than 316 base metal, depending on the corrosive media. Where the weldment is exposed to severe corrodants, the surface layers should be deposited with a more corrosion-resistant filler metal.

A8.3.50 EC2209. The nominal composition (wt %) of this classification is 22.5 Cr, 8.5 Ni, 3 Mo, and 0.15 N. Filler metal of this classification is used primarily to weld duplex stainless steels which contain approximately 22% chromium such as UNS S31803 and S32205. Deposits of this alloy have “duplex” microstructures consisting of an austenite-ferrite matrix. These stainless steels are characterized by high tensile strength, resistance to stress corrosion cracking, and improved resistance to pitting.

A8.3.51 EC2553. The nominal composition (wt %) of this classification is 25.5 Cr, 5.5 Ni, 3.4 Mo, 2 Cu, and 0.2 N. Filler metal of this classification is used primarily to weld duplex stainless steels UNS S32550 which contain approximately 25% chromium. Deposits of this alloy have a “duplex” microstructure consisting of an austenite-ferrite matrix. These stainless steels are characterized by high tensile strength, resistance to stress corrosion cracking, and improved resistance to pitting.

A8.3.52 EC2594. The nominal composition (wt %) of this classification is 25.5 Cr, 9.2 Ni, 3.5 Mo, and 0.25 N. The sum of the Cr + 3.3(Mo + 0.5 W) + 16 N, known as the Pitting Resistance Equivalent Number (PREN), is at least 40, thereby allowing the weld metal to be called a ‘superduplex stainless steel’. This number is a semi-quantitative indicator of resistance to pitting in aqueous chloride-containing environments. It is designed for the welding of superduplex stainless steels UNS S32750 and 32760 (wrought), and UNS J93380 and J93404 (cast). It can also be used for the welding of UNS S32550, J93370, and J93372 when not subject to sulfurous or sulfuric acids in service. It can also be used for

welding carbon and low alloy steels to duplex stainless steels as well as to weld 'standard' duplex stainless steel such as UNS S32205 and J92205, especially for root runs in pipe.

A8.3.53 EC33-31. The nominal composition (wt %) of this classification is 33 Cr, 31Ni, and 1.6 Mo, with low carbon. The filler metal is used for welding nickel-chromium-iron alloy (UNS R20033) to itself and to carbon steel, and for weld overlay on boiler tubes. The weld metal is resistant to high temperature corrosive environments of coal fired power plant boilers.

A8.3.54 EC3556. The nominal composition (wt %) of this classification is 31 Fe, 20 Ni, 22 Cr, 18 Co, 3 Mo, and 2.5 W. Filler metal of this classification is used for welding 31 Fe, 20 Ni, 22 Cr, 18 Co, 3 Mo, 2.5 W (UNS R30556) base metal to itself, for joining steel to other nickel alloys, and for surfacing steel by the gas tungsten arc, gas metal arc, and plasma arc welding processes. The filler metal is resistant to high-temperature corrosive environments containing sulfur. Typical specifications for 31 Fe, 20 Ni, 22 Cr, 18 Co, 3 Mo, 2.5 W base metal are ASTM B435, B572, B619, B622, and B626 (UNS R30556).

A9. Special Tests

It is recognized that supplementary tests may be required for certain applications. In such cases, tests to determine specific properties such as strength at elevated or cryogenic temperatures may be required. For impact testing at any temperature, the requirements of Impact Test (Clause 14) for specimen type and size should be followed. AWS A5.01M/A5.01 contains provisions for ordering such tests. This clause is included for the guidance of those who desire to specify such special tests. Those tests may be conducted as agreed by supplier and purchaser.

Tests of joint specimens may be desired when the intended application involves the welding of dissimilar metals. Procedures for the mechanical testing of such joints should be in accordance with AWS B4.0, *Standard Methods for Mechanical Testing of Welds*. Tests of joint specimens may be influenced by the properties of the base metal and may not provide adequate tests of the weld metal. Such tests should be considered as tests for qualifying the electrodes or rods. Where fabrication codes require testing welds in heat-treated conditions other than those specified in Table 6, all-weld-metal tests of heat-treated specimens may be desired. For the preparation of such specimens the procedures outlined in 9.4 should be used.

A9.1 Corrosion or Scaling Tests. Although welds made with electrodes or rods in this specification commonly are used in corrosion- and heat-resisting applications, tests for those properties are not included in the specification. Such special tests pertinent to the intended application may be conducted as agreed upon between the purchaser and supplier. This subclause is included for the guidance of those who desire such special tests.

A9.1.1 Corrosion or scaling tests of joint specimens have the advantage that the joint design and welding procedure can be made identical to those being used in fabrication. However, the user must be aware that these are tests of the combined properties of the weld metal, the heat-affected zone of the base metal, and the unaffected base metal. It is difficult to obtain reproducible data when a difference exists between the corrosion or oxidation rates of the various metal structures (weld metal, heat-affected zone, and unaffected base metal). Test samples cannot be readily standardized if welding procedure and joint design are to be considered variables. Joint specimens for corrosion tests should not be used for qualifying the electrode.

A9.1.2 All-weld-metal specimens for testing corrosion or scale resistance are prepared by following the procedure outlined for the preparation of pads for chemical analysis (see Clause 9). The pad size should be at least 3/4 in [19 mm] in height by 2-1/2 in [65 mm] wide by 1 + n/8 in [25 + n/16 mm] long, where "n" represents the number of specimens required from the pad. Specimens measuring 1/2 × 2 × 1/4 in [13 × 51 × 6.4 mm] are machined from the top surface of the pad in such a way that the 2 in [51 mm] dimension of the specimen is parallel to the 2-1/2 in [65 mm] width dimension of the pad and the 1/2 in [13 mm] dimension is parallel to the length of the pad.

A9.1.3 The heat treatments, surface finish, and marking of the specimens prior to testing should be in accordance with standard practices for tests of similar alloys in the wrought or cast forms. The testing procedure should correspond to ASTM G4, *Standard Method for Conducting Corrosion Tests in Plant Equipment*, or ASTM A262, *Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels*.

A10. Discontinued Classifications

Some classifications have been discontinued from one revision of this specification to another. This results either from changes in commercial practice or changes in the classification system used in the specification. The classifications that have been discontinued are listed in Table A.3 along with the year in which they were last included in this specification.

A11. General Safety Considerations

A11.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Annex Clause A5. Safety and health information is available from other sources, including, but not limited to Safety and Health Fact Sheets, ANSI Z49.1 *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations.

A11.2 Safety and Health Fact Sheets. The Safety and Health Fact Sheets are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

Table A.3
Discontinued Classifications

Classification	Year of Last Publication
EXXXT-2	1980
E309LCbTX-X ^a	1995
E410NiTiTX-X	1995
E410NiTiT0-3	1995
E502TX-X ^b	1995
E505TX-X ^b	1995

^a E309LCbTX-X is now E309LNbTX-X.

^b Classifications E502TX-X and E505TX-X have been moved from this revision to AWS A5.29/5.29M as new classifications E8XTX-B6/E8XTX-B6L and E8XTX-B8/E8XTX-B8L, respectively.

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

B6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

AWS Filler Metal Specifications by Material and Welding Process

	OFW	SMAW	GTAW GMAW PAW	FCAW	SAW	ESW	EGW	Brazing
Carbon Steel	A5.2	A5.1, A5.35	A5.18	A5.20	A5.17	A5.25	A5.26	A5.8, A5.31
Low-Alloy Steel	A5.2	A5.5	A5.28	A5.29	A5.23	A5.25	A5.26	A5.8, A5.31
Stainless Steel		A5.4, A5.35	A5.9, A5.22	A5.22	A5.9, A5.22, A5.39	A5.9, A5.22, A5.39	A5.9	A5.8, A5.31
Cast Iron	A5.15	A5.15	A5.15	A5.15				A5.8, A5.31
Nickel Alloys		A5.11, A5.35	A5.14, A5.34	A5.34	A5.14, A5.34, A5.39	A5.14, A5.34, A5.39		A5.8, A5.31
Aluminum Alloys		A5.3	A5.10					A5.8, A5.31
Copper Alloys		A5.6	A5.7					A5.8, A5.31
Titanium Alloys			A5.16					A5.8, A5.31
Zirconium Alloys			A5.24					A5.8, A5.31
Magnesium Alloys			A5.19					A5.8, A5.31
Tungsten Electrodes			A5.12					
Brazing Alloys and Fluxes								A5.8, A5.31
Surfacing Alloys	A5.21	A5.13	A5.21	A5.21	A5.21			
Consumable Inserts			A5.30					
Shielding Gases			A5.32	A5.32			A5.32	

AWS Filler Metal Specifications and Related Documents

Designation	Title
A4.2M (ISO 8249 MOD)	<i>Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal</i>
A4.3-ADD1	<i>Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding</i>
A4.4M	<i>Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings</i>
A4.5M/A4.5 (ISO 15792-3 MOD)	<i>Standard Methods for Classification Testing of Positional Capacity and Root Penetration of Welding Consumables in a Fillet Weld</i>
A5.01M/A5.01 (ISO 14344 MOD)	<i>Welding and Brazing Consumables—Procurement of Filler Materials and Fluxes</i>
A5.02/A5.02M	<i>Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes</i>
A5.1/A5.1M	<i>Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding</i>
A5.2/A5.2M	<i>Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding</i>
A5.3/A5.3M	<i>Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.4/A5.4M	<i>Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding</i>
A5.5/A5.5M	<i>Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding</i>
A5.6/A5.6M	<i>Specification for Copper and Copper-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.7/A5.7M	<i>Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes</i>
A5.8M/A5.8	<i>Specification for Filler Metals for Brazing and Braze Welding</i>
A5.9/A5.9M (ISO 14343 MOD)	<i>Specification for Bare Stainless Steel Welding Electrodes and Rods</i>
A5.10/A5.10M (ISO 18273 MOD)	<i>Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods</i>
A5.11/A5.11M	<i>Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding</i>
A5.12M/A5.12 (ISO 6848 MOD)	<i>Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting</i>
A5.13/A5.13M	<i>Specification for Surfacing Electrodes for Shielded Metal Arc Welding</i>
A5.14/A5.14M	<i>Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods</i>
A5.15	<i>Specification for Welding Electrodes and Rods for Cast Iron</i>
A5.16/A5.16M (ISO 24034 MOD)	<i>Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods</i>
A5.17/A5.17M	<i>Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.18/A5.18M	<i>Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.19	<i>Specification for Magnesium-Alloy Welding Electrodes and Rods</i>
A5.20/A5.20M	<i>Specification for Carbon Steel Electrodes for Flux Cored Arc Welding</i>
A5.21/A5.21M	<i>Specification for Bare Electrodes and Rods for Surfacing</i>
A5.22/A5.22M	<i>Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods</i>
A5.23/A5.23M	<i>Specification for Low-Alloy and High Manganese Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.24/A5.24M	<i>Specification for Zirconium and Zirconium-Alloy Welding Electrodes and Rods</i>
A5.25/A5.25M	<i>Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding</i>
A5.26/A5.26M	<i>Specification for Carbon and Low-Alloy Steel Electrodes for Electrogas Welding</i>
A5.28/A5.28M	<i>Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.29/A5.29M	<i>Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding</i>
A5.30/A5.30M	<i>Specification for Consumable Inserts</i>
A5.31M/A5.31	<i>Specification for Fluxes for Brazing and Braze Welding</i>
A5.32M/A5.32 (ISO 14175 MOD)	<i>Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes</i>
A5.34/A5.34M	<i>Specification for Nickel-Alloy Flux Cored and Metal Cored Welding Electrodes</i>
A5.35/A5.35M-AMD1	<i>Specification for Covered Electrodes for Underwater Wet Shielded Metal Arc Welding</i>
A5.39/A5.39M	<i>Specification for Stainless Steel and Nickel-Alloy Electrodes and Fluxes for Submerged Arc and Electroslag Welding</i>

INTENTIONALLY LEFT BLANK

SPECIFICATION FOR LOW-ALLOY AND HIGH MANGANESE STEEL ELECTRODES AND FLUXES FOR SUBMERGED ARC WELDING



SFA-5.23/SFA-5.23M



(Identical with AWS Specification A5.23/A5.23M:2021. In case of dispute, the original AWS text applies.)

Specification for Low-Alloy and High Manganese Steel Electrodes and Fluxes for Submerged Arc Welding

1. Scope

1.1 This specification prescribes requirements for the classification of solid and composite carbon steel, low-alloy steel, and high manganese steel electrodes and flux-electrode combinations for submerged arc welding (SAW). This specification covers low-alloy and high manganese electrodes and low-alloy and high manganese multiple-pass flux-electrode classifications. This specification also addresses carbon steel, low-alloy steel, and high manganese steel two-run flux-electrode classifications. The multiple-pass classification of flux-electrode combinations for carbon steel SAW is not within the scope of this specification, but is covered in AWS A5.17/A5.17M.

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to weld metal properties. The specification with the designation A5.23 uses U.S. Customary Units. The specification A5.23M uses SI Units. The latter are shown within brackets [], in appropriate columns in tables and figures and in paragraphs numbered with an “M” suffix. Standard dimensions based on either system may be used for the sizing of electrodes, packaging, or both under specification A5.23 or A5.23M.

1.3 Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in Annex A Clauses A5 and A11. Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to or revisions of any of these publications do not apply.

American Welding Society (AWS) documents:

AWS A1.1, *Metric Practice Guide for the Welding Industry*

AWS A3.0M/A3.0 *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

AWS A4.3 ADD1, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*

AWS A5.01M/A5.01 (ISO 14344 MOD), *Welding and Brazing Consumables—Procurement of Filler Metals and Fluxes*

AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*

AWS A5.17/A5.17M, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*

AWS B4.0, *Standard Methods for Mechanical Testing of Welds*

American National Standards Institute (ANSI) document:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

ASTM International documents:

ASTM A36/A36M, *Specification for Carbon Structural Steel*

ASTM A131/A131M, *Specification for Structural Steel for Ships*

ASTM A203/A203M, *Specification for Pressure Vessel Plates, Alloy Steel, Nickel*

ASTM A204/A204M, *Specification for Pressure Vessel Plates, Alloy Steel, Molybdenum*

ASTM A285/A285M, *Specification for Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength*

ASTM A335/A335M *Standard Specification for Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service*

ASTM A387/A387M, *Specification for Pressure Vessel Plates, Alloy Steel, Chromium-Molybdenum*

ASTM A514/A514M, *Specification for High-Yield-Strength, Quenched and Tempered Alloy Steel Plate, Suitable for Quenching*

ASTM A515/A515M, *Specification for Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service*

ASTM A516/A516M, *Specification for Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service*

ASTM A517/A517M, *Specification for Pressure Vessel Plates, Alloy Steel, High-Strength, Quenched and Tempered*

ASTM A533/A533M, *Specification for Pressure Vessel Plates, Alloy Steel, Quenched and Tempered, Manganese-Molybdenum and Manganese-Molybdenum-Nickel*

ASTM A537/A537M, *Specification for Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel*

ASTM A543/A543M, *Specification for Pressure Vessel Plates, Alloy Steel, Quenched and Tempered, Nickel-Chromium-Molybdenum*

ASTM A572/A572M, *Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel*

ASTM A588/A588M, *Specification for High-Strength Low-Alloy Structural Steel, up to 50 ksi [345 MPa] Minimum Yield Point with Atmospheric Corrosion Resistance*

ASTM A1106/A1106M, *Standard Specification for Pressure Vessel Plate, Alloy Steel, Austenitic High Manganese for Cryogenic Application*

ASTM E23, *Standard Test Methods for Notched Bar Impact Testing of Metallic Materials*

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

ASTM E350, *Standard Test Methods for Chemical Analysis of Carbon Steel, Low Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron*

ASTM E353, *Standard Test Methods for Chemical Analysis of Stainless, Heat-Resisting, Maraging, and Other Similar Chromium-Nickel-Iron Alloys*

ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*

ASTM E2033, *Standard Practice for Radiographic Examination Using Computed Radiography (Photostimulable Luminescence Method)*

ASTM E2698, *Standard Practice for Radiographic Examination Using Digital Detector Arrays*

International Organization for Standardization (ISO) document:

ISO 80000-1, *Quantities and Units — Part 1: General*

3. Classification

3.1 The SAW electrodes and fluxes covered by the A5.23 specification utilize a classification system based upon U.S. Customary Units and are classified according to the following:

(1) The mechanical properties of the weld metal obtained from a multiple-pass groove weld, a two-run butt weld, or both; made with a combination of a particular flux and a particular classification of electrode, as specified in Tables 1 and 2.

(2) The condition of heat treatment in which the properties are obtained, as specified in 9.4 or 9.5, as applicable (and as shown in Figure 1 or Figure 2, as applicable).

(3) For multiple-pass classifications, the chemical composition of the weld metal obtained with the combination of a particular flux and a particular classification of electrode as specified in Table 3. Weld metal chemical composition is not specified for two-run classifications under this specification (see Figure 1 or Figure 2, as applicable).

(4) The chemical composition of either the electrode (for solid electrodes) as specified in Table 4, or the weld metal produced with a particular flux (for composite electrodes) as specified in Table 3.

3.1M The SAW electrodes and fluxes covered by the A5.23M specification utilize a classification system based upon the International System of Units (SI) and are classified according to the following:

(1) The mechanical properties of the weld metal obtained from a multiple-pass groove weld, a two-run butt weld, or both; made with a combination of a particular flux and a particular classification of electrode, as specified in Tables 1M and 2.

(2) The condition of heat treatment in which the properties are obtained, as specified in 9.4 or 9.5, as applicable (and as shown in Figure 1M or Figure 2M, as applicable).

(3) For multiple-pass classifications, the chemical composition of the weld metal obtained with the combination of a particular flux and a particular classification of electrode as specified in Table 3. Weld metal chemical composition is not specified for two-run classifications under this specification (see Figure 1M or Figure 2M, as applicable).

(4) The chemical composition of either the electrode (for solid electrodes) as specified in Table 4, or the weld metal produced with a particular flux (for composite electrodes) as specified in Table 3.

3.2 Fluxes may be classified under any number of classifications; for weld metal in either or both the as-welded and postweld heat treated conditions, for weld metal deposited using different electrode classifications, for multiple-pass or two-run classifications, or any combination thereof. Flux-electrode combinations may be classified under A5.23 with U.S. Customary Units, under A5.23M using the International System of Units (SI), or both. Flux-electrode combinations classified under both A5.23 and A5.23M must meet all of the requirements for classification under each system. The classification systems are shown in Figures 1 and 1M for multiple-pass classifications and in Figures 2 and 2M for two-run classifications.

3.3 The electrodes and fluxes classified under this specification are intended for SAW, but that is not to prohibit their use with any other process for which they are found suitable.

4. Acceptance

Acceptance of the electrodes and fluxes shall be in accordance with the provisions of AWS A5.01M/A5.01 and the tests and requirements of this specification. See A3 (in Annex A) for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

5. Certification

By affixing the AWS specification and classification designations to the packaging or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification. See A4 (in Annex A) for further information concerning certification and the testing called for to meet this requirement.

6. Rounding Procedure

For the purpose of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest 1000 psi (1 ksi) for tensile and yield strength for A5.23, to the nearest 10 MPa for tensile and yield strength for A5.23M and to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfil the requirements for the classification under test.

7. Summary of Tests

7.1 Chemical analysis of the electrode is the only test required for classification of a solid electrode under this specification. The chemical analysis of the rod stock from which the solid electrode is made may also be used provided the electrode manufacturing process does not alter the chemical composition. For composite electrodes, chemical analysis of the weld metal produced with the composite electrode and a particular flux is required.

7.2 The tests required for each flux-electrode classification are specified in Table 5. The purpose of these tests is to determine the mechanical properties and soundness of the weld metal. The base metal for test assemblies, preparation of the test samples, the welding and testing procedures to be employed, and the results required are given in Clauses 9 through 14.

7.3 Classification is based upon a 5/32 in [4.0 mm] electrode size as standard. If this size electrode is not manufactured, the closest size shall be used for classification tests. See Table 6, Note d and Table 7, Note e.

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Material, specimens, or samples for retest may be taken from the original test assembly or sample or from new test assemblies or samples. For chemical analysis, retest need be only for those specific elements that failed to meet the test requirement. If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that, during preparation or after completion of any test, it is clearly determined that prescribed or proper procedures were not followed in preparing the weld test assembly or test specimen(s) or in conducting the test, the test shall be considered invalid, without regard to whether the test was actually completed or whether test results met or failed to meet the requirement. That test shall be repeated following proper prescribed procedures. In this case, the requirement for doubling the number of test specimens does not apply.

9. Weld Test Assemblies

9.1 Requirements for Classification

9.1.1 Classification of Solid Electrodes. No weld test assembly is required for classification of solid electrodes.

9.1.2 Classification of Composite Electrodes. The chemical analysis of weld metal produced with the composite electrode and a particular flux is required for classification of a composite electrode under this specification. The weld pad shown in Figure 3 is used to meet this requirement for the classification of composite electrodes. The welding parameters for the multiple-pass groove weld, as specified in Table 6, shall be used. As an alternative to the weld pad, the sample for chemical analysis of composite electrode weld metal may be taken from the groove weld in Figure 4. Note g of Table 3 allows the sample for chemical analysis to be taken from the reduced section of the fractured tension test specimen or from a corresponding location (or any location above it) in the weld metal in the groove weld in Figure 4. In case of dispute, the weld pad shall be the referee method.

9.1.3 Classification of Flux-Electrode Combinations. One groove weld test assembly is required for each multiple-pass classification of a flux-solid electrode combination or a flux-composite electrode combination. This is the groove weld in Figure 4 for mechanical properties and soundness of weld metal. A second test assembly, the weld pad in Figure 3, is required for chemical analysis of the weld metal. However, Note g of Table 3 allows the sample for chemical analysis to be taken from the reduced section of the fractured tension test specimen or from a corresponding location (or any location above it) in the weld metal in the groove weld in Figure 4, thereby avoiding the need to make the weld pad. In case of dispute, the weld pad shall be the referee method.

One butt weld test assembly is required for each two-run classification of a flux-solid electrode combination or flux-composite electrode combination. This is the two-run weld test assembly in Figure 5 for mechanical properties and soundness of weld metal.

9.2 Preparation. Preparation of each weld test assembly shall be as prescribed in 9.3, 9.4, and 9.5. The base metal for the weld pad, the multiple-pass groove weld, and the two-run weld assemblies shall be as required in Table 8 and shall meet the requirements of the ASTM specification shown there or a chemically equivalent steel. Testing of the assemblies shall be as prescribed in Clauses 10 through 13.

9.3 Weld Pad. For composite electrodes or for any flux-electrode multiple-pass classification, a weld pad shall be prepared as specified in Figure 3, except when either alternative in 9.1.2 or 9.1.3 is selected. Base metal of any convenient size and of the type specified in Table 8, shall be used as the base metal for the weld pad. The surface of the base metal on which the filler metal is deposited shall be clean and free from scale. The pad shall be welded in the flat position, three beads per layer, four layers high, using the flux for which classification is intended.

The welding parameters for the groove weld, as specified in Table 6, shall be used except that the preheat temperature shall not be less than 60°F [15°C] and the interpass temperature shall not exceed 300°F [150°C]. The slag shall be removed after each pass. The pad may be quenched in water between passes but shall be dry before the start of each pass. Testing of this assembly shall be as specified in Clause 10, Chemical Analysis.

9.4 Groove Weld for Multiple-Pass Classifications

9.4.1 For mechanical properties and soundness testing of a flux-electrode combination for multiple-pass classification, a test assembly shall be prepared and welded as specified in Figure 4 and Table 6 using base metal of the appropriate type specified in Table 8. Preheat and interpass temperatures shall be as specified in Table 9. The surfaces to be welded shall be clean and free of scale. Prior to welding, the assembly may be preset so that the welded joint will be sufficiently flat after welding to facilitate removal of the test specimens. As an alternative, restraint or a combination of restraint and presetting may be used to keep the welded joint within 5° of plane. A welded test assembly that is more than 5° out of plane shall be discarded. Straightening of the test assembly is prohibited. Testing of this assembly shall be as specified in Clauses 10 through 13, with the assembly in either the as-welded or the postweld heat treated condition, according to the classification of the weld metal (see Figures 1 and 1M). When tests are to be conducted in each condition (as-welded and postweld heat treated) two such assemblies, or one single assembly of sufficient length to provide the specimens required for both conditions, shall be prepared. In the latter case, the single assembly shall be cut transverse to the weld into two pieces. One of the pieces shall be tested in the as-welded condition and the other piece shall be heat treated prior to testing.

9.4.1.1 When postweld heat treatment is required, the heat treatment shall be applied to the test assembly before the specimens for mechanical testing are removed. This heat treatment may be applied either before or after the radiographic examination.

9.4.1.2 Any multiple-pass groove weld test assembly to be heat treated shall be heat treated at the time and temperature specified in Table 9 for the applicable weld metal designation. The welded test assembly shall be put into a suitable furnace at a temperature not greater than 600°F [315°C]. The temperature shall be raised at a rate of 150°F [85°C] to 500°F [280°C] per hour until the holding temperature specified in Table 9 is attained. This temperature shall be maintained for 1 hour (–0, +15 minutes), except as indicated in note e of Table 9.

9.4.1.3 The test assembly shall then be allowed to cool in the furnace at a rate not greater than 350°F [200°C] per hour. After the test assembly has reached 600°F [315°C] it may be removed from the furnace and allowed to cool in still air.

9.5 Butt Weld for Two-Run Classifications

9.5.1 For mechanical properties and soundness testing of a flux-electrode combination for two-run classification, a test assembly shall be prepared and welded as specified in Figure 5 and Table 7 using base metal of the appropriate type specified in Table 8. The surfaces to be welded shall be clean and free of scale. Prior to welding, the assembly may be preset such that the welded joint will be sufficiently flat to facilitate removal of the test specimens. As an alternative, restraint or a combination of restraint and presetting may be used to keep the welded joint sufficiently flat after welding. Straightening of the test assembly is prohibited. Testing shall be as specified in Clauses 10 through 13, with the assembly in either the as-welded or postweld heat treated condition, according to the classification of the weld metal (see Figures 2 and 2M). When tests are to be conducted in each condition (as-welded and postweld heat treated) two such assemblies, or one single assembly of sufficient length to provide the specimens required for both conditions, shall be prepared. In the latter case, the single assembly shall be cut transverse to the weld into two pieces. One of the pieces shall be tested in the as-welded condition and the other piece shall be heat treated prior to testing.

9.5.1.1 When postweld heat treatment is required, the heat treatment shall be applied to the test assembly before the specimens for mechanical testing are removed. This heat treatment may be applied either before or after the radiographic examination.

9.5.1.2 Any two-run butt weld test assembly to be heat treated shall be put into a suitable furnace at a temperature not greater than 600°F [315°C]. The temperature shall be raised at the rate of 150°F [85°C] to 500°F [280°C] per hour until the postweld heat treatment temperature of 1150°F ± 25°F [620°C ± 15°C] is attained. This temperature shall be maintained for 30 minutes (–0, +7 minutes). The above postweld heat treat procedure also applies to FJTPXG-EXX flux-electrode classifications unless otherwise specified by the purchaser.

9.5.1.3 The test assembly shall then be allowed to cool in the furnace at a rate not greater than 350°F [200°C] per hour. After the test assembly has reached 600°F [315°C] it may be removed from the furnace and allowed to cool in still air.

9.6 Diffusible Hydrogen. In those cases in which an optional supplemental diffusible hydrogen designator is to be added to the flux-electrode classification designation, diffusible hydrogen test assemblies shall be prepared, welded, and tested as specified in Clause 14, Diffusible Hydrogen Test.

10. Chemical Analysis

10.1 For solid electrodes, a sample of the electrode or the rod stock from which it is made shall be prepared for chemical analysis. Solid electrodes, when analyzed for elements that are present in a coating (copper flashing, for example), shall be analyzed without removing the coating. When the electrode is analyzed for elements other than those in the coating, the coating shall be removed if its presence affects the results of the analysis for other elements. Rod stock analyzed for elements not in the coating may be analyzed prior to reducing the rod to the finished electrode diameter and applying the coating.

10.2 For composite electrodes and for the multiple-pass classification of flux-electrode combinations, the sample for analysis shall be taken from the weld pad in Figure 3, from the reduced section of the fractured tension test specimen in Figure 4, or from a corresponding location (or any location above it) in the weld metal in the butt weld in Figure 4. Weld

metal from the butt weld used for two-run classification (Figure 5) may not be used for the purpose of classifying composite electrodes. In case of dispute, the weld pad in Figure 3 shall be used as the referee method.

The top surface of the pad described in 9.3 and shown in Figure 3 shall be removed and discarded and a sample for analysis shall be obtained from the underlying metal of the fourth layer of the weld pad by any means that will not change the chemical composition. The sample shall be free of slag. The sample shall be taken at least 3/8 in [10 mm] from the nearest surface of the base metal. The sample from the reduced section of the fractured tension test specimen or from a corresponding location (or any location above it) in the groove weld in Figure 4 shall be prepared for analysis by any suitable means that will not change the chemical composition.

10.3 The sample shall be analyzed by accepted analytical methods. The referee method shall be the procedure in the latest edition of ASTM E350 or ASTM E353, as appropriate for the metal type.

10.4 For composite electrodes and for the multiple-pass classification of flux-electrode combinations, the results of the weld metal analysis shall meet the requirements of Table 3 for the applicable weld metal designation. For solid electrodes, the results of the electrode analysis shall meet the requirements of Table 4 for the classification of electrode being tested.

10.5 *For two-run classifications, the chemical composition of the weld metal is not specified, but reporting of the chemical composition of the base and weld metal are required and shall include C, Mn, Si, S, P, Cu, Cr, Ni, Mo, V, Nb, Ti, and B. The base metal chemical composition may be obtained from the specific steel used for the certification test assembly or metal from the heat of steel used for the certification test assembly. A certified material test report from the base metal supplier traceable to the specific heat of steel used for the certification test assembly may be used. Weld metal chemical analysis shall be obtained from the weld deposit of the second pass.*

11. Radiographic Test

11.1 The groove weld for multiple-pass classifications described in 9.4 and shown in Figure 4 shall be radiographed to evaluate the soundness of the weld metal. In preparation for radiography, the backing shall be removed and both surfaces of the weld shall be machined or ground smooth and flush with the original surfaces of the base metal or with a uniform reinforcement not exceeding 3/32 in [2.5 mm]. It is permitted on both sides of the test assembly to remove base metal to a depth of 1/16 in [1.5 mm] in order to facilitate backing and/or buildup removal. The thickness of the weld metal shall not be reduced by more than 1/16 in [1.5 mm], so that the thickness of the prepared radiographic test specimen equals at least the thickness of the base metal minus 1/16 in [1.5 mm]. Both surfaces of the test assembly, in the area of the weld, shall be smooth enough to avoid difficulty in interpreting the radiograph.

The butt weld for two-run classifications described in 9.5 and shown in Figure 5 shall be radiographed to evaluate the soundness of the weld metal. In preparation for radiography, both ends of the test joint may be trimmed off to remove run-on and run-off tabs, if any, and any excess weld joint material. The surfaces of both weld beads may be machined or ground smooth and flush with the original surfaces of the base metal or with a uniform reinforcement not exceeding 3/32 in [2.5 mm]. It is permitted on both sides of the test assembly to remove base metal to a depth of 1/16 in [1.5 mm] nominal below the original base metal surface in order to facilitate buildup removal. The thickness of the weld metal shall not be reduced by more than 1/16 in [1.5 mm] so that the thickness of the prepared radiographic test specimen equals at least the thickness of the base metal minus 1/16 in [1.5 mm]. Both surfaces of the test assembly, in the area of the weld, shall be smooth enough to avoid difficulty in interpreting the radiograph.

11.2 The weld shall be radiographed in accordance with one of the following. The quality level of inspection shall be 2-2T.

(1) **Film Radiology:** ASTM E1032.

(2) **Computed Radiology (CR):** ASTM E2033 and the requirements of ASTM E1032, except where CR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2033, refers to phosphor imaging plate.

(3) **Digital Radiology (DR):** ASTM E2698 and the requirements of ASTM E1032, except where DR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2698, refers to digital detector array (DDA).

11.3 The soundness of the weld metal meets the requirements of this specification if the radiograph shows:

- (1) no cracks, no incomplete fusion, no incomplete penetration;
- (2) no slag inclusions longer than $5/16$ in [8 mm], no groups of slag inclusions in line that have an aggregate length greater than the thickness of the weld in a length 12 times the thickness of the weld except when the distance between the successive inclusions exceeds six times the length of the longest inclusion in the group; and
- (3) no rounded indications in excess of those permitted by the radiographic standards in Figure 6.

In evaluating the radiograph for the multiple-pass groove weld, 1 in [25 mm] of the weld on each end of the test assembly shall be disregarded. For the two-run butt weld, evaluation shall be made on a 10 in [250 mm] continuous length, as a minimum.

11.3.1 A rounded indication is an indication (on the radiograph) whose length is no more than three times its width. Rounded indications may be circular or irregular in shape, and they may have tails. The size of a rounded indication is the largest dimension of the indication, including any tail that may be present. The indication may be of porosity or slag inclusions.

11.3.2 Indications whose largest dimension does not exceed $1/64$ in [0.4 mm] shall be disregarded. Test assemblies with any rounded indications larger than the large indications permitted in Figure 6 do not meet the requirements of this specification.

12. Tension Test

12.1 For multiple-pass classifications, one all-weld metal tension test specimen, as specified in the Tension Test clause of AWS B4.0, shall be machined from the groove weld described in 9.4 and shown in Figure 4. The all-weld-metal tension specimen shall have a nominal diameter of 0.500 in [12.5 mm] and a nominal gage length to diameter ratio of 4:1.

12.1.1 For flux-electrode combinations classified in the postweld heat-treated condition, the weld metal shall be heat-treated as shown in Table 9 before final machining of the specimen (refer to 9.4.1).

12.1.2 For flux-electrode classifications to be tested in the as-welded condition, the weld test assembly or tension test specimen may be aged at temperatures up to 220°F [105°C] for up to 48 hours, then allowed to cool to room temperature. In case of dispute, aging the tension test specimen shall be the referee method. If the tension specimen or the test assembly is aged, that fact, together with the manner of aging, shall be recorded on the test certificate. Refer to A10.6 in Annex A for a discussion on the purpose of aging.

12.1.3 The specimen shall be tested in the manner described in the Tension Test clause of AWS B4.0.

12.1.4 The results of the tension test shall meet the requirements specified in Table 1 or Table 1M, as applicable.

12.2 For two-run classifications, one longitudinal tension test specimen, as specified in the Tension Test clause of AWS B4.0 shall be machined from the butt weld described in 9.5 and shown in Figure 5. The tensile specimen shall have a nominal diameter of 0.250 in [6.0 mm] and a nominal gage length to diameter ratio of 4:1. The reduced section of the longitudinal tensile specimen shall be located entirely within the weld zone.

12.2.1 For flux-electrode combinations classified in the postweld heat-treated condition, the weld metal shall be heat treated as described in 9.5.1 before final machining of the specimen.

12.2.2 For flux-electrode classifications to be tested in the as-welded condition, the weld test assembly or tension test specimen may be aged at temperatures up to 220°F [105°C] for up to 48 hours, then allowed to cool to room temperature. In case of dispute, aging the tension test specimen shall be the referee method. If the tension specimen or the test assembly is aged, that fact, together with the manner of aging, shall be recorded on the test certificate. Refer to A10.6 in Annex A for a discussion on the purpose of aging.

12.2.3 The specimen shall be tested in the manner described in the Tension Test clause of AWS B4.0.

12.2.4 The results of the tension test shall meet the requirements specified in Table 1 or Table 1M, as applicable.

13. Impact Test

13.1 Five full-size Charpy V-notch impact specimens, as specified in the Fracture Toughness Test clause of AWS B4.0, shall be machined from the test assembly shown in Figure 4 or Figure 5, as applicable, for those classifications for which impact testing is required in Table 5. The notch shall be smoothly machined and shall be square with the longitudinal edge of the specimen within one degree. The geometry of the notch shall be measured on at least one specimen in a set of five specimens. Measurement shall be done at a minimum 10X magnification. The correct location of the notch shall be verified by etching before or after machining.

13.2 The five specimens shall be tested in accordance with the Fracture Toughness Test clause of AWS B4.0. The test temperature shall be that specified in Table 2 for the classification under test.

13.3 In evaluating the test results, the lowest and the highest values obtained shall be disregarded. Two of the remaining three values shall equal or exceed the specified 20 ft-lbf [27 J] energy level. One of the three may be lower, but not lower than 15 ft-lbf [20 J], and the average of the three shall be not less than the required 20 ft-lbf [27 J] energy level.

13.4 For classifications with the “N” (nuclear) designation, three additional specimens shall be prepared. These specimens shall be tested at 60°F to 90°F [15°C to 32°C]. Two of the three values shall equal or exceed 75 ft-lbf [100 J], and the third value shall not be lower than 70 ft-lbf [95 J]. The average of the three shall equal or exceed 75 ft-lbf [100 J].

13.5 For classifications with an impact designator of “32” per A5.23 or an impact designator of “20” per A5.23M, the lateral expansion of the three Charpy specimens remaining after discarding the specimens with the highest and lowest absorbed energy levels shall be measured in accordance with ASTM E23. The average of these three specimens shall exhibit a lateral expansion of at least 0.015 in [0.38 mm], as specified in Table 2.

14. Diffusible Hydrogen Test

14.1 Each flux-electrode combination to be identified by an optional supplemental diffusible hydrogen designator shall be tested according to one of the methods given in AWS A4.3. Based upon the average value of test results which satisfy the requirements of Table 10, the appropriate diffusible hydrogen designator may be added to the end of the classification. *Austenitic weld metal, including that classified as Mn2, is not suitable for diffusible hydrogen determination.*

14.2 The welding procedure shown in Table 6 for the multiple-pass groove weld test assembly shall be used for the diffusible hydrogen test. The travel speed, however, may be increased up to a maximum of 28 in/min [12 mm/s]. This adjustment in travel speed is permitted in order to establish a weld bead width that is appropriate for the specimen. The flux, electrode, or both, may be baked to restore the moisture content before testing to the as-manufactured condition. When this is done, the baking time and temperature shall be noted on the certificate. The manufacturer of the flux, electrode, or both, should be consulted for their recommendation regarding the time and temperature for restoring their products to the as-manufactured condition.

14.3 For purposes of certifying compliance with diffusible hydrogen requirements, the reference atmospheric condition shall be an absolute humidity of ten (10) grains of moisture/lb [1.43 g/kg] of dry air at the time of welding. The actual atmospheric conditions shall be reported along with the average diffusible hydrogen value for the test according to AWS A4.3.

14.4 When the absolute humidity equals or exceeds the reference condition at the time of preparation of the test assembly, the test shall be acceptable as demonstrating compliance with the requirements of this specification, provided the actual test results satisfy the diffusible hydrogen requirements for the applicable designator. If the actual test results for a flux-electrode combination meet the requirements for the lower or lowest hydrogen designator, as specified in Table 10, the flux-electrode combination also meets the requirements for all higher designators in Table 10 without need to retest.

15. Method of Manufacture

15.1 Electrodes and Fluxes. The electrodes and fluxes classified according to this specification may be manufactured by any method that will produce material that meets the requirements of this specification.

15.2 Crushed Slag. Slag formed during the welding process that is subsequently crushed for use as a welding flux is defined as crushed slag. Crushed slag and blends of crushed slag with the original brand of unused (virgin) flux may be classified as welding flux under this specification. When classifying a blend of crushed slag with virgin flux, the ratio of the blend mixture shall not vary from nominal by more than 10% of the minor component. For example, a nominal blend of 40% crushed slag with 60% virgin flux shall contain at least 36%, but no more than 44% crushed slag. The classification of more than one blend ratio of crushed slag with the original brand of unused (virgin) flux is permitted under this specification. In each case, however, the nominal blend ratio shall be noted on the packaging or on the corresponding lot certificate, as applicable. See A6.1.4 in Annex A.

16. Electrode Requirements

16.1 Standard Sizes. Standard sizes for electrodes in the different package forms (coils with support, coils without support, spools, and drums) are as specified in AWS A5.02/A5.02M.

16.2 Finish and Uniformity

16.2.1 Finish and uniformity shall be as specified in AWS A5.02/A5.02M.

16.2.2 A suitable protective coating may be applied to any filler metal in this specification, however the coating composition must be included when analyzing and reporting the composition of the electrode.

16.3 Standard Package Forms

16.3.1 Standard package forms are coils with support, coils without support, spools, and drums. Standard package dimensions for each form shall be as specified in AWS A5.02/A5.02M. Package forms and sizes other than these shall be as agreed between purchaser and supplier.

16.4 Winding Requirements

16.4.1 Winding requirements shall be as specified in AWS A5.02/A5.02M.

16.4.2 The cast and helix of the electrode shall be as specified in AWS A5.02/A5.02M.

16.5 Electrode Identification. Product information and the precautionary information shall be as specified in AWS A5.02/A5.02M. Coils without support shall have a tag containing this information securely attached to the filler metal at the inside end of the coil.

16.6 Packaging. Electrodes shall be suitably packaged to ensure against damage during shipment and storage under normal conditions.

16.7 Marking of Packages

16.7.1 The product information specified in AWS A5.02/A5.02M and the following (as a minimum) shall be legibly marked so as to be visible from the outside of each unit package.

(1) AWS specification and classification along with the applicable optional and supplemental designators. The year of issuance may be excluded. It is not required that all classifications published for the electrode (with various fluxes, with and without PWHT, etc.) be included on the packaging.

(2) Supplier's name and trade designation.

(3) In the case of a composite electrode, the trade designation of the flux (or fluxes) with which it is classified.

(4) Size and net weight.

(5) Lot, control, or heat number.

16.7.2 The appropriate precautionary information as given in ANSI Z49.1 (as a minimum) or its equivalent shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages enclosed within a larger package. Typical examples of "warning labels" and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

17. Flux Requirements

17.1 Form and Particle Size. Flux shall be granular in form and shall be capable of flowing freely through the flux feeding tubes, valves, and nozzles of standard SAW equipment. Particle size is not specified here, but when addressed, shall be a matter of agreement between the purchaser and the supplier.

17.2 Usability. The flux shall permit the production of uniform, well-shaped beads that merge smoothly with each other and the base metal. Undercut, if any, shall not be so deep or so widespread that a subsequent bead will not remove it.

17.3 Packaging

17.3.1 Flux shall be suitably packaged to ensure against damage during shipment.

17.3.2 Flux, in its original unopened container, shall withstand storage under normal conditions for at least six months without damage to its welding characteristics or the properties of the weld. Heating the flux to assure dryness may be necessary when the very best properties (of which the materials are capable) are required. For specific recommendations, consult the manufacturer.

17.4 Marking of Packages

17.4.1 The following product information (as a minimum) shall be legibly marked so as to be visible from the outside of each unit package.

(1) AWS specification and classification along with the applicable optional, supplemental designators. The year of issuance may be excluded. For flux-composite electrode classifications the trade designation of the composite electrode shall be indicated. It is not required that all of the classifications published for the flux (with different electrodes, with and without PWHT, etc.) be included on the packaging.

(2) Supplier's name, trade designation, and country of manufacture. In the case of crushed slags (or blends of crushed slag with virgin flux), the crusher (or crusher/blender), not the original producer, shall be considered the supplier. Crushed slag or a blend of crushed slag with virgin flux shall have a unique trade designation that clearly differentiates it from the original virgin flux used in its manufacture. See also A6.1.4 in Annex A.

(3) Net weight.

(4) Lot, control, or heat number.

(5) Particle size, if more than one particle size of flux of that trade designation is produced.

17.4.2 The appropriate precautionary information as given in ANSI Z49.1 (as a minimum) or its equivalent shall be prominently displayed in legible print on all packages of flux, including individual unit packages enclosed within a larger package. Typical examples of "warning labels" and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

Table 1
A5.23 Tension Test Requirements

Flux-Electrode Classifications ^a		Tensile Strength (psi)	Minimum Yield Strength at 0.2% Offset (psi)	Minimum Elongation (%)
Multiple-Pass Classifications	F7XX-EXX-XX	70 000 to 95 000	58 000	22
	F8XX-EXX-XX	80 000 to 100 000	68 000	20
	F9XX-EXX-XX	90 000 to 110 000	78 000	17
	F10XX-EXX-XX	100 000 to 120 000	88 000	16
	F10XX-EXX-Mn2	100 000 minimum	58 000	22
	F11XX-EXX-XX	110 000 to 130 000	98 000	15 ^b
	F12XX-EXX-XX	120 000 to 140 000	108 000	14 ^b
	F13XX-EXX-XX	130 000 to 150 000	118 000	14 ^b
Two-Run Classifications	F6TXX-EXX	60 000 minimum	50 000	22
	F7TXX-EXX	70 000 minimum	60 000	22
	F8TXX-EXX	80 000 minimum	70 000	20
	F9TXX-EXX	90 000 minimum	80 000	17
	F10TXX-EXX	100 000 minimum	90 000	16
	F11TXX-EXX	110 000 minimum	100 000	15
	F12TXX-EXX	120 000 minimum	110 000	14
	F13TXX-EXX	130 000 minimum	120 000	14

^a The letter "S" will appear after the "F" as part of the classification designation when the flux being classified is a crushed slag or a blend of crushed slag with unused (virgin) flux. The letter "C" will appear after the "E" as part of the classification designation when the electrode used is a composite electrode. For two-run classifications, the letter "C" will appear after the impact designator (immediately before the hyphen) to indicate that the base steel used for classification is not one of the base steels prescribed in Table 8 but is a different steel, as agreed between purchaser and supplier. The letter "X" used in various places in this table stands for, respectively, the condition of heat treatment, the toughness of the weld metal, and the classification of the weld metal. See Figure 1 or 2, as applicable, for a complete explanation of the classification designators.

^b Elongation may be reduced by one percentage point for F11XX-EXX-XX, F11XX-ECXX-XX, F12XX-EXX-XX, F12XX-ECXX-XX, F13XX-EXX-XX, and F13XX-ECXX-XX weld metals in the upper 25% of their tensile strength range.

Table 1M
A5.23M Tension Test Requirements

Flux-Electrode Classifications ^a		Tensile Strength (MPa)	Minimum Yield Strength at 0.2% Offset (MPa)	Minimum Elongation (%)
Multiple-Pass Classifications	F49XX-EXX-XX	490 to 660	400	22
	F55XX-EXX-XX	550 to 700	470	20
	F62XX-EXX-XX	620 to 760	540	17
	F69XX-EXX-XX	690 to 830	610	16
	F69XX-EXX-Mn2	690 minimum	400	22
	F76XX-EXX-XX	760 to 900	680	15 ^b
	F83XX-EXX-XX	830 to 970	740	14 ^b
	F90XX-EXX-XX	900 to 1040	810	14 ^b
Two-Run Classifications	F43TXX-EXX	430 minimum	350	22
	F49TXX-EXX	490 minimum	415	22
	F55TXX-EXX	550 minimum	490	20
	F62TXX-EXX	620 minimum	555	17
	F69TXX-EXX	690 minimum	625	16
	F76TXX-EXX	760 minimum	690	15
	F83TXX-EXX	830 minimum	760	14
	F90TXX-EXX	900 minimum	830	14

^a The letter “S” will appear after the “F” as part of the classification designation when the flux being classified is a crushed slag or a blend of crushed slag with unused (virgin) flux. The letter “C” will appear after the “E” as part of the classification designation when the electrode used is a composite electrode. For two-run classifications, the letter “G” will appear after the impact designator (immediately before the hyphen) to indicate that the base steel used for classification is not one of the base steels prescribed in Table 8 but is a different steel, as agreed between purchaser and supplier. The letter “X” used in various places in this table stands for, respectively, the condition of heat treatment, the toughness of the weld metal, and the classification of the weld metal. See Figure 1M or 2M, as applicable, for a complete explanation of the classification designators.

^b Elongation may be reduced by one percentage point for F76-EXX-XX, F76-ECXX-XX, F83XX-EXX-XX, F83XX-ECXX-XX, F90XX-EXX-XX, and F90XX-ECXX-XX weld metals in the upper 25% of their tensile strength range.

Table 2
Impact Test Requirements

A5.23 Requirements			A5.23M Requirements		
A5.23 Impact Designator ^{a,c}	Maximum Test Temperature ^b (°F)	Minimum Average Energy Level or Lateral Expansion ^d	A5.23M Impact Designator ^{a,c}	Maximum Test Temperature ^b (°C)	Minimum Average Energy Level or Lateral Expansion ^d
0	0	20 ft-lbf	0	0	27 J
2	−20	20 ft-lbf	2	−20	27 J
4	−40	20 ft-lbf	3	−30	27 J
5	−50	20 ft-lbf	4	−40	27 J
6	−60	20 ft-lbf	5	−50	27 J
8	−80	20 ft-lbf	6	−60	27 J
10	−100	20 ft-lbf	7	−70	27 J
15	−150	20 ft-lbf	10	−100	27 J
32	−320	0.015 in	20	−196	0.38 mm
Z	No Impact Requirements		Z	No Impact Requirements	

^a Based on the results of the impact tests of the weld metal, the manufacturer shall insert in the classification the appropriate designator from this table, as indicated in Figure 1, 1M, 2, or 2M, as applicable.

^b Weld metal from a specific flux-electrode combination that meets the impact requirements at a given temperature also meets the requirements at all higher temperatures in this table. For example, weld metal meeting the A5.23 requirements for designator “5” also meets the requirements for designators 4, 2, 0, and Z. (Weld metal meeting the A5.23M requirements for designator “5” also meets the requirements for designators 4, 3, 2, 0, and Z.)

^c When classifying flux-electrode combinations to A5.23 using U.S. Customary Units, the Impact Designator indicates the impact test temperature in °F. When classifying to A5.23M using the International System of Units (SI), the Impact Designator indicates the impact test temperature in °C. With the exception of the Impact Designator “4,” a given Impact Designator will indicate different temperatures depending upon whether classification is according to A5.23 in U.S. Customary Units or according to A5.23M in the International System of Units (SI). For example, a “2” Impact Designator when classifying to A5.23 indicates a test temperature of −20°F. When classifying to A5.23M, the “2” Impact Designator indicates a test temperature of −20°C, which is −4°F.

^d Requirements for impact designator “32” [impact designator “20”] are lateral expansion values. See 13.5 for more details.

Table 3
Chemical Composition Requirements for Weld Metal^a

Weld Metal Designation ^{b,c}	UNS Number ^d	Weight Percent ^{e,f,g}									
		C	Mn	Si	S	P	Cr	Ni	Mo	Cu	Other ^h
A1	W17041	0.12	1.00	0.80	0.030	0.030	—	—	0.40–0.65	0.35	—
A2	W17042	0.12	1.40	0.80	0.030	0.030	—	—	0.40–0.65	0.35	—
A3	W17043	0.15	2.10	0.80	0.030	0.030	—	—	0.40–0.65	0.35	—
A4	W17044	0.15	1.60	0.80	0.030	0.030	—	—	0.40–0.65	0.35	—
B1	W51040	0.12	1.60	0.80	0.030	0.030	0.40–0.65	—	0.40–0.65	0.35	—
B2 ⁱ	W52040	0.05–0.15	1.20	0.80	0.030	0.030	1.00–1.50	—	0.40–0.65	0.35	—
B2H	W52240	0.10–0.25	1.20	0.80	0.020	0.020	1.00–1.50	—	0.40–0.65	0.35	V: 0.30
B3 ⁱ	W53040	0.05–0.15	1.20	0.80	0.030	0.030	2.00–2.50	—	0.90–1.20	0.35	—
B4	W53340	0.12	1.20	0.80	0.030	0.030	1.75–2.25	—	0.40–0.65	0.35	—
B5	W51340	0.18	1.20	0.80	0.030	0.030	0.40–0.65	—	0.90–1.20	0.35	—
B6	W50240	0.12	1.20	0.80	0.030	0.030	4.50–6.00	—	0.40–0.65	0.35	—
B6H	W50140	0.10–0.25	1.20	0.80	0.030	0.030	4.50–6.00	—	0.40–0.65	0.35	—
B8	W50440	0.12	1.20	0.80	0.030	0.030	8.00–10.00	—	0.80–1.20	0.35	—
B23	K20857	0.04–0.12	1.00	0.80	0.015	0.020	1.9–2.9	0.50	0.30	0.25	W: 1.50–2.00 V: 0.15–0.30 Nb: 0.02–0.10 B: 0.006 Al: 0.04 N: 0.07
B24	K20885	0.04–0.12	1.00	0.80	0.015	0.020	1.9–2.9	0.30	0.80–1.20	0.25	V: 0.15–0.30 Nb: 0.02–0.10 Ti: 0.10 B: 0.006 Al: 0.04 N: 0.05
B91	W50442	0.08–0.13	1.20 ^j	0.80	0.010	0.010	8.0–10.5	0.80 ^j	0.85–1.20	0.25	Nb: 0.02–0.10 N: 0.02–0.07 V: 0.15–0.25 Al: 0.04

(Continued)

Table 3 (Continued)
Chemical Composition Requirements for Weld Metal^a

Weld Metal Designation ^{b,c}	UNS Number ^d	Weight Percent ^{e,f,g}									
		C	Mn	Si	S	P	Cr	Ni	Mo	Cu	Other ^h
B91(1.2)	W50442	0.08–0.13	1.20 ^j	0.80	0.010	0.010	8.0–10.5	0.80 ^j	0.85–1.20	0.25	Nb: 0.02–0.10 N: 0.02–0.07 V: 0.15–0.25 Al: 0.04
B91(1.0)	W50442	0.08–0.13	1.20 ^j	0.80	0.010	0.010	8.0–10.5	0.80 ^j	0.85–1.20	0.25	Nb: 0.02–0.10 N: 0.02–0.07 V: 0.15–0.25 Al: 0.04
B115	—	0.06–0.13	1.00	0.15–0.50	0.010	0.015	9.5–12.0	0.45	0.40–0.65	0.20	V: 0.10–0.30 Nb: 0.02–0.10 N: 0.02–0.06 Al: 0.04
F1	W21150	0.12	0.70–1.50	0.80	0.030	0.030	0.15	0.90–1.70	0.55	0.35	—
F2	W20240	0.17	1.25–2.25	0.80	0.030	0.030	—	0.40–0.80	0.40–0.65	0.35	—
F3	W21140	0.17	1.25–2.25	0.80	0.030	0.030	—	0.70–1.10	0.40–0.65	0.35	—
F4	W20440	0.17	1.60	0.80	0.035	0.030	0.60	0.40–0.80	0.25	0.35	Ti + V + Zr: 0.03
F5	W22540	0.17	1.20–1.80	0.80	0.020	0.020	0.65	2.00–2.80	0.30–0.80	0.50	—
F6	W22640	0.14	0.80–1.85	0.80	0.020	0.030	0.65	1.50–2.25	0.60	0.40	—
M1	W21240	0.10	0.60–1.60	0.80	0.030	0.030	0.15	1.25–2.00	0.35	0.30	Ti + V + Zr: 0.03
M2	W21340	0.10	0.90–1.80	0.80	0.020	0.020	0.35	1.40–2.10	0.25–0.65	0.30	Ti + V + Zr: 0.03
M3	W22240	0.10	0.90–1.80	0.80	0.020	0.020	0.65	1.80–2.60	0.20–0.70	0.30	Ti + V + Zr: 0.03
M4	W22440	0.10	1.30–2.25	0.80	0.020	0.020	0.80	2.00–2.80	0.30–0.80	0.30	Ti + V + Zr: 0.03
M5	W21345	0.12	1.60–2.50	0.50	0.015	0.015	0.40	1.40–2.10	0.20–0.50	0.30	Ti: 0.03 V: 0.02 Zr: 0.02
M6	W21346	0.12	1.60–2.50	0.50	0.015	0.015	0.40	1.40–2.10	0.70–1.00	0.30	Ti: 0.03 V: 0.02 Zr: 0.02
Mn2	—	0.25–0.50	16.0–24.0	1.5	0.015	0.025	1.5–3.5	2.0	1.5	0.50	—
Ni1	W21040	0.12	1.60 ^k	0.80	0.025	0.030	0.15	0.75–1.10	0.35	0.35	Ti + V + Zr: 0.05

(Continued)

Table 3 (Continued)
Chemical Composition Requirements for Weld Metal^a

Weld Metal Designation ^{b,c}	UNS Number ^d	Weight Percent ^{e,f,g}									
		C	Mn	Si	S	P	Cr	Ni	Mo	Cu	Other ^h
Ni2	W22040	0.12	1.60 ^k	0.80	0.025	0.030	—	2.00–2.90	—	0.35	—
Ni3	W23040	0.12	1.60 ^k	0.80	0.025	0.030	0.15	2.80–3.80	—	0.35	—
Ni4	W21250	0.14	1.60	0.80	0.025	0.030	—	1.40–2.10	0.10–0.35	0.35	—
Ni5	W21042	0.12	1.60 ^k	0.80	0.025	0.030	—	0.70–1.10	0.10–0.35	0.35	—
Ni6	W21042	0.14	1.60 ^k	0.80	0.025	0.030	—	0.70–1.10	0.10–0.35	0.35	—
W	W20140	0.12	0.50–1.60	0.80	0.030	0.035	0.45–0.70	0.40–0.80	—	0.30–0.75	—
G		As agreed between supplier and purchaser									

^a These requirements are applicable to both flux-solid electrode and flux-composite electrode combinations.

^b The weld metal designation for composite electrodes is obtained by placing an “EC” before the appropriate electrode designation.

^c The letter “N,” when added as a suffix is an optional supplemental designator indicating that the limits on the phosphorous, vanadium, and copper are as follows: P = 0.012% max., V = 0.05% max., and Cu = 0.08% max. Additional requirements are given in 13.4. See A2.1 in Annex A for a discussion of the intended use of “N” designator electrodes.

^d Refer to ASTM D5-56/SAE HS-1086, *Metals & Alloys in the Unified Numbering System*.

^e The weld metal shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total (excluding iron) does not exceed 0.50%.

^f Single values are maximum.

^g As a substitute for the weld pad in Figure 3, the sample for chemical analysis may be taken from the reduced section of the fractured tension test specimen (see 10.2) or from a corresponding location (or any location above it) in the weld metal in the groove weld in Figure 4. In case of dispute, the weld pad shall be the referee method.

^h Analysis for B is required to be reported if intentionally added, or if it is known to be present at levels greater than 0.0010%.

ⁱ The letter “R” when added as a suffix is an optional supplemental designator indicating that the limits on sulfur, phosphorous, copper, arsenic, tin, and antimony are as follows: S = 0.010% max., P = 0.010% max., Cu = 0.15% max., As = 0.005% max., Sn = 0.005% max., and Sb = 0.005% max. These reduced residual limits are necessary to meet the “X” factor requirements for step cooling applications.

^j The designation B91 requires Mn + Ni 1.40% maximum. The designation B91(1.2) requires Mn + Ni 1.20% maximum. The designation B91(1.0) requires Mn + Ni 1.00% maximum. A composition meeting the B91(1.0) requirements will also meet the requirements of B91(1.2) and B91. A composition meeting the B91(1.2) will also meet the requirements of B91. See A7.2.3.1 in Annex A.

^k Manganese in the Ni1, Ni2, Ni3, Ni5, and Ni6 designated weld metals may be 1.80% maximum when the carbon is restricted to 0.10% maximum.

Table 4
Chemical Composition Requirements for Solid Electrodes

Electrode AWS Classification ^c	UNS Number ^d	Weight Percent ^{a, b}										
		C	Mn	Si	S	P	Cr	Ni	Mo	Cu ^e	V	Other ^f
EL8 ^g	K01008	0.10	0.25– 0.60	0.07	0.030	0.030	—	—	—	0.35	—	—
EL8K ^g	K01009	0.10	0.25– 0.60	0.10– 0.25	0.030	0.030	—	—	—	0.35	—	—
EL12 ^g	K01012	0.04– 0.14	0.25– 0.60	0.10	0.030	0.030	—	—	—	0.35	—	—
EM11K ^g	K01111	0.07– 0.15	1.00– 1.50	0.65– 0.85	0.030	0.025	—	—	—	0.35	—	—
EM12 ^g	K01112	0.06– 0.15	0.80– 1.25	0.10	0.030	0.030	—	—	—	0.35	—	—
EM12K ^g	K01113	0.05– 0.15	0.80– 1.25	0.10– 0.35	0.030	0.030	—	—	—	0.35	—	—
EM13K ^g	K01313	0.06– 0.16	0.90– 1.40	0.35– 0.75	0.030	0.030	—	—	—	0.35	—	—
EM14K ^g	K01314	0.06– 0.19	0.90– 1.40	0.35– 0.75	0.025	0.025	—	—	—	0.35	—	Ti: 0.03–0.17
EM15K ^g	K01515	0.10– 0.20	0.80– 1.25	0.10– 0.35	0.030	0.030	—	—	—	0.35	—	—
EH10K ^g	K01210	0.07– 0.15	1.30– 1.70	0.05– 0.25	0.025	0.025	—	—	—	0.35	—	—
EH11K ^g	K11140	0.06– 0.15	1.40– 1.85	0.80– 1.15	0.030	0.030	—	—	—	0.35	—	—
EH12K ^g	K01213	0.06– 0.15	1.50– 2.00	0.20– 0.65	0.025	0.025	—	—	—	0.35	—	—
EH14 ^g	K11585	0.10– 0.20	1.70– 2.20	0.10	0.030	0.030	—	—	—	0.35	—	—
EA1	K11222	0.05– 0.15	0.65– 1.00	0.20	0.025	0.025	—	—	0.45– 0.65	0.35	—	—
EA1TiB	K11020	0.05– 0.15	0.65– 1.00	0.35	0.025	0.025	—	—	0.45– 0.65	0.35	—	Ti: 0.05–0.30 B: 0.005–0.030
EA2TiB	K11126	0.05– 0.17	0.95– 1.35	0.35	0.025	0.025	—	—	0.45– 0.65	0.35	—	Ti: 0.05–0.30 B: 0.005–0.030
EA2	K11223	0.05– 0.17	0.95– 1.35	0.20	0.025	0.025	—	—	0.45– 0.65	0.35	—	—
EA3	K11423	0.05– 0.17	1.65– 2.20	0.20	0.025	0.025	—	—	0.45– 0.65	0.35	—	—
EA3K	K21451	0.05– 0.15	1.60– 2.10	0.50– 0.80	0.025	0.025	—	—	0.40– 0.60	0.35	—	—
EA4	K11424	0.05– 0.15	1.20– 1.70	0.20	0.025	0.025	—	—	0.45– 0.65	0.35	—	—
EB1	K11043	0.10	0.40– 0.80	0.05– 0.30	0.025	0.025	0.40– 0.75	—	0.45– 0.65	0.35	—	—

(Continued)

Table 4 (Continued)
Chemical Composition Requirements for Solid Electrodes

Electrode AWS Classification ^c	UNS Number ^d	Weight Percent ^{a, b}										
		C	Mn	Si	S	P	Cr	Ni	Mo	Cu ^e	V	Other ^f
EB2 ^h	K11172	0.07– 0.15	0.45– 1.00	0.05– 0.30	0.025	0.025	1.00– 1.75	—	0.45– 0.65	0.35	—	—
EB2H	K23016	0.28– 0.33	0.45– 0.65	0.55– 0.75	0.015	0.015	1.00– 1.50	—	0.40– 0.65	0.30	0.20– 0.30	—
EB3 ^h	K31115	0.05– 0.15	0.40– 0.80	0.05– 0.30	0.025	0.025	2.25– 3.00	—	0.90– 1.10	0.35	—	—
EB5	K12187	0.15– 0.23	0.40– 0.70	0.40– 0.60	0.025	0.025	0.45– 0.65	—	0.90– 1.20	0.30	—	—
EB6	S50280	0.10	0.35– 0.70	0.05– 0.50	0.025	0.025	4.50– 6.50	—	0.45– 0.70	0.35	—	—
EB6H	S50180	0.25– 0.40	0.75– 1.00	0.25– 0.50	0.025	0.025	4.80– 6.00	—	0.45– 0.65	0.35	—	—
EB8	S50480	0.10	0.30– 0.65	0.05– 0.50	0.025	0.025	8.00– 10.50	—	0.80– 1.20	0.35	—	—
EB23	K20857	0.05– 0.12	1.10	0.50	0.015	0.015	1.9– 3.0	0.50	0.50	0.10	0.15– 0.30	W: 1.50–2.00 Nb: 0.02–0.10 B: 0.006 Al: 0.04 N: 0.05
EB24	K20885	0.04– 0.12	1.00	0.50	0.015	0.020	1.9– 3.0	0.30	0.80– 1.20	0.10	0.15– 0.30	Nb: 0.02–0.10 Ti: 0.10 B: 0.006 Al: 0.04 N: 0.07
EB91	S50482	0.07– 0.13	1.25 ⁱ	0.50	0.010	0.010	8.50– 10.50	1.00 ^j	0.85– 1.15	0.10	0.15– 0.25	Nb: 0.02–0.10 N: 0.03–0.07 Al: 0.04
EB115	—	0.06– 0.13	0.55	0.15– 0.50	0.010	0.015	9.5– 12.0	0.45	0.40– 0.65	0.20	0.10– 0.30	Nb: 0.02–0.10 N: 0.02–0.06 Al: 0.04
EF1	K11160	0.07– 0.15	0.90– 1.70	0.15– 0.35	0.025	0.025	—	0.95– 1.60	0.25– 0.55	0.35	—	—
EF2	K21450	0.10– 0.18	1.70– 2.40	0.20	0.025	0.025	—	0.40– 0.80	0.40– 0.65	0.35	—	—
EF3	K21485	0.10– 0.18	1.50– 2.40	0.30	0.025	0.025	—	0.70– 1.10	0.40– 0.65	0.35	—	—
EF4	K12048	0.16– 0.23	0.60– 0.90	0.15– 0.35	0.030	0.025	0.40– 0.60	0.40– 0.80	0.15– 0.30	0.35	—	—
EF5	K41370	0.10– 0.17	1.70– 2.20	0.20	0.015	0.010	0.25– 0.50	2.30– 2.80	0.45– 0.65	0.50	—	—
EF6	K21135	0.07– 0.15	1.45– 1.90	0.10– 0.30	0.015	0.015	0.20– 0.55	1.75– 2.25	0.40– 0.65	0.35	—	—
EM2 ^j	K10882	0.10	1.25– 1.80	0.20– 0.60	0.015	0.010	0.30	1.40– 2.10	0.25– 0.55	0.25	0.05	Ti: 0.10 Zr: 0.10 Al: 0.10

(Continued)

Table 4 (Continued)
Chemical Composition Requirements for Solid Electrodes

Electrode AWS Classification ^c	UNS Number ^d	Weight Percent ^{a, b}										Other ^f
		C	Mn	Si	S	P	Cr	Ni	Mo	Cu ^e	V	
EM3 ^j	K21015	0.10	1.40– 1.80	0.20– 0.60	0.015	0.010	0.55	1.90– 2.60	0.25– 0.65	0.25	0.04	Ti: 0.10 Zr: 0.10 Al: 0.10
EM4 ^j	K21030	0.10	1.40– 1.80	0.20– 0.60	0.015	0.010	0.60	2.00– 2.80	0.30– 0.65	0.25	0.03	Ti: 0.10 Zr: 0.10 Al: 0.10
ENi1	K11040	0.12	0.75– 1.25	0.05– 0.30	0.020	0.020	0.15	0.75– 1.25	0.30	0.35	—	—
ENi1K	K11058	0.12	0.80– 1.40	0.40– 0.80	0.020	0.020	—	0.75– 1.25	—	0.35	—	—
ENi2	K21010	0.12	0.75– 1.25	0.05– 0.30	0.020	0.020	—	2.10– 2.90	—	0.35	—	—
ENi3	K31310	0.13	0.60– 1.20	0.05– 0.30	0.020	0.020	0.15	3.10– 3.80	—	0.35	—	—
ENi4	K11485	0.12– 0.19	0.60– 1.00	0.10– 0.30	0.020	0.015	—	1.60– 2.10	0.10– 0.30	0.35	—	—
ENi5	K11240	0.12	1.20– 1.60	0.05– 0.30	0.020	0.020	—	0.75– 1.25	0.10– 0.30	0.35	—	—
ENi6	K11240	0.07– 0.15	1.20– 1.60	0.05– 0.30	0.020	0.020	—	0.75– 1.25	0.10– 0.30	0.35	—	—
EW	K11245	0.12	0.35– 0.65	0.20– 0.35	0.030	0.025	0.50– 0.80	0.40– 0.80	—	0.30– 0.80	—	—
EG	Not Specified											

^a The electrode shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total (excluding iron) does not exceed 0.50%.

^b Single values are maximum.

^c The letter “N,” when added as a suffix to the electrode classification, is an optional supplemental designator indicating that the limits on phosphorous, vanadium, and copper are as follows: P = 0.012% max., V = 0.05% max., Cu = 0.08% max. See A2.1 in the Annex for a discussion of the intended use of “N” designator electrodes.

^d Refer to ASTM D5-56/SAE HS-1086, *Metals & Alloys in the Unified Numbering System*.

^e The copper limit includes any copper coating that may be applied to the electrode.

^f Analysis for B is required to be reported if intentionally added, or if it is known to be present at levels greater than 0.0010%.

^g This electrode is also classified under AWS A5.17/A5.17M. It is included in this specification because it can be used with an alloy flux to deposit some of the weld metals designated in Table 3. In addition, this carbon steel electrode can be used for the two-run classification of flux-electrode combinations according to the provisions of this specification.

^h The letter “R” when added as a suffix is an optional supplemental designator indicating that the limits on sulfur, phosphorous, copper, arsenic, tin and antimony are as follows: S = 0.010% max., P = 0.010% max., Cu = 0.15% max., As = 0.005% max., Sn = 0.005% max., and Sb = 0.005% max. These reduced residual limits are necessary to meet “X” factor requirements for step cooling applications.

ⁱ See A7.2.3.1 in Annex A for a discussion of the B91 alloy and recommendation regarding the Mn + Ni level achieved in the weld deposit. See also Note j of Table 3 for limits on the Mn + Ni content of the B91 weld deposit.

^j The composition ranges of classifications with the “EM” prefix are intended to conform to the ranges of similar electrodes in the military specifications.

Table 5
Tests Required for Classification

AWS Classification	Chemical Analysis			Radiographic Test	Tension Test	Impact Test	Diffusible Hydrogen Test
	Base Metal	Electrode	Weld Metal				
All Solid Electrodes	Not Required	Required	Not Required	Not Required	Not Required	Not Required	Not Required
All Composite Electrodes	Not Required	Not Required	Required	Not Required	Not Required	Not Required	Not Required
All Flux—Solid or Composite Electrode Multiple-Pass Classifications	Not Required	Not Required	Required	Required	Required	Required ^a	(Note b)
All Flux—Solid or Composite Electrode Two-Run Classifications	Required	Not Required	Required	Required	Required	Required ^a	(Note b)

^a When the “Z” impact designator (no impact requirement—Table 2) is used, the Impact Test is not required.

^b Diffusible hydrogen test is required only when specified by the purchaser or when the manufacturer puts the diffusible hydrogen designator on the label (see also Clause A10 in Annex A).

Table 6
Welding Parameters for Multiple-Pass Groove Weld Test Assembly

Welding Conditions for Solid Electrodes^{a, b, c}

Electrode Size ^d		Welding Current (amperes) ^e	Arc Voltage (volts)	Electrode Extension ^f		Travel Speed		Current Type ^g	Preheat and Interpass Temperature
in	mm			in	mm	in/min (±1)	mm/sec (±0.5)		
1/16	1.6	250 to 350	26 to 29	1/2 to 3/4	13 to 19	12	5.0	AC or DC either polarity	Refer to Table 9 for the Preheat and Interpass Temperatures Applicable to the Weld Metal Being Classified
5/64	2.0	300 to 400	26 to 29	1/2 to 3/4	13 to 19	13	5.5		
3/32	2.4	350 to 450	27 to 30	3/4 to 1-1/4	19 to 32	14	6.0		
—	2.5	350 to 450	27 to 30	3/4 to 1-1/4	19 to 32	14	6.0		
7/64	2.8	400 to 500	27 to 30	3/4 to 1-1/4	19 to 32	14	6.0		
—	3.0	400 to 500	27 to 30	1 to 1-1/2	25 to 38	15	6.5		
1/8	3.2	425 to 525	27 to 30	1 to 1-1/2	25 to 38	15	6.5		
5/32	4.0	475 to 575	27 to 30	1 to 1-1/2	25 to 38	16	7.0		
3/16	4.8	525 to 625	27 to 30	1 to 1-1/2	25 to 38	17	7.0		
—	5.0	550 to 650	27 to 30	1 to 1-1/2	25 to 38	17	7.0		
7/32	5.6	575 to 675	28 to 31	1-1/4 to 1-3/4	32 to 44	18	7.5		
—	6.0	625 to 725	28 to 31	1-1/4 to 1-3/4	32 to 44	19	8.0		
1/4	6.4	700 to 800	28 to 32	1-1/2 to 2	38 to 50	20	8.5		

^a Values specified in inches or in/min apply to A5.23. Values specified in mm or mm/sec apply to A5.23M.

^b These welding conditions are intended for machine or automatic welding with straight progression (no weaving). Welding shall be performed in the flat position. The first layer shall be produced in either 1 or 2 passes. All other layers shall be produced in 2 or 3 passes per layer except the last, which shall be produced in 2, 3, or 4 passes. The completed weld shall be at least flush with the surface of the test plate.

^c Welding conditions for composite electrodes shall be as agreed between purchaser and supplier.

^d Classification is based on the properties of weld metal with 5/32 in [4.0 mm] electrodes or the closest size manufactured, if 5/32 in [4.0 mm] is not manufactured. The conditions given above for sizes other than 5/32 in [4.0 mm] are to be used when classification is based on those sizes, or when they are required for lot acceptance testing under AWS A5.01M/A5.01 (unless otherwise specified by the purchaser).

^e Lower currents may be used for the first layer.

^f The electrode extension is the contact tube-to-work distance. When an electrode manufacturer recommends a contact tube-to-work distance outside the range shown, that recommendation shall be followed ±1/4 in [6.5 mm].

^g In case of dispute, DCEP (direct current electrode positive) shall be used as the referee current.

Table 7
Welding Parameters for Two-Run Weld Test Assembly^{a, b}

Electrode Diameter		Procedure Type ^c	Preheat/Interbead Temperature	Heat Input ^d (each pass)
in	mm			
5/32 ^e	4.0 ^e	DCEP (single electrode) or AC (single electrode) or DCEP lead, AC trail (tandem) or AC lead, AC trail (tandem)	212°F [115°C] Maximum	55 kJ/in–80 kJ/in [2.2 kJ/mm–3.1 kJ/mm]

^a The test assembly shall be welded in the flat position in two runs, one from each side. The welding procedures shall be in conformance with the requirements of this table and shall be consistent with accepted welding practice. The procedure used shall ensure adequate tie-in of the weld beads made from each side. The requirements listed above apply to both solid electrodes and composite electrodes.

^b These welding conditions are intended for machine or automatic welding with straight progression (no weaving).

^c Single electrode procedures with either DCEP (direct current, electrode positive) or AC (alternating current) or two-electrode tandem procedures (DCEP/AC or AC/AC) may be used for classification purposes. The procedure type used shall be the same for both weld passes. In case of dispute, DCEP shall be used as the referee current.

^d The calculation to be used for heat input is:

$$(1) \text{ Heat Input (kJ/in)} = \frac{\text{volts} \times \text{amps} \times 60}{\text{travel speed (in/min)} \times 1000} \text{ or } \frac{\text{volts} \times \text{amps} \times 60 \times \text{arc time (min)}}{\text{weld length (in)} \times 1000}$$

$$(2) \text{ Heat Input (kJ/mm)} = \frac{\text{volts} \times \text{amps} \times 60}{\text{travel speed (mm/min)} \times 1000} \text{ or } \frac{\text{volts} \times \text{amps} \times 60 \times \text{arc time (min)}}{\text{weld length (mm)} \times 1000}$$

For two wire tandem procedures the heat input is the arithmetic sum of the heat inputs calculated for each electrode.

^e Classification is based upon the properties of the weld made with 5/32 in [4.0 mm] electrodes or the closest size manufactured, if 5/32 in [4.0 mm] is not manufactured. An alternate electrode diameter may also be required, in some cases, for lot acceptance testing under AWS A5.01M/A5.01, unless other conditions are specified by the purchaser. The heat input requirements specified above for 5/32 in [4.0 mm] shall be used when using alternate diameters of electrode.

Table 8
Base Metals for Test Assemblies

Classification Type	Weld Metal Designation	Base Metal	
		ASTM Standard ^{a, b}	UNS Number ^c
Multiple-Pass Classifications	A1, A2, A3, and A4	A204 Grade A	K11820
	B2, B2H, and B5	A387 Grade 11	K11789
	B3 and B4	A387 Grade 22	K21590
	B6 and B6H	A387 Grade 5	S50200
	B8	A387 Grade 9	S50400
	B23	See Note a	See Note a
	B24	See Note a	See Note a
	B91	A387 Grade 91	S50460
	<i>B115</i>	<i>A335 Grade P115 or A182 Grade F115 or A387 Grade 91</i>	<i>K91060, S50460</i>
	F1, F2, F3, and F4	A537 Class 1 or 2, or A533 (any type or grade in this specification)	K12437, K12521, K12539, K12529, K12554
	F5 and F6	A514 or A517 (any type or grade in this specification)	K11511, K11576, K11625, K11630, K11646, K11683, K11856, K21604, or K21650
	M1, M2, M3, M4, M5, and M6	A514 or A517 (any type or grade in this specification), or A543 Type B or C	K11511, K11576, K11625, K11630, K11646, K11683, K11856, K21604, K21650, or K42339
	<i>Mn2</i>	<i>A1106</i>	<i>K92594</i>
	Nil	A516 Grade 60, 65, or 70, A537 Class 1 or 2	K02100, K02403, K02700, or K12437
	Ni2	A537 Class 1 or 2, or A203 Grade A or B	K12437, K21703, or K22103
	Ni3	A203 Grade D or E	K31718 or K32018
	Ni4, Ni5, and Ni6	A537 Class 1 or 2, or A203 Grade A or B	K12437, K21703, K22103
Two-Run Classifications ^c	W	A572 or A588 (any type or grade in this specification)	K02303, K02304, K02305, K02306, K11430, K12040, K12043, or K11538
	G	(Note d)	—
	Not Applicable	A131 Grade AH36	K11852
		A516 Grade 70	K02700

^a For multiple-pass flux-electrode classifications, ASTM A36, A285 Grade C, A515 Grade 70, or A516 Grade 70 may be used for any weld metal classification in this specification. In that case, the groove faces and the contacting face of the backing shall be buttered as shown in Figure 4, using a flux-electrode combination of the same weld metal composition as that specified for the combination being tested, or using an electrode of the specified composition classified in another AWS low-alloy steel filler metal specification. Alternately, for the indicated weld metal classification, the corresponding base metals may be used for weld test assemblies without buttering. In case of dispute, buttered A 36 shall be the referee material.

^b Chemically equivalent steels in other U.S. customary grades or in any metric grades, whose properties are expressed in SI Units, may also be used.

^c As designated in ASTM DS-56/SAE HS-1086, *Metals & Alloys in the Unified Numbering System*.

^d For the "G" classification (multiple-pass flux-electrode classifications only), ASTM A36, A285 Grade C, A515 Grade 70, or A 516 Grade 70 may be used; however, the groove weld faces and the contacting face of the backing shall be buttered as shown in Figure 4, using either the flux-electrode combination being classified or using a matching composition in another AWS low-alloy filler metal specification. Alternatively, base metal for which the flux-electrode combination is recommended by the manufacturer can be used for this test.

^e Base metal different from that prescribed in this table may be used for two-run classification purposes, as agreed between supplier and purchaser. This substitution of base metal is indicated by the addition of a "G" to the classification as indicated in Figures 2 and 2M.

Table 9
Preheat, Interpass, and Postweld Heat Treatment
Temperatures for Multiple-Pass Classifications^{a, b}

Weld Metal Designation	Preheat and Interpass Temperature ^c		Postweld Heat Treatment Temperature ^d	
	°F	°C	°F	°C
A1, A2, A3, A4, B1, B5, Ni1, Ni2, Ni3, Ni4, Ni5, Ni6, F1, F2, F3	300 ± 25	150 ± 15	1150 ± 25	620 ± 15
B2, B2H	300 ± 25	150 ± 15	1275 ± 25	690 ± 15
B3, B4	400 ± 25	205 ± 15	1275 ± 25	690 ± 15
B6, B6H, B8	400 ± 100	205 ± 50	1375 ± 25	745 ± 15
B91, B115	500 ± 100	260 ± 50	1400 ± 25 ^e	760 ± 15 ^e
B23, B24	425 ± 50	210 ± 20	1365 ± 25 ^e	740 ± 15 ^e
F4 ^f , F5 ^f , F6 ^f	300 ± 25	150 ± 15	1050 ± 25	565 ± 15
M1 ^f , M2 ^f , M3 ^f , M4 ^f , M5 ^f , M6 ^f , W ^f	300 ± 25	150 ± 15	1125 ± 25	605 ± 15
Mn2 ^{f, g}	50 to 350	10 to 175	None	None
G	Not Specified			

^a These temperatures are specified for fluxes and electrodes tested and classified under this specification and are not necessarily for production use. The specific requirements for production welding shall be determined by the user. They may or may not differ from those called for here (see A8 in Annex A).

^b The preheat, interpass, and postweld heat treatment temperatures, as applicable, for multiple-pass flux-electrode classifications are listed for specific weld metal compositions as shown above (see 9.4). For two-run classifications the preheat and interpass temperatures are specified in Table 7 and the postweld heat treatment requirements are given in 9.5.

^c The preheat and interpass temperatures listed here shall be used for the test assemblies regardless of whether the flux-electrode combination is classified in the as-welded or postweld heat treated condition. They are required for purposes of uniformity and may or may not be indicative of those that might be satisfactory for fabrication of any particular weldment. The fabricator shall determine what is required for the application (see also A8 in Annex A).

^d Unless noted otherwise, weld metal specimens for flux-electrode combinations classified in the postweld heat treated condition shall be heat treated for one hour at the temperature shown for that classification (see 9.4).

^e PWHT at specified temperature for two hours –0, +15 minutes.

^f These classifications are normally used in the as-welded condition.

^g Because the Mn2 classification weld metal is austenitic, the mechanical properties are not highly sensitive to cooling rate. Therefore, narrow ranges of preheat and interpass temperatures are not necessary.

Table 10
Diffusible Hydrogen Requirements^a

AWS A5.23/A5.23M Flux-Electrode Classifications ^b	Optional Supplemental Diffusible Hydrogen Designator ^c	Average Diffusible Hydrogen, Maximum ^d (ml/100 g Deposited Metal)
All	H16	16
	H8	8
	H4	4
	H2	2

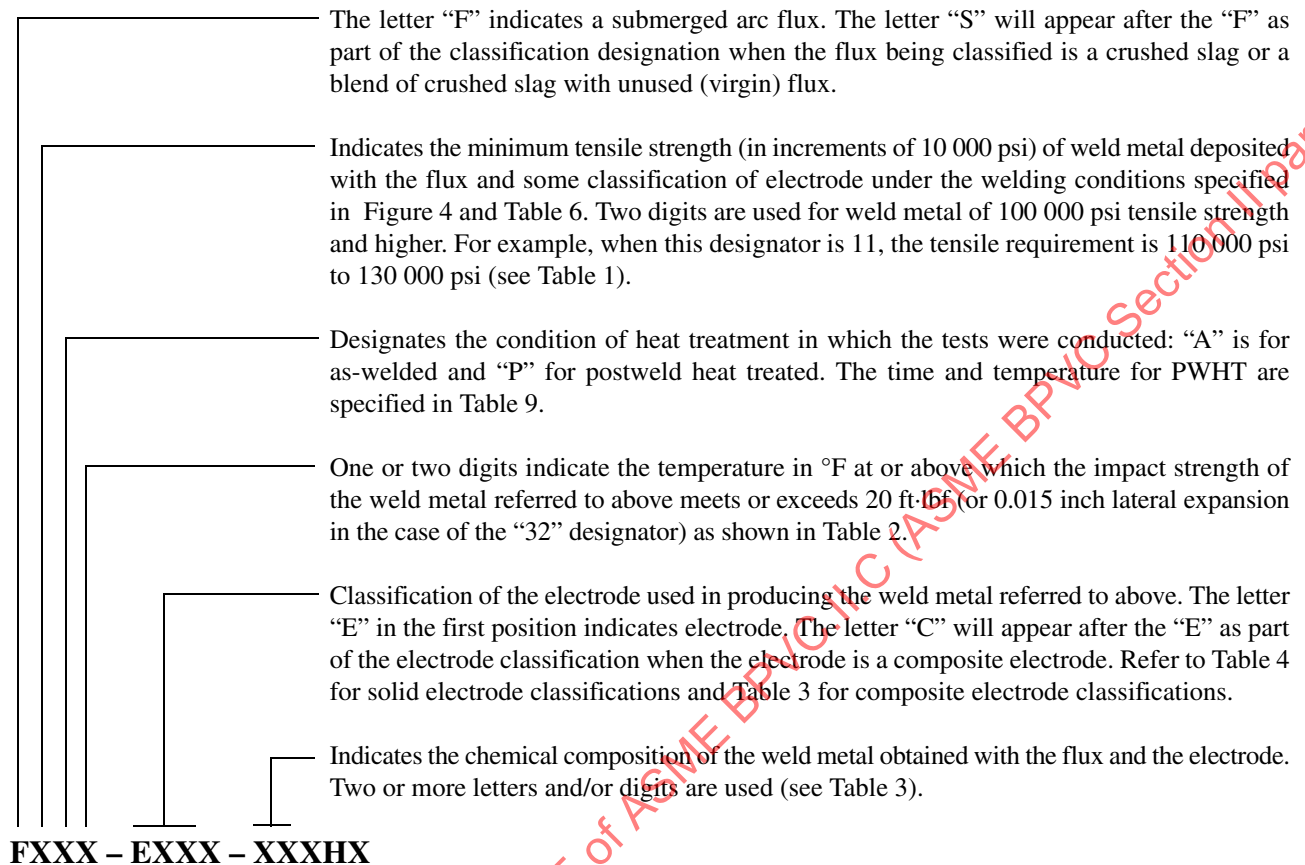
^a The diffusible hydrogen test is required only when specified by the purchaser or when the manufacturer puts the diffusible hydrogen designator on the label (see also Clause A10 in Annex A).

^b A hydrogen designator shall not be used with “Mn2” weld metal designation. See 14.1.

^c This designator is added to the end of the flux-electrode classification (see Figure 1, 1M, 2, or 2M, as applicable).

^d Flux-electrode combinations meeting the requirements for an H2 designator also meet the requirements for H4, H8, and H16. Flux-electrode combinations meeting requirements for an H4 designator also meet the requirement for an H8 and H16. Flux-electrode combinations meeting the requirements for an H8 designator also meet the requirements for H16.

Mandatory Classification Designators^a



Optional, Supplemental Designators^b

Optional supplemental diffusible hydrogen designator (see Table 10).

Optional supplemental designator for special limits on residuals. See notes to Tables 3 and 4 for descriptions of these designators.

^a The combination of these designators constitutes the flux-electrode classification.

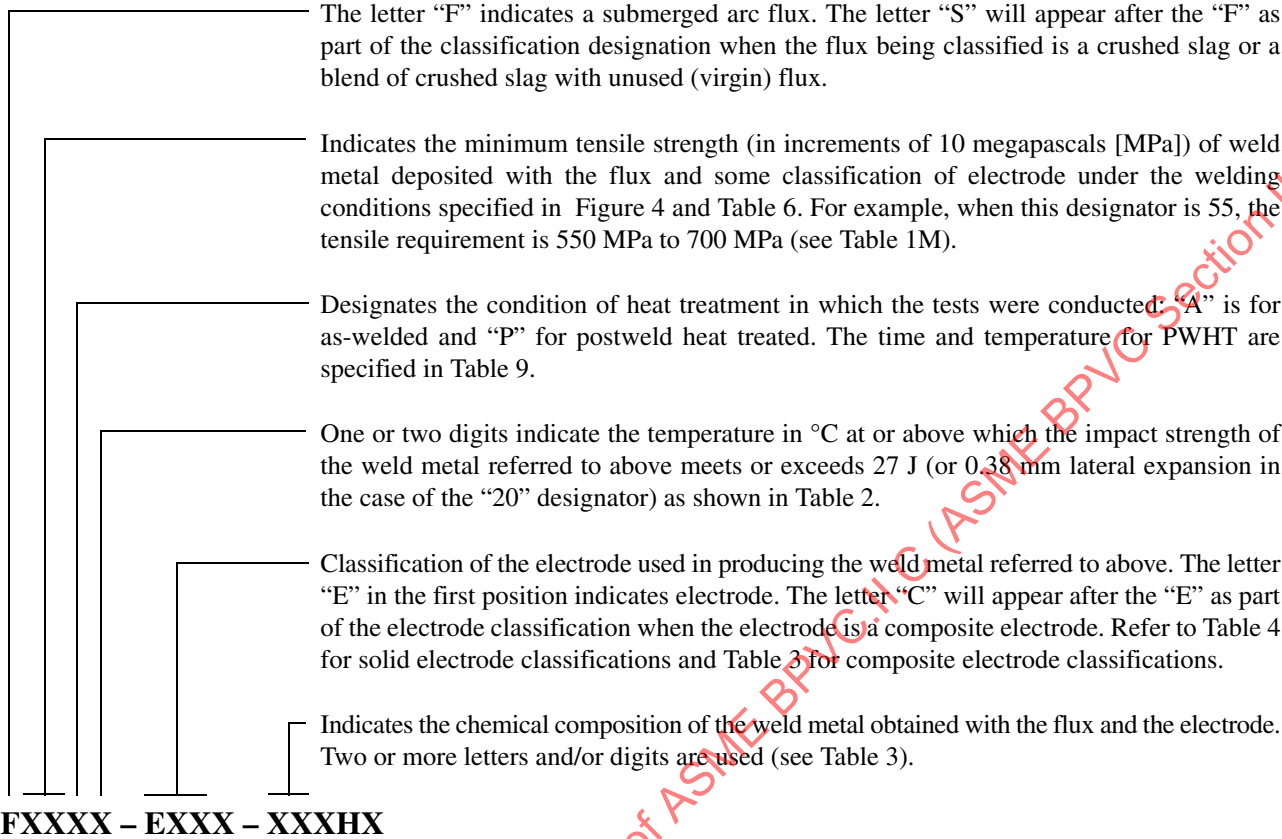
^b These designators are optional and do not constitute a part of the flux-electrode classification.

EXAMPLE

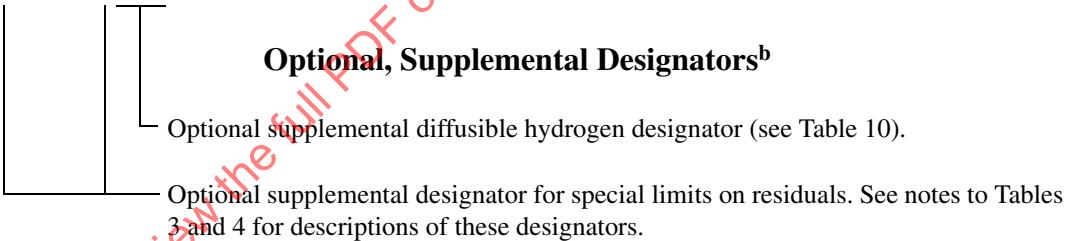
F9P0-EB3-B3 is a complete designation for a flux-electrode combination. It refers to a flux that will produce weld metal which, in the postweld heat treated condition, will have a tensile strength of 90 000 psi to 110 000 psi and Charpy V-notch impact strength of at least 20 ft·lbf at 0°F when produced with an EB3 electrode under the conditions called for in this specification. The composition of the weld metal will meet the requirements for a B3 designation as specified in Table 3.

Figure 1—A5.23 Multiple-Pass Classification System for U.S. Customary Units

Mandatory Classification Designators^a



Optional, Supplemental Designators^b



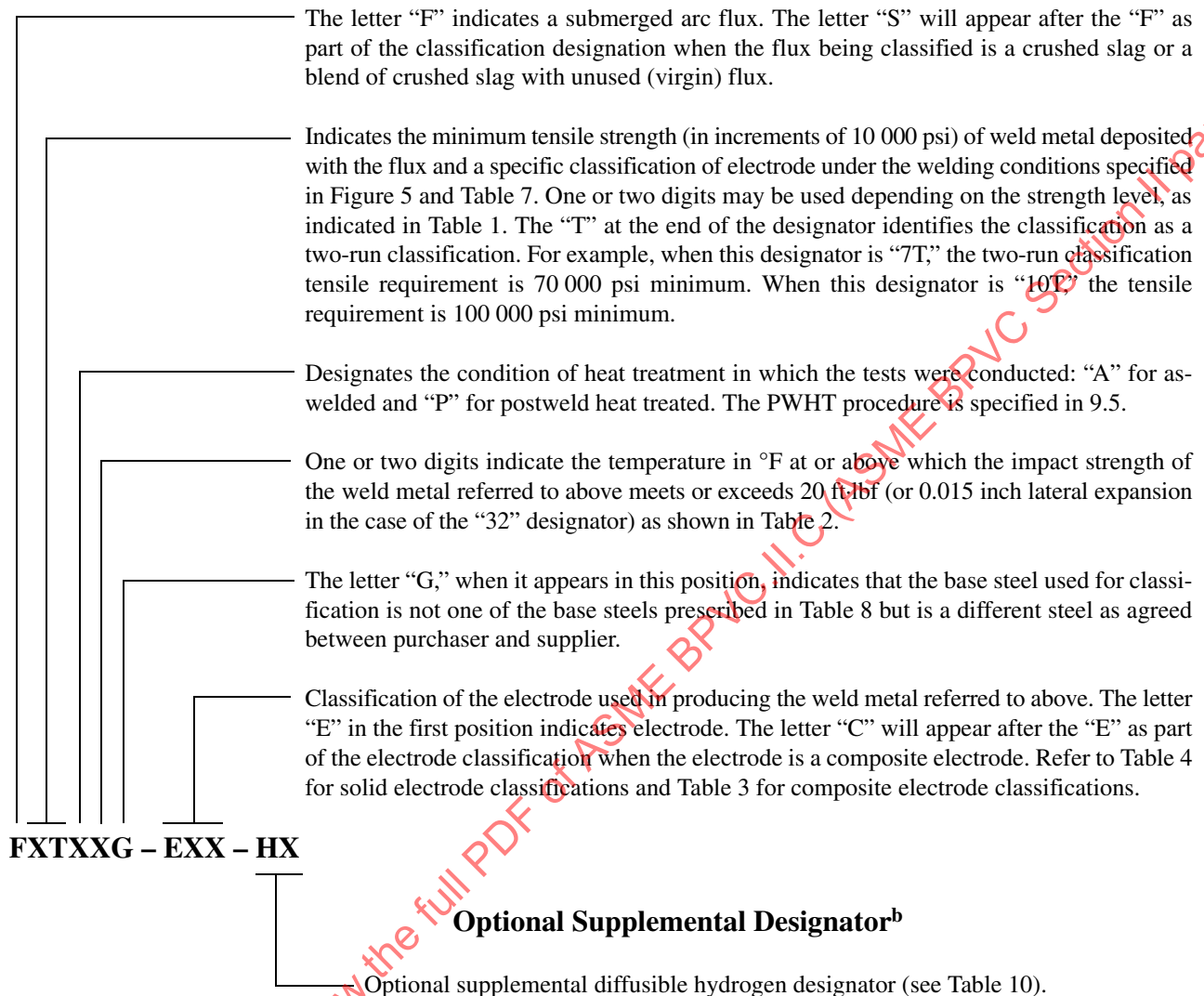
^a The combination of these designators constitutes the flux-electrode classification.
^b These designators are optional and do not constitute a part of the flux-electrode classification.

EXAMPLE

F62P2-EB3-B3 is a complete designation for a flux-electrode combination. It refers to a flux that will produce weld metal which, in the postweld heat treated condition, will have a tensile strength of 620 MPa to 760 MPa and Charpy V-notch impact strength of at least 27 J at –20°C when produced with an EB3 electrode under the conditions called for in this specification. The composition of the weld metal will meet the requirements for a B3 designation as specified in Table 3.

Figure 1M—A5.23M Multiple-Pass Classification System for the International System of Units (SI)

Mandatory Classification Designators^a



^a The combination of these designators constitutes the flux-electrode classification.

^b This designator is optional.

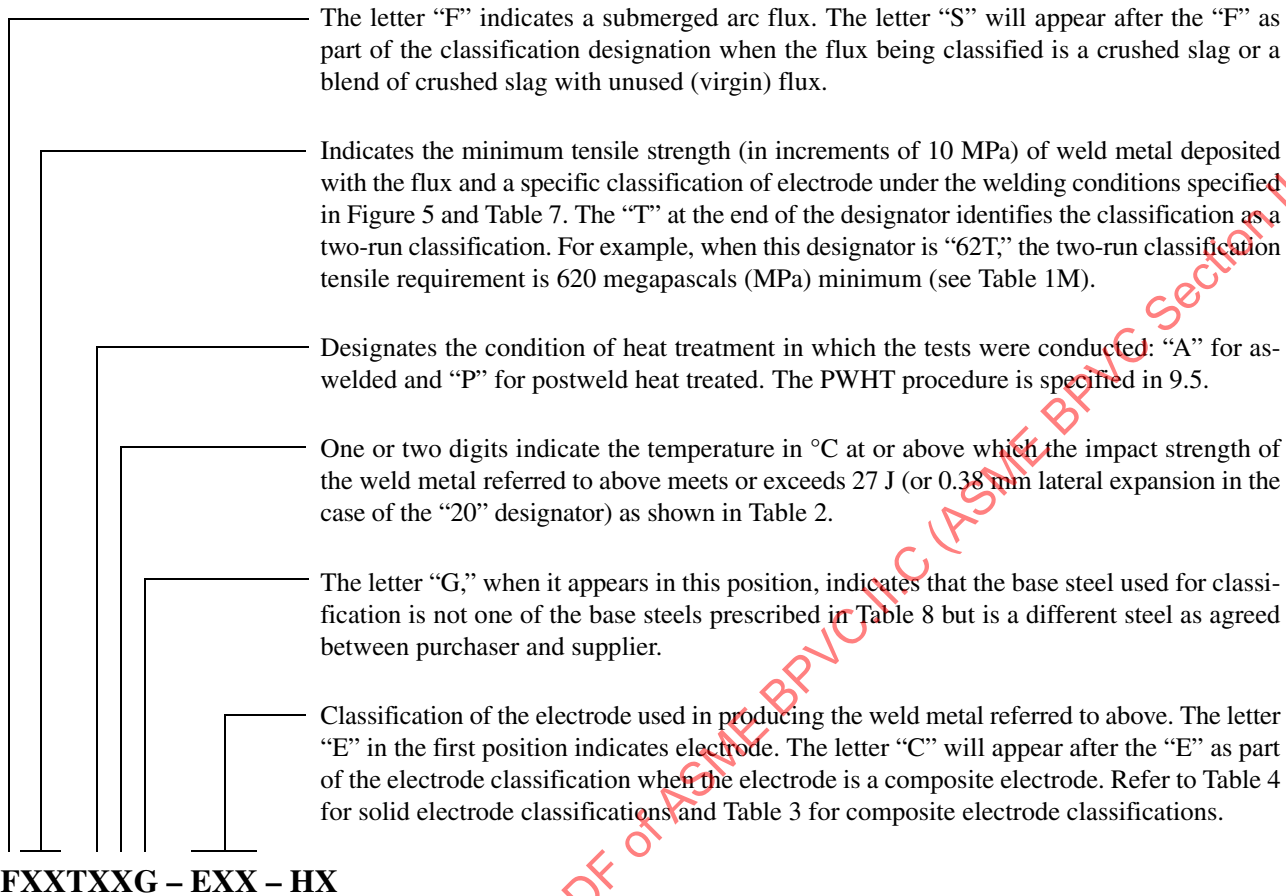
EXAMPLES

F7TA4-EM12K is a complete designation for a flux-electrode two-run classification. It refers to a flux that, when used with an EM12K electrode to weld the base plate prescribed in Table 8 in accordance with the two-run welding conditions called for in this specification, will produce weld metal in the as-welded condition having a minimum tensile strength of 70 000 psi and Charpy V-notch impact strength of at least 20 ft·lbf at –40°F.

F10TP2G-EA3 is a complete designation for a flux-electrode two-run classification. It refers to a flux that, when used with an EA3 electrode in accordance with the two-run welding conditions called for in this specification, will produce weld metal in the postweld heat treated condition having a minimum tensile strength of 100 000 psi and Charpy V-notch impact strength of at least 20 ft·lbf at –20°F. The “G” in the classification indicates that the base steel used is not as prescribed in Table 8 but is some other steel as agreed between purchaser and supplier.

Figure 2—A5.23 Two-Run Classification System for U.S. Customary Units

Mandatory Classification Designators^a



Optional Supplemental Designator^b

Optional supplemental diffusible hydrogen designator (see Table 10).

^a The combination of these designators constitutes the flux-electrode classification.

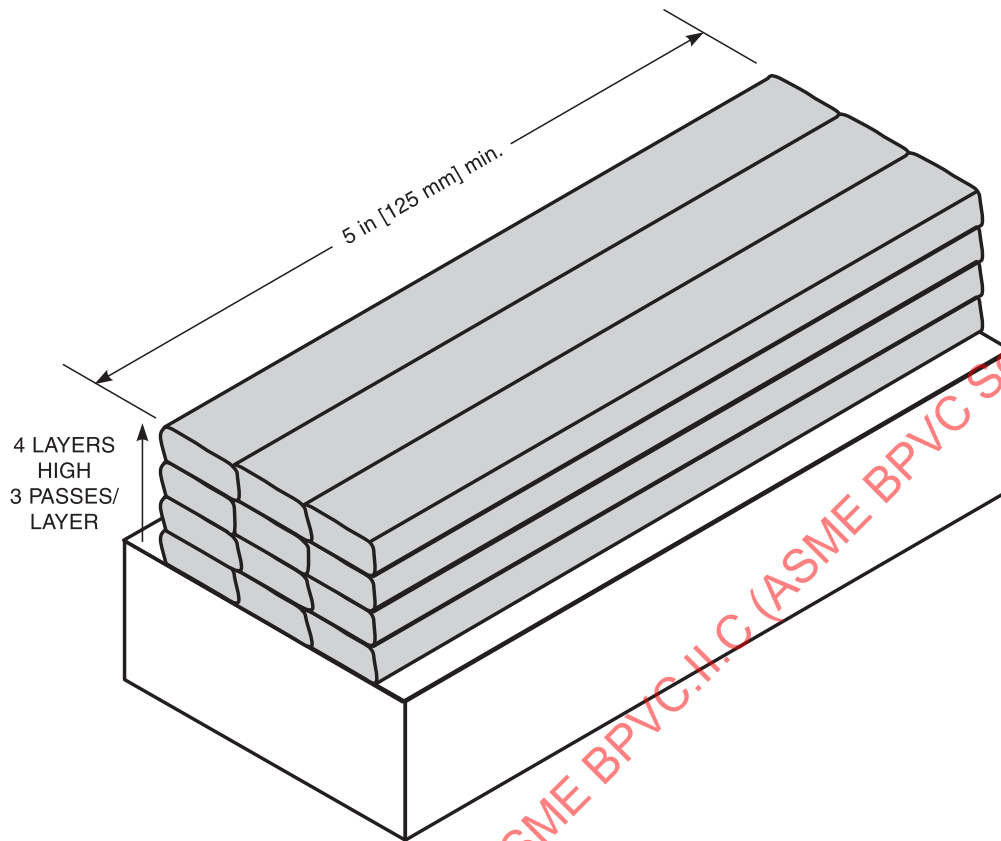
^b This designator is optional.

EXAMPLES

F55TA3-EM12K is a complete designation for a flux-electrode two-run classification. It refers to a flux that, when used with an EM12K electrode to weld the base plate prescribed in Table 8 in accordance with the two-run welding conditions called for in this specification, will produce weld metal in the as-welded condition having a minimum tensile strength of 550 MPa and Charpy V-notch impact strength of at least 27 J at -30°C.

F62TP4G-EA1 is a complete designation for a flux-electrode two-run classification. It refers to a flux that, when used with an EA1 electrode in accordance with the two-run welding conditions called for in this specification, will produce weld metal in the postweld heat treated condition having a minimum tensile strength of 620 MPa and Charpy V-notch impact strength of at least 27 J at -40°C. The "G" in the classification indicates that the base steel used is not as prescribed in Table 8 but is some other steel as agreed between purchaser and supplier.

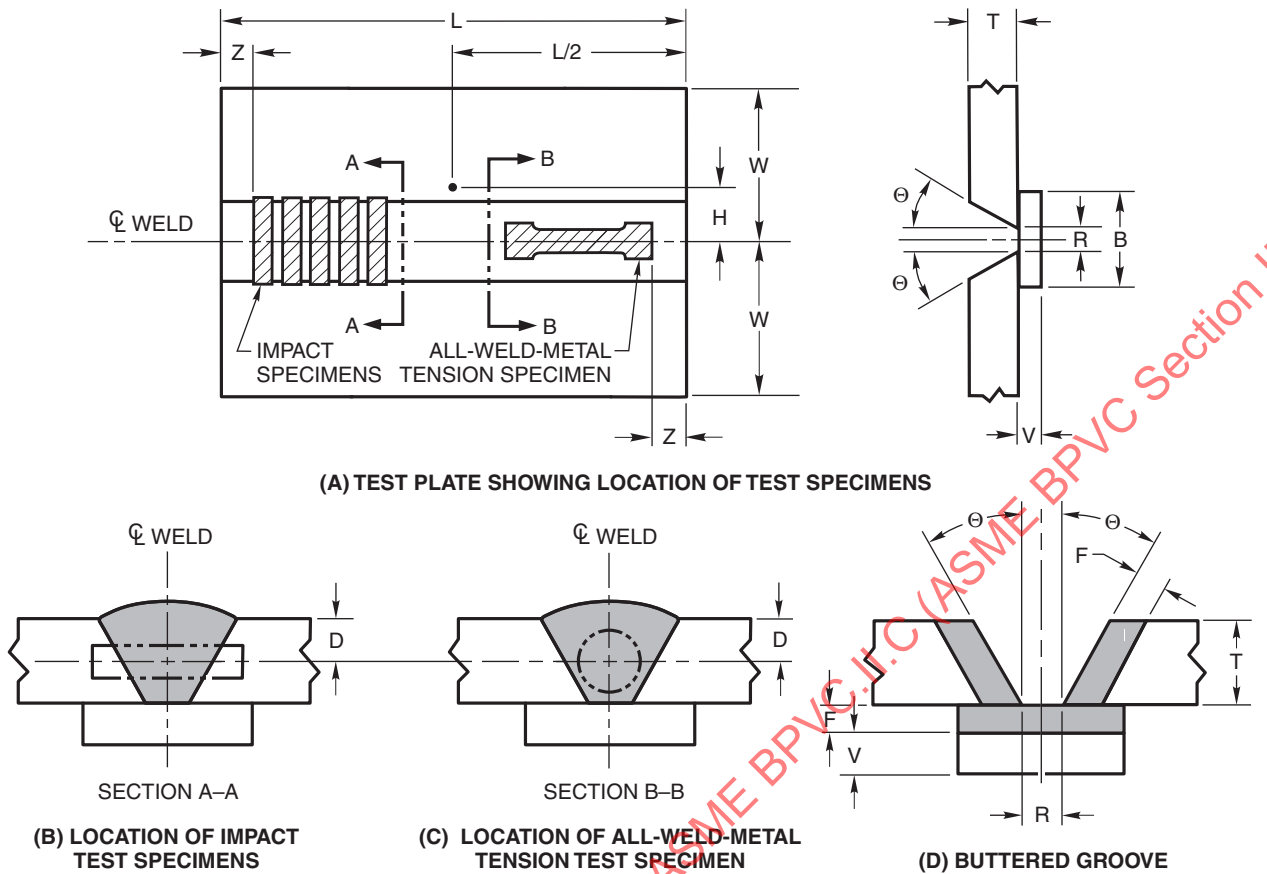
Figure 2M—A5.23M Two-Run Classification System for International System of Units (SI)



Notes:

1. Width, thickness, and length of the base metal plate may be any dimensions suitable for the electrode diameter and welding procedure. The base plate shall be of the type specified in Table 8 for the applicable weld metal designation.
2. Weld beads shall be deposited without oscillation. The welding conditions shall be in accordance with the welding parameters specified in Table 6 for the multiple-pass groove weld.
3. The first and last 2 in [50 mm] of the weld length shall be discarded. The top surface shall be removed, and chemical analysis shall be taken from the underlying metal of the fourth layer of the weld pad.

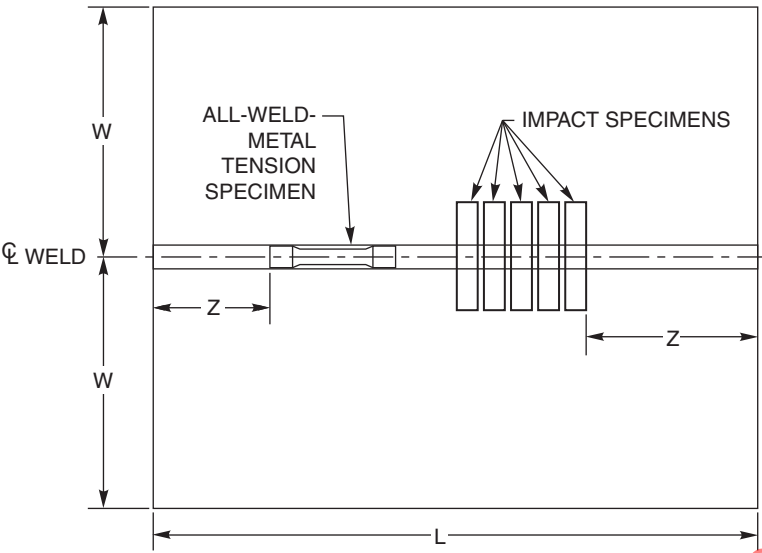
Figure 3—Weld Pad for Chemical Analysis of Weld Metal



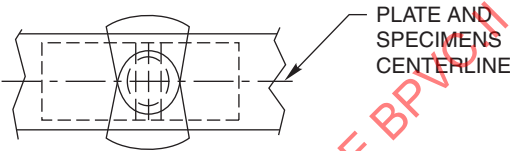
Dimension	Description	A5.23 (in)	A5.23M (mm)
L	Length, min.	12	300
T	Thickness	$1 \pm 1/16$	25 ± 1.5
W	Width, min.	5	125
V	Backing Strip Thickness: When No Butter Layer is Applied, min. Including Butter Layer when Applied, min.	$1/2$ $1/2$	12 12
D	Top Surface to Specimen Center	$3/8 \pm 1/32$	10 ± 1.0
B	Backing Strip Width, min.	2	50
R	Root Opening	$1/2 \pm 1/16$	12 ± 1.5
Z	Discard, min.	1	25
Θ	Bevel Angle	$15^\circ \pm 2^\circ$	
H	Approximate Point of Temperature Measurement	1	25
F	Butter layer thickness, min.	$1/8$	3

Note: See Table 8 Note a for details of buttered alternative base metal usage.

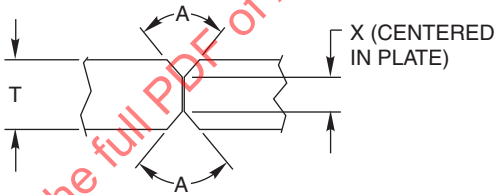
Figure 4—Multiple-Pass Groove Weld Test Assembly



(A) LOCATION OF TEST SPECIMENS



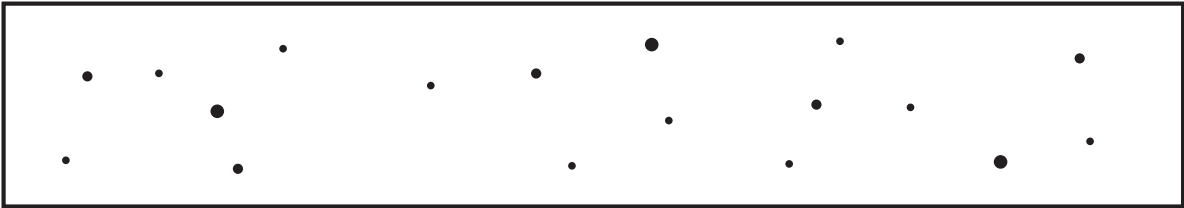
(B) LOCATION OF IMPACT AND TENSION TEST SPECIMENS



(C) JOINT CONFIGURATION

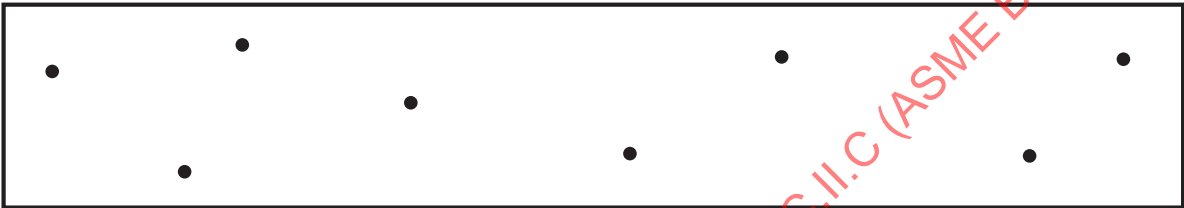
Dimension	Description	A5.23 (in)	A5.23M (mm)
A	Included angle (max.)	90°	
L	Length (min.)	12	300
T	Thickness	1/2 ± 1/16	12 ± 1.5
W	Width (min.)	5	125
X	Land (min.)	3/16	5
Z	Discard (min.)	1	25

Figure 5—Two-Run Weld Test Assembly



(A) ASSORTED ROUNDED INDICATIONS

MAXIMUM SIZE PERMITTED: 1/16 in [1.6 mm] max
NUMBER OF INDICATIONS PERMITTED IN ANY 6 in [150 mm] OF WELD: 18 max,
WITH THE FOLLOWING RESTRICTIONS IN THE NUMBER OF INDICATIONS OF EACH SIZE:
LARGE INDICATIONS (3/64 in to 1/16 in [1.2 mm to 1.6 mm]): 3 max.
MEDIUM INDICATIONS (1/32 in to 3/64 in [0.8 mm to 1.2 mm]): 5 max.
SMALL INDICATIONS (1/64 in to 1/32 in [0.4 mm to 0.8 mm]): 10 max.



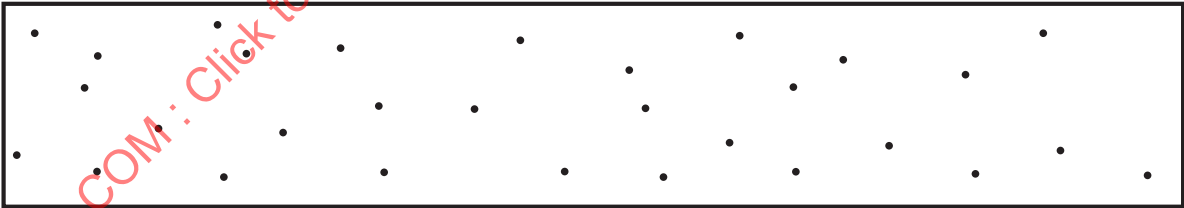
(B) LARGE ROUNDED INDICATIONS

SIZE PERMITTED: 3/64 in to 1/16 in [1.2 mm to 1.6 mm]
NUMBER OF INDICATIONS PERMITTED IN ANY 6 in [150 mm] OF WELD: 8 max.



(C) MEDIUM ROUNDED INDICATIONS

SIZE PERMITTED: 1/32 in to 3/64 in [0.8 mm to 1.2 mm]
NUMBER OF INDICATIONS PERMITTED IN ANY 6 in [150 mm] OF WELD: 15 max.



(D) SMALL ROUNDED INDICATIONS

SIZE PERMITTED: 1/64 in to 1/32 in [0.4 mm to 0.8 mm]
NUMBER OF INDICATIONS PERMITTED IN ANY 6 in [150 mm] OF WELD: 30 max.

Notes:

1. The chart which is most representative of the size of the rounded indications in the radiograph of the test assembly shall be used for determination of conformance with this specification. Rounded indications smaller than 1/64 in [0.4 mm] shall be disregarded. The largest dimension of the indication (including any tail) is the size of the indication.
2. These radiographic requirements are for test welds made in the laboratory specifically for classification purposes. They are more restrictive than those usually encountered in general fabrication.

Figure 6—Radiographic Standards for Rounded Indications

Annex A (Informative)

Guide to AWS Specification for Low-Alloy and High Manganese Steel Electrodes and Fluxes for Submerged Arc Welding

This annex is not a part of this standard and is included for information purposes only.

A1. Introduction

The purpose of this guide is to correlate the electrode and flux classifications with their intended applications so the specification can be used effectively. Appropriate base metal specifications are referred to whenever that can be done and when it would be helpful. Such references are intended only as examples rather than complete listings of the materials for which each flux or electrode is suitable.

A2. Classification System

A2.1 Classification of Electrodes. The system for identifying the electrode classifications in this specification follows the standard pattern used in other AWS filler metal specifications. The letter “E” (or “EC” for composite electrodes) at the beginning of each classification designation stands for electrode. The remainder of the designation indicates the chemical composition of the electrode or, in the case of composite electrodes, the chemical composition of the weld metal obtained with a particular flux. See Figure 1, 1M, 2, or 2M, as applicable.

For solid carbon steel electrodes, the letter “L” after the “E” indicates that the solid electrode is comparatively low in manganese content. The letter “M” after the “E” indicates medium manganese content, while the letter “H” after the “E” indicates comparatively high manganese content. The one or two digits following the manganese designator indicate the nominal carbon content of the electrode. Note that the above indicators of manganese and carbon content are not applicable to solid low-alloy steel electrodes. For solid low-alloy steel electrodes, one or two letters after the “E” are used to indicate the general alloy type. Subsequent digits identify the specific classification. The letter “K,” which appears in some designations, indicates a higher silicon content in the electrode. Solid carbon and low-alloy steel electrodes are classified only on the basis of their chemical composition, as specified in Table 4 of this specification.

A composite electrode is indicated by the letter “C” after the “E” and a numeric or alphanumeric suffix. The composition of a composite electrode may include metallic elements in the core material that are also present as oxides, fluorides, etc., of those same elements. Therefore, the chemical analysis of a composite electrode may not be directly comparable to an analysis made on a solid electrode. For this reason, the composition of composite electrodes is not used for classification purposes under this specification, and the user is referred to weld metal composition (Table 3) with a particular flux, rather than to electrode composition.

As examples, consider the following electrode designations: EL12, EM12K, EB3, EM3, and ECB3. As in other specifications, the prefix “E” designates an electrode. The EL12 and EM12K are solid carbon steel electrodes and the EB3 and EM3 are solid low-alloy steel electrodes. Their compositions are given in Table 4. The ECB3, however, is a composite electrode as indicated by the “C” after the “E.” Composite electrodes are classified by the composition of the weld metal produced with a specific flux as shown in Table 3. An ECB3 electrode, therefore, is a composite electrode which, when used with a particular flux, will produce weld metal meeting the requirements for a B3 deposit as shown in Table 3.

The letter “N” when added as a suffix is an optional supplemental designator indicating that the electrode is intended for certain very special welds in nuclear applications. These welds are found in the core belt region of the reactor vessel. This region is subject to intense neutron radiation, and it is necessary, therefore, that the phosphorus, vanadium, and copper contents of this weld metal be limited in order to resist neutron radiation-induced embrittlement. It is also necessary that the weld metal have a high upper-shelf energy level in order to withstand some embrittlement, yet remain serviceable over the years. These electrodes are not required elsewhere; however, they could be used anywhere that weld metal with an exceptionally high upper-shelf energy level is required.

A2.2 “G” Classification

A2.2.1 This specification includes electrode classified as “EG” (or “ECG”). The “G” indicates that the electrode is of a *general* classification. It is *general* because not all of the particular requirements specified for each of the other classifications are specified for this classification. The intent, in establishing this classification, is to provide a means by which electrodes that differ in one respect or another (chemical composition, for example) from all other classifications (meaning that the composition of the electrode, in the case of the example, does not meet the composition specified for any of the classifications in the specification) can still be classified according to the specification. The purpose is to allow a useful electrode, one that otherwise would have to wait for a revision of the specification, to be classified immediately under the existing specification. This means, then, that two electrodes, each bearing the same “G” classification, may be quite different in some certain respects (chemical composition, for example).

A2.2.2 For the two-run classification a “G” is used in the classification designation when, as agreed between supplier and purchaser, a difference in base material from that specified is used for qualification. See the second example in Figures 2 and 2M.

A2.2.3 The point of difference between filler metal of a “G” classification and filler metal of a similar classification without the “G” (or even with it, for that matter) may be further clarified from the use of the words “not required” and “not specified” in the specification. The use of these words is as follows:

Not Required is used in those areas of the specification that specify the tests that must be conducted in order to classify a welding material. It indicates that that test is not required because the results for the particular test are not a requirement for that particular classification. When a test is “not required,” it is not necessary to conduct the corresponding test in order to classify a filler metal to that classification. When a purchaser wants the information provided by that test in order to consider a particular product of that classification for a certain application, the purchaser will have to arrange for that information with the supplier of the product. The purchaser will have to establish with that supplier just what the testing procedure and the acceptance requirements are to be for that test. The purchaser may want to incorporate that information (via AWS A5.01M/A5.01) in the purchase order.

Not Specified is used in those areas of the specification that refer to the results of some particular test. It indicates that the requirements for that test are not specified for that particular classification. If the required results from a specific test are listed as “not specified” but the test in question is shown as “required” then the test results must be reported.

A2.2.4 Request for Filler Metal Classification. When a flux or electrode cannot be classified other than with a “G” classification, the manufacturer may request that a classification be established. The manufacturer shall do this using the following procedure.

(1) A request to establish a new filler metal classification must be submitted in writing. The request needs to provide sufficient detail to permit the Committee on Filler Metals and Allied Materials and the relevant subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate or if neither is necessary. In particular, the request needs to include:

- (a) A declaration that the new classification will be offered for sale commercially.
- (b) All classification requirements as given for existing classifications, such as chemical composition ranges, mechanical property requirements, and usability test requirements.
- (c) Any conditions for conducting the tests used to demonstrate that the product meets the classification requirements. It would be sufficient, for example, to state that welding conditions are the same as for other classifications.
- (d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the annex).

(e) Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.

(f) A request for a new classification without the above information will be considered incomplete. The secretary will return the request to the requester for further information.

(2) The request should be sent to the secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters.

A2.3 Classification of Fluxes. Fluxes are classified on the basis of the mechanical properties of the weld metal they produce with a certain classification of electrode, under the specific test conditions called for in this specification. Multiple-pass flux-electrode classifications also have requirements for weld metal composition. Refer to Figure 1, 1M, 2, or 2M, as applicable.

A2.3.1 It should be noted that flux of any specific trade designation may have many classifications. The number is limited only by the number of different electrode classifications, the condition of heat treatment (as-welded and postweld heat treated), and whether multiple-pass and two-run welding can meet the classification requirements. The flux marking lists at least one and may list all classifications to which the flux conforms. It should also be noted that the specific usability or operating characteristics of the various fluxes of the same classification may differ in one respect or another.

A2.3.2 Solid electrodes having the same classification are usually interchangeable when used with a specific flux. Composite electrodes may not be.

A3. Acceptance

Acceptance of all fluxes and electrodes classified under this specification is in accordance with AWS A5.01M/A5.01, as the specification states. Any testing a purchaser requires of the supplier for fluxes or electrodes shipped in accordance with this specification needs to be clearly stated in the purchase order according to the provisions of AWS A5.01M/A5.01. In the absence of any such statement in the purchase order, the supplier may ship the fluxes or electrodes with whatever testing the supplier normally conducts on flux or electrode of that classification, as specified in Schedule F, Table 1, of AWS A5.01M/A5.01. Testing in accordance with any other Schedule in that table must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations and optional supplemental designators, if applicable, on the packaging enclosing the product, or the classification on the product itself constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification. The only testing requirement implicit in this *certification* is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that that material met the requirements of the specification. Representative material, in this case, is material from any production run of that classification using the same formulation. *Certification* is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the *certification* required by the specification is the classification test of *representative material* cited above, and the Manufacturer's Quality Assurance Program in AWS A5.01M/A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes in the atmosphere to which welding operators are exposed during welding. They are:

- (1) Dimensions of the space in which the welding is done (with special regard to the height of the ceiling).

- (2) Number of welding operators working in that space.
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes used.
- (4) The proximity of the welding operators to the fumes, as these fumes issue from the welding zone, and to the gases and dusts in the space in which they are working.
- (5) The ventilation provided to the space in which the welding is done.

A5.2 American National Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the Clause on Ventilation in that document. See also AWS F3.2, *Ventilation Guide for Weld Fume*, for more detailed descriptions of ventilation options.

A.6 Description and Intended Use

A6.1 Types of Flux. SAW fluxes are granular, fusible mineral compounds of various proportions and quantities, manufactured by any of several different methods. Some fluxes may contain intimately mixed metallic ingredients to deoxidize the weld pool. Any flux is likely to produce weld metal of somewhat different composition from that of the electrode used with it due to chemical reactions in the arc and sometimes to the presence of metallic ingredients in the flux. A change in the arc voltage during welding will change the quantity of flux interacting with a given quantity of electrode and may therefore change the composition of the weld metal. This latter change provides a means of describing fluxes as “neutral,” “active,” or “alloy.”

A6.1.1 Neutral Fluxes. Neutral fluxes are those which will not produce any significant change in the weld metal chemical composition as a result of a large change in the arc voltage and thus, the amount of flux melted. The primary use for neutral fluxes is in multiple-pass welding, especially when the base metal exceeds 1 in [25 mm] in thickness. Note the following considerations concerning neutral fluxes:

(1) Since neutral fluxes contain little or no deoxidizers, they must rely on the electrode to provide deoxidation. Single-pass welds with insufficient deoxidation on heavily oxidized base metal may be prone to porosity, centerline cracking, or both.

(2) While neutral fluxes maintain the chemical composition of the weld metal even when the voltage is changed, the chemical composition of the weld metal may not be the same as that of the electrode. Some neutral fluxes decompose in the heat of the arc and release oxygen, resulting in a lower carbon value in the weld metal than the carbon content of the electrode itself. Some neutral fluxes contain manganese silicate, which can decompose in the heat of the arc and add manganese and silicon to the weld metal even though no metallic manganese or silicon was added to these particular fluxes. These changes in the chemical composition of the weld metal are fairly consistent, even when there are large changes in voltage.

(3) Even when a neutral flux is used to maintain the weld metal chemical composition through a range of welding voltages, weld metal properties such as strength level and impact properties can change because of changes in other welding parameters such as depth of fusion, heat input, and number of passes.

A6.1.2 Active Fluxes. Active fluxes are those which contain small amounts of manganese, silicon, or both. These deoxidizers are added to the flux to provide improved resistance to porosity and weld cracking caused by contaminants on or in the base metal. The primary use for active fluxes is to make single-pass welds, especially on oxidized base metal. Note the following considerations concerning active fluxes:

(1) Since active fluxes do contain some deoxidizers, the manganese, silicon, or both in the weld metal will vary with changes in arc voltage. An increase in manganese or silicon increases the strength and hardness of the weld metal in multiple-pass welds but may lower the impact properties. For this reason, the voltage may need to be more tightly controlled for multiple-pass welds with active fluxes than when using neutral fluxes.

(2) Some fluxes are more active than others. This means they offer more resistance to porosity due to base metal surface oxides in single-pass welds than a flux which is less active, but may pose more problems in multiple-pass welding.

A6.1.3 Alloy Fluxes. Alloy fluxes are those which can be used with a carbon steel electrode to make alloy weld metal. Some alloy for the weld metal is added as ingredients in the flux. As with active fluxes, where the recovery of manganese and silicon is affected significantly by arc voltage, so with alloy fluxes, the recovery of alloy elements from the flux is affected significantly by the arc voltage. With alloy fluxes, the manufacturer's recommendations should be closely followed if desired weld metal compositions are to be obtained. The use as a welding flux of crushed slags generated from alloy flux is not recommended.

A6.1.4 Crushed Slags. Slag formed during the welding process that is subsequently crushed for use as a welding flux is defined as a *crushed slag*. This is different from a recycled flux which was never fused into a slag and can often be collected from a clean surface and reused without crushing. Crushed slags and blends of crushed slag with unused (virgin) flux may be classified as a welding flux under this specification, but shall not be considered to be the same as a virgin flux. Although it is possible to crush and reuse submerged arc slag as a welding flux, the crushed slag, regardless of any addition of virgin flux to it, is a new and chemically different flux. This is because the slag formed during SAW does not have the same chemical composition or welding characteristics as the virgin flux. Its composition is affected by the composition of the original flux, chemical reactions which occur due to the welding arc, the base metal and electrode compositions, and the welding parameters.

Blends of crushed slag with the original brand of virgin flux from which it was generated cannot be assumed to conform to the classification of either component, even when both the crushed slag and virgin flux conform to the same classification (except for the "S" designator). It shall be the responsibility of the crusher or fabricator partner who performs the blending, to verify that any intended blend of crushed slag with the original brand of virgin flux is in full conformance with the classification requirements of this specification.

As with any flux product, the manufacturer (crusher) shall follow a detailed processing procedure with controlled input material, preparation, crushing, and blending, which will ensure that a standard flux product meeting the requirements of the classification is attained.

Slag generated by a fabricator from a specific brand of flux under controlled welding conditions, segregated at all points during collection and processing from other sources of slag or contaminants, crushed by the fabricator or another crushing organization, possibly blended with a specific virgin flux and returned to the same fabricator for use as a welding flux, is defined as closed-loop crushed slag.

Closed-loop crushed slags, or blends of closed-loop crushed slag with the original brand of virgin flux ensure better control of input material by virtue of the inherent partnering of the fabricator with the crusher. In some instances, these partners may be one and the same. When blending crushed slag with virgin flux, changes in the original virgin flux trade designation or in the blending ratio can affect the quality of the final product.

A6.2 Wall Neutrality Number. The Wall Neutrality Number (N) is a convenient measure of relative flux neutrality. The Wall Neutrality Number addresses fluxes and electrodes for welding carbon steel with regard to the weld metal manganese and silicon content. It does not address alloy fluxes. For a flux-electrode combination to be considered neutral, it should have an N value of 35 or lower. The lower the number, the more neutral the flux.

Determination of the Wall Neutrality Number can be done in accordance with the following:

- (1) A weld pad of the type shown in Figure 3 is welded with the flux-electrode combination being tested. The welding parameters shall be as specified in Table 6 for the groove weld test assembly for the diameter of electrode being used.
- (2) A second weld pad is welded using the same parameters, except that the arc voltage is increased by 8 volts.
- (3) The top surface of each of the weld pads is ground or machined smooth to clean metal. Samples sufficient for analysis are removed by machining. Weld metal is analyzed only from the top (fourth) layer of the weld pad. The samples are analyzed separately for silicon and manganese.
- (4) The Wall Neutrality Number depends on the change in silicon, regardless of whether it increases or decreases, and on the change in manganese, regardless of whether it increases or decreases. The Wall Neutrality Number is the absolute value (ignoring positive or negative signs) and is calculated as follows:

$$N = 100 (|\Delta\%Si| + |\Delta\%Mn|)$$

where $\Delta\%Si$ is the difference in silicon content of the two pads and $\Delta\%Mn$ is the corresponding difference in manganese content.

A7. Description and Intended Use of Electrodes

A7.1 Choice of Electrodes. In choosing an electrode classification for SAW, the most important considerations are the mechanical properties expected of the weld metal, the requirements for weld metal composition, whether the weld is to be single-pass or multiple-pass, the cleanliness and composition of the steel to be welded, and the type of flux to be used. It is important to note that the mechanical properties obtained on a one-run or two-run weld are often quite different than those obtained on a multiple-pass weld made with the same flux and electrode. For that reason, a two-run flux-electrode classification option is included in this specification to provide for an alternate classification system based upon welding conditions that more closely reflect limited pass applications. The AWS A5.23/A5.23M specification (instead of the AWS A5.17/A5.17M specification) was selected for the inclusion of a two-run classification system because for these types of applications it is common commercial practice to use a low-alloy electrode for the welding of carbon steel to enhance the weld metal mechanical properties. For example, an EA1 molybdenum-bearing electrode is routinely used in pipemills to improve the strength level and impact properties of the two-run welds made to manufacture pipe. In addition, the strength level requirements for two-run welds such as used for the manufacture of pipe can be significantly higher than those shown in A5.17/A5.17M and are more consistent with the strength levels included in A5.23/A5.23M.

A certain minimum weld metal manganese content is necessary to avoid centerline cracking. This minimum depends upon restraint of the joint and upon the weld metal composition. In the event that centerline cracking is encountered, especially with a low manganese electrode (see Table 4) and neutral flux, a change to a higher manganese electrode, a change to a more active flux, or both, may eliminate the problem.

Certain fluxes, generally considered to be neutral, tend to remove carbon and manganese to a limited extent and to replace these elements with silicon. With such fluxes, a silicon-killed electrode is often not necessary though it may be used. Other fluxes add no silicon and may therefore require the use of a silicon-killed electrode for proper wetting and freedom from porosity. The flux manufacturer should be consulted for electrode recommendations suitable for a given flux.

When welding single-pass fillet welds, especially on scaly base metal, it is important that the flux, electrode, or both, provide sufficient deoxidation to avoid unacceptable porosity. Silicon is a more powerful deoxidizer than manganese. In such applications, use of a silicon-killed electrode or of an active flux, or both may be essential. Again, manufacturer's recommendations should be consulted.

Composite electrodes are generally designed for a specific flux. The flux identification is required (see 16.7.1) to be marked on the electrode package. Before using a composite electrode with a flux not indicated on the electrode package, the electrode producer should be contacted for recommendations. A composite electrode might be chosen for a higher melting rate and lower depth of fusion at a given current level than would be obtained under the same conditions with a solid electrode.

A7.2 Chemical Composition. For the welding of low-alloy steel, the chemical composition of the weld metal produced is often the primary consideration for electrode selection. Together with appropriate heat treatments, each composition can achieve a wide range of corrosion resistance and mechanical properties at various service temperatures. It is usually desirable for weld metal to match the chemical composition and the mechanical properties of the base metal as closely as possible. In fact, many of the electrodes classified to this specification have been developed for specific base metal grades or classes. If an optimum match is not possible, engineering judgment together with weld testing may be required to select the most suitable electrodes. Table 3 provides detailed weld metal chemical composition requirements. Tables 1, 1M, and 2 list the mechanical properties of the weld metal in the as-welded condition or in the postweld heat-treated condition when the weldment is subjected to the PWHT requirements in Table 9. It should be noted that changes in welding variables or heat treatment can be expected to affect the mechanical properties. However, except for the effects of dilution, the chemical composition can be expected to remain reasonably unchanged when using a neutral flux.

The electrode classification identifies the chemical composition of the electrode. The following paragraphs highlight the differences between these electrodes and electrode groups and indicate typical applications.

A7.2.1 EL8, EL8K, EL12, EM11K, EM12, EM12K, EM13K, EM14K, EM15K, EH10K, EH11K, EH12K, and EH14 (Carbon Steel) Electrodes. These electrodes are carbon steel electrodes which vary from one another in their carbon, manganese, and silicon contents. An electrode from this group is selected for use with a particular flux to provide the best combination of these elements to meet application requirements. These requirements can include (but are not limited to) resistance to cracking and porosity, welding characteristics, welding speed, bead appearance, and weld metal

mechanical properties. The EM14K electrodes also contain small additions of titanium, although they are considered carbon steel electrodes. The titanium functions to improve strength and toughness under certain conditions of high heat input welding or PWHT. The manufacturer should be consulted for specific recommendations.

A7.2.2 EA1, EA2, EA3, EA3K, and EA4 (C-Mo Steel) Electrodes. These electrodes are similar to the medium manganese and high manganese carbon steel electrodes shown above except that 0.5% molybdenum is added. This addition increases the strength of the weld metal, especially at elevated temperatures, and provides some increase in corrosion resistance. Typical applications include the welding of C-Mo steel base metals such as ASTM A204 plate and ASTM A335-P1 pipe. Electrodes of this type are particularly useful in developing impact strength on single-pass welds such as are used in the manufacture of line pipe.

A7.2.3 EB1, EB2, EB2H, EB3, EB5, EB6, EB6H, EB8, EB23, EB24, EB91, and EB115 (Cr-Mo Steel) Electrodes. These electrodes produce weld metal that contains between 0.5% and 12% chromium and between 0.5% and 1% molybdenum. They are designed to produce weld metal for high temperature service.

The letter “R” when added as a suffix to the EB2 or EB3 electrode classification or to the B2 or B3 weld metal designation is an optional supplemental designator indicating that the electrode will meet the reduced residual limits necessary to meet “X” factor requirements for step cooling applications.

Since all Cr-Mo weld deposits will air harden in still air, both preheat and postweld heat treatment are required for most applications.

A7.2.3.1 EB91 (previously EB9) is a 9% Cr-1% Mo electrode modified with niobium and vanadium designed to provide improved creep strength, and oxidation and corrosion resistance at elevated temperatures. Due to the higher elevated temperature properties of this alloy, components that are now fabricated from stainless and ferritic steels may be fabricated from a single alloy, eliminating problems associated with dissimilar welds.

In addition to the classification requirements of this specification, impact toughness and high temperature creep strength properties should be determined. Due to the influence of various levels of carbon and niobium (columbium), specific values and testing must be agreed to by the purchaser and supplier.

Thermal treatment of the B91 alloy is critical and must be closely controlled. The temperature at which the microstructure has complete transformation into martensite (M_f) is relatively low; therefore, upon completion of welding and before postweld heat treatment, it is recommended that the weldment be allowed to cool below 200°F [93°C] to maximize transformation to martensite. The maximum allowable temperature for PWHT is also critical in that the lower transformation temperature (A_{c1}) is also comparably low. *To aid in allowing for an adequate postweld heat treatment, the restriction of Mn + Ni has been imposed (see Table 3, Note j).* The combination of Mn and Ni tends to lower the A_{c1} temperature to the point where the PWHT temperature approaches the A_{c1} , possibly causing partial transformation of the microstructure. By restricting the Mn + Ni, the PWHT temperature will be sufficiently below the A_{c1} to avoid this partial transformation. See Table 3 for B91 designations with lower Mn + Ni levels.

A7.2.3.2 EB115 is a 10.5% Cr-0.5% Mo electrode modified with niobium and vanadium to provide improved creep strength, oxidation, and corrosion resistance at elevated temperatures. This filler metal is similar to the EB91 type but has a higher Cr content to enhance the oxidation resistance, and a higher vanadium to niobium ratio to ensure long-term rupture strength in the time-dependent regime

A7.2.4 EF4, EF5, and EF6 (Cr-Ni-Mo Steel) Electrodes. These electrodes use a combination of Cr, Ni, and Mo to develop the strength levels and notch toughness required for a number of high-strength, low-alloy or microalloyed structural steels.

A7.2.5 EM2, EM3, and EM4 (High-Strength, Low-Alloy Steel) Electrodes. These electrodes may contain a combination of Cr, Ni, Mo, Ti, Zr, and Al. They are intended to produce high-strength deposits meeting 100 000 psi [690 MPa], 110 000 psi [760 MPa], or 120 000 psi [830 MPa] minimum tensile requirements to weld steels such as HY80 and HY100. They are most typically used for weldments not subject to PWHT.

A7.2.6 ECMn2. Weld metal of this composition has been designed for joining austenitic steels of similar composition used for containing liquid natural gas and other cryogenic liquids. Weld metal of this composition is also used for welding nickel steels such as 3-1/2% and 9% nickel steels.

A7.2.7 ENi1, ENi1K, ENi2, and ENi3 (Ni Steel) Electrodes. These electrodes have been designed to produce weld metal with increased strength without being hardenable or with increased notch toughness at temperatures as low as -100°F (-73°C) or lower. They have been specified with nickel contents which fall into three nominal levels of 1% Ni, 2.5% Ni, and 3.5% Ni. With carbon levels of up to 0.12%, strength increases and weld deposits can meet 80 000 psi [550 MPa] minimum tensile strength requirements. However, with lower levels of carbon, low temperature toughness improves to match the base metal properties of nickel steels such as ASTM A203 Gr. E, ASTM A352 LC3 and LC4 classifications.

Many low-alloy steels require PWHT to stress relieve the weld or temper the weld metal and heat-affected zone (HAZ) to achieve increased ductility. It is often acceptable to exceed the PWHT holding temperatures shown in Table 9. However, for many applications, nickel steel weld metal can be used without PWHT. If PWHT is to be specified for a nickel steel weldment, the holding temperature should not exceed the maximum temperature given in Table 9 for the classification considered since nickel steels can be embrittled at higher temperatures.

A7.2.8 ENi4, ENi5, ENi6, EF1, EF2, and EF3 (Ni-Mo Steel) Electrodes. These electrodes contain between 0.5% and 2% nickel and between 0.25% and 0.5% molybdenum. They are typically used for multiple-pass welding of high-strength, low-alloy, or microalloyed structural steels where a combination of strength and good notch toughness is required.

A7.2.9 EW (Weathering Steel) Electrode. This electrode has been designed to produce weld metal that matches the corrosion resistance and the coloring of the ASTM weathering-type structural steels. These special properties are achieved by the addition of about 0.5% copper to the weld metal. To meet strength, ductility, and notch toughness in the weld metal, some chromium and nickel additions are also made. This electrode is used to weld the typical weathering steel, such as ASTM A242 and ASTM A588.

A7.2.10 EG (General Low-Alloy Steel) Electrodes. These electrodes are described in A2.2. These electrode classifications may be either modifications of other discrete classifications or totally new classifications. Purchaser and user should obtain from the supplier the description and intended use for any EG electrode.

A8. Mechanical Properties of Submerged Arc Welds

Tables 1, 1M, and 2 (as applicable) of this specification list the mechanical properties required of weld metal for both multiple-pass and two-run flux-electrode classifications. The mechanical properties are determined from specimens prepared according to the procedures called for in this specification. The multiple-pass procedure (for multiple-pass flux-electrode classifications) minimizes dilution from the base metal and provides a finer grain structure due to the reheating of the deposited metal by subsequent weld passes. Therefore, this classification procedure more accurately reflects the properties of the undiluted weld metal from each flux-electrode classification. The two-run procedure (for two-run flux-electrode classifications) more accurately reflects the properties of as-deposited weld metal made with a particular flux and electrode under conditions of high base plate dilution. For this reason the composition of the base material is highly influential on the composition and mechanical properties of two-run weld deposits.

While electrodes are generally interchangeable, fluxes are not. For this reason, a classification system with standardized test methods is necessary to relate the fluxes and electrodes to the properties of their weld metal. Chemical reactions between the molten portion of the flux and electrode, and dilution by the base metal all affect the composition of the weld metal.

The mechanical properties of a weld are a function of its chemical composition, cooling rate, and PWHT. High amperage, single-pass welds have a greater depth of fusion and hence greater dilution by the base metal than lower current, multiple-pass welds. Large, single-pass welds solidify and cool more slowly than the smaller weld beads of a multiple-pass weld, and succeeding passes of a multiple-pass weld subject the weld metal of previous passes to a variety of temperature and cooling cycles that alter the metallurgical structure of different portions of those beads. For these reasons, the properties of a single-pass weld may be different from those of a multiple-pass weld made with the same electrode and flux.

The weld metal properties in this specification are determined in either the as-welded condition or after a postweld heat treatment, or both. For multiple-pass classifications tested in the postweld heat treated condition ("P" designator, see Figure 1 or 1M, as applicable) the PWHT procedure is as indicated in Table 9 and 9.4. For two-run classifications tested in the postweld heat treated condition ("P" designator, see Figure 2 or 2M, as applicable) the PWHT procedure is as indicated in 9.5. Most of the weld metals are suitable for service in either condition, but the specification cannot cover all of the

conditions that such weld metal may encounter in fabrication or service. Hence, the classifications in this specification require that the weld metals be produced and tested under certain specific conditions.

Procedures employed in practice may require voltage, amperage, type of current, number of welding arcs, and travel speeds that are considerably different from those required in this specification. In addition, differences encountered in electrode size, electrode composition, electrode extension, joint configuration, preheat temperature, interpass temperature, and postweld heat treatment can have a significant effect on the properties of the weld. Within a particular electrode classification, the electrode composition can vary sufficiently to produce variations in the mechanical properties of the weld deposit in both the as-welded and postweld heat treated conditions.

For multiple-pass welds, postweld heat treatment times in excess of the time used for multiple-pass classification purposes in this specification may have a major influence on the strength and toughness of the weld metal. The user should be aware of this and understand that the mechanical properties of weld metal produced with other procedures than those required in this specification may differ from the properties required by Tables 1, 1M, and 2 of this specification, as applicable.

A9. Special Tests

It is recognized that supplementary tests may be required for certain applications. In such cases, tests to determine specific properties such as corrosion resistance, scaling resistance or strength at elevated or cryogenic temperatures may be required. AWS A5.01M/A5.01 contains provisions for ordering such tests. This clause is included for the guidance of those who choose to specify such special tests. These tests may be conducted as agreed upon between the purchaser and supplier.

A10. Diffusible Hydrogen Test

A10.1 The SAW process is generally considered to be a low-hydrogen welding process. As the weld metal or HAZ strength or hardness increases, the concentration of diffusible hydrogen that will cause cracking under given conditions of restraint and heat input becomes lower. This cracking (or its detection) is usually delayed some hours after cooling. It may appear as transverse weld cracks, longitudinal cracks (especially in the root beads), and toe or underbead cracks in the HAZ.

A10.2 Since the available diffusible hydrogen level strongly influences the tendency towards hydrogen-induced cracking, it may be desirable to measure the diffusible hydrogen content resulting from welding with a particular flux-electrode combination. This specification has, therefore, included the use of optional designators for diffusible hydrogen to indicate the maximum average value obtained under a clearly defined test condition in AWS A4.3, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*.

A10.3 The user of this information is cautioned that actual fabrication conditions may result in different diffusible hydrogen values from those indicated by the designator.

A10.4 Fluxes and composite electrodes can be contaminated by the condensation of moisture from the atmosphere and in some cases can absorb significant moisture if stored in a humid environment in damaged or open packages, especially if unprotected for long periods of time. In extreme cases of high humidity, even overnight exposure of unprotected flux or composite electrode can lead to a significant increase of diffusible hydrogen. In the event the flux or composite electrode has been exposed, the manufacturer should be consulted regarding probable damage to its low-hydrogen characteristics and possible reconditioning of the flux or composite electrode. Solid electrodes can also be contaminated under the same conditions. In this case, the moisture contamination is on the surface and can be seen as surface rust.

A10.5 Flux-electrode combinations for some classifications may not be available in the H16, H8, H4, or H2 diffusible hydrogen levels. The manufacturer of a given flux or composite electrode should be consulted for availability of products meeting these limits.

A10.6 Aging of Tensile Specimens. Weld metals may contain significant quantities of hydrogen for some time after they have been made. Most of this hydrogen gradually escapes over time. This may take several weeks at room temperature or several hours at elevated temperatures. As a result of this eventual change in hydrogen level, ductility of the weld metal

increases toward its inherent value, while yield, tensile, and impact strengths remain relatively unchanged. The A5.23 and A5.23M specifications permit the aging of the test specimens or weld test assembly at elevated temperatures not exceeding 220°F [105°C] for up to 48 hours before cooling them to room temperature and subjecting them to testing. The purpose of this treatment is to facilitate removal of hydrogen from the test specimen in order to minimize wide variations in test results.

Aging treatments are sometimes used for low hydrogen electrode deposits, especially when testing high strength deposits. Note that aging may involve holding test specimens or weld test assemblies at room temperature for several days or holding at a somewhat higher temperature for a shorter period of time. Consequently, users are cautioned to employ adequate preheat and interpass temperatures to avoid the deleterious effects of hydrogen in production welds. It should be kept in mind that aging test assemblies may not remove as much diffusible hydrogen as aging the individual specimens. The purchaser may, by mutual agreement with the supplier, have the thermal aging of specimens prohibited for all mechanical testing done to schedule I or J of AWS A5.01M/A5.01.

A11. General Safety Considerations

A11.1 Safety issues and concerns are addressed in this standard, although health issues and concerns are beyond the scope of this standard. Some safety and health information can be *found* in Annex Clause A5. Safety and health information is available from other sources including, but not limited to, Safety and Health Fact Sheets, ANSI Z49.1, and applicable federal and state regulations.

A11.2 Safety and Health Fact Sheets. The Safety and Health Fact Sheets are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

Table A.1
Comparison of Solid Electrode Designations^a

AWS A5.23/A5.23M Classification	ISO 14171 ^b Designation		ISO 24598 ^c Designation		ISO 26304 ^d Designation	
	ISO 14171-A	ISO 14171-B	ISO 24598-A	ISO 24598-B	ISO 26304-A	ISO 26304-B
EL8 ^e	S1	(SU11)	—	—	—	—
EL8K ^e	S1Si1	SU08	—	—	—	—
EL12 ^e	S1	(SU11)	—	—	—	—
EM11K ^e	—	SU111	—	—	—	—
EM12 ^e	S2	(SU22)	—	—	—	—
EM12K ^e	S2Si	SU21	—	—	—	—
EM13K ^e	S2Si2	SU25	—	—	—	—
EM14K ^e	—	SU24	—	—	—	—
EM15K ^e	S2Si	(SU21)	—	—	—	—
EH10K ^e	S3Si	SU10	—	—	—	—
EH11K ^e	—	SU31	—	—	—	—
EH12K ^e	S4Si	(SU42)	—	—	—	—
EH14 ^e	—	(SU41)	—	—	—	—
EA1	—	SU1M3	(SMo)	SU1M3	—	—
EA1TiB	—	SUM3TiB	—	—	—	—
EA2	S2Mo	(SU2M3)	SMo	SU3M3	—	—
EA2TiB	—	SU2M3TiB	—	—	—	—
EA3	S4Mo	SU4M3	—	SU4M3	—	—
EA3K	—	SU4M31	—	SU4M31	—	—
EA4	S3Mo	SU3M3	SMnMo	—	—	—
EB1	—	—	—	SUCM	—	—
EB2	—	—	SCrMo1	SU1CM	—	—
EB2H	—	—	—	SU1CMVH	—	—
EB3	—	—	SCrMo2	SU2C1M	—	—
EB5	—	—	—	SUC1MH	—	—
EB6	—	—	SCrMo5	SU5CM	—	—
EB6H	—	—	—	SU5CMH	—	—
EB8	—	—	SCrMo9	SU9C1M	—	—
EB23	—	—	—	—	—	—
EB24	—	—	—	—	—	—
EB91	—	—	—	SU9C1MV	—	—

(Continued)

Table A.1 (Continued)
Comparison of Solid Electrode Designations^a

AWS A5.23/A5.23M Classification	ISO 14171 ^b Designation		ISO 24598 ^c Designation		ISO 26304 ^d Designation	
	ISO 14171-A	ISO 14171-B	ISO 24598-A	ISO 24598-B	ISO 26304-A	ISO 26304-B
EF1	—	—	—	—	S2Ni1Mo	SUN2M2
EF2	—	—	—	—	—	SUN1M3
EF3	—	—	—	—	—	SUN2M33
EF4	—	—	—	—	—	SUN1C1M1
EF5	—	—	—	—	—	SUN5CM3
EF6	—	—	—	—	—	SUN4C1M3
EM2	—	—	—	—	—	SUN3M2
EM3	—	—	—	—	—	SUN4M2
EM4	—	—	—	—	—	SUN5M3
ENi1	S2Ni1	SUN2	—	—	—	—
ENi1K	—	SUN21	—	—	—	—
ENi2	—	SUN5	—	—	—	—
ENi3	S2Ni3	SUN7	—	—	—	—
ENi4	—	SUN4M1	—	—	—	SUN4M1
ENi5	—	SUN2M1	—	—	—	SUN2M1
ENi6	—	—	—	—	—	—
EW	—	SUNCC1	—	—	—	—

^a The requirements for the equivalent classifications shown are not necessarily identical in every respect.

^b ISO 14171, *Welding Consumables — Wire Electrodes and Wire-Flux Combinations for Submerged Arc Welding of Non-Alloy and Fine Grain Steels — Classification*, is a cohabitation document providing for classification utilizing a system based upon the yield strength and the average impact energy for all-weld metal of 47 J (ISO 14171-A), or utilizing a system based upon the tensile strength and the average impact energy for all-weld metal of 27 J (ISO 14171-B).

^c ISO 24598 *Welding Consumables — Solid Wire Electrodes, Tubular Cored Electrodes and Electrode-Flux Combinations for Submerged Arc Welding of Creep-Resisting Steels — Classification*, is a cohabitation document. The classification according to system A is mainly based on EN 12070. The classification according to system B is mainly based upon standards used around the Pacific Rim.

^d ISO 26304, *Welding Consumables — Solid Wire Electrodes, Tubular Cored Electrodes and Electrode/Flux Combinations for Submerged Arc Welding of High Strength Steels — Classification*, is a cohabitation document. The classification according to system A is mainly based on EN 14295. The classification according to system B is mainly based upon standards used around the Pacific Rim.

^e These solid wire electrode classifications also appear in AWS A5.17/A5.17M.

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

B6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

SPECIFICATION FOR ZIRCONIUM AND ZIRCONIUM-ALLOY WELDING ELECTRODES AND RODS



SFA-5.24/SFA-5.24M



(Identical with AWS Specification A5.24/A5.24M:2023. In case of dispute, the original AWS text applies.)

Specification for Zirconium and Zirconium-Alloy Welding Electrodes and Rods

1. Scope

1.1 This specification prescribes requirements for the classification of zirconium and zirconium-alloy electrodes and rods for gas metal arc, gas tungsten arc, and plasma arc welding.

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements *are* not exact equivalents; therefore, each system must be used independently *of the other, without combining values in any way when referring to material properties. The specification with the designation A5.24 uses U.S. Customary Units. The specification A5.24M uses SI Units.* The latter are shown within brackets [] or in appropriate columns in tables. *Standard dimensions based on either system may be used for sizing of electrodes or packaging or both under A5.24 or A5.24M specifications.*

1.3 Safety and health issues and concerns are beyond the scope of this standard; *some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in Annex Clauses A5 and A10.* Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. Unless otherwise defined in this document, welding terms are as defined in AWS A3.0M/A3.0. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to or revisions of any of these publications do not apply.

2.1 American Welding Society (AWS) documents:

- (1) AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*;
- (2) AWS A5.01M/A5.01 (ISO 14344 MOD), *Welding and Brazing Consumables—Procurement of Filler Metals and Fluxes*
- (3) AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*

2.2 American National Standards Institute (ANSI) documents:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

2.3 ASTM International (ASTM) documents:

- (1) ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*
- (2) ASTM E1409, *Standard Test Method for Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by Inert Gas Fusion Technique*
- (3) ASTM E1447, *Standard Test Method for Determination of Hydrogen in Titanium and Titanium Alloys by Inert Gas Fusion Thermal Conductivity/Infrared Detection Method*
- (4) ASTM E1552, *Standard Test Method for Determining Hafnium in Zirconium and Zirconium Alloys by Direct Current Plasma – Atomic Emission Spectrometry*
- (5) ASTM E1941, *Standard Test Method for Determination of Carbon in Refractory and Reactive Metals and Their Alloys by Combustion Analysis*
- (6) ASTM E2371, *Standard Test Method for Analysis of Titanium and Titanium Alloys by Direct Current Plasma and Inductively Coupled Plasma Atomic Spectrometry (Performance Based Test Methodology)*

2.4 International Organization for Standardization (ISO) document:

- (1) ISO 80000-1:2009, *Quantities and units—Part 1: General. Corrected by ISO 80000-1:2009/Cor 1:2011*

3. Classification

3.1 The welding materials covered by the AWS A5.24/A5.24M specification are classified using a system that is independent of U.S. Customary Units and the International System of Units (SI). Classification is according to chemical composition, as specified in Table 1.

Table 1
Chemical Composition Requirements for Zirconium and Zirconium-Alloy Electrodes and Rods

AWS Classification	UNS Number ^b	Weight Percent ^a								
		Zirconium and Hafnium	Hafnium	Iron and Chromium	Tin	Oxygen ^c	Hydrogen ^c	Nitrogen ^c	Carbon ^c	Niobium
ERZr2	R62702	99.0 min	4.5	0.20	—	0.11–0.15	0.005	0.015	0.03	—
ERZr3	R62704	97.5 min	4.5	0.20–0.40	1.0–2.0	0.11–0.16	0.005	0.015	0.03	—
ERZr4	R62705	95.5 min	4.5	0.20	—	0.11–0.16	0.005	0.015	0.03	2.0–3.0

^a Single values are maximum, except as noted.

^b SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System*, is published by SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

^c Analysis of the interstitial elements C, O, H, and N shall be conducted on samples of filler metal taken after the filler metal has been reduced to its final diameter and all processing operations have been completed. Analysis of the other elements may be conducted on these same samples or it may have been conducted on samples taken from the ingot or the rod stock from which the filler metal is made. In case of dispute, samples from the finished filler metal shall be the referee method.

3.2 Materials classified under one classification shall not be classified under any other classification of this specification. An electrode or rod may be classified under both A5.24 and A5.24M specifications.

3.3 The filler metals classified under this specification are intended for gas metal arc welding, gas tungsten arc welding, and plasma arc welding processes, but that is not to prohibit their use with any other process for which they are found suitable.

4. Acceptance

Acceptance of the electrode or rod shall be in accordance with the provisions of AWS A5.01M/A5.01 and the tests and requirements of this specification. See A3 (in Annex A) for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

5. Certification

By affixing the AWS specification and classification designations to the packaging or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification. See A4 (in Annex A) for further information concerning certification and the testing called for to meet this requirement.

6. Rounding Procedure

For the purpose of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfill the requirements for the classification under test.

7. Summary of Tests

The only test required for classification of a product under this specification is full chemical analysis of the filler metal after all thermal and chemical processing or, as permitted in footnote c of Table 1, partial chemical analysis of the rod stock or original producer's melt being used to produce such filler metal, together with partial chemical analysis of the finished filler metal when analyzing for interstitial elements, C, O, H, and N.

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Material for retest may be taken from the original sample or from a new sample taken from the same heat and lot of material as the original sample. Retest need be only for those specific elements that failed to meet the test requirement. If the results of one or both retests fail to meet the requirement, the materials under test shall be considered as not meeting the requirements of this specification for that classification.

If during preparation or after completion of any test it is clearly determined that specified or proper procedures were not followed in preparing the test specimens or in conducting the test, the test shall be considered invalid without regard to whether the test was actually completed, or whether test results met or failed to meet the requirement. That test shall be repeated, following proper specified procedures. In this case, the requirement for doubling the number of test specimens does not apply. For any sample that is invalidated, a new sample shall be cut from the same heat and lot of wire and tested for all original elements.

9. Chemical Analysis

9.1 A sample of the filler metal, or the stock from which it is made, shall be prepared for chemical analysis except as provided in Table 1, footnote c.

9.2 The sample shall be analyzed by accepted analytical methods. *In case of dispute, the referee method shall be from applicable ASTM specifications such as E1409, E1447, E1552, E1941, and E2371, depending on the element under test.*

Carbon shall be determined in accordance with ASTM E1941, hydrogen in accordance with ASTM E1447, oxygen and nitrogen in accordance with ASTM E1409, hafnium in accordance with ASTM E1552, and other elements in accordance with ASTM E2371. Other analytical methods may be used if acceptable to the purchaser.

9.3 The results of the analysis shall meet the requirements of Table 1 for the classification of filler metal under test.

10. Method of Manufacture

The welding electrodes and rods classified according to this specification may be manufactured by any method that will produce material that meets the requirements of this specification.

11. Standard Sizes and Shapes

Standard sizes for electrodes and rods in different package forms (straight lengths, coils with support, coils without support, and spools) are referenced in AWS A5.02/A5.02M.

12. Finish and Uniformity

12.1 Finish and uniformity shall be as specified in AWS A5.02/A5.02M.

13. Standard Package Forms

13.1 Standard package forms are straight lengths, coils with support, coils without support, and spools. Standard package dimensions are provided in AWS A5.02/A5.02M. Package forms, sizes, and weights other than these shall be as agreed upon between purchaser and supplier.

13.2 The liners in coils with support shall be designed and constructed per AWS A5.02/A5.02M to prevent distortion of the coil during normal handling and use, and shall be clean and dry enough to maintain the cleanliness of the filler metal.

13.3 Spools shall be designed and constructed per AWS A5.02/A5.02M to prevent distortion of the filler metal during normal handling and use and shall be clean and dry enough to maintain the cleanliness of the filler metal.

14. Winding Requirements

14.1 Winding requirements shall be as specified in AWS A5.02/A5.02M.

14.2 The cast and helix of filler metal shall be as specified in AWS A5.02/A5.02M.

14.2.1 The cast and helix of filler metal on 4 in [100 mm] spools shall be such that a specimen long enough to produce a single loop, when cut from the spool and laid unrestrained on a flat surface will:

- (1) form a circle not less than 4 in [100 mm] nor more than 9 in [230 mm] in diameter, and
- (2) rise above the flat surface no more than 0.5 in [13 mm] at any location.

14.2.2 The cast and helix of filler metal on 8 in [200 mm] spools shall be such that a specimen long enough to produce a single loop, when cut from the spool and laid unrestrained on a flat surface will:

- (1) form a circle not less than 10 in [250 mm] nor more than 20 in [500 mm] in diameter, and
- (2) rise above the flat surface no more than 0.75 in [19 mm] at any location.

14.2.3 The cast and helix of filler metal on 12 in [300 mm] spools shall be such that a specimen long enough to produce a single loop, when cut from the spool and laid unrestrained on a flat surface will:

- (1) form a circle not less than 15 in [380 mm] nor more than 30 in [760 mm] in diameter, and
- (2) rise above the flat surface no more than 1 in [25 mm] at any location.

14.2.4 The cast and helix of filler metal on 13.5 in [340 mm] spools shall be such that a specimen long enough to produce a single loop, when cut from the spool and laid unrestrained on a flat surface will:

- (1) form a circle not less than 15 in [380 mm] nor more than 40 in [1000 mm] in diameter, and
- (2) rise above the flat surface no more than 1 in [25 mm] at any location.

15. Filler Metal Identification

15.1 Filler metal identification, including marking of bare straight lengths of filler rod, product information and precautionary information shall be as specified in AWS A5.02/A5.02M.

15.2 Product information and the precautionary information shall be as specified in AWS A5.02/A5.02M.

16. Packaging

Electrodes and rods shall be suitably packaged to prevent damage during shipment and storage under normal conditions.

17. Marking of Packages

17.1 The product information (as a minimum) that shall be legibly marked and visible from the outside of each unit package shall be as specified in AWS A5.02/A5.02M.

17.2 The appropriate precautionary information as given in ANSI Z49.1, (as a minimum) or its equivalent, shall be prominently displayed in legible print on all packages of welding material, including individual unit packages enclosed within a larger package. Typical examples of "warning labels" and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

Annex A (Informative)

Guide to AWS Specification for Zirconium and Zirconium-Alloy Welding Electrodes and Rods

This annex is not part of this standard but is included for informational purposes only.

A1. Introduction

The purpose of this guide is to correlate the filler metal classifications with their intended applications so that the specification can be used effectively. Appropriate base metal specifications are referred to whenever that can be done and when it would be helpful. Such references are intended only as examples rather than complete listings of the materials for which each filler metal is suitable.

A2. Classification System

A2.1 The system for identifying the filler metal classifications in this specification follows the standard pattern used in other AWS filler metal specifications. The letter “E” at the beginning of each classification designation stands for electrode, and the letter “R” stands for welding rod. Since these filler metals are used as electrodes in gas metal arc welding and as rods in gas tungsten arc welding and plasma arc welding, both letters are used.

A2.2 The chemical symbol “Zr” appears after “R” as a means of identifying the filler metals as unalloyed zirconium or a zirconium-base alloy. The numeral following “Zr” provides a means of identifying different variations in the composition.

A2.3 Table A1 provides a correlation of the classifications in this edition with those in earlier editions and with other specifications for zirconium alloy filler metals. The ASTM/ASME Specifications listed are also widely used in industry as shown in Annex B.

A2.4 Request for Filler Metal Classification

(1) A request to establish a new filler metal classification must be submitted in writing. The request needs to provide sufficient detail to permit the Committee on Filler Metals and Allied Materials and the relevant Subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

- (a) A declaration that the new classification will be offered for sale commercially.
- (b) All classification requirements are as given for existing classifications, such as chemical composition ranges, mechanical property requirements, and usability test requirements.
- (c) Any conditions for conducting the tests used to demonstrate that the filler metal meets the classification requirements. (It would be sufficient, for example, to state that welding conditions are the same as for other classifications.)
- (d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the Annex).
- (e) Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.

Table A1
Specification Cross Index—Including Discontinued Zirconium Electrodes

Filler Metal												Base Metal
2023		2014		2005		1990		1979		1976		ASTM/ASME Base Number Grade Designations
AWS Classification	UNS Number	AWS Classification	UNS Number	AWS Classification	UNS Number	AWS Classification	UNS Number	AWS Classification	UNS Number	AWS Classification	UNS Number	
—	—	—	—	—	—	—	—	—	—	ERZr1	—	—
ERZr2	R62702	ERZr2	R60702	ERZr2	R60702	ERZr2	R60702	ERZr2	R60702	ERZr2	R60702	Unalloyed Zr
ERZr3	R62704	ERZr3	R60704	ERZr3	R60704	ERZr3	R60704	ERZr3	R60704	ERZr3	R60704	Zr-Fe-Sn-Cr
ERZr4	R62705	ERZr4	R60705	ERZr4	R60705	ERZr4	R60705	ERZr4	R60705	—	R60705	Zr-2.5%Nb

(f) A request for a new classification without the above information will be considered incomplete. The Secretary will return the request to the requester for further information.

(2) In order to comply with the AWS Policy on Patented Items, Trademarks, and Restraint of Trade, if the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester shall disclose this. *In these cases, the patent holder must allow the use of this technology, such as by license. The Secretary will provide examples of acceptable wording to the patent holder, as required.*

(3) The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters for processing.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01M/A5.01. Any testing a purchaser requires of the supplier for material shipped in accordance with this specification, needs to be clearly stated in the purchase order. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing the supplier normally conducts on material of that classification, as specified in Schedule F of Table 1, of AWS A5.01M/A5.01. Testing in accordance with any other Schedule *must* be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product or of placing the classification on the product itself constitutes the supplier's (manufacturer's) certification that the product meets all the requirements of the specification.

The only testing requirement implicit in this certification is that the manufacturer has conducted the tests required by the specification on material that is representative of that being shipped and that the material met the requirements of the specification. *Certification* is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the *certification* required by the specification is the classification test of *representative material* cited above, and the Manufacturer's Quality Assurance Program in AWS A5.01M/A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes *in the atmosphere* to which welders and welding operators are exposed during welding. They are:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling)
- (2) Number of welders and welding operators working in that space
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes used
- (4) The proximity of the welders, welding operators, and other personnel to the fumes, as these fumes issue from the welding zone, and to the gases and dusts in the space in which they are working
- (5) The ventilation provided to the space in which the welding is done

A5.2 American National Standard Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society) discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the Clause on Ventilation in that document. See also AWS F3.2M/F3.2, *Ventilation Guide for Weld Fume* for more detailed descriptions of ventilation options.

A6. Welding Considerations

Zirconium and zirconium alloys can be welded by gas metal arc, gas tungsten arc, plasma arc, electron beam, and laser beam welding processes. Zirconium is a reactive metal and is sensitive to embrittlement by oxygen, nitrogen and hydrogen at temperatures above 1100 °F [590 °C]. Consequently, the metal should be protected from atmospheric contamination. This can be provided by shielding the metal with high purity inert gas, or by placing in an inert gas chamber or a vacuum of 10^{-4} torr [0.013 Pa] or lower. During arc welding, the zirconium should be shielded from the atmosphere until it is cooled below about 800 °F [430 °C]. Adequate protection by auxiliary inert gas shielding should be provided when welding in air, and for critical applications the welding should be done in a gas tight chamber thoroughly purged of air and filled with high purity “low dew point” inert gas as shown in AWS A5.32M/A5.32 (ISO 14175:2008 MOD), *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes*.

The zirconium metal should be free of heavy oxide and chemically clean prior to welding, as contamination from oxide, water, grease, and dirt will also cause embrittlement.

Zirconium welding rods must be chemically clean and free of heavy oxide, absorbed moisture, grease, and dirt. The welding rod should be kept in the inert gas during welding and the oxide at the tip, formed upon cooling, must be removed before reusing the rod.

Zirconium can be successfully fusion welded to titanium, tantalum, niobium (columbium), and vanadium although the weld metal will be stronger and less ductile than the base metals. Zirconium cannot be welded to other common structural alloys of copper, iron, nickel, and aluminum as brittle zirconium intermetallic alloys are formed which produce extremely brittle welds.

A7. Description and Intended Use of Electrodes and Rods

A7.1 The ERZr2 classification is a “commercially pure” zirconium. It produces weld metal having good strength and ductility. The tensile strength should be at least 55 ksi [380 MPa]. These electrodes and rods are intended to be used for welding the UNS R60702 zirconium alloy.

A7.2 The ERZr3 classification contains tin as an alloying element. Tin increases the strength of the weld metal yet allows it to retain good ductility. The strength should be at least 60 ksi [410 MPa]. These electrodes and rods are intended only for welding UNS R60704 zirconium alloy. Weld metal from ERZr3 filler metal may not resist corrosion as well as that from ERZr2 filler metal.

A7.3 The ERZr4 classification contains niobium (columbium) as an alloying element. It produces weld metal of good ductility with a tensile strength of at least 80 ksi [550 MPa]. These electrodes and rods are used only to weld UNS R60705 zirconium alloy. Weld metal from ERZr4 filler metal may not resist corrosion as well as that from ERZr2 filler metal. All welds utilizing ERZr4 filler metal should be postweld heat treated to reduce the susceptibility for delayed hydride cracking.

A8. Special Tests

It is recognized that supplementary tests may be required for certain applications. In such cases, tests to determine specific properties such as corrosion resistance, scale resistance, or strength at elevated or cryogenic temperatures may be required. AWS A5.01M/A5.01 contains provisions for ordering such tests. This clause is included for the guidance of those who desire to specify such special tests.

A8.1 Corrosion Tests. Although welds made with electrodes and rods in this specification are commonly used in corrosion applications, tests for those properties are not included in the specification. When required for a particular application, tests can be conducted on specimens taken from either a weld pad or a welded joint. Specimens from a joint are suitable for qualifying the welding procedure (for a specific application involving corrosion or oxidation resistance) but not for qualifying the electrode. Tests on specimens from a joint have the disadvantage of being a combined test of the properties of the weld metal, the heat-affected zone, and the unaffected base metal. With them, it is more difficult to obtain reproducible data (when a difference exists in the properties of the metal in the various parts of the specimen).

Specimens taken from a joint have the advantage of being able to duplicate the joint design and the welding sequence planned for fabrication.

A8.1.1 Specimens for testing the corrosion *or* oxidation resistance of the weld metal alone are prepared by following a procedure agreed upon between purchaser and supplier. The pad size should be at least 3/4 in [19 mm] in height, 2-1/2 in [65 mm] in width, and $1 + 5/8 n$ (in) [$25 + 16 n$ {mm}] in length, where n represents the number of specimens required from the pad. Specimens measuring $1/2 \times 2 \times 1/4$ in [$13 \times 50 \times 6.4$ mm] are machined from the top of the pad in a manner such that the 2 in [50 mm] dimension of the specimen is parallel with the 2-1/2 in [65 mm] dimension of the pad and the 1/2 in [13 mm] dimension is parallel with the length of the pad.

A8.1.2 The heat treatment, surface finish, and marking of the specimens prior to testing should be in accordance with standard practices for tests of similar alloys in the wrought or cast forms. The testing procedures should correspond to those of ASTM G4, *Standard Practice for Conducting Plant Corrosion Tests in Field Applications*, or ASTM G31, *Recommended Practice for Laboratory Immersion Corrosion Testing of Metals*, as the case may be.

A9. Discontinued Classifications

One classification has been discontinued from one revision of this specification to another. This results either from changes in commercial practice or changes in the classification system used in the specification. The classification that has been discontinued is listed in Table A1, along with the year in which it was last included in the specification.

A10. General Safety Considerations

A10.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Annex Clause A5. Safety and health information is available from other sources, including, but not limited to Safety and Health Fact Sheets, ANSI Z49.1, *Safety in Welding, Cutting and Allied Processes*, and applicable federal and state regulations.

A10.2 Safety and Health Fact Sheets. Safety and Health Fact Sheets are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

Annex B (Informative)

Informative References

This annex is not part of this standard but is included for informational purposes only.

ASME SB-493/SB-493M, Standard Specification for Zirconium and Zirconium Alloy Forgings

ASME SB-523/SB-523M, Standard Specification for Seamless and Welded Zirconium and Zirconium Alloy Tubes

ASME SB-550/SB-550M, Standard Specification for Zirconium and Zirconium Alloy Bar and Wire

ASME SB-551/SB-551M, Standard Specification for Zirconium and Zirconium Alloy Strip, Sheet, and Plate

ASME SB-653/SB-653M, Standard Specification for Seamless and Welded Zirconium and Zirconium Alloy Welding Fittings

ASME SB-658/SB-658M, Standard Specification for Seamless and Welded Zirconium and Zirconium Alloy Pipe

ASME SB-752/SB-752M, Standard Specification for Castings, Zirconium-Base, Corrosion Resistant, for General Application

ASTM B493/B493M, Standard Specification for Zirconium and Zirconium Alloy Forgings

ASTM B495, Standard Specification for Zirconium and Zirconium Alloy Ingots

ASTM B523/B523M, Standard Specification for Seamless and Welded Zirconium and Zirconium Alloy Tubes

ASTM B550/B550M, Standard Specification for Zirconium and Zirconium Alloy Bar and Wire

ASTM B551/B551M, Standard Specification for Zirconium and Zirconium Alloy Strip, Sheet, and Plate

ASTM B653/B653M, Standard Specification for Seamless and Welded Zirconium and Zirconium Alloy Welding Fittings

ASTM B658/B658M, Standard Specification for Seamless and Welded Zirconium and Zirconium Alloy Pipe

ASTM B752, Standard Specification for Castings, Zirconium-Base, Corrosion Resistant, for General Application

Annex C (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

C1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

C2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

C3. General Procedure for all Requests

C3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

C3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

C3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

C3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

C3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

C3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

C4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

C5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

C6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

SPECIFICATION FOR CARBON AND LOW-ALLOY STEEL ELECTRODES AND FLUXES FOR ELECTROSLAG WELDING



SFA-5.25/SFA-5.25M



(25)

(Identical with AWS Specification A5.25/A5.25M:2023. In case of dispute, the original AWS text applies.)

Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding

1. Scope

1.1 This specification prescribes requirements for the classification of electrodes (both solid and composite metal cored) and fluxes for electroslag welding of carbon and low-alloy steels.

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to material properties. The specification A5.25 uses U.S. Customary Units; and the specification A5.25M uses SI Units. The latter are shown within brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing of filler metal or packaging or both under A5.25 or A5.25M specifications.

1.3 Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in Annex Clauses A5 and A8.

Safety and Health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. Unless otherwise defined in this document, welding terms are as defined in AWS A3.0M/A3.0. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to or revisions of any of these publications do not apply.

American Welding Society (AWS) documents:

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

AWS A5.01M/A5.01 (ISO 14344 MOD), *Welding and Brazing Consumables—Procurement of Filler Metals and Fluxes*

AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*

AWS B4.0, *Standard Methods for Mechanical Testing of Welds*

American National Standards Institute (ANSI) document:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

ASTM International (ASTM) documents:

ASTM A36/A36M, *Standard Specification for Carbon Structural Steel*

ASTM A242/A242M, *Standard Specification for High-Strength Low-Alloy Structural Steel*

ASTM A515/A515M, *Standard Specification for Pressure Vessel Plates, Carbon Steel for Intermediate and Higher-Temperature Service*

ASTM A537/A537M, *Standard Specification for Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel*

ASTM A572/A572M, *Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel*

ASTM A588/A588M, *Standard Specification for High-Strength Low-Alloy Structural Steel, up to 50 ksi [345 MPa] Minimum Yield Point, with Atmospheric Corrosion Resistance*

ASTM A633/A633M, *Standard Specification for Normalized High-Strength Low-Alloy Structural Steel Plates*

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

ASTM E350, *Standard Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron and Wrought Iron*

ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*

ASTM E2033, *Standard Practice for Radiographic Examination Using Computed Radiography (Photostimulable Luminescence Method)*

ASTM E2698, *Standard Practice for Radiological Examination Using Digital Detector Arrays*

International Organization for Standardization (ISO) document:

ISO 80000-1:2022, *Quantities and Units — Part 1: General*

3. Classification

3.1 The solid electrodes covered by this A5.25 specification utilize a classification system based upon U.S. Customary Units and are classified according to the chemical composition of the electrode, as specified in Table 1. The mechanical properties of the weld metal of a specific flux/wire combination are as specified in Tables 3 and 4.

3.2 The composite metal cored electrodes covered by the A5.25 specification utilize a classification system based upon U.S. Customary Units and are classified according to the chemical composition of the weld metal produced with a specific flux/wire combination as specified in Table 2 and the mechanical properties of the weld metal, as specified in Tables 3 and 4.

3.3 The solid electrodes covered by the A5.25M specification utilize a classification system based upon the International System of Units (SI) and are classified according to the chemical composition of the electrode, as specified in Table 1. The mechanical properties of the weld metal of a specific flux/wire combination are as specified in Tables 3M and 4M.

3.4 The composite metal cored electrodes covered by the A5.25M specification utilize a classification system based upon the International System of Units (SI) and are classified according to the chemical composition of the weld metal produced with a specific flux/wire combination as specified in Table 2 and the mechanical properties of the weld metal, as specified in Tables 3M and 4M.

Table 1
Chemical Composition Requirements for Solid Electrodes

AWS Classification ^c	UNS Number ^d	Weight-Percent ^{a, b}											
		C	Mn	P	S	Si	Ni	Cr	Mo	Cu ^e	Ti	Zr	Al
Medium-Manganese Classes													
EM5K-EW	K10726	0.07	0.90—1.40	0.025	0.030	0.40–0.70	—	—	—	0.35	0.05–0.15	0.02–0.12	0.05–0.15
EM12-EW	K01112	0.06–0.15	0.80–1.25	0.030	0.030	0.10	—	—	—	0.35	—	—	—
EM12K-EW	K01113	0.05–0.15	0.80–1.25	0.030	0.030	0.10–0.35	—	—	—	0.35	—	—	—
EM13K-EW	K01313	0.06–0.16	0.90–1.40	0.030	0.030	0.35–0.75	—	—	—	0.35	—	—	—
EM15K-EW	K01515	0.10–0.20	0.80–1.25	0.030	0.030	0.10–0.35	—	—	—	0.35	—	—	—
High-Manganese Classes													
EH14-EW	K11585	0.10–0.20	1.70–2.20	0.030	0.030	0.10	—	—	—	0.35	—	—	—
Special Classes													
EWS-EW	K11245	0.07–0.12	0.35–0.65	0.030	0.030	0.22–0.37	0.40–0.75	0.50–0.80	—	0.25–0.55	—	—	—
EA3K-EW ^f	K10945	0.07–0.12	1.60–2.10	0.025	0.025	0.50–0.80	0.15	—	0.40–0.60	0.35	—	—	—
EH10K-EW	K01010	0.07–0.14	1.40–2.00	0.025	0.030	0.15–0.30	—	—	—	—	—	—	—
EH11K-EW	K11140	0.06–0.15	1.40–1.85	0.025	0.030	0.80–1.15	—	—	—	0.35	—	—	—
ES-G-EW	—	Not Specified ^g											

^a The electrode shall be analyzed for the specific elements for which values are shown in this table. Analysis is required to be reported for boron (B) if intentionally added, or if it is known to be present at levels greater than 0.0010%. If the presence of unspecified elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total (excluding iron) does not exceed 0.50%.

^b Single values are maximums.

^c Chemical composition requirements may be similar to those in other AWS specifications; see Table A.1 in Annex A.

^d SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System*.

^e The copper limit includes copper that may be applied as a coating on the electrode.

^f Formerly classified EH10Mo-EW in ANSI/AWS A5.25-91.

^g Composition shall be reported; the requirements are those agreed to by the purchaser and the supplier.

Table 2
Chemical Composition Requirements for Weld Metal
from Composite Metal Cored Electrodes^a

AWS Classification	UNS Numbers ^d	Weight Percent ^{b,c}									
		C	Mn	P	S	Si	Ni	Cr	Mo	Cu	V
EWT1	W06040	0.13	2.00	0.03	0.03	0.60	—	—	—	—	—
EWT2	W20140	0.12	0.50–1.60	0.03	0.04	0.25–0.80	0.40–0.80	0.40–0.70	—	0.25–0.75	—
EWT3	W22340	0.12	1.00–2.00	0.02	0.03	0.15–0.50	1.50–2.50	0.20	0.40–0.65	—	0.05
EWTG	—	Not Specified ^e									

^a The flux used when classifying composite electrodes shall be one with which the electrode is classified for mechanical properties (see Tables 3 or 3M and 4 or 4M).

^b The weld metal shall be analyzed for the specific elements for which values are shown in this table. Analysis is required to be reported for boron (B) if intentionally added, or if it is known to be present at levels greater than 0.0010%. If the presence of unspecified elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total (excluding iron) does not exceed 0.50%.

^c Single values are maximums.

^d SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System*.

^e Composition shall be reported; the requirements are those agreed to by the purchaser and supplier.

Table 3
A5.25 Tension Test Requirements (As Welded)

AWS A5.25 Classification ^a	Tensile Strength	Yield Strength, min. ^b	Elongation, min. ^b
	psi	psi	percent
FES6Z-XXX FES60-XXX FES62-XXX	60 000 to 80 000	36 000	24
FES7Z-XXX FES70-XXX FES72-XXX	70 000 to 95 000	50 000	22
FES8Z-XXX FES80-XXX FES82-XXX	80 000 to 100 000	60 000	20

^a The letters “XXX” as used in AWS A5.25 Classification column in this table refer to the electrode classification used.

^b Yield strength as 0.2% offset and elongation in 2 inch gage length.

Table 3M
A5.25M Tension Test Requirements (As Welded)

AWS A5.25M Classification ^a	Tensile Strength	Yield Strength, min. ^b	Elongation, min. ^b
	MPa	MPa	percent
FES43Z-XXX FES432-XXX FES433-XXX	430 to 550	250	24
FES49Z-XXX FES492-XXX FES493-XXX	490 to 650	350	22
FES55Z-XXX FES552-XXX FES553-XXX	550 to 700	410	20

^a The letters “XXX” as used in the AWS A5.25M Classification column in this table refer to the electrode classification used.

^b Yield strength at 0.2% offset and elongation in 50 mm gage length.

Table 4
A5.25 Impact Test Requirements (As Welded)^a

AWS A5.25 Classification ^b	Average Impact Strength, min. ^c ft·lbf
FES6Z-XXX FES7Z-XXX FES8Z-XXX	Not specified
FES60-XXX FES70-XXX FES80-XXX	15 @ 0 °F
FES62-XXX FES72-XXX FES82-XXX	15 @ -20 °F

^a A flux-electrode combination that meets impact requirements at a given temperature also meets the requirements at all higher temperatures in this table. In this manner, FESX2-XXX may also be classified as FESX0-XXX and FESXZ-XXX and FESX0-XXX may be classified as FESXZ-XXX.

^b The letters "XXX" used in the AWS Classification column in this table refer to the electrode classification used.

^c Both the highest and lowest of the five test values obtained shall be disregarded in computing the impact strength. Two of the remaining three values shall equal or exceed 15 ft·lbf and one of the three remaining values may be lower than 15 ft·lbf, but not lower than 10 ft·lbf. The average of the three shall not be less than the 15 ft·lbf specified.

Table 4M
A5.25M Impact Test Requirements (As Welded)^a

AWS A5.25M Classification ^b	Average Impact Strength, min. ^c J
FES43Z-XXX FES49Z-XXX FES55Z-XXX	Not specified
FES432-XXX FES492-XXX FES552-XXX	20 @ -20 °C
FES433-XXX FES493-XXX FES553-XXX	20 @ -30 °C

^a A flux-electrode combination that meets impact requirements at a given temperature also meets the requirements at all higher temperatures in this table. In this manner, FESXX3-XXX may also be classified as FESXX2-XXX and FESXXXZ-XXX and FESXX2-XXX may be classified as FESXXXZ-XXX.

^b The letters "XXX" used in the AWS Classification column in this table refer to the electrode classification used.

^c Both the highest and lowest of the five test values obtained shall be disregarded in computing the impact strength. Two of the remaining three values shall equal or exceed 20 J and one of the three remaining values may be lower than 20 J, but not lower than 14 J. The average of the three shall not be less than the 20 J specified.

3.5 Fluxes covered by this specification are classified according to the mechanical properties of the weld metal as specified in Tables 3 and 4, when using an electrode of a particular classification.

3.6 Electrodes classified under one classification shall not be classified under any other classification in this specification. Fluxes may be classified under any number of classifications using a different electrode for each. Fluxes may be classified with electrodes under both A5.25 and A5.25M. Fluxes classified as FESX2-XXX may also be classified as FESX0-XXX and FESXZ-XXX, as specifically permitted by Note a to Table 4. Likewise, FESXX3-XXX may also be classified as FESXX2-XXX and FESXXXZ-XXX, as specifically permitted by Note (a) to Table 4M.

3.7 The electrodes and fluxes classified under this specification are intended for electroslag welding, but that is not to prohibit their use with any other process for which they are found suitable.

4. Acceptance

Acceptance of the electrodes and fluxes shall be in accordance with the provisions of AWS A5.01M/A5.01 and the tests and requirements of this specification. See A3 (in Annex A) for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

5. Certification

By affixing the AWS specification and classification designations to the packaging or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification. See A4 (in Annex A) for further information concerning certification and the testing called for to meet this requirement.

6. Rounding Procedure

For the purpose of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest 1000 psi (1 ksi) for tensile and yield strength for A5.25; and to the nearest 10 MPa for tensile and yield strength for A5.25M; and to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfill the requirements for the classification under test.

7. Summary of Tests

7.1 Chemical analysis of solid electrodes is the only test required for classification of a solid electrode under this specification, as shown in Table 5.

7.2 Chemical analysis of undiluted weld metal from the composite electrode and a specific flux of a particular manufacturer and trade designation is the only test required for classification of a composite electrode under this specification, as shown in Table 5.

7.3 The tests required for classification of each electrode/flux combination are specified in Table 5. The purpose of these tests is to determine the mechanical properties and soundness of the weld. The base metal for the weld test assemblies, the welding and testing procedures to be employed, and the results required are given in Clauses 8 through 13.

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Specimens for retest may be taken from the original test assembly or from one or two new test assemblies. For chemical analysis, if the retest specimens are taken from the original assembly, retest need be only for those specific elements that failed to meet the test requirement. If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

If it is clearly determined the specified or proper procedures were not followed in the preparation or testing of the test specimen(s), the test shall be considered invalid, without regard to whether the test was completed or whether the test results met or failed to meet the requirement. That test shall be repeated, following proper specified procedures. In this case, the requirement for doubling the number of test specimens does not apply.

Table 5
Required Tests

Material to be Classified	AWS Classification ^a	Chemical Analysis		Radiographic Test	Tension Test	Impact Test
		Electrode	Weld Metal			
Solid Electrodes	All	Required	Not Required	Not Required	Not Required	Not Required
Composite Electrodes ^b	All	Not Required	Required	Not Required	Not Required	Not Required
Fluxes	FES6Z-XXX FES7Z-XXX FES8Z-XXX FES43Z-XXX FES49Z-XXX FES55Z-XXX	Not Required	Not Required	Required	Required	Not Required
	FES60-XXX FES70-XXX FES80-XXX FES432-XXX FES492-XXX FES552-XXX	Not Required	Not Required	Required	Required	Required
	FES62-XXX FES72-XXX FES82-XXX FES433-XXX FES493-XXX FES553-XXX	Not Required	Not Required	Required	Required	Required

^a The letters “XXX” used in the AWS Classification column in this table refer to the electrode classification used.

^b The flux used when classifying composite electrodes shall be one with which the electrode is classified for mechanical properties.

9. Weld Test Assemblies

9.1 No weld test assemblies are required for classification of solid electrodes. For classification of composite electrodes, chemical analysis is conducted on the weld ingot resulting from the setup illustrated in Figure 1.

In addition to the above, one weld test assembly is required for each classification of an electrode-flux combination. It is the groove weld in Figure 2 for mechanical properties and soundness of the weld metal in the as-welded condition.

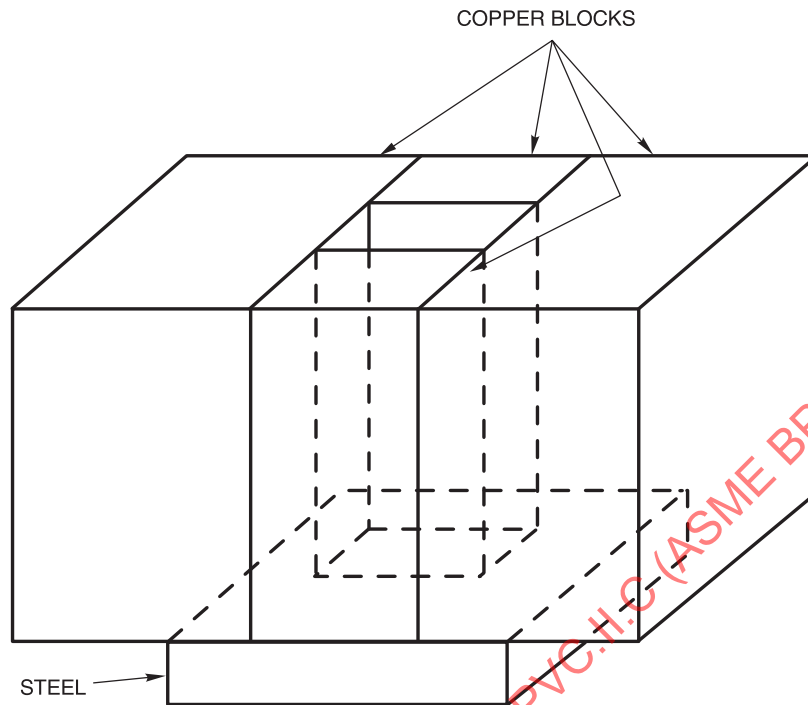
9.2 Preparation of each weld test assembly shall be as specified in 9.3 and 9.4. The base metal for each assembly shall be as required in Table 6 and shall meet the requirements of the appropriate ASTM specification shown there, or an equivalent specification. Testing of the assemblies shall be as prescribed in Clauses 10 through 13.

9.3 Weld Ingot. An ingot shall be prepared and welded as specified in Figure 1. Testing shall be as specified in Clause 10.

9.4 Groove Weld. A test assembly shall be chosen and welded as specified in Figure 2 using base metal of the appropriate type specified in Table 6. Testing of this assembly shall be as specified in Clauses 11 through 13. The assembly shall be tested in the as-welded condition.

10. Chemical Analysis

10.1 For solid electrodes, a sample of the electrode shall be prepared for chemical analysis. Solid electrodes, when analyzed for elements that are present in a coating (copper flashing, for example), shall be analyzed without removing the coating. When the electrode is analyzed for elements other than those in the coating, the coating must be removed if its presence affects the results of the analysis for other elements. Rod stock analyzed for elements not in the coating may be analyzed prior to reducing the rod to finished electrode diameter and applying the coating.



Notes:

1. Weld ingot shall be deposited by electroslag welding in a water-cooled copper mold using welding conditions shown in Figure 2.
2. Weld ingot shall be of any convenient shape that provides approximately 4 in² [25 cm²] of weld metal cross section.
3. The weld ingot shall be started on a piece of carbon steel of sufficient size as to avoid complete fusion, and the copper mold shall be a sufficient heat sink to avoid contamination of the ingot by molten copper.
4. The sample for chemical analysis shall be taken at least 2 in [50 mm] above the bottom of the ingot, and at least 2 in [50 mm] below the crater.
5. Consumable guide tubes shall be used for preparing the weld ingot if guide tubes were used in welding the groove weld test assembly, as use of consumable guide tubes will affect chemical composition.

Figure 1—Weld Ingot Preparation

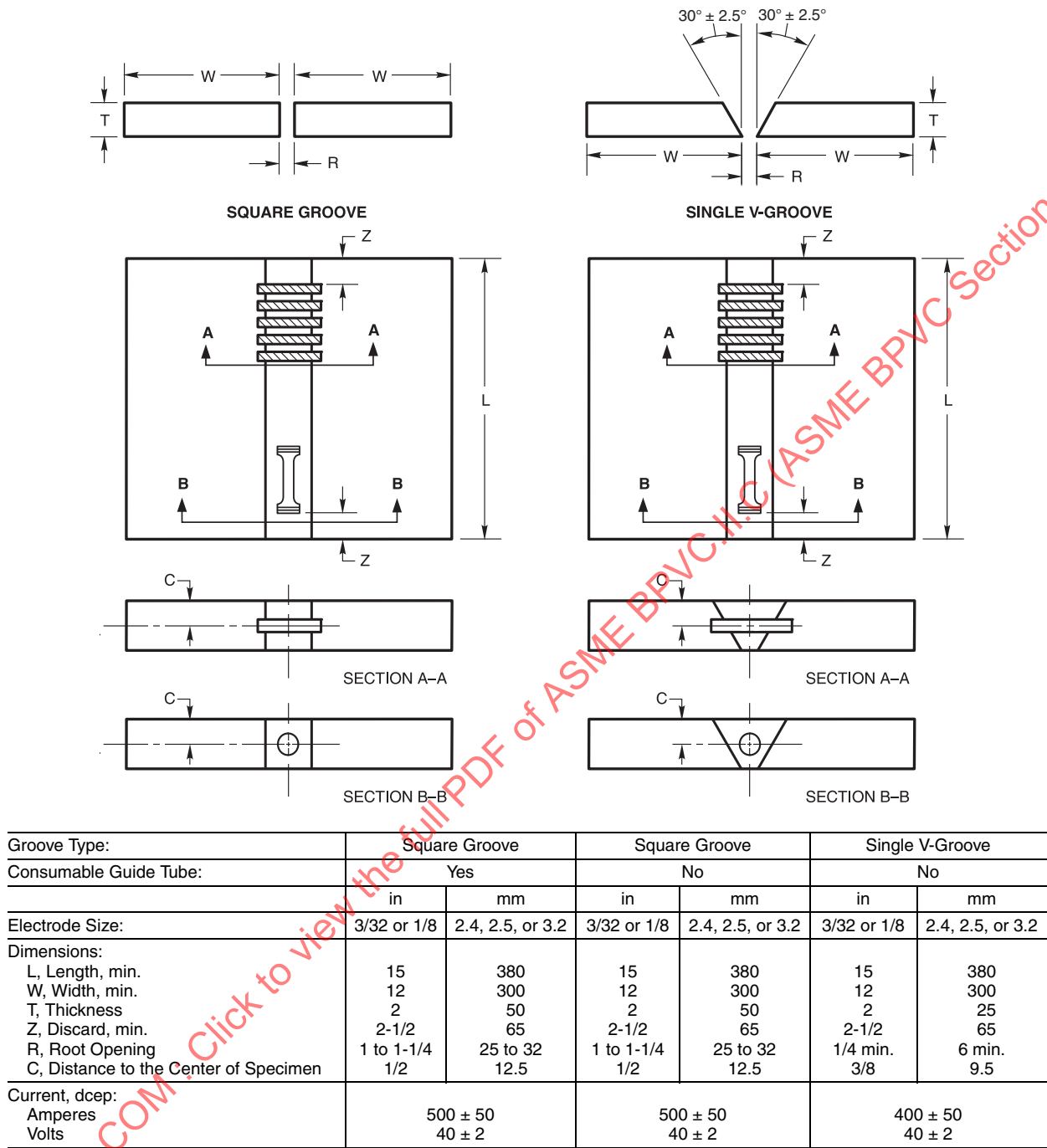
10.2 Composite electrodes shall be analyzed in the form of undiluted weld metal, not electrode. The sample for analysis shall be taken from weld metal obtained with the electrode and a specific flux of a particular manufacturer and trade designation with which it was classified. The sample shall come from an ingot (Figure 1). The top surface of the ingot shall be removed and discarded. The sample shall be taken from the underlying metal at a location at least 2 in [50 mm] from the start of the ingot and at least 2 in [50 mm] from below the crater. The sample shall be free of slag.

10.3 The sample shall be analyzed by accepted analytical methods. The referee method shall be ASTM E350.

10.4 The results of the analysis shall meet the requirements of Table 1 for solid electrodes or Table 2 for composite electrodes, for the classification of electrode under test.

11. Radiographic Test

11.1 The groove weld described in 9.4 and shown in Figure 2, shall be radiographed to evaluate the soundness of the weld metal. In preparation for radiography, both surfaces of the weld may be machined or ground smooth and flush with the original surfaces of the base metal or with a uniform reinforcement not exceeding 3/32 in [2.5 mm]. It is permitted on both sides of the test assembly to remove base metal to a depth of 1/16 in [1.5 mm] nominal below the original base



- Notes:
1. Weld test assembly shall be welded in the vertical position with upward progression.
 2. The test assembly shall be chosen and fixtured based on the manufacturer's recommendations. Water-cooled copper shoes shall be used except when using consumable guide tubes. For welding with consumable guide tubes, follow the manufacturer's recommendations regarding the use of water-cooled shoes. When using water cooling, the outgoing water temperature shall not exceed 180 °F [82 °C] near the exit point.
 3. If the manufacturer does not make the electrode size specified, the nearest size may be used. For sizes other than that shown, follow the manufacturer's recommended procedure.
 4. Welding shall begin with the assembly at room temperature, 65 °F [18 °C] minimum. No external heat shall be applied during welding. Run-on and run-off tabs are not required if the test assembly is of sufficient length to provide the required test specimens.
 5. The weld shall be completed in one pass.
 6. No thermal treatment shall be performed on the assembly subsequent to the completion of welding.

Figure 2—Groove Weld Test Assembly for Mechanical Properties and Soundness

Table 6
Base Metals for Weld Test Assemblies

AWS Classification		
A5.25	A5.25M	ASTM Base Metal Specification
FES6X-XXX	FES43X-XXX	ASTM A36
FES7X-XXX	FES49X-XXX	ASTM A242 Type 2 or A572 Grade 50
FES8X-XXX	FES55X-XXX	ASTM A537 Class 2, A572 Grade 60 or 65, or A633 Grade E
The following classifications are exceptions to the above general requirements:		
FESXX-EWS-EW FESXX-EWT2	FESYYY-EWS-EW FESYYY-EWT2	ASTM A588

metal surface in order to facilitate backing and/or buildup removal. The thickness of the weld metal shall not be reduced by more than 1/16 in [1.5 mm], so that the thickness of the prepared radiographic test specimen equals at least the thickness of the base metal minus 1/16 in [1.5 mm]. Both surfaces of the test assembly, in the area of the weld, shall be smooth enough to avoid difficulty in interpreting the radiograph.

11.2 The weld shall be radiographed in accordance with one of the following. The quality level of inspection shall be 2-2T.

(1) Film Radiology: ASTM E1032.

(2) Computed Radiology (CR): ASTM E2033 and the requirements of ASTM E1032, except where CR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2033, refers to phosphor imaging plate.

(3) Digital Radiology (DR): ASTM E2698 and the requirements of ASTM E1032, except where DR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2698, refers to digital detector array (DDA).

11.3 The soundness of the weld metal meets the requirements of this specification if the radiograph shows no cracks, no incomplete fusion, and no rounded indications in excess of those permitted by the radiographic standards in Figure 3.

In evaluating the radiograph, 2-1/2 in [65 mm] of the weld on each end of the test assembly shall be disregarded.

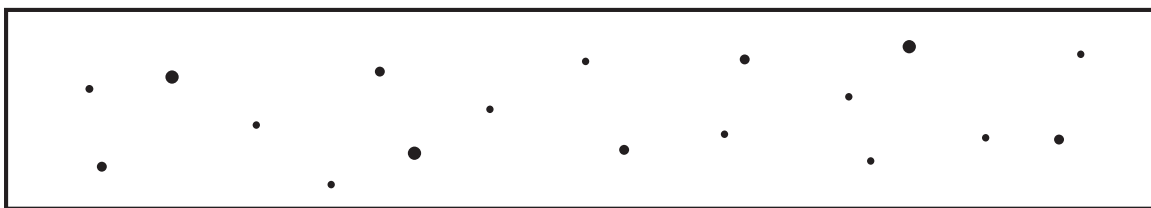
A rounded indication is an indication (on the radiograph) whose length is no more than three times its width. Rounded indications may be circular or irregular in shape, and they may have tails. The size of a rounded indication is the largest dimension of the indication, including any tail that may be present. The indication may be of porosity or slag. Indications whose largest dimension does not exceed 1/64 in [0.4 mm] shall be disregarded. Test assemblies with indications greater than the large indications permitted in the radiographic standards do not meet the requirements of this specification.

12. Tension Test

12.1 One all-weld-metal tension test specimen, as specified in the Tension Test clause of AWS B4.0, shall be machined from the groove weld described in 9.4 and shown in Figure 2. The all-weld-metal tensile specimen shall have a nominal diameter of 0.500 in [12.5 mm] and a nominal gage length-to-diameter ratio of 4:1.

12.2 The specimen shall be tested in the manner described in the Tension Test clause of AWS B4.0.

12.3 The results of the tension test shall meet the requirements specified in Table 3 or Table 3M, as applicable.



Assorted Rounded Indications

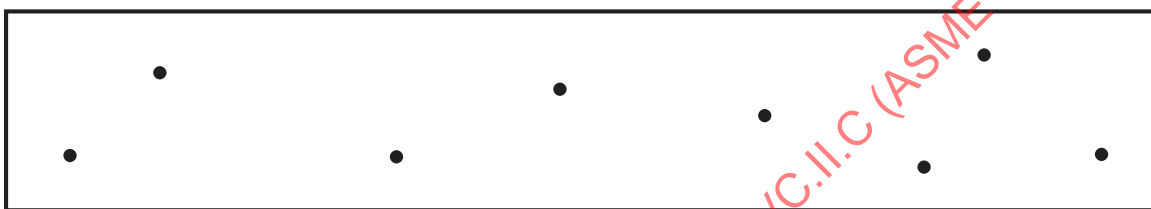
Size permitted is 1/64 in [0.4 mm] to 1/16 in [1.6 mm].

Number permitted in any 6 in [150 mm] of weld is 18, with the following restrictions:

Large: 3/64 in [1.2 mm] to 1/16 in [1.6 mm]—3 permitted.

Medium: 1/32 in [0.8 mm] to 3/64 in [1.2 mm]—5 permitted.

Small: 1/64 in [0.4 mm] to 1/32 in [0.8 mm]—10 permitted.



Large Rounded Indications

Size permitted is 3/64 in [1.2 mm] to 1/16 in [1.6 mm].

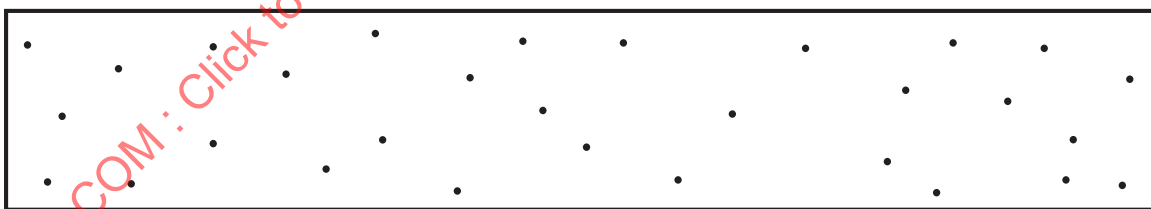
Number permitted in any 6 in [150 mm] of weld is 8.



Medium Rounded Indications

Size permitted is 1/32 in [0.8 mm] to 3/64 in [1.2 mm].

Number permitted in any 6 in [150 mm] of weld is 15.



Small Rounded Indications

Size permitted is 1/64 in [0.4 mm] to 1/32 in [0.8 mm].

Number permitted in any 6 in [150 mm] of weld is 30.

Notes:

1. The chart that is most representative of the size of the rounded indications in the radiograph of the test assembly shall be used to determine conformance with this specification. Rounded indications smaller than 1/64 in [0.4 mm] shall be disregarded. The largest dimension of the indication (including any tail) is the size of the indication.
2. These radiographic requirements are for test welds made in the laboratory specifically for classification purposes. They are more restrictive than those usually encountered in general fabrication.

Figure 3—Radiographic Standards for 6 in [150 mm] Length

13. Impact Test

13.1 Five Charpy V-notch impact test specimens, as specified in the Fracture Toughness Test clause of AWS B4.0, shall be machined from the test assembly as shown in Figure 2, for those flux-electrode classifications for which impact testing is required in Table 5.

The Charpy V-notch specimens shall have the notched surface and the struck surface parallel with each other within 0.002 in [0.05 mm]. The other two surfaces of the specimen shall be square with the notched or struck surfaces within 10 minutes of a degree. The notch shall be smoothly machined.

The geometry of the notch shall be measured on at least one specimen in a set of five specimens. Measurement shall be done at a minimum 10X magnification. The correct location of the notch shall be verified by etching before or after machining.

13.2 The five specimens shall be tested in accordance with the Fracture Toughness Test section of AWS B4.0. The test temperature shall be at or below the temperature specified in Table 4 or Table 4M, as applicable, for the classification under test.

13.3 In evaluating the test results, the lowest and the highest values obtained shall be disregarded. Two of the remaining three values shall equal, or exceed, the specified 15 ft-lbf [20 J] energy level. One of the three may be lower, but not lower than 10 ft-lbf [14 J], and the average of the three shall be not less than the required 15 ft-lbf [20 J] energy level.

14. Method of Manufacture

The electrodes and fluxes classified according to this specification may be manufactured by any method that will produce material that meets the requirements of this specification.

15. Electrode Requirements

15.1 Standard Sizes. Standard sizes for electrodes in the different package forms (coils with support, coils without support, spools and drums are as specified in AWS A5.02/A5.02M).

15.2 Finish and Uniformity

15.2.1 Finish and uniformity shall be as specified AWS A5.02/A5.02M.

15.2.2 A suitable protective coating may be applied to any of the electrodes in this specification.

15.3 Standard Package Forms

15.3.1 Standard package forms are coils with support, coils without support, spools, and drums. Standard package dimensions and weights and other requirements for each form shall be as specified in AWS A5.02/A5.02M.

15.4 Winding Requirements

15.4.1 Winding requirements shall be as specified in AWS A5.02/A5.02M.

15.4.2 The cast and helix of electrode in coils, spools, and drums shall be as specified in AWS A5.02/A5.02M.

15.5 Electrode Identification

15.5.1 Filler metal identification, product information and precautionary information shall be as specified in AWS A5.02/A5.02M.

15.5.2 Coils without support shall have a tag containing this information securely attached to the filler metal at the inside end of the coil.

15.6 Packaging. Electrodes shall be suitably packaged to prevent damage during shipment and storage under normal conditions.

15.7 Marking of Packages

15.7.1 The product information (as a minimum) that shall be legibly marked and visible from the outside of each unit package shall be as specified in AWS A5.02/A5.02M.

15.7.2 The appropriate precautionary information as given in ANSI Z49.1, (as a minimum), or its equivalent, shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages enclosed within a larger package. Typical examples of “warning labels” and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

16. Flux Requirements

16.1 Form and Particle Size. Flux shall be granular in form and shall be capable of flowing freely through the flux feeding tubes, valves, and nozzles of standard electroslag welding equipment. Particle size is not specified here, but when addressed, shall be agreed upon between the purchaser and supplier.

16.2 Usability. The flux shall permit the production of uniform, well-shaped welds that merge smoothly with the base metal. The molten slag shall have electrical properties suitable for electroslag operation.

16.3 Packaging

16.3.1 Flux shall be suitably packaged to prevent damage during shipment.

16.3.2 Flux, in its original unopened container, shall withstand storage under normal conditions for at least six months without damage to its welding characteristics or the properties of the weld. Heating the flux to assure dryness may be necessary when the very best properties (of which the materials are capable) are required. For specific recommendations, consult the manufacturer.

16.4 Marking of Packages

16.4.1 The following product information (as a minimum) shall be legibly marked and visible from the outside of each unit package.

- (1) AWS specification and classification designations for the appropriate flux-electrode combination (year of issue may be excluded)
- (2) Supplier's name and trade designation
- (3) The trade designation of each composite electrode with which the flux manufacturer has classified the flux, if applicable
- (4) Net weight
- (5) Lot, control, or heat number
- (6) Particle size, if more than one size is produced

16.4.2 The appropriate precautionary information as given in ANSI Z49.1, (as a minimum), or its equivalent, shall be prominently displayed in legible print on all packages of flux, including individual unit packages enclosed within a larger package. Typical examples of “warning labels” and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

Annex A (Informative)

Guide to AWS Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding

This annex is not part of this standard but is included for informational purposes only.

A1. Introduction

The purpose of this annex is to correlate the electrode and flux classifications with their intended applications so the specification can be used effectively. Reference to appropriate base-metal specifications is made whenever that can be done and when it would be helpful. Such references are intended only as examples rather than complete listings of the materials for which each filler metal is suitable.

A2. Classification System

A2.1 Classification of Electrodes. The system for identifying the electrode classifications in this specification follows the standard pattern used in other AWS filler metal specifications. The letter “E” at the beginning of each classification designation stands for electrode. The remainder of the designation indicates the chemical composition of the electrode, or, in the case of composite metal cored electrodes, of the weld metal obtained with a particular flux (see Figure A.1).

The letter “M” indicates that the solid electrode is of a medium manganese content, while the letter “H” would indicate a comparatively high manganese content. The one or two digits following the manganese designator indicate the nominal carbon content of the electrode. The letter “K,” which appears in some designations, indicates that the electrode is made from a heat of silicon-killed steel. The designation for a solid wire is followed by the suffix “EW.” Solid electrodes are classified only on the basis of their chemical composition, as specified in Table 1 of this specification. A composite electrode is indicated by the letters “WT” after the “E,” and a numerical suffix. The composition of a composite electrode is meaningless, and the user is therefore referred to weld metal composition (Table 2) with a particular flux, rather than to electrode composition.

A comparison of solid electrode classifications in this specification and those of other specifications is shown in Table A.1.

A2.2 Classification of Fluxes. Fluxes are classified on the basis of the mechanical properties of the weld metal made with some particular classification of electrode, under the specific test conditions called for in this specification.

For example, consider the following flux classifications:

FES60-EH14-EW FES72-EWT2

The prefix “FES” designates a flux for electroslag welding. In the case of the designations for A5.25, this is followed by a single digit representing the minimum tensile strength required of the weld metal in units of 10 000 psi (see Table 3); for the designations for A5.25M, the FES is followed by two digits (43, 49, or 55), representing the minimum tensile strength in units of 10 MPa (see Table 3M).

The digit that follows is a number or the letter “Z.” This digit refers to the impact strength of the weld metal. Specifically, it designates the temperature at (and above) which the weld metal meets, or exceeds, the required 15 ft-lbf [20 J] Charpy V-notch impact strength (except for the letter “Z,” which indicates that no impact strength requirement is specified in Table 4 or 4M). These mechanical property designators are followed by the designation of the electrode used in classifying the flux (see Tables 1 and 2). The suffix (EM12-EW, EH10K-EW, EWT2, etc.) included after the first hyphen refers to the electrode classification with which the flux will produce weld metal that meets the specified mechanical properties when tested as called for in the specification.

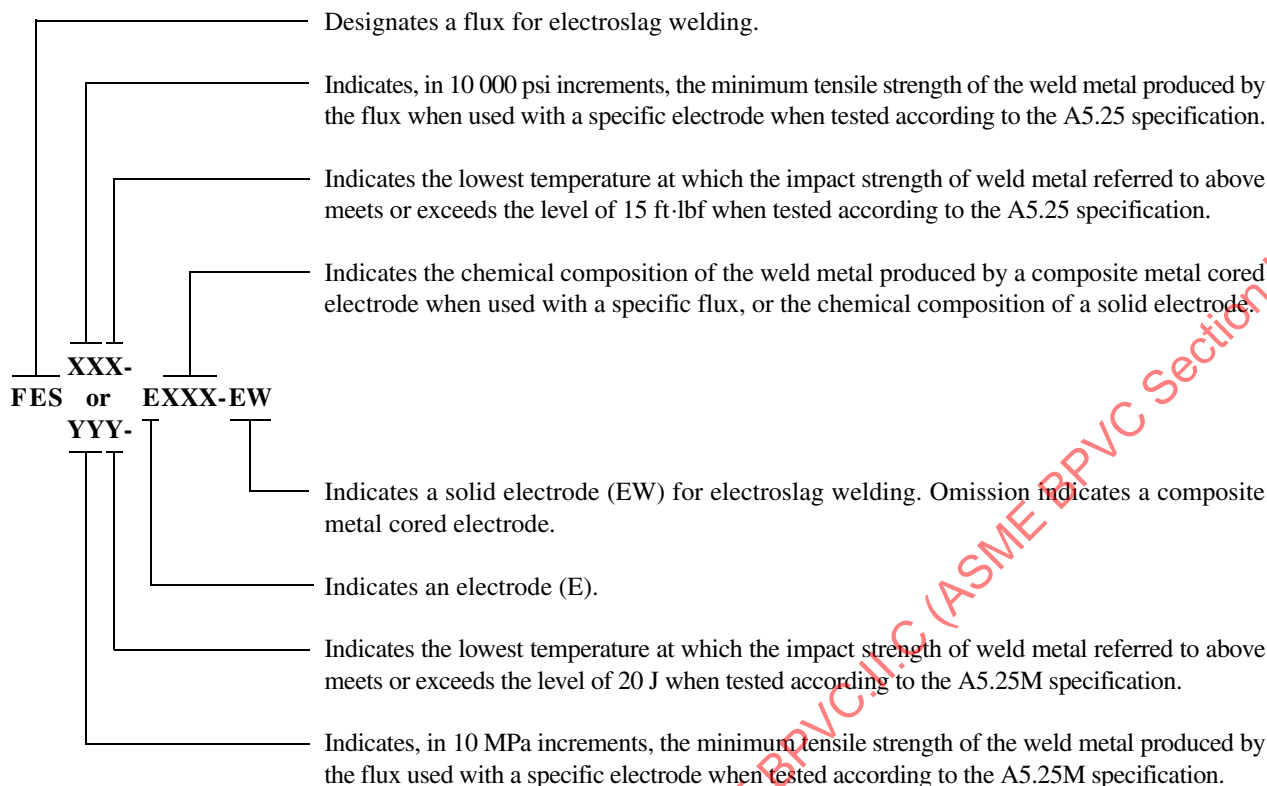
**Figure A.1—Classification System**

Table A.1
Comparison of A5.25/A5.25M:2023 Classifications and
Classifications in Other AWS Specifications and Proposed ISO Designations

AWS A5.25/A5.25M Classification	Similar Classifications ^a				
	AWS A5.17	AWS A5.18	AWS A5.23	AWS A5.26	AWS A5.28
EM5K-EW	—	ER70S-2	—	EGXXS-2	—
EM12-EW	EM12	—	EM12	—	—
EM12K-EW	EM12K	—	EM12K	—	—
EM13K-EW	EM13K	ER70S-3	EM13K	EGXXS-3	—
EM15K-EW	EM15K	—	EM15K	—	—
EH14-EW	EH14	—	EM14	—	—
EWS-EW	—	—	EW	—	—
EA3K-EW ^b	—	—	EA3K	EGXXS-D2	ER80S-D2
EH10K-EW	—	—	EH10K	—	—
EH11K-EW	EH11K	ER70S-6	EH11K	EGXXS-6	—

^a Classifications are similar, but not necessarily identical in composition:

AWS A5.17, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*

AWS A5.18, *Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding*

AWS A5.23, *Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*

AWS A5.26, *Specification for Carbon and Low-Alloy Steel Electrodes for Electrode Gas Welding*

AWS A5.28, *Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding*

^b Formerly classified as EH10Mo-EW in AWS A5.25-91.

It should be noted that flux of any specific trade designation may have many classifications. The number is limited only by the number of different electrode classifications with which the flux can meet the classification requirements. The flux package marking lists at least one, and may list all, classifications to which the flux conforms. Solid electrodes having the same classification are interchangeable when used with a specific flux; composite metal-cored electrodes may not be. However, the specific usability (or operating) characteristics of various fluxes of the same classification may differ in one respect or another.

A2.3 “G” Classification

A2.3.1 This specification includes filler metals classified as ES-G-EW or EWTG. The “G” indicates that the filler metal is of a *general* classification. It is *general* because the filler metal may not meet all requirements for any other classification. The purpose is to allow a useful filler metal to receive a classification before the specification is revised.

One filler metal of a “G” classification is not interchangeable with another filler metal of the same classification.

A2.3.2 The point of difference between a particular filler metal of a “G” classification and all other filler metals with or without the “G” may be seen from the use of the words “not required” and “not specified” in the specification. The use of these words is as follows:

Not Required is used in those areas that specify the tests that must be conducted in order to classify a filler metal. The words indicate that there is no requirement for that test for that particular classification. When a test is “not required”, it is not necessary to conduct the corresponding test in order to classify a filler metal to that classification. When a purchaser wants the information provided by that test in order to consider a particular product of that classification for a certain application, the purchaser will have to arrange for that information with the supplier of the product. The purchaser will have to establish with that supplier just what the testing procedure and the acceptance requirements are to be for that test. The purchaser may want to incorporate that information (via AWS A5.01M/A5.01) in the purchase order.

Not Specified is used in those areas of the specification that refer to the results of some particular test. It indicates that the requirements for that test are not specified for that particular classification. If the results from a specific test are listed as “not specified” but the test in question is shown as “required” then the test results must be reported.

A2.3.3 Request for Filler Metal Classification: When a filler metal cannot be classified other than as a “G” classification, a manufacturer may request that a new classification be established. The manufacturer shall do this using the following procedure:

(1) A request to establish a new filler metal classification must be submitted in writing. The request needs to provide sufficient detail to permit the Committee on Filler Metals and Allied Materials and the relevant Subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

- (a) A declaration that the new classification will be offered for sale commercially.
- (b) All classification requirements as given for existing classifications, such as chemical composition ranges, mechanical property requirements, and usability test requirements.
- (c) Any conditions for conducting the tests used to demonstrate that the filler metal meets the classification requirements. (It would be sufficient, for example, to state that welding conditions are the same as for other classifications.)
- (d) Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.
- (e) A request for a new classification without the above will be considered incomplete. The Secretary will return the request to the requester for further information.

(2) In order to comply with the AWS Policy on Patented Items, Trademarks, and Restraint of Trade, if the proposed new classification is patented, if a patent is pending for it, or if there is any intention to apply for a patent, the requester shall disclose this. In these cases, the patent holder must allow the use of this technology, such as by license. The Secretary will provide examples of acceptable wording to the patent holder, as required.

(3) The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters for processing.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01M/A5.01 and the tests and requirements of this specification. Any testing a purchaser requires of the supplier for material shipped in accordance with this specification shall be clearly stated in the purchase order. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing the supplier normally conducts on material of that classification, as specified in Schedule F of AWS A5.01M/A5.01. Testing in accordance with any other Schedule must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product or of placing the classification on the product itself constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification. The only testing requirement implicit in this *certification* is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that that material met the requirements of the specification. Representative material, in this case, is material from any production run of that classification using the same formulation. *Certification* is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the *certification* required by the specification is the classification test of *representative material*, cited above, and the Manufacturer's Quality Assurance Program, in AWS A5.01M/A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes in the atmosphere to which welders are exposed during welding. They are:

- (1) Dimensions of the space in which the welding is done (with special regard to the height of the ceiling)
- (2) Number of welders and welding operators working in that space
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes used
- (4) The proximity of the welders to the fumes, as these fumes issue from the welding zone, and to the gases and dusts in the space in which they are working
- (5) The ventilation provided to the space in which the welding is done

A5.2 American National Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the Clause on Ventilation in that document. See also AWS F3.2M/F3.2, *Ventilation Guide for Weld Fume* for more detailed descriptions of ventilation options.

A6. Welding Considerations

A6.1 Electroslag welding is a process producing coalescence of metals with molten slag which melts the filler metal and the surfaces of the workpiece to be welded. The process is initiated by starting an arc beneath a layer of granular welding flux. The arc is then extinguished by the conductive slag which is kept molten by its resistance to electric current passing between the electrode and the workpiece. The weld pool is shielded by this slag which covers the full cross section of the joint as welding progresses. The joint is generally welded in a single pass.

A6.2 Heat generated by the resistance to the current through the molten slag is sufficient to fuse the edges of the work-piece and melt the welding electrode. Since no arc exists, the welding action is quiet and spatter-free. The liquid metal coming from the filler metal and the fused base metal collects in a pool beneath the slag bath and slowly solidifies to form the weld.

A6.3 Because of the necessity to contain the large volume of molten slag and weld metal produced in electrosag welding, the process is used for welding in the vertical position. Water-cooled or solid copper backing shoes are usually used on each side of the joint to retain the molten metal and slag pool and to act as a mold to cool and shape the weld faces. The copper backing shoes are normally moved upward on the plate surfaces as welding progresses.

A6.4 The entire assembly—including electrode, copper shoes, wire-feeding mechanism, controls, and oscillator—generally moves vertically during operation. The length of vertical travel is unlimited and is dependent upon the design of the equipment used.

Because of the uniform heat distribution throughout the plate thickness during welding, electrosag welds are virtually free of axial or transverse distortion; however, the joint may contract. The weld interface contour is a function of the welding voltage, current, and slag pool depth. The weld metal usually consists of approximately 30% to 50% of base metal.

A6.5 The standard joint preparation is a square groove in a butt joint. Joint preparations other than square grooves in butt joints can be used.

A6.6 The consumable guide method uses a metal tube extending the full length of the weld joint to guide the electrode to the welding zone. The molds and all wire-feeding equipment remain stationary, with the electrode being the only moving part. The guide tube melts into the weld pool as the pool rises, supplying additional filler metal.

In some applications, the guide tubes are covered with a flux to insulate the tube if it should contact the base metal or copper backing shoes. The coating also helps to replenish flux that solidifies on the surface of the copper shoes forming the weld-face contour. The flux coating thus helps to maintain a level of molten slag adequate to provide resistance heating and to protect the weld pool from atmospheric contamination. The manufacturer should be consulted for specific recommendations regarding consumable guide tubes.

The effect of the consumable guide tube generally is to dilute the alloy content of the weld metal. Consumable guide tubes are not classified per this specification; therefore, weld-metal strength and toughness should be tested by the user.

A6.7 The specification requires the use of certain base metals for classification purposes. This does not signify any restriction on the application of the process for joining other base metals, but rather, provides a means for obtaining reproducible results. Electrosag welding is a “high dilution” process, meaning that the base metal forms a significant portion of the weld metal. The type of base metal, especially given the wide variety of available low-alloy structural steels, will influence the mechanical and other properties of the joint. Weld procedure qualification tests, as distinguished from filler metal classification tests, should be used for assessing the properties of welds for a given application.

A6.8 Electrosag welding is a high-deposition process for thick plates. Since it usually is operated as a single-pass process, the weld metal and heat-affected zone (HAZ) are subject to no subsequent weld thermal cycles, such as is common with conventional multipass arc welding of thick materials. The weld metal is characterized by large unrefined dendrites. The relatively wide HAZ is characterized by large grains. The as-welded mechanical properties of the weld and HAZ may therefore be somewhat lower than that of the base metal.

This specification requires a minimum of 15 ft-lbf [20 J] at the specified temperature while most other AWS filler metal specifications require 20 ft-lbf [27 J]. Considerable improvement in mechanical properties can be effected by a postweld heat treatment. Subcritical stress relieving heat treatments are generally less effective for electrosag welding than for arc welding. For this reason, many code requirements require an austenitizing, or normalizing, postweld heat treatment.

All of the aforementioned postweld heat treatments (*i.e.*, subcritical stress relief, austenitizing, normalizing) may have a pronounced effect on weld metal mechanical properties, both strength levels and Charpy V-notch toughness. The strength levels of the heat-treated weld deposit can be expected to be lower than those in the as-welded condition. For this reason, the user is cautioned to conduct actual tests to determine the effect of the heat treatment on the mechanical properties obtained.

A7. Discontinued Classifications

The following classifications have been discontinued over the life of this specification:

<u>Discontinued Classification</u>	<u>Last Published</u>
EH10Mo-EW	1991
EWT4	1991

A8. General Safety Considerations

A8.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in annex clause A5. Safety and health information is available from other sources, including, but not limited to Safety and Health Fact Sheets, ANSI Z49.1 *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations.

A8.2 Safety and Health Fact Sheets. Safety and Health Fact Sheets are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

B6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

AWS Filler Metal Specifications by Material and Welding Process

	OFW	SMAW	GTAW GMAW PAW	FCAW	SAW	ESW	EGW	Brazing
Carbon Steel	A5.2	A5.1, A5.35	A5.18	A5.20	A5.17	A5.25	A5.26	A5.8, A5.31
Low-Alloy Steel	A5.2	A5.5	A5.28	A5.29	A5.23	A5.25	A5.26	A5.8, A5.31
Stainless Steel		A5.4, A5.35	A5.9, A5.22	A5.22	A5.9, A5.22, A5.39	A5.9, A5.22, A5.39	A5.9	A5.8, A5.31
Cast Iron	A5.15	A5.15	A5.15	A5.15				A5.8, A5.31
Nickel Alloys		A5.11, A5.35	A5.14, A5.34	A5.34	A5.14, A5.34, A5.39	A5.14, A5.34, A5.39		A5.8, A5.31
Aluminum Alloys		A5.3	A5.10					A5.8, A5.31
Copper Alloys		A5.6	A5.7					A5.8, A5.31
Titanium Alloys			A5.16					A5.8, A5.31
Zirconium Alloys			A5.24					A5.8, A5.31
Magnesium Alloys			A5.19					A5.8, A5.31
Tungsten Electrodes			A5.12					
Brazing Alloys and Fluxes								A5.8, A5.31
Surfacing Alloys	A5.21	A5.13	A5.21	A5.21	A5.21			
Consumable Inserts			A5.30					
Shielding Gases			A5.32	A5.32			A5.32	

AWS Filler Metal Specifications and Related Documents

Designation	Title
A4.2M (ISO 8249 MOD)	<i>Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal</i>
A4.3-ADD1	<i>Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding</i>
A4.4M	<i>Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings</i>
A4.5M/A4.5 (ISO 15792-3 MOD)	<i>Standard Methods for Classification Testing of Positional Capacity and Root Penetration of Welding Consumables in a Fillet Weld</i>
A5.01M/A5.01 (ISO 14344 MOD)	<i>Welding and Brazing Consumables—Procurement of Filler Metals and Fluxes</i>
A5.02/A5.02M	<i>Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes</i>
A5.1/A5.1M	<i>Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding</i>
A5.2/A5.2M	<i>Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding</i>
A5.3/A5.3M	<i>Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.4/A5.4M	<i>Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding</i>
A5.5/A5.5M	<i>Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding</i>
A5.6/A5.6M	<i>Specification for Copper and Copper-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.7/A5.7M	<i>Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes</i>
A5.8M/A5.8	<i>Specification for Filler Metals for Brazing and Braze Welding</i>
A5.9/A5.9M (ISO 14343 MOD)	<i>Specification for Bare Stainless Steel Welding Electrodes and Rods</i>
A5.10/A5.10M (ISO 18273 MOD)	<i>Welding Consumables—Wire Electrodes, Wires, and Rods for Welding of Aluminum and Aluminum-Alloys—Classification</i>
A5.11/A5.11M	<i>Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding</i>
A5.12M/A5.12 (ISO 6848 MOD)	<i>Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting</i>
A5.13/A5.13M	<i>Specification for Surfacing Electrodes for Shielded Metal Arc Welding</i>
A5.14/A5.14M	<i>Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods</i>
A5.15	<i>Specification for Welding Electrodes and Rods for Cast Iron</i>
A5.16/A5.16M (ISO 24034 MOD)	<i>Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods</i>
A5.17/A5.17M	<i>Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.18/A5.18M	<i>Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.19	<i>Specification for Magnesium-Alloy Welding Electrodes and Rods</i>
A5.20/A5.20M	<i>Specification for Carbon Steel Electrodes for Flux Cored Arc Welding</i>
A5.21/A5.21M	<i>Specification for Bare Electrodes and Rods for Surfacing</i>
A5.22/A5.22M	<i>Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods</i>
A5.23/A5.23M	<i>Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.24/A5.24M	<i>Specification for Zirconium and Zirconium-Alloy Welding Electrodes and Rods</i>
A5.25/A5.25M	<i>Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding</i>
A5.26/A5.26M	<i>Specification for Carbon and Low-Alloy Steel Electrodes for Electrode Gas Welding</i>
A5.28/A5.28M	<i>Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.29/A5.29M	<i>Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding</i>
A5.30/A5.30M	<i>Specification for Consumable Inserts</i>
A5.31M/A5.31	<i>Specification for Fluxes for Brazing and Braze Welding</i>
A5.32M/A5.32 (ISO 14175 MOD)	<i>Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes</i>
A5.34/A5.34M	<i>Specification for Nickel-Alloy Flux Cored and Metal Cored Welding Electrodes</i>
A5.35/A5.35M-AMD1	<i>Specification for Covered Electrodes for Underwater Wet Shielded Metal Arc Welding</i>
A5.39/A5.39M	<i>Specification for Stainless Steel and Nickel-Alloy Electrodes and Fluxes for Submerged Arc and Electroslag Welding</i>

SPECIFICATION FOR CARBON AND LOW-ALLOY STEEL ELECTRODES FOR ELECTROGAS WELDING



SFA-5.26/SFA-5.26M



(Identical with AWS Specification AWS A5.26/A5.26M:2020. In case of dispute, the original AWS text applies.)

Specification for Carbon and Low-Alloy Steel Electrodes for Electrode Gas Welding

1. Scope

1.1 This specification prescribes requirements for the classification of carbon and low-alloy steel electrodes for electrode gas welding. It covers solid and tubular (flux cored and metal cored) electrodes, for use either with or without external gas shielding.

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to material properties. The specification designated A5.26 uses U.S. Customary Units. The specification designated A5.26M uses the International System of Units (SI). The latter are shown within brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing of electrodes, packaging, or both under A5.26 or A5.26M specifications.

Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in the non-mandatory annex, Clauses A5 and A9.

Safety and Health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by material manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

American Welding Society (AWS) standards:

- AWS A1.1, *Metric Guide for the Welding Industry*

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

AWS A5.01M/A5.01, *Welding Consumables—Procurement of Filler Metals and Fluxes*

AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*

AWS A5.32M/A5.32 (ISO 14175 MOD), *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes*

AWS B4.0, *Standard Methods for Mechanical Testing of Welds*

AWS F3.2M/F3.2, *Ventilation Guide for Weld Fume*

American National Standards Institute (ANSI) standard:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

ASTM International (ASTM) documents:

ASTM A36/A36M, *Standard Specification for Carbon Structural Steel*

ASTM A242/A242M, *Standard Specification for High-Strength Low-Alloy Structural Steel*

ASTM A537/A537M, *Standard Specification for Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel*

ASTM A572/A572M, *Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel*

ASTM A588/A588M, *Standard Specification for High-Strength Low-Alloy Structural Steel, up to 50 ksi [345 MPa] Minimum Yield Point, with Atmospheric Corrosion Resistance*

ASTM A633/A633M, *Standard Specification for Normalized High-Strength Low-Alloy Structural Steel Plates*

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

ASTM E350, *Standard Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron and Wrought Iron*

ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*

ASTM E2033, *Standard Practice for Radiographic Examination Using Computed Radiography*

ASTM E2698, *Standard Practice for Radiographic Examination Using Digital Detector Arrays*

International Organization for Standardization (ISO) standards:

ISO 544, *Welding consumables — Technical delivery conditions for filler materials and fluxes — Type of product, dimensions, tolerances and markings*

ISO 80000-1:2009, *Quantities and units — Part 1: General*

3. Classification

3.1 The solid electrodes covered by the A5.26 specification utilize a classification system based upon U.S. Customary Units and are classified according to the chemical composition of the electrode, as specified in Table 1 and the mechanical properties of the weld metal as specified in Tables 2 and 3.

Table 1
Chemical Composition Requirements for Solid Electrodes

AWS Classification ^c	UNS Number ^d	Weight Percent ^{a,b}											Other Elements, Total ^f
		C	Mn	S	P	Si	Ni	Mo	Cu ^e	Ti	Zr	Al	
EGXXS-1	K01313	0.07–0.19	0.90–1.40	0.035	0.025	0.30–0.50	—	—	0.35	—	—	—	0.50
EGXXS-2	K10726	0.07	0.90–1.40	0.035	0.025	0.40–0.70	—	—	0.35	0.05–0.15	0.02–0.12	0.05–0.15	0.50
EGXXS-3	K11022	0.06–0.15	0.90–1.40	0.035	0.025	0.45–0.75	—	—	0.35	—	—	—	0.50
EGXXS-5	K11357	0.07–0.19	0.90–1.40	0.035	0.025	0.30–0.60	—	—	0.35	—	—	0.50–0.90	0.50
EGXXS-6	K11140	0.06–0.15	1.40–1.85	0.035	0.025	0.80–1.15	—	—	0.35	—	—	—	0.50
EGXXS-D2	K10945	0.07–0.12	1.60–2.10	0.035	0.025	0.50–0.80	0.15	0.40–0.60	0.35	—	—	—	0.50
EGXXS-G	—	Not Specified ^g											

^a Analysis of the electrode shall be made for the elements for which specific values are shown in this table. All other elements not specified shall be reported, if intentionally added. The total of these unspecified elements and all other elements not intentionally added (excluding iron) shall not exceed the limit specified for “Other Elements, Total.”

^b Single values are maximums.

^c The letters “XX” as used in the AWS classification column of this table refer respectively to the tensile strength designator (see Table 2) and the impact designator (see Table 3).

^d SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System*.

^e The copper limit includes copper that may be applied as a coating on the electrode.

^f An analysis of the electrode for boron is required and shall be reported if this element is intentionally added or if it is known to be present at levels in excess of 0.0010%.

^g Composition shall be reported with the requirements as agreed to by the purchaser and the supplier.

Table 2
Tension Test Requirements (As Welded)

Tensile Strength Designator		For A5.26 U.S. Customary Units			For A5.26M International System of Units (SI)		
A5.26 U.S. Customary Units	A5.26M International System of Units (SI)	Tensile Strength (ksi)	Minimum Yield Strength ^a (ksi)	Minimum Percent Elongation ^b	Tensile Strength (MPa)	Minimum Yield Strength ^a (MPa)	Minimum Percent Elongation ^b
6	43	60–80	36	24	430–550	250	24
7	49	70–95	50	22	490–660	350	22
8	55	80–100	60	20	550–700	410	20

^a Yield strength at 0.2% offset.

^b In a 2 in [50 mm] gage length, nominal diameter of 0.500 in [12.5 mm] and a nominal gage length-to-diameter ratio of 4:1 per AWS B4.0.

Table 3
Charpy Impact Test Requirements

A5.26 Requirements U.S. Customary Units			A5.26M Requirements International System of Units (SI)		
Impact Designator ^{a,b}	Maximum Test Temperature ^c (°F)	Minimum Average Energy Level	Impact Designator ^{a,b}	Maximum Test Temperature ^c (°C)	Minimum Average Energy Level
0	0	20 ft·lbf	2	−20	27 Joules
2	−20		3	−30	
4	−40		4	−40	
6	−60		5	−50	
Z	No Impact Requirements		Z	No Impact Requirements	

^a Based on the results of the impact tests of the weld metal, the manufacturer shall insert in the classification the appropriate designator from Table 3 above, as indicated in Figure 1.

^b When classifying an electrode to A5.26 using U.S. Customary Units the Impact Designator indicates the maximum impact test temperature in °F. When classifying to A5.26M using the International System of Units (SI) the Impact Designator indicates the maximum impact test temperature in °C. With the exception of the Impact Designator “4” a given Impact Designator will indicate different temperatures depending upon whether classification is according to A5.26 in U.S. Customary Units or according to A5.26M in the International System of Units (SI). For example, a “2” Impact Designator when classifying to A5.26 indicates a test temperature of −20°F. When classifying to A5.26M the “2” Impact Designator indicates a test temperature of −20°C, which is −4°F.

^c Weld metal from an electrode that meets the impact requirements at a given temperature also meets the requirements at all higher temperatures in this table. For example, weld metal meeting the A5.26 requirements for designator “6” also meets the requirements for designators 4, 2, 0, and Z. (Weld metal meeting the A5.26M requirements for designator “5” also meets the requirements for designators 4, 3, 2, and Z.) In these cases, the actual temperature used for testing shall be listed on the certification documentation when issued.

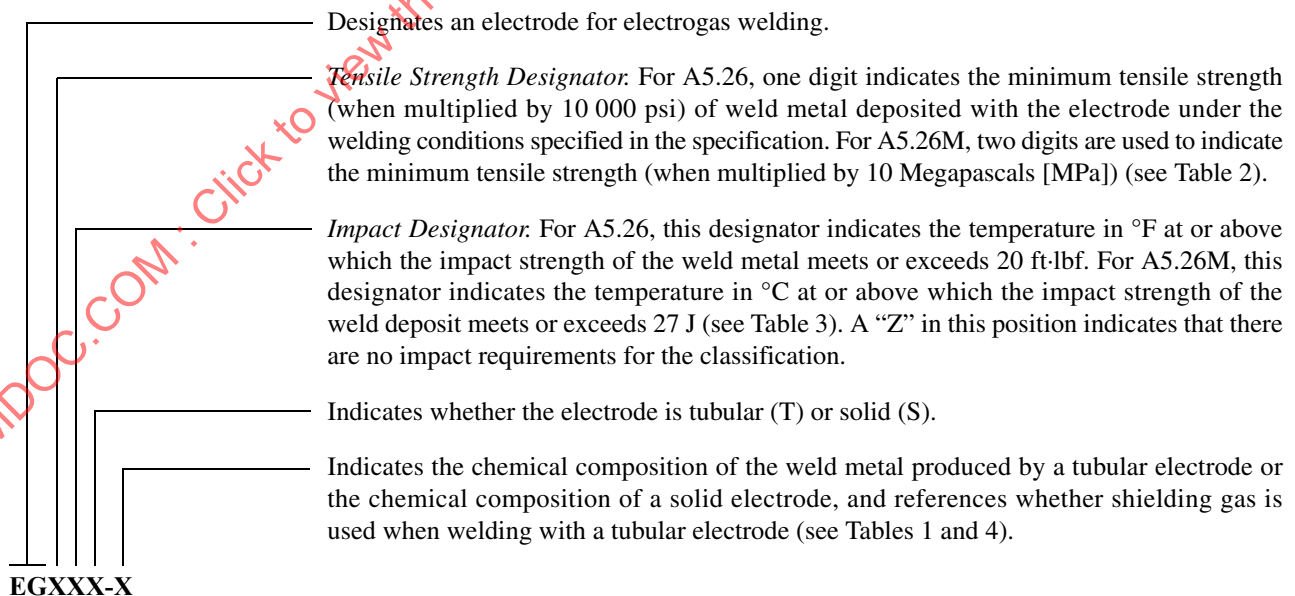


Figure 1—Classification System

3.2 The tubular electrodes covered by the A5.26 specification utilize a classification system based upon U.S. Customary Units and are classified according to the need for external shielding gas (Table 4) and the chemical composition and mechanical properties of the weld metal, as specified in Tables 2, 3, and 4.

3.3 The solid electrodes covered by the A5.26M specification utilize a classification system based upon the International System of Units (SI) and are classified according to the chemical composition of the electrode, as specified in Table 1 and the mechanical properties of the weld metal as specified in Tables 2 and 3.

3.4 The tubular electrodes covered by the A5.26M specification utilize a classification system based upon the International System of Units (SI) and are classified according to the need for external shielding gas (Table 4) and the chemical composition and mechanical properties of the weld metal, as specified in Tables 2, 3, and 4.

3.5 Electrodes classified under one classification shall not be classified under any other classification in this specification, except as specifically permitted by Note (c) to Table 3.

3.6 The electrodes classified under this specification are intended for electrogas welding, but that is not to prohibit their use with any other process for which they are found suitable.

4. Acceptance

Acceptance¹ of the electrodes shall be in accordance with the provisions of AWS A5.01M/A5.01.

5. Certification

By affixing the AWS Specification and Classification designations to the packaging, or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification. See A4 (in Annex A) for further information concerning certification and the testing called for to meet this requirement.

6. Rounding Procedure

For the purpose of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in Clause B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If the average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest 1000 psi (1 ksi) for tensile and yield strength for A5.26 (to the nearest 10 MPa for tensile and yield strength for A5.26M) and to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfill the requirements for the classification under test.

7. Summary of Tests

The tests required for each classification are specified in Table 6. The purpose of these tests is to determine the chemical composition, the mechanical properties, and soundness of the weld. The preparation of test samples, the testing procedures to be employed, and the results required are given in Clauses 9 through 13.

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Specimens for retest may be taken from the original test assembly or from one or two new test assemblies. For chemical analysis, retest need be only for those specific elements that failed to meet the test requirement.

¹ See A3 (in Annex A) for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

Table 4
Chemical Composition Requirements for Weld Metal from Tubular Electrodes

AWS Classification ^a		UNS Number ^d	Shielding Gas ^e	Weight Percent ^{b,c}										Other Elements, Total ^f
A5.26	A5.26M			C	Mn	P	S	Si	Ni	Cr	Mo	Cu	V	
EG6XT-1	EG43XT-1	W06301	None	(g)	1.7	0.03	0.03	0.50	0.30	0.20	0.35	0.35	0.08	0.50
EG7XT-1	EG49XT-1	W07301	None	(g)	1.7	0.03	0.03	0.50	0.30	0.20	0.35	0.35	0.08	0.50
EG8XT-1	EG55XT-1	—	None	(g)	1.8	0.03	0.03	0.90	0.30	0.20	0.25–0.65	0.35	0.08	0.50
EG6XT-2	EG43XT-2	W06302	C1	(g)	2.0	0.03	0.03	0.90	0.30	0.20	0.35	0.35	0.08	0.50
EG7XT-2	EG49XT-2	W07302	C1	(g)	2.0	0.03	0.03	0.90	0.30	0.20	0.35	0.35	0.08	0.50
EGXXT-Ni1	EGXXXT-Ni1	W21033	C1	0.10	1.0–1.8	0.03	0.03	0.50	0.70–1.10	—	0.30	0.35	—	0.50
EGXXT-NM1	EGXXXT-NM1	W22334	M21 or C1	0.12	1.0–2.0	0.02	0.03	0.15–0.50	1.5–2.0	0.20	0.40–0.65	0.35	0.05	0.50
EGXXT-NM2	EGXXXT-NM2	W22333	C1	0.12	1.1–2.1	0.03	0.03	0.20–0.60	1.1–2.0	0.20	0.10–0.35	0.35	0.05	0.50
EGXXT-W	EGXXXT-W	W20131	C1	0.12	0.50–1.3	0.03	0.03	0.30–0.80	0.40–0.80	0.45–0.70	—	0.30–0.75	—	0.50
EGXXT-G	EGXXXT-G	—	—	—	—	—	—	—	—	—	—	—	—	Not Specified ^h

^a The letters “XX” or “XXX” as used in the AWS classification column in this table refer respectively to the designator(s) for tensile strength of the weld metal (see Table 2) and the designator for impact strength (see Table 3). The single letter “X” as used in the AWS classification column refers to the designator for impact strength (see Table 3).

^b Analysis of the weld metal shall be made for the elements for which specific values are shown in this table. All other elements not specified shall be reported, if intentionally added. The total of these unspecified elements and all other elements not intentionally added (excluding iron) shall not exceed the limit specified for “Other Elements, Total.”

^c Single values are maximums.

^d SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System*.

^e See Table 5.

^f An analysis of the weld deposit for boron is required and shall be reported if this element is intentionally added or if it is known to be present at levels in excess of 0.0010%.

^g Composition range of carbon not specified for these classifications, but the amount shall be determined and reported.

^h Composition shall be reported with the requirements as agreed to by the purchaser and supplier.

Table 5
Composition Requirements for Shielding Gases

AWS A5.26/A5.26M Shielding Gas Designator ^a	AWS A5.32M/A5.32 Composition Ranges for Indicated Main/Sub Group	
	Oxidizing Components % CO ₂	Balance of Gas Mixture
C1	100	—
M21	15 < CO ₂ ≤ 25	Argon

^a The shielding gas designators are identical to the Main group/Sub-group symbols used in AWS A5.32M/A5.32. The AWS A5.32M/A5.32 shielding gas designation begins with “AWS A5.32M/A5.32.” That part of the designation has been omitted from the Shielding Gas Designator for brevity.

Table 6
Tests Required for Classification

General Electrode Category	Electrode Classification	Chemical Analysis		Radiographic Test	Tension Test	Impact Test ^a
		Electrode	Weld Metal			
Solid	EGXXS-X	Required	Not Required	Required	Required	Required
	EGXXS-G ^b					
Tubular	EGXXT-X	Not Required	Required	Required	Required	Required
	EGXXT-G ^c					

^a When the “Z” impact designator is used, the impact test is not required (see Table 3).

^b When a “G” appears in the position shown, it indicates that the electrode composition is “as agreed to by the purchaser and the supplier.”

^c When a “G” appears in the position shown, it indicates that the weld metal composition and/or shielding gas, if used, are “as agreed to by the purchaser and the supplier.”

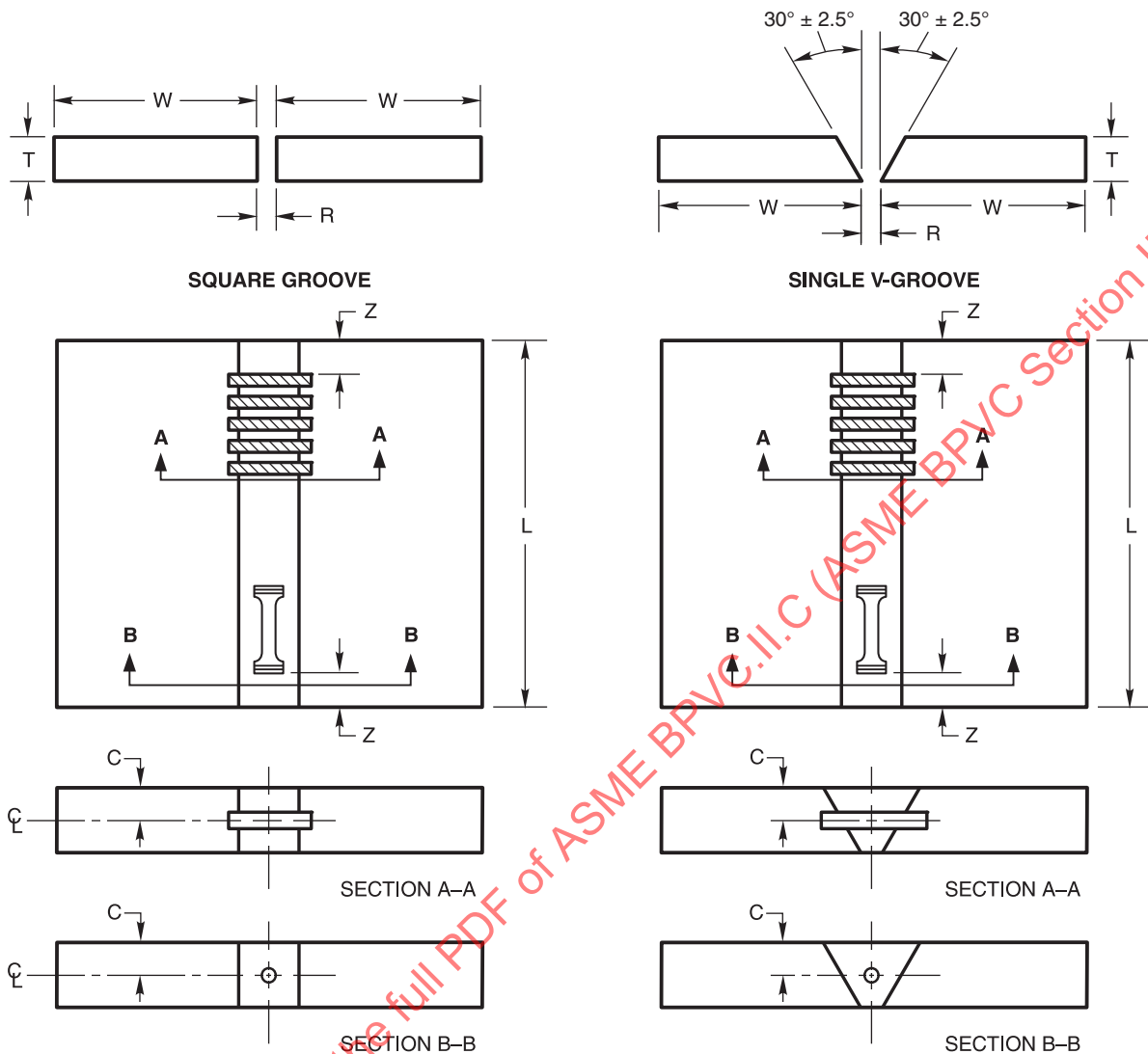
If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that during preparation or after completion of any test, it is clearly determined that prescribed or proper procedures were not followed in preparing the weld test assembly or test specimens or in conducting the test, the test shall be considered invalid without regard to whether the test was actually completed, or whether test results met, or failed to meet, the requirement. That test shall be repeated, following prescribed procedures. In this case the requirement for doubling of the number of test specimens does not apply.

9. Weld Test Assemblies

9.1 One or more of the following weld test assemblies are required for classification testing. They are:

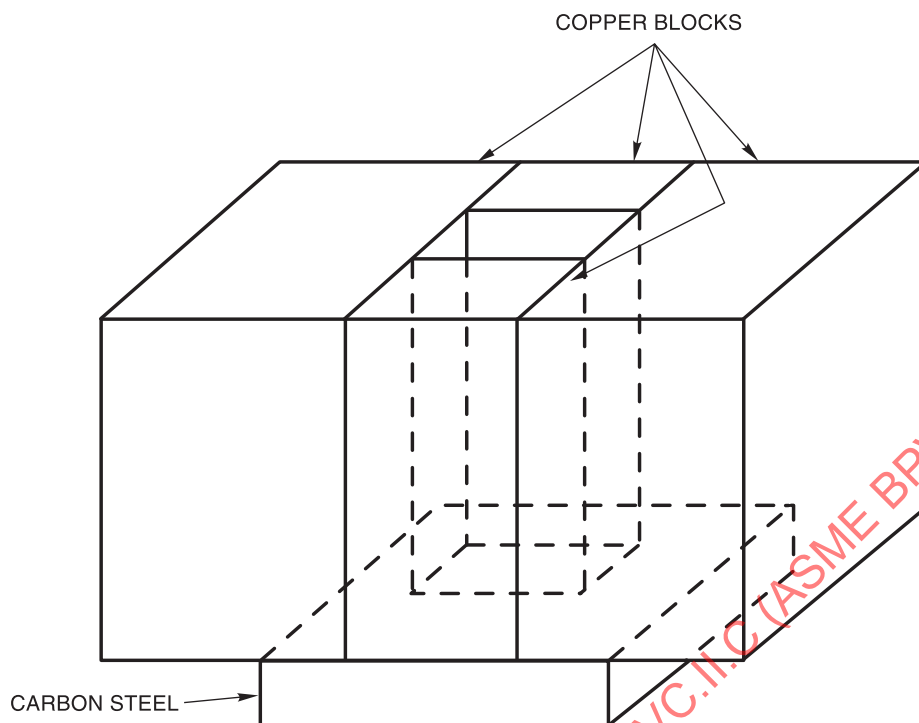
- (1) The groove weld in Figure 2 for mechanical properties and soundness of the weld metal for all classifications.
- (2) The weld ingot in Figure 3 for chemical analysis of the weld metal.



Electrode Type	Gas Shielded		Gas Shielded		Self-Shielded	
Shielding Gas	M21		C1		None	
Groove Type ^a	Square Groove		Square Groove		Square Groove	
	in	mm	in	mm	in	mm
Electrode Size	5/64	2.0	3/32 or 1/8	2.4, 2.5, or 3.0	3/32 or 0.120	2.4, 2.5, or 3.0
Dimensions:						
L, Length, min.	15	380	15	380	15	380
W, Width, min.	12	300	12	300	12	300
T, Nominal Thickness	1	25	1	25	1	25
Z, Discard, min.	2-1/2	65	2-1/2	65	2-1/2	65
R, Root Opening	5/8 ± 1/16	16 ± 1	5/8 ± 1/16 ^a	16 ± 1 ^a	3/4 ± 1/16	19 ± 1
C, Distance to the Center of Specimen	1/2	12.5	1/2	12.5	1/2	12.5
Current, dcep:						
Amperes	400 ± 50		500 ± 50		650 ± 40	
Volts	36 ± 2		36 ± 2		41 ± 2	

^a Single V-groove joint is optional for gas shielded and 3/32 in [2.4 mm, 2.5mm] self-shielded classifications only. In case of dispute, the square groove assembly is the referee method. Root opening, R, for single-V groove is 5/32 in ± 1/32 in [4 mm ± 0.8 mm].

Figure 2—Groove Weld Test Assembly for Mechanical Properties and Soundness



Notes:

1. Weld ingot shall be deposited by arc welding in a water-cooled copper mold using welding conditions shown in Figure 2.
2. The ingot shall be of any convenient shape that provides weld metal with approximately 1 in² [625 mm²] of cross section.
3. The ingot shall be started on a carbon steel base and the copper mold shall be of a size sufficient to avoid contamination of the ingot by molten copper.
4. The sample for chemical analysis shall be taken at least 2 in [50 mm] above the bottom of the ingot, and at least 2 in [50 mm] below the crater.

Figure 3—Weld Ingot

The sample for chemical analysis of weld metal from tubular electrodes may be taken from the reduced section of the fractured tension test specimen or from a corresponding location in the weld metal in the groove weld in Figure 2 thereby avoiding the need to make the weld ingot. In case of dispute, the weld ingot shall be the referee method for chemical analysis.

9.2 Preparation of each weld test assembly shall be as prescribed in 9.3 and 9.4. The base metal for each assembly shall be as required in Table 7 and shall meet the requirements of the ASTM specification shown there, or a chemically equivalent specification. Testing of the assemblies shall be as prescribed in 10.2, 10.3, and Clauses 11 through 13.

9.3 Weld Ingot. A weld ingot shall be prepared as specified in Figure 3 except when the alternative in 9.1 (taking the sample from the broken tension test specimen or from a corresponding location in the groove weld in Figure 2) is selected.

9.4 Groove Weld. A test assembly shall be prepared and welded as specified in Figure 2, using base metal of the appropriate type specified in Table 7.

9.4.1 Welding shall be in the flat position with approximately vertical welding progression and shall be completed in one pass. The assembly shall be restrained or preset to prevent warpage in excess of 5°. An assembly that is warped more than 5° out of plane shall be discarded. Test assemblies shall not be straightened. Fixturing of the test assembly shall be based on the manufacturer's recommendations. Water-cooled copper shoes shall be used except when using consumable

Table 7
Base Metals for Test Assemblies

AWS Classification		
A5.26	A5.26M	Base Metal
EG6XT-X EG6XS-X	EG43XT-X EG43XS-X	ASTM A36
EG7XT-X EG7XS-X	EG49XT-X EG49XS-X	ASTM A242 Type 2, or A572 Grade 50
EG8XT-X EG8XS-X	EG55XT-X EG55XS-X	ASTM A537 Class 2, A572 Grade 60 or 65, or A633 Grade E
The following classifications are exceptions to the above general requirements:		
EGXXT-W	EGXXXT-W	ASTM A588

guide tubes. For welding with consumable guide tubes, follow the manufacturer's recommendations regarding the use of water-cooled shoes and report the composition, size, and type of consumable guide tube on the certificate. When using water cooling, the outgoing water temperature shall not exceed 180°F [80°C] near the exit point.

9.4.2 If the manufacturer does not make the electrode size specified, the nearest size may be used. For sizes other than those shown, the manufacturer's recommended procedure shall be used.

9.4.3 Welding shall begin with the assembly at room temperature, 65°F [18°C] minimum. No external heat shall be applied during welding. Postweld heat treatment shall not be applied to the test assembly. Starting and runoff tabs are not required if the test assembly without weld tabs is sufficient to provide the required test specimens.

10. Chemical Analysis

10.1 For solid electrodes, a sample of the electrode shall be prepared for chemical analysis. Solid electrodes, when analyzed for elements that are present in a coating (copper flashing, for example), shall be analyzed without removing the coating. When the electrode is analyzed for elements other than those in the coating, the coating must be removed if its presence affects the results of the analysis for other elements.

10.2 Tubular electrodes shall be analyzed in the form of weld metal, not electrode. The sample for analysis shall be taken from weld metal obtained with the electrode (and the shielding gas with which it is classified, for those classifications for which an external shielding gas is required). The sample shall come from an ingot (Figure 3), the reduced section of the fractured tension test specimen, or the groove weld in Figure 2.

When the ingot is used, the top surface of the ingot (described in 9.3 and shown in Figure 3) shall be removed and discarded and a sample for analysis shall be obtained from the underlying metal at a location at least 2 in [50 mm] from both the start and crater ends of the ingot by any appropriate mechanical means. The sample shall be free of slag.

When the reduced section of the fractured tension test specimen or a sample from the groove weld in Figure 2 is used, the sample shall be prepared by any suitable mechanical means. The sample from the groove weld shall be taken at least 2 in [50 mm] from both the start and crater ends of the weld.

10.3 The sample shall be analyzed by accepted analytical methods. The referee method shall be ASTM E350.

10.4 The results of the analysis shall meet the requirements of Table 1 for solid electrodes and Table 4 for tubular electrodes, for the classification of electrode under test.

11. Radiographic Test

11.1 The groove weld described in 9.4 and shown in Figure 2 shall be radiographed to evaluate the soundness of the weld metal. In preparation for radiography, both surfaces of the weld may be machined or ground smooth and flush with the original surfaces of the base metal or with a uniform reinforcement not exceeding 3/32 in [2.5 mm].

It is permitted on both sides of the test assembly to remove base metal to a depth of 1/16 in [1.5 mm] nominal below the original base metal surface in order to facilitate backing and/or buildup removal. The thickness of the weld metal shall not be reduced by more than 1/16 in [1.5 mm] so that the thickness of the prepared radiographic test specimen equals at least the thickness of the base metal minus 1/16 in [1.5 mm]. Both surfaces of the test assembly, in the area of the weld, shall be smooth enough to avoid difficulty in interpreting the radiograph.

11.2 The quality level of inspection shall be 2-2T. The weld shall be radiographed in accordance with one of the following:

(1) *Film Radiology*: ASTM E1032.

(2) *Computed Radiology (CR)*: ASTM E2033 and the requirements of ASTM E1032 except where CR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2033, refers to phosphor imaging plate.

(3) *Digital Radiology (DR)*: ASTM E2698 and the requirements of ASTM E1032 except where DR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2698, refers to digital detector array (DDA).

11.3 The soundness of the weld metal meets the requirements of this specification if the radiograph shows:

(1) No cracks, no incomplete fusion, and no incomplete penetration

(2) No slag inclusions longer than 1/4 in [6 mm] or 1/3 of the thickness of the weld, whichever is greater, or no groups of slag inclusions in line that have an aggregate length greater than the thickness of the weld in a length 12 times the thickness of the weld except when the distance between the successive inclusions exceeds six times the length of the longest inclusion in the group

(3) No rounded indications in excess of those permitted by the radiographic standards in Figure 4.

In evaluating the radiograph, 2-1/2 in [65 mm] of the weld on each end of the test assembly shall be disregarded.

11.3.1 A rounded indication is an indication (on the radiograph) whose length is no more than three times its width. Rounded indications may be circular or irregular in shape and may have tails. The size of a rounded indication is the largest dimension of the indication, including any tail that may be present.

11.3.2 The indication may be of porosity or slag. Indications whose largest dimension does not exceed 1/64 in [0.4 mm] shall be disregarded. Test assemblies with indications greater than the largest indications permitted in the radiographic standards do not meet the requirements of this specification.

12. Tension Test

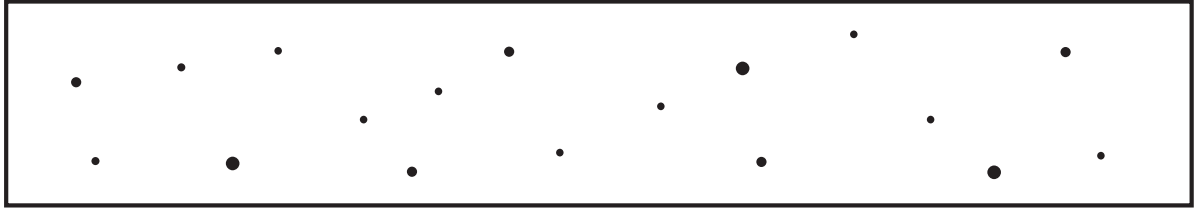
12.1 One all-weld-metal tension test specimen, as specified in the Tension Test clause of AWS B4.0, shall be machined from the welded test assembly described in 9.4 and shown in Figure 2. The tension test specimen shall have a nominal diameter of 0.500 in [12.5mm] and a nominal gage length to diameter ratio of 4:1.

12.2 The specimen shall be tested in the manner described in the Tension Test clause of AWS B4.0.

12.3 The results of the tension test shall meet the requirements specified in Table 2.

13. Impact Test

13.1 Five full-size Charpy V-notch impact specimens, as specified in the Fracture Toughness Test section of AWS B4.0, shall be machined from the welded test assembly shown in Figure 2, for those classifications for which impact testing is required in Table 6.

**(A) ASSORTED ROUNDED INDICATIONS**

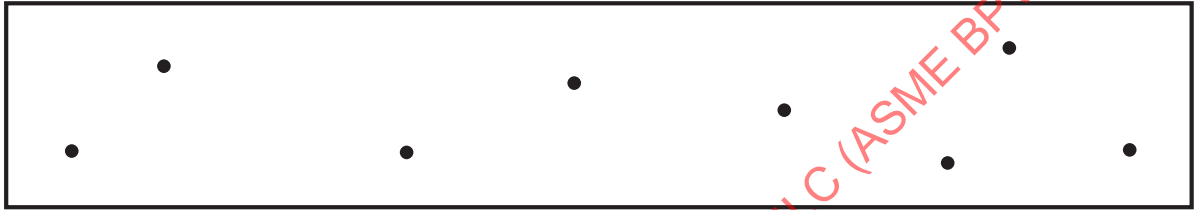
SIZE 1/64 in to 1/16 in [0.4 mm TO 1.6 mm] DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 18, WITH THE FOLLOWING RESTRICTIONS:

MAXIMUM NUMBER OF LARGE 3/64 in TO 1/16 in [1.2 mm TO 1.6 mm] DIAMETER AND/OR LENGTH INDICATIONS = 3.

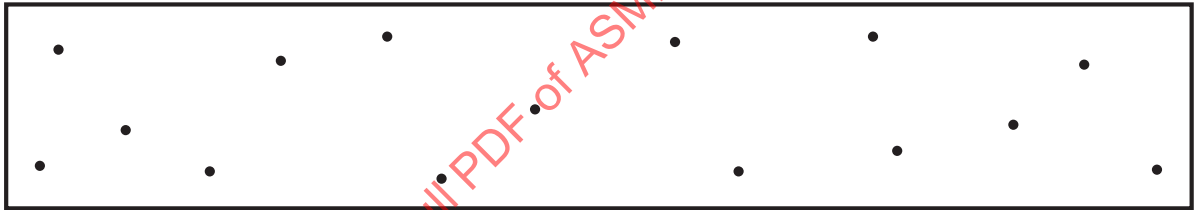
MAXIMUM NUMBER OF MEDIUM 1/32 in TO 3/64 in [0.8 mm TO 1.2 mm] DIAMETER AND/OR LENGTH INDICATIONS = 5.

MAXIMUM NUMBER OF SMALL 1/64 in TO 1/32 in [0.4 mm TO 0.8 mm] DIAMETER AND/OR LENGTH INDICATIONS = 10.

**(B) LARGE ROUNDED INDICATIONS**

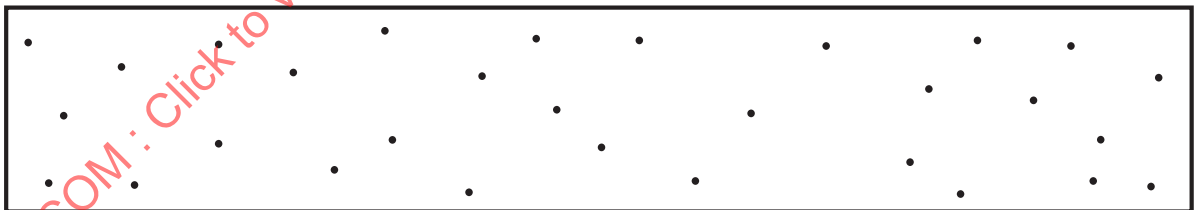
SIZE 3/64 in to 1/16 in [1.2 mm TO 1.6 mm] DIAMETER AND/OR LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 8.

**(C) MEDIUM ROUNDED INDICATIONS**

SIZE 1/32 in to 3/64 in [0.8 mm TO 1.2 mm] DIAMETER AND/OR LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 15.

**(D) SMALL ROUNDED INDICATIONS**

SIZE 1/64 in to 1/32 in [0.4 mm TO 0.8 mm] DIAMETER AND/OR LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in [150 mm] OF WELD = 30.

Notes:

1. In using these standards the chart which is most representative of the size of the porosity and/or inclusions present in the test specimen radiograph shall be used for determining conformance to these radiographic standards.
2. Since these are test welds specifically made in the laboratory for classification purposes, the radiographic requirements for these test welds are more rigid than those which may be required for general fabrication.
3. Indications smaller than 1/64 in [0.4 mm] shall be disregarded.

Figure 4—Radiographic Acceptance Standards

The Charpy V-Notch specimens shall have the notched surface and the struck surface parallel with each other within 0.002 in [0.05 mm]. The other two surfaces of the specimen shall be square with the notched or struck surfaces within 10 minutes of a degree. The notch shall be smoothly machined and shall be square with the longitudinal edge of the specimen within 2°.

The geometry of the notch shall be measured on at least one specimen in a set of five specimens. Measurement shall be done at a minimum 10X magnification on either a shadowgraph or metallograph. The correct location of the notch shall be verified by etching before or after machining.

13.2 The five specimens shall be tested in accordance with the Fracture Toughness Test section of AWS B4.0. The test temperature shall be that specified in Table 3 for the classification under test.

13.3 In evaluating the test results, the lowest and the highest values obtained shall be disregarded. Two of the remaining three values shall equal, or exceed, the specified 20 ft·lbf [27 J] energy level. One of the three may be lower, but not lower than 15 ft·lbf [20 J], and the average of the three shall be not less than the required 20 ft·lbf [27 J] energy level.

14. Method of Manufacture

The electrodes classified according to this specification may be manufactured by any method that will produce material that meets the requirements of this specification.

15. Standard Sizes

Standard sizes for filler metal in the different package forms (coils with support, coils without support, spools and drums) are as specified in AWS A5.02/A5.02M.

16. Finish and Uniformity

Finish and uniformity shall be as specified in AWS A5.02/A5.02M.

17. Standard Package Forms

Standard package forms are coils with support, coils without support, spools, and drums. Standard package dimensions and weights and other requirements for each form shall be as specified in AWS A5.02/A5.02M.

18. Winding Requirements

18.1 Winding requirements shall be as specified in AWS A5.02/A5.02M. The outermost layer of electrode on spools shall be at least 1/8 in [3 mm] from the rim (the OD) of the flanges of the spool.

18.2 The cast and helix of filler metal shall be as specified in AWS A5.02/A5.02M.

19. Filler Metal Identification

Filler Metal Identification, product information and the precautionary information shall be as specified in AWS A5.02/A5.02M.

20. Packaging

Electrodes shall be suitably packaged to ensure against damage during shipment and storage under normal conditions.

21. Marking of Packages

21.1 The product information (as a minimum) that shall be legibly marked so as to be visible from the outside of each unit package shall be as specified in AWS A5.02/A5.02M.

21.2 The appropriate precautionary information, as given in ANSI Z49.1 (as a minimum) or its equivalent shall be prominently displayed in legible print on all packages of electrodes including individual unit packages enclosed within a larger package.

ASMENORMDOC.COM : Click to view the full PDF of ASME BPVC.II.C (ASME BPVC Section II Part C) 2025

Annex A (Informative)

Guide to AWS Specification for Carbon and Low-Alloy Steel Electrodes for Electroslag Welding

This annex is not part of *this standard*, but is included for informational purposes only.

A1. Introduction

The purpose of this guide is to correlate the electrode classifications with their intended applications so the specification can be used effectively. Reference to appropriate base metal specifications is made whenever that can be done and when it would be helpful. Such references are intended as examples rather than complete listings of the base metals for which each filler metal is suitable.

A2. Classification System

A2.1 The system for identifying the electrode classifications in this specification follows the standard pattern used in other AWS filler metal specifications (see Figure 1). The letters “EG” at the beginning of each classification designation show that the electrode is intended for use with the electroslag welding process. Some of the solid electrode classifications are similar to those in other AWS Specifications as shown in Table A.1.

Table A.1
Comparisons of A5.26/A5.26M Classifications
and Classifications in Other AWS Specifications

AWS A5.26/A5.26M Classification	Similar Classifications ^a				
	AWS A5.17	AWS A5.18	AWS A5.23	AWS A5.25	AWS A5.28
EGXXS-1	—	—	—	—	—
EGXXS-2	—	ER70S-2	—	EM5K-EW	—
EGXXS-3	EM13K	ER70S-3	—	EM13K-EW	—
EGXXS-5	—	ER70S-5	—	—	—
EGXXS-6	EH11K	ER70S-6	—	EH11K-EW	—
EGXXS-D2	—	—	EA3K	EH10Mo-EW	ER80S-D2

^a Classifications are similar but not necessarily identical in composition:

AWS A5.17/A5.17M, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*

AWS A5.18/A5.18M, *Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding*

AWS A5.23/A5.23M, *Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*

AWS A5.25/A5.25M, *Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding*

AWS A5.28/A5.28M, *Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding*

In the case of the designations for A5.26, this is followed by the Tensile Strength Designator a single digit (6, 7, or 8) representing the minimum tensile strength of the weld metal in units of 10 000 psi. For the designations of A5.26M, the “EG” is followed by two digits (43, 49, or 55) representing the minimum tensile strength in units of 10 MPa (see Table 2).

The digit that follows is the Impact Designator, a number or the letter “Z.” The number designates the temperature at which (and/or above which) the weld metal meets or exceeds the required 20 ft-lbf [27 J] Charpy V-notch impact strength. The letter “Z” indicates that no impact strength requirement is specified.

The next letter, either S or T, indicates that the electrode is solid (S) or tubular (flux cored or metal cored) (T). The designator (digits or letters) following the hyphen in the classification indicates the chemical composition (of weld metal for the tubular electrodes and of the electrode itself for solid electrodes) and the type or absence of shielding gas required in the case of tubular electrodes only.

A2.2 “G” Classification

A2.2.1 This specification includes filler metals classified as EGXXT-G or EGXXS-G. The last “G” indicates that the filler metal is of a general classification. It is “general” because not all of the particular requirements specified for each of the other classifications are specified for this classification. The intent in establishing this classification is to provide a means by which filler metals that differ in one respect or another (chemical composition, for example) from all other classifications (meaning that the composition of the filler metal, in the case of the example, does not meet the composition specified for any of the classifications in the specification) can still be classified according to the specification. The purpose is to allow a useful filler metal—one that otherwise would have to await a revision of the specification—to be classified immediately, under the existing specification. This means, then, that two filler metals, each bearing the same “G” classification, may be quite different in some certain respect (chemical composition, again, for example).

A2.2.2 The point of difference (although not necessarily the amount of that difference) between filler metal of a “G” classification and filler metal of a similar classification without the “G” (or even with it, for that matter) will be readily apparent from the use of the words not required and not specified in the specification. The use of these words is as follows:

Not Specified is used in those areas of the specification that refer to the results of some particular test. It indicates that the requirements for that test are not specified for that particular classification.

Not Required is used in those areas of the specification that refer to the tests that must be conducted in order to classify a welding material. It indicates that that test is not required because the requirements (results) for the test have not been specified for that particular classification. Restating the case, when a requirement is not specified, it is not necessary to conduct the corresponding test in order to classify a filler metal to that classification. When a purchaser wants the information provided by that test in order to consider a particular product of that classification for a certain application, the purchaser will have to arrange for that information with the supplier of the product. The purchaser will have to establish with that supplier just what the testing procedure and the acceptance requirements are to be, for that test. The purchaser may want to incorporate that information [via AWS A5.01M/A5.01] into the purchase order.

A2.2.3 Request for Filler Metal Classification

(1) When a filler metal cannot be classified other than as a “G” classification, a manufacturer may request that a new classification be established. The manufacturer shall do this using the following procedure:

(2) A request to establish a new filler metal classification must be submitted in writing. The request needs to provide sufficient detail to permit the Committee on Filler Metals and Allied Materials and the relevant Subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, or if neither is necessary. In particular, the request needs to include:

- (a) Declaration that the new classification will be offered for sale commercially.
- (b) All classification requirements as given for existing classifications, such as, chemical composition ranges, mechanical property requirements, and usability test requirements.
- (c) Any conditions for conducting the tests used to demonstrate that the filler metal meets the classification requirements. It would be sufficient, for example, to state that welding conditions are the same as for other classifications.
- (d) Information on Descriptions and Intended Use, which parallels that for existing classifications (for that clause of the Annex).

(e) Actual test data for all tests required for classification according to the requirements of the specification for a minimum of two production heats/lots must be provided. In addition, if the specification is silent regarding mechanical properties, test data submitted shall include appropriate weld metal mechanical properties from a minimum of two production heats/lots.

(f) A request for a new classification without the above will be considered incomplete. The Secretary will return the request to the requester for further information.

(3) The request should be sent to the Secretary of the Committee on Filler Metals and Allied Materials at AWS Headquarters.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01M/A5.01 or the tests and requirements of this specification. Any testing a purchaser requires of the supplier for material shipped in accordance with this specification, shall be clearly stated in the purchase order. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing is normally conducted on material of that classification, as specified in Schedule F, Table 1, of AWS A5.01M/A5.01. Testing in accordance with any other Schedule in that Table must be specifically required by the purchase order. In such cases, acceptance of the material shipped shall be in accordance with those requirements.

A4. Certification

The act of placing the AWS Specification and Classification designations on the packaging enclosing the product or the classification on the product itself, constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification.

The only testing requirement implicit in this certification is that the manufacturer actually has conducted the tests required by the specification on material that is representative of that being shipped and that the material met the requirements of the specification.

Representative material, in this case, is any production run of that classification using the same formulation. "Certification" is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the certification required by the specification is the classification test of representative material cited above and the Manufacturer's Quality Assurance Program in AWS A5.01M/A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes in the atmosphere to which welders and welding operators are exposed during welding. They are:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling)
- (2) Number of welders and welding operators working in that space
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes used
- (4) The proximity of the welders or welding operators to the fumes as the fumes issue from the welding zone, and to the gases and dusts in the space in which they are working
- (5) The ventilation provided to the space in which the welding is done

A5.2 American National Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the clause on protection of personnel and the general area and ventilation in that document. See also AWS F3.2M/F3.2, *Ventilation Guide for Weld Fume* for more detailed description of ventilation options.

A6. Welding Considerations

A6.1 Electrode gas welding is an arc welding process that uses solid electrodes with gas shielding, tubular cored electrodes with gas shielding, or tubular cored electrodes without gas shielding (self-shielded). Operating on direct current, the electrode deposits filler metal in the cavity formed by the water-cooled or solid backing shoe(s) that bridges the groove between the joint members. The joint normally is made in a single pass, though with special fixturing multipass joints have been welded.

A6.2 Flux cored electrodes used with the electrode gas welding process are designed specifically for compatibility with the process. The flux produces a thin layer of slag between the weld metal and copper backing shoes without accumulating excessive slag above the weld pool. The nonmetallic content of the flux core is lower than that of conventional gas shielded and self-shielded flux cored electrodes.

A6.3 Because of the large volume of molten weld metal produced in electrode gas welding and the necessity to contain it, the process is used for welding in the flat position with approximately vertical progression. Joints are readily welded in plate assemblies that are as much as 15° from the vertical, or where the joint in vertical plate assemblies may be as much as 15° from vertical, or both.

A6.4 The entire assembly, including electrode, copper shoes, wire-feeding mechanism, controls, and oscillator, generally moves vertically during operation. When consumable guide tubes are used, vertical movement of the equipment may not be required. The length of vertical travel is unlimited and is dependent upon the design of the equipment used.

A6.5 The standard joint geometry is a simple square groove in a butt joint. Joint geometries other than square grooves in butt joints can be used.

A6.6 Certain classifications can be used with consumable guide tubes. These guide tubes are generally AISI Grades 1008 to 1020 carbon steel tubing. In some applications, the guide tubes are covered with a flux which provides a protective slag and insulates the tube should it contact the side wall or copper backing shoes. Other applications use ceramic fusible insulators in the shape of washers affixed to the tubes. The manufacturer should be consulted for specific recommendations regarding consumable guide tubes.

The effect of the consumable guide tubes is generally to dilute the alloy content of the weld metal. Consumable guide tubes are not classified per this specification; therefore, weld metal strength and toughness should be tested by the user.

A6.7 The specification requires the use of certain base metals for classification purposes. This does not signify any restriction on the application of the process for joining other base metals, but rather to provide a means for obtaining reproducible results. Electrode gas welding is a "high-dilution" process, meaning that the base metal forms a significant portion of the weld metal. The type of base metal, especially given the wide variety of available low-alloy structural steels, will influence the mechanical and other properties of the joint and weld procedure qualification tests, as distinguished from filler metal classification tests, should be used for assessing the properties of welds for a given application.

A6.8 Electrode gas welding is generally a high-deposition process, especially when applied to thick plates. Since it usually is operated as a single-pass process, the weld metal and heat-affected zones (HAZs) are subject to no subsequent weld thermal cycles, such as is common with conventional multipass arc welding of thick materials. The relatively wide HAZ on thick plates is often characterized by large grains. On these types of applications, the as-welded mechanical properties of the weld and HAZ may, therefore, be somewhat lower than the base metal, and should be adequately tested and evaluated for the intended application.

A7. Description and Intended Use of Electrodes

This specification contains classifications that describe three categories of electrodes: solid electrodes for use with gas shielding, *tubular* (flux cored or metal cored) electrodes for use with gas shielding, and self-shielded *tubular* (flux cored) electrodes which require no external gas shielding.

A7.1 Solid Electrodes. The classifications for solid electrodes contained in this specification are very similar in electrode chemical composition to, or, in many cases, identical in electrode chemical composition to classifications contained in AWS A5.18, *Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding*, and AWS A5.28, *Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding*. The user should be aware that the mechanical properties obtained when using these electrodes with the electrogas welding process will differ from those obtained when using them with the gas metal or gas tungsten arc welding processes.

Weld metal mechanical properties obtained with the use of solid electrodes with the electrogas welding process are very dependent on the type of gas employed. The change from one gas type or blend to another (either more reactive or less reactive) will affect the chemical composition of the weld metal and the resulting mechanical properties. In some cases, this change in mechanical properties may be significant enough to necessitate a change in the electrode classification. For this reason, care should be taken to test the electrode with the gas or gas blend which will be used in production.

A7.2 Tubular Electrodes. The classifications for *tubular* (flux cored and metal cored) electrodes contained in this specification are based on weld metal chemical composition and the type of, or absence of, an external shielding gas, as shown in Table 4. Once again, it is important for the user to remember that the change from one gas type or blend to another (either more reactive or less reactive) will affect the chemical composition of the weld metal and the resulting mechanical properties.

It should be noted that the EGXXT-1 and EGXXT-2 classifications in this specification are totally different from the EXXT-1 and EXXT-2 classifications contained in AWS A5.20, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*, and AWS A5.29, *Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding*.

A7.2.1 EGXXT-1 Classification. Electrodes of the EGXXT-1 (and EGXXT-1) classifications are self-shielded electrodes which require no external shielding gas. Electrodes of these classifications are designed for the core materials to provide a slag cover, along with the appropriate alloys, deoxidizers, denitrifiers, and shielding materials. These often consist of fluorides, metallic alloys, and alkali and alkali earth oxides and carbonates. EGXXT-1 electrodes are designed for welding many structural steels such as ASTM A36, A572, and A515, as well as many grades used in ship construction. Typical applications include bases for heavy equipment, storage tanks, ship hulls, structural members and pressure vessels.

A7.2.2 EGXXT-2 Classification. Electrodes of the EGXXT-2 (and EGXXT-2) classifications are gas shielded electrodes designed for use with carbon dioxide shielding gas. Typical applications would be similar to those of EGXXT-1 electrodes, except the use of an external shielding gas would normally confine their use to a *wind-protected* environment.

A7.2.3 EGXXT-Ni1 Classification. Electrodes of the EGXXT-Ni1 (and EGXXT-Ni1) classifications are gas shielded electrodes designed for use with carbon dioxide shielding gas. These electrodes are similar to EGXXT-2 electrodes except they produce weld metal with approximately 1% nickel.

A7.2.4 EGXXT-NM1 and -NM2 Classifications. Electrodes of the EGXXT-NM1 (EGXXT-NM1) and EGXXT-NM2 (EGXXT-NM2) classifications are gas shielded electrodes designed for use with carbon dioxide shielding gas (or an argon/carbon dioxide blend in the case of EGXXT-NM2). These electrodes produce weld metal alloyed with various levels of nickel and molybdenum.

A7.2.5 EGXXT-W Classification. Electrodes of the EGXXT-W (and EGXXT-W) classifications are gas shielded electrodes designed for use with carbon dioxide shielding gas. These electrodes produce weld metal which is intended for use on bare exposed applications of weathering steels, such as ASTM A242 and A588.

A7.2.6 EGXXT-G Classification. Electrodes of the EGXXT-G (and EGXXT-G) classifications are those electrodes not included in the preceding classifications, and for which only mechanical property requirements are specified. The electrode supplier should be consulted for the composition, properties, characteristics, and intended use of electrodes of this classification. (See A2.2 for further information.)

Table A.2
Discontinued Classifications

Discontinued Classification	Last Published	Replaced by
EGXXS-1B	1978	EGXXS-D2 in A5.26-91
EGXXS-GB	1978	EGXXS-G in A5.26-91
EGXXT3	1978	EGXXS-Ni1 in A5.26-91
EGXXT4	1978	EGXXT-NM1 in A5.26-91
EGXXT5	1978	EGXXT-W in A5.26-91

A8. Discontinued Classifications

The classifications shown in Table A.2 have been discontinued over the life of this specification.

A9. General Safety Considerations

A9.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Annex Clause A5. Safety and health information is available from other sources, including, but not limited to Safety and Health Fact Sheets, ANSI Z49.1, and applicable regulatory agencies.

A9.2 Safety and Health Fact Sheets. The Safety and Health Fact Sheets are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised, and additional sheets added periodically.

Annex B (Informative)

Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

B6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

INTENTIONALLY LEFT BLANK

SPECIFICATION FOR LOW-ALLOY STEEL ELECTRODES AND RODS FOR GAS SHIELDED ARC WELDING



SFA-5.28/SFA-5.28M



(25)

(Identical with AWS Specification A5.28/A5.28M:2022. In case of dispute, the original AWS text applies.)

Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding

1. Scope

1.1 This specification prescribes requirements for the classification of low-alloy steel electrodes (solid, composite stranded and composite metal cored) for gas metal arc welding (GMAW) and low-alloy steel rods (solid, composite stranded and composite metal cored) for gas tungsten arc welding (GTAW) and plasma arc welding (PAW). With two exceptions (the 20% manganese types “Mn1” and “Mn2”), iron is the only element whose content exceeds 10.5% in undiluted weld metal deposited by these electrodes or rods, as applicable.

1.2 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other, without combining values in any way. In selecting rational metric units, AWS A1.1, *Metric Practice Guide for the Welding Industry* and ISO 544, *Welding Consumables-Technical Delivery Conditions for Welding Filler Materials and Fluxes-Type of Product, Dimensions, Tolerances and Markings*, are used where suitable. Tables and figures make use of both U.S. Customary and SI units, which, with the application of the specified tolerances, provide for interchangeability of products in both U.S. Customary and SI Units. The specification with the designation A5.28 uses U.S. Customary Units. The specification A5.28M uses SI Units. The latter are shown within brackets [] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing of electrodes or packaging or both under the A5.28 or A5.28M specifications.

1.3 Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein. Some safety and health information can be found in the nonmandatory annex, Clauses B5 and B10.

Safety and Health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by material manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable federal and state regulations.

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

American Welding Society (AWS) Standards:

AWS A1.1, *Metric Practice Guide for the Welding Industry*

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

AWS A5.01M/A5.01 (ISO 14344:2010 MOD), *Welding and Brazing Consumables—Procurement of Filler Metals and Fluxes*

AWS A5.02/A5.02M, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*

AWS A5.18/A5.18M, *Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding*

AWS A5.32M/A5.32 (ISO 14175: 2008 MOD), *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes*

AWS A4.3, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*

AWS B4.0, *Standard Methods for Mechanical Testing of Welds*

American National Standards Institutes (ANSI) document:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

ASTM International (ASTM) documents:

ASTM A36/A36M, *Standard Specification for Carbon Structural Steel*

ASTM A203/A203M, *Standard Specification for Pressure Vessel Plates, Alloy Steel, Nickel*

ASTM A285/A285M, *Standard Specification for Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength*

ASTM A335/A335M, *Standard Specification for Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service*

ASTM A387/A387M, *Standard Specification for Pressure Vessel Plates, Alloy Steel, Chromium-Molybdenum*

ASTM A514/A514M, *Standard Specification for High-Yield-Strength, Quenched and Tempered, Alloy Steel Plate, Suitable for Welding*

ASTM A515/A515M, *Standard Specification for Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service*

ASTM A516/A516M, *Standard Specification for Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service*

ASTM A517/A517M, *Standard Specification for Pressure Vessel Plates, Alloy Steel, High-Strength, Quenched and Tempered*

ASTM A537/A537M, *Standard Specification for Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel*

ASTM A572/A572M, *Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel*

ASTM A588/A588M, *Standard Specification for High-Strength Structural Steel with 50 ksi [345 MPa] Minimum Yield Point to 4 in [100 mm] Thick*

ASTM A1106/A1106M, *Standard Specification for Pressure Vessel Plate, Alloy Steel, Austenitic High Manganese for Cryogenic Application*

ASTM E23, *Standard Test Methods for Notched Bar Impact Testing of Metallic Materials*

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

ASTM E350, *Standard Test Method for Chemical Analysis of Carbon Steel, Low Alloy Steel, Silicon Electrical Steel, Ingot Iron and Wrought Iron*

ASTM E353, *Standard Test Methods for Chemical Analysis of Stainless, Heat-Resisting, Maraging, and Other Similar Chromium-Nickel-Iron Alloys*

ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*.

ASTM E2033, *Standard Test Method for Radiographic Examination Using Computed Radiography (Photostimulable Luminescence Method)*.

ASTM E2698, *Standard Test Method for Radiographic Examination Using Digital Detector Arrays*.

International Organization for Standardization (ISO) documents:

ISO 544, *Welding Consumables—Technical Delivery Conditions for Welding Filler Materials and Fluxes—Type of Product, Dimensions, Tolerances and Markings*

ISO 15792-1-Amendment 1, *Test methods—Part 1: Test Methods for All-weld Metal Test Specimens in Steel, Nickel and Nickel Alloys*

ISO 80000-1:2009/COR 1:2011, *Quantities and Units—Part 1: General*

United States Department of Defense (DODSSP) publications:

MIL-S-16216, *Military Specification, Steel Plate, Alloy, Structural, High Yield Strength (HY-80 and HY-100)*

NAVSEA Technical Publication T9074-BD-GIB-010/0300, *Base Materials for Critical Applications: Requirements for Low Alloy Steel Plate, Forgings, Castings, Shapes, Bars, and Heads of HY-80/100/130 and HSLA-80/100, Appendix B (16216) Steel Plate, Alloy, Structural, High-Yield Strength (HY-80 and HY-100)*.

American Petroleum Institute (API) document:

Spec 5L, *Specification for Line Pipe*

3. Classification

3.1 Solid Electrodes and Rods

3.1.1 The solid electrodes and rods covered by this A5.28 specification utilize a classification system based upon U.S. Customary Units as shown in Figure 1. They are classified according to the chemical composition of the electrode, as specified in Table 1, and the mechanical properties of the weld metal as specified in Tables 2 and 3 with the shielding gas specified in Table 2.

3.1.2 The solid electrodes and rods covered by this A5.28M specification utilize a classification system based upon the International System of Units (SI) as shown in Figure 1. They are classified according to the chemical composition of the electrode or rod as specified in Table 1, and the mechanical properties of the weld metal, as specified in Tables 2 and 3 with the shielding gas specified in Table 2.

3.1.3 Either one of the two GMAW weld assemblies in Figure 2, using shielding gas in Table 2, is required and sufficient to classify solid wires offered as an electrode or an electrode and rod. The GTAW groove weld in Figure 2 is required for solid wires offered as a rod only. The GTAW weld assembly may be requested in addition to the GMAW assembly as an option and as agreed upon between the purchaser and the supplier.

3.2 Composite Metal Cored and Composite Stranded Electrodes and Rods

3.2.1 The composite metal cored and composite stranded electrodes and rods covered by this A5.28 specification also utilize a classification system based upon U.S. Customary Units as shown in Figure 1. They are classified according to the chemical composition and mechanical properties of the weld metal as specified in Tables 2, 3, and 4 with the shielding gas specified in Table 2.

3.2.2 The composite metal cored and composite stranded electrodes and rods covered by this A5.28M specification also utilize a classification system based upon the International System of Units (SI) as shown in Figure 1. They are classified according to the chemical composition and mechanical properties of the weld metal as specified in Tables 2, 3, and 4 with the shielding gas specified in Table 2.

3.2.3 Either one of the two GMAW weld assemblies in Figure 2, using shielding gas in Table 2, is required for composite filler metals classified as an electrode. The GTAW groove weld in Figure 2 is required for composite filler metals classified as a rod. Either one of the two GMAW weld assemblies and the GTAW weld assembly in Figure 2 are required for composite filler metals classified as an electrode and rod.

3.3 Electrodes and rods classified under one classification shall not be classified under any other classification in this specification with the exception of the following:

(1) ER80S-D2 [ER55S-D2] may also be classified as ER90S-D2 [ER62S-D2] provided the product meets the requirements of both classifications.

(2) Electrodes and rods may be classified under A5.28 using U.S. Customary Units, or under A5.28M using the International System of Units (SI), or both. Electrodes and rods classified under either unit system must meet all requirements for classification under that unit system.

(3) Electrodes and rods may be classified with both a defined chemical composition designator and a “-G” composition designator.

3.4 The welding electrodes and rods classified under this specification are intended for GMAW, GTAW, and PAW, but that is not to prohibit their use with any other process (or any other shielding gas, or combination of shielding gases) for which they are found suitable. *See Clauses 14.4 and B8.4 for information on optional shielding gas range designators.*

4. Acceptance

Acceptance of the electrodes and rods shall be in accordance with the provisions of AWS A5.01M/A5.01. See Clause B3, Acceptance (in Annex B) for further information concerning acceptance, testing of the material shipped, and AWS A5.01M/A5.01.

5. Certification

By affixing the AWS specification and classification designations to the packaging, or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification. See Clause B4, Certification (in Annex B) for further information concerning certification and the testing called for to meet this requirement.

6. Rounding Procedure

For purposes of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding rules of ASTM E29 or Rule A in B.3 of ISO 80000-1 (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding. If an average value is to be compared to the specified limit, rounding shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest 1 000 psi for tensile and yield strength for A5.28 classifications and to the nearest 10 MPa for tensile and yield strength for A5.28M classifications and to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded results shall fulfill the requirements for the classification under test.

7. Summary of Tests

7.1 The tests required for each classification are specified in Table 5. The purpose of these tests is to determine the chemical composition of the electrode or rod or weld metal, and the mechanical properties and soundness of the weld

metal. The base metal for the weld test assemblies, the welding and testing procedures to be employed, and the results required are given in Clauses 9 through 13.

7.2 This document provides for optional supplemental tests and designations which are not required for classification but which are included to provide additional information which may be useful to the user. See Figure 1, Clause 14, and Annex A.

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Specimens for retest may be taken from the original test assembly or sample, or from one or two new test assemblies or samples. For chemical analysis, retest need be only for those specific elements that failed to meet their requirement. If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that, during preparation or after completion of any test, it is clearly determined that specified or proper procedures were not followed in preparing the weld test assembly or test specimens, or in conducting the test, the test shall be considered invalid, without regard to whether the test was actually completed, or whether the test results met, or failed to meet, the requirement. That test shall be repeated, following proper specified procedures. In this case, the requirement for doubling the number of test specimens does not apply.

9. Weld Test Assemblies

9.1 At least one weld test assembly is required, and two may be required (depending on the electrode—solid as opposed to composite—and the manner in which the sample for chemical analysis is taken), as specified in Table 5. They are as follows:

- (1) Either one of the two GMAW groove weld assemblies in Figure 2 for mechanical properties and soundness of the weld metal for both solid and composite electrodes based on gas metal arc welding.
- (2) The GTAW groove weld in Figure 2 for mechanical properties and soundness based on gas tungsten arc welding of solid filler metals classified as rods only and all composite filler metals classified as rods.
- (3) The weld pad in Figure 3 for chemical analysis of the weld metal from composite stranded and composite metal cored filler metals.
- (4) The sample for chemical analysis of weld metal from composite electrodes or rods may be taken from the reduced section of the fractured all-weld-metal tension test specimen or from the corresponding location or from any location above it along the weld centerline in the groove weld used for mechanical properties and soundness in Figure 2, thereby avoiding the need to make a weld pad. In case of dispute, the sample from either groove weld in Figure 2 as just described, shall be the referee method.

9.2 Preparation of each weld test assembly shall be as specified in 9.3 and 9.4. The base metal for each assembly shall be as required in Table 6 and shall meet the requirements of the specification shown there, or a chemically equivalent specification. Testing of each assembly shall be as specified in 10.2, 10.3, and Clauses 11 through 13.

9.3 Groove Weld

9.3.1 For all classifications, a test assembly shall be prepared and welded as specified in Figure 2, using base metal of the appropriate type specified in Table 6, and the preheat and interpass temperature specified in Table 7. The electrode used for either GMAW test assembly shall be 0.045 in or 1/16 in [1.2 mm or 1.6 mm] diameter (or the diameter the manufacturer produces that is closest to one of these, if these diameters are not produced) and welded as specified in Table 8. The rod used for the GTAW test assembly shall be 3/32 in or 1/8 in [2.4 mm or 3.2 mm] diameter (or the diameter the manufacturer produces that is closest to one of these, if these diameters are not produced). The GTAW test assembly shall be prepared and welded, when required in Clauses 3.1.3 or 3.2.3, as specified in Figure 2 and Table 9.

Welding shall be performed in the flat position, and the assembly shall be restrained (or preset) during welding to prevent warpage in excess of 5°. A welded assembly that is warped more than 5° out of plane shall be discarded. Test assemblies

shall not be straightened. The test assembly shall be tack welded at or above room temperature and welding shall begin within the preheat and interpass temperature range specified in Table 7. Welding shall continue until the assembly has reached the interpass temperature specified in Table 7, measured by temperature indicating crayons or surface thermometers at the location shown in Figure 2.

For the remainder of the weld, the range between preheat and interpass temperature as specified in Table 7 shall be maintained. Should it be necessary to interrupt welding, the assembly shall be allowed to cool in still air at room temperature. The assembly shall be reheated to within the preheat and interpass temperature range specified in Table 7 before welding is resumed. When welding has been completed and the assembly has cooled, the assembly shall be prepared and tested as specified in Clauses 11, Radiographic Test; 12, Tension Test; and 13, Impact Test. Testing shall be performed in the as-welded or postweld heat-treated condition, as specified in Table 7.

9.3.2 When postweld heat treatment (PWHT) is required in Table 7, the heat treatment shall be applied to the test assembly before removal of the mechanical test specimens. This PWHT may be done either before or after the radiographic examination. If radiographic examination is conducted prior to PWHT, the weldment shall first be allowed to cool in still air to below 200 °F [93 °C].

9.3.2.1 The furnace shall be at a temperature not higher than 600 °F [320 °C] when the test assembly is placed in it. The heating rate, from that point to the holding temperature specified in Table 7, shall not exceed 400 °F per hour [220 °C per hour].

9.3.2.2 The test assembly shall be maintained at the temperature specified in Table 7 for the specified time (-0, +15 minutes).

9.3.2.3 When the specified holding time has been completed, the assembly shall be allowed to cool in the furnace to a temperature below 600 °F [320 °C] at a rate not exceeding 350 °F per hour [190 °C per hour]. The assembly may be removed from the furnace at any temperature below 600 °F [320 °C] and allowed to cool in still air to room temperature. Testing of the assembly shall be as specified in Clauses 11 through 13.

9.4 Weld Pad. A weld pad shall be prepared using composite stranded and composite metal cored electrodes and rods as shown in Figure 3, except when, as permitted in 9.1, the sample for analysis is taken from the groove weld (Figure 2) or the fractured all-weld-metal tension test specimen. Base metal of any convenient size which will satisfy the minimum requirements of Figure 3, and of a type specified in Table 6, shall be used as the base for the weld pad. See Table 6, notes a and c, for the use of an alternate base metal. The surface of the base metal on which the filler metal is deposited shall be clean. The pad shall be welded in the flat position with multiple layers to obtain undiluted weld metal (4 layers minimum). The filler metal size shall be 0.045 in or 1/16 in [1.2 mm or 1.6 mm] for electrodes, or 3/32 in or 1/8 in [2.4 mm or 3.2 mm] for rods, or the size that the manufacturer produces that is closest to one of these, if these sizes are not produced. The preheat temperature shall not be less than 60 °F [15 °C] and the interpass temperature shall not exceed that specified in Table 7. Any slag shall be removed after each pass. The pad may be quenched in water between passes (temperature of the water not specified). The dimensions of the completed pad shall be as shown in Figure 3. Testing of this assembly shall be as specified in 10.2 and 10.3. The results shall meet the requirements of Table 4.

10. Chemical Analysis

10.1 A sample of the solid electrode or rod stock from which it is made shall be prepared for chemical analysis. Solid filler metal, when analyzed for elements that are present in a coating (copper flashing, for example), shall be analyzed without removing the coating. When the filler metal is analyzed for elements other than those in the coating, the coating shall be removed, if its presence affects the results of the analysis for the other elements.

10.2 Composite stranded or metal cored electrodes or rods shall be analyzed in the form of weld metal, not filler metal. The sample for analysis shall be taken from weld metal obtained with the electrode or rod and the shielding gas as specified in Table 2. The sample may be taken from the weld pad prepared in accordance with 9.4, from an area of the groove weld as specified in 9.1, or from the reduced section of the fractured tension test specimen. In case of dispute, the area of the groove weld described in 9.1 including the tensile specimen shall be the referee method.

The top surface of the pad described in 9.4 and shown in Figure 3 shall be removed and discarded. A sample for analysis shall be obtained from the underlying metal, no closer than 3/8 in [9.5 mm] to the surface of the base metal in Figure 3, by any appropriate means that will not affect the composition. The sample shall be free of slag. When the sample is taken

from the groove weld or the reduced section of the fractured tension test specimen, that material shall be prepared for analysis by any suitable means that will not affect the composition.

10.3 The sample obtained as specified in 10.1 or 10.2 shall be analyzed by accepted analytical methods. *The referee method shall be ASTM E350, with the exception of the Mn1 and Mn2 classifications. For the Mn1 and Mn2 classifications, the referee method shall be ASTM E353.*

10.4 The results of the analysis shall meet the requirements of Table 1 for solid electrodes or rods or Table 4 for composite electrodes or rods for the classification of electrode or rod under test.

11. Radiographic Test

11.1 The groove weld described in 9.3.1 and shown in Figure 2 shall be radiographed to evaluate the soundness of the weld metal. In preparation for radiography, the backing shall be removed and both surfaces of the weld shall be machined or ground smooth. It is permitted on both sides of the test assembly to remove base metal to a depth of 1/16 in [1.5 mm] nominal below the original base metal surface in order to facilitate backing and/or buildup removal. Thickness of the weld metal shall not be reduced by more than 1/16 in [1.5 mm] less than the nominal base metal thickness. Both surfaces of the test assembly, in the area of the weld, shall be smooth enough to avoid difficulty in interpreting the radiograph.

11.2 The weld shall be radiographed in accordance with one of the following. The quality level of inspection shall be 2-2T.

(1) Film Radiology: ASTM E1032.

(2) Computed Radiology (CR): ASTM E2033 and the requirements of ASTM E1032 except where CR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2033, refers to phosphor imaging plate.

(3) Digital Radiology (DR): ASTM E2698 and the requirements of ASTM E1032 except where DR differs from film. The term film, as used within ASTM E1032, applicable to performing radiography in accordance with ASTM E2698, refers to digital detector array (DDA).

11.3 The soundness of the weld metal meets the requirements of this specification if the radiograph shows no cracks, no incomplete fusion, and no rounded indications in excess of those permitted by the radiographic standards in Figure 4. In evaluating the radiograph, 1 in [25 mm] of the weld on each end of the test assembly shall be disregarded.

A rounded indication is an indication (on the radiograph) whose length is no more than 3 times its width. Rounded indications may be circular, elliptical, conical, or irregular in shape, and they may have tails. The size of a rounded indication is the largest dimension of the indication, including any tail that may be present. The indication may be of porosity or slag. Indications whose largest dimension does not exceed 1/64 in [0.4 mm] shall be disregarded. Test assemblies with indications larger than the largest indications permitted in the radiographic standards (Figure 4) do not meet the requirements of this specification.

12. Tension Test

12.1 One all-weld-metal round tension test specimen, as specified in the Tension Tests Clause of AWS B4.0, shall be machined from the weld test assembly described in 9.3.1, and shown in Figure 2, as required in Table 5. The tensile specimen, when machined from the GMAW weld test assembly shown in Figure 2, shall have a nominal diameter of 0.500 in [12.5 mm] and a nominal gage length-to-diameter ratio of 4:1. The tensile specimen, when machined from the GTAW weld test assembly shown in Figure 2, shall have a nominal diameter of 0.350 in [9 mm] and a nominal gage length-to-diameter ratio of 4:1. Other dimensions of the tension test specimen shall be as specified in the Tension Tests Clause of AWS B4.0.

12.1.1 After machining, but before testing, the specimen may be aged at 200 °F to 220 °F [95 °C to 105 °C] for up to 48 hours, then allowed to cool to room temperature. Refer to B8.3 for a discussion on the purpose of aging.

12.1.2 The specimen shall be tested in the manner described in the Tension Tests Clause of AWS B4.0.

12.1.3 The results of the all-weld-metal tension test shall meet the requirements specified in Table 2. Test reports shall indicate if the specimen was tested in the aged condition.

13. Impact Test

13.1 For those classifications for which impact testing is required in Table 3 and Table 5, five Charpy V-notch impact test specimens, as specified in the Fracture Toughness Tests Clause of AWS B4.0, shall be machined from the test assembly shown in Figure 2.

The Charpy V-Notch specimens shall have the notched surface and the surface to be struck parallel within 0.002 in [0.05 mm]. The other two surfaces shall be square with the notched or struck surface within ± 10 minutes of a degree. The notch shall be smoothly cut and be square with the longitudinal edge of the specimen within one degree. Test specimens shall not contain metal that has been affected thermally as a result of cutting or preparation.

The geometry of the notch shall be measured on at least one specimen in a set of five specimens. Measurement shall be done at a minimum 10 times magnification on either a shadowgraph or metallograph. The correct location of the notch shall be verified by etching before or after machining.

13.2 The five specimens shall be tested in accordance with the Fracture Toughness Tests Clause of AWS B4.0. The test temperature shall be that specified in Table 3 or lower for the classification under test. The actual test temperature shall be shown on test reports.

13.3 In evaluating the test results, the lowest and the highest absorbed energy values obtained shall be disregarded.

13.3.1 For classifications requiring 20 ft•lbf [27 J] minimum absorbed energy level, at least two of the remaining three values shall equal, or exceed, the specified 20 ft•lbf [27 J] absorbed energy level. One of the three may be lower, but not lower than 15 ft•lbf [20 J], and the average of the three shall be not less than the required 20 ft•lbf [27 J] energy level.

13.3.2 For classifications requiring 50 ft•lbf [68 J] absorbed energy level, at least two of the remaining three values shall equal, or exceed, the specified 50 ft•lbf [68 J] energy level. One of the three may be lower, but not lower than 40 ft•lbf [54 J], and the average of the three shall be not less than the required 50 ft•lbf [68 J] energy level.

13.3.3 For classifications requiring lateral expansion testing, the lateral expansion of the three Charpy specimens remaining after discarding the specimens with the highest and lowest absorbed energy levels shall be measured in accordance with ASTM E23. All three of these specimens shall exhibit a lateral expansion of at least 0.015 in [0.38 mm]. However, if the average of these three specimens is at least 0.015 in [0.38 mm] and one of the three specimens is lower than 0.015 in [0.38 mm], an additional set of three specimens shall be tested. If all three of the additional set of specimens exhibit a lateral expansion of at least 0.015 in [0.38 mm], these results may be reported and used to determine conformity with the classification. The additional set of three specimens may be taken from the original test assembly or from a new test assembly that was welded and postweld heat treated (if required) to the requirements of this standard.

14. Optional, Supplemental Tests and Requirements

Provisions are made in this specification for additional tests. These tests are optional and are not required for electrode classification. The optional, supplemental designators which indicate conformance to the supplemental test requirements do not constitute a part of the electrode classification.

14.1 Diffusible Hydrogen Test. An optional, supplemental designator (H2, H4, H8 or H16) is used to indicate the diffusible hydrogen content of the deposited weld metal. Refer to Clause A1 in Annex A.

14.2 Supplemental Designators to Indicate Conformance to Reduced Levels of Mn + Ni in B91 and B92 Type Electrodes and Deposits. Some applications of the B91 and B92 alloy types may require lower levels of Mn + Ni than the 1.40% maximum specified in Table 1 or Table 4. Supplemental designators (1.0) and (1.2) are provided to indicate that the solid electrode (rod) composition or the weld deposit, as applicable, meets 1.00% or 1.20% maximum Mn + Ni, respectively. Conformance with the supplemental designator (1.0) satisfies the requirements of the supplemental designator (1.2) as well as the B91 or B92 classification requirements. Conformance with the supplemental designator (1.2) satisfies the requirements of the B91 or B92 classification. All other requirements of the B91 or B92 classifications

apply to classifications with supplemental designators and are listed in other tables throughout this specification only as the B91 or B92 classifications. Refer to footnote g in Table 1 or footnote g in Table 4, as applicable. Refer also to Clause A2 in Annex A.

14.3 “J” Designator for Indicating Conformance to Supplemental Impact Requirements. It is recognized that occasionally an electrode or rod can deposit weld metal fully capable of meeting Charpy V-Notch requirements at lower temperatures from the requirements specified for the electrode or rod classification. In these cases, a manufacturer may test Charpy V-Notch properties at a test temperature 20 °F [10 °C] lower than the test temperature shown for that classification in Table 3. The manufacturer may add the optional, supplemental designator, J, after the composition designator provided the impact test results still meet the minimum absorbed energy requirements of Table 3. The optional, supplemental designator, J, is not to be used for lateral expansion at lower temperatures. Conformance to impact absorbed energy requirements at the lower test temperature satisfies the classification requirements. Refer also to Clause A3 in Annex A.

14.4 “OE” Optional Supplemental Shielding Gas Range Designator. *This test is an optional test and is not required for classification. The “OE H/L” designation added to the end of the classification (see Figure 1) does not constitute a part of the electrode classification. Preparation and testing shall be as prescribed in Clauses 9 through 13, using the shielding gases of the appropriate oxygen equivalent as shown in Table A.2 based on the optional designators to be applied. Oxygen equivalent shall be calculated as shown in Equation 1, with the percentages in volume percent. Testing shall also be conducted as prescribed in Clause 14.1 if an optional “HX” diffusible hydrogen designation is applied. Testing shall also be conducted as prescribed in Clause 14.2 if an optional Mn + Ni designation is applied, and as prescribed in Clause 14.3 if an optional “J” designator is applied. Test results for all classification tests, including any optional supplemental designators applied, shall meet the requirements for the classification under test.*

$$\text{Equation 1: } \% \text{ Oxygen Equivalent of a shielding gas (OE)} = \% \text{ O}_2 \text{ in the shielding gas} + (0.5 \times \% \text{ CO}_2) \text{ in the shielding gas}$$

A minimum of two shielding gases must be tested, but one or both of the tests may be the test(s) conducted for electrode classification. All the same tests shall be conducted and all the same requirements shall be met with those gases as those for the electrode classification and any optional supplemental designators. It is not required for the welding conditions to be identical for each of the gases tested, but all the welding conditions in Table 8 and the testing results shall meet all the requirements of this specification for the classification including any optional supplemental designators applied to the classification. The designators for the highest and lowest oxygen equivalent shielding gases that were tested and met all requirements may be added to an electrode classification, as shown in Figure 1 and footnote e of Table A.2. See clause B8.4 in Annex B for more information on this optional supplemental designator.

15. Method of Manufacture

The electrodes and rods classified according to this specification may be manufactured by any method that will produce electrodes and rods that meet the requirements of this specification.

16. Standard Sizes

16.1 Standard sizes for electrodes and rods in the different package forms (straight lengths, coils with support, coils without support, spools and drums) are as specified in AWS A5.02/A5.02M.

17. Finish and Uniformity

17.1. Finish and uniformity shall be as specified in AWS A5.02/A5.02M.

18. Standard Package Forms

18.1 Standard package forms are straight lengths, coils with support, coils without support, spools, and drums. Standard package dimensions and weights and other requirements for each form shall be as specified in AWS A5.02/A5.02M.

19. Winding Requirements

19.1 Winding requirements shall be as specified in AWS A5.02/A5.02M.

19.2 The cast and helix of coils, spools and drums shall be as specified in AWS A5.02/A5.02M with certain additional requirements below.

19.2.1 The cast and helix of solid filler metal on 4 in [100 mm] spools shall be such that a specimen long enough to produce a single loop, when cut from the spool and laid unrestrained on a flat surface, will

- (1) Form a circle not less than 4 in [100 mm] nor more than 9 in [230 mm] in diameter
- (2) Rise above the flat surface no more than 1/2 in [13 mm] at any location

19.2.2 The cast and helix of solid filler metal on all other package forms shall be such that a specimen long enough to produce a single loop, when cut from the package and laid unrestrained on a flat surface, will

- (1) Form a circle not less than 12 in [300 mm] for 0.030 in [0.8 mm] and smaller sizes, or not less than 15 in [380 mm] for 0.035 in [0.9 mm] and larger sizes
- (2) Rise above the flat surface no more than 1 in [25 mm] at any location

Certain bulk packages may contain wire that has been elastically twisted or otherwise treated to provide straight wire feed. Wire from these packages will not form a circle when cut. Traditional cast and helix measurements may have no relevance. Wire thus treated shall conform only to the winding requirements of 19.1 and 19.2. Any method of wire form inspection shall be as agreed between purchaser and supplier.

20. Filler Metal Identification

Filler metal identification, including marking of bare straight lengths of filler rod, product information and the precautionary information shall be as specified in AWS A5.02/A5.02M.

21. Packaging

Electrodes and rods shall be suitably packaged to ensure against damage during shipment and storage under normal conditions.

22. Marking of Packages

22.1 The product information (as a minimum) that shall be legibly marked so as to be visible from the outside of each unit package shall be as specified in AWS A5.02/A5.02M.

22.2 The appropriate precautionary information given in ANSI Z49.1, latest edition, (as a minimum), shall be prominently displayed in legible print on all packages, including individual unit packages within a larger package. Typical examples of "warning labels" and precautionary information are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

Table 1
Chemical Composition Requirements for Solid Electrodes and Rods^{a,b}

AWS Classification ^c		UNS ^d Number	Weight Percent														Other Specified Elements
A5.28	A5.28M		C	Mn	Si	P	S	Ni	Cr	Mo	V	Ti	Zr	Al	Cu ^e		
Carbon-Molybdenum Steel Electrodes and Rods																	
ER70S-A1	ER49S-A1	K11235	0.12	1.30	0.30-0.70	0.025	0.025	0.20	—	0.40-0.65	—	—	—	—	0.35	—	
Chromium-Molybdenum Steel Electrodes and Rods																	
ER80S-B2	ER55S-B2	K20900	0.07-0.12	0.40-0.70	0.40-0.70	0.025	0.025	0.20	1.20-1.50	0.40-0.65	—	—	—	—	0.35	—	
ER70S-B2L	ER49S-B2L	K20500	0.05	0.40-0.70	0.40-0.70	0.025	0.025	0.20	1.20-1.50	0.40-0.65	—	—	—	—	0.35	—	
ER80S-B2Si	ER55S-B2Si	—	0.08-0.14	0.80-1.20	0.50-0.80	0.020	0.020	0.20	0.90-1.30	0.40-0.65	—	—	—	—	0.35	—	
ER80S-B2Mn	ER55S-B2Mn	—	0.04-0.12	0.80-1.50	0.30-0.90	0.025	0.025	—	1.00-1.60	0.40-0.65	—	—	—	—	0.40		
ER90S-B23	ER62S-B23	—	0.04-0.12	1.10	0.60	0.015	0.015	0.50	1.90-2.90	0.50	0.15-0.30	—	—	0.04	0.25	W: 1.50-2.00, B: 0.010 Nb: 0.02-0.10, N: 0.05	
ER80S-B23Mn	ER55S-B23Mn	—	0.02-0.10	0.80-1.60	0.10-0.70	0.020	0.015	0.30-1.00	2.00-2.60	0.05-0.30	0.10-0.50	—	—	—	0.40	W: 1.00-2.00 Nb: 0.02-0.08	
R90S-B24	R62S-B24	—	0.04-0.12	1.00	0.60	0.015	0.010	0.30	1.90-2.90	0.80-1.20	0.15-0.30	0.10	—	0.04	0.25	B: 0.010, N: 0.05 Nb: 0.02-0.10	
ER90S-B3	ER62S-B3	K30960	0.07-0.12	0.40-0.70	0.40-0.70	0.025	0.025	0.20	2.30-2.70	0.90-1.20	—	—	—	—	0.35	—	
ER80S-B3L	ER55S-B3L	K30560	0.05	0.40-0.70	0.40-0.70	0.025	0.025	0.20	2.30-2.70	0.90-1.20	—	—	—	—	0.35	—	
ER90S-B3Si	ER62S-B3Si	—	0.04-0.12	0.80-1.20	0.50-0.80	0.020	0.020	0.20	2.30-3.00	0.90-1.20	—	—	—	—	0.35	—	
ER90S-B3Mn	ER62S-B3Mn	—	0.05-0.15	0.50-1.20	0.10-0.60	0.025	0.025	—	2.10-2.70	0.85-1.20	—	—	—	—	0.40	—	
ER90S-B3MnSi	ER62S-B3MnSi	—	0.04-0.12	0.75-1.50	0.30-0.90	0.025	0.025	—	2.10-2.70	0.90-1.20	—	—	—	—	0.40	—	
ER80S-B6	ER55S-B6	S50280	0.10	0.40-0.70	0.50	0.025	0.025	0.60	4.50-6.00	0.45-0.65	—	—	—	—	0.35	—	
ER80S-B8	ER55S-B8	S50480	0.10	0.40-0.70	0.50	0.025	0.025	0.50	8.00-10.50	0.80-1.20	—	—	—	—	0.35	—	

(Continued)

Table 1 (Continued)
Chemical Composition Requirements for Solid Electrodes and Rods^{a,b}

AWS Classification ^c		UNS ^d Number	Weight Percent													
A5.28	A5.28M		C	Mn	Si	P	S	Ni	Cr	Mo	V	Ti	Zr	Al	Cu ^e	Other Specified Elements
ER90S-B91 ^{f,g,h}	ER62S-B91 ^{f,g,h}	—	0.07-0.13	1.20 ^g	0.15-0.50	0.010	0.010	0.80 ^g	8.0-10.5	0.85-1.20	0.15-0.30	—	—	0.04	0.20	Nb: 0.02-0.10 N: 0.03-0.07
ER90S-B91C	ER62S-B91C	—	0.05-0.12	0.50-1.25	0.50	0.015	0.015	0.10-0.80	8.0-10.5	0.80-1.20	0.10-0.35	—	—	—	0.40	Nb: 0.01-0.08 N: 0.01-0.05
ER90S-B91CMn	ER62S-B91CMn	—	0.05-0.12	1.20-1.90	0.10-0.60	0.015	0.015	0.20-1.00	8.0-10.5	0.80-1.20	0.15-0.50	—	—	—	0.40	Nb: 0.01-0.08 N: 0.01-0.05
ER90S-B92 ^{g,h}	ER62S-B92 ^{g,h}	—	0.08-0.15	1.20 ^g	0.15-0.50	0.015	0.010	0.80 ^g	8.0-10.0	0.30-0.70	0.15-0.30	—	—	0.04	0.25	Nb: 0.04-0.08, B: 0.006 W: 1.5-2.0, N: 0.03-0.08
ER90S-B92Co	ER62S-B92Co	—	0.08-0.15	1.20 ^g	0.15-0.50	0.015	0.010	0.80 ^g	8.0-10.0	0.30-0.70	0.15-0.30	—	—	0.04	0.25	Nb: 0.02-0.08 W: 1.5-2.0 B: 0.006, N: 0.03-0.08 Co: 0.80-2.00
ER90S-B115	ER62S-B115	K91060	0.06-0.13	0.55	0.15-0.50	0.015	0.010	0.45	9.5-12.0	0.40-0.65	0.10-0.30	—	—	—	0.20	Nb: 0.02-0.10 N: 0.02-0.06
Manganese-Molybdenum Steel Electrodes and Rods																
ER80S-D2 ER90S-D2	ER62S-D2 ER55S-D2	K10945 K10945	0.07-0.12	1.60-2.10	0.50-0.80	0.025	0.025	0.15	—	0.40-0.60	—	—	—	—	0.50	—
R80S-D3	R55S-D3	—	0.04-0.10	1.10-1.75	0.30-0.90	0.030	0.030	0.15	—	0.40-0.65	—	—	—	—	0.50	—
Nickel Steel Electrodes and Rods																
ER80S-Ni1	ER55S-Ni1	K11260	0.12	1.25	0.40-0.80	0.025	0.025	0.80-1.10	0.15	0.35	0.05	—	—	—	0.35	—
ER80S-Ni2	ER55S-Ni2	K21240	0.12	1.25	0.40-0.80	0.025	0.025	2.00-2.75	—	—	—	—	—	—	0.35	—
ER80S-Ni3	ER55S-Ni3	K31240	0.12	1.25	0.20-0.80	0.025	0.025	3.00-3.75	—	—	—	—	—	—	0.35	—
ER70S-Ni4	ER49S-Ni4	—	0.10	0.40-1.40	0.50	0.025	0.025	4.00-4.75	0.15	0.35	0.05	—	—	—	0.35	—

(Continued)

Table 1 (Continued)
Chemical Composition Requirements for Solid Electrodes and Rods^{a,b}

AWS Classification ^c		UNS ^d Number	Weight Percent														Other Specified Elements
A5.28	A5.28M		C	Mn	Si	P	S	Ni	Cr	Mo	V	Ti	Zr	Al	Cu ^e		
Nickel-Molybdenum Steel Electrodes and Rods																	
R70S-Ni5 ER80S-Ni5	R49S-Ni5 ER55S-Ni5	—	0.03-0.12	0.70-1.60	0.20-0.90	0.025	0.025	0.60-1.00	0.15	0.35	0.05	0.10	—	—	0.35	—	
R90S-F3	R62S-F3	K21485	0.10-0.18	1.50-2.40	0.30	0.025	0.025	0.70-1.10	—	0.40-0.65	—	—	—	—	0.35	—	
R80S-M1	R55S-M1	—	0.04-0.10	1.00-1.60	0.50	0.030	0.030	0.60-1.10	0.15	0.20-0.65	0.05	—	—	—	0.35	—	
ER100S-1	ER69S-1	K10882	0.08	1.25-1.80	0.20-0.55	0.010	0.010	1.40-2.10	0.30	0.25-0.55	0.05	0.10	0.10	0.10	0.25	—	
ER110S-1	ER76S-1	K21015	0.09	1.40-1.80	0.20-0.55	0.010	0.010	1.90-2.60	0.50	0.25-0.55	0.04	0.10	0.10	0.10	0.25	—	
ER120S-1	ER83S-1	K21030	0.10	1.40-1.80	0.25-0.60	0.010	0.010	2.00-2.80	0.60	0.30-0.65	0.03	0.10	0.10	0.10	0.25	—	
R110S-M5	R76S-M5	—	0.04-0.12	0.90-1.40	0.40	0.025	0.025	2.60-3.20	0.10-0.60	0.50-0.90	0.05	0.10	0.10	0.10	0.25	—	
ER110S-M6	ER76S-M6	—	0.04-0.12	1.60-2.10	0.50-0.80	0.020	0.020	1.30-1.90	0.15-0.40	0.30-0.65	0.03	0.10	0.10	0.10	0.30	—	
ER100S-M7	ER69S-M7	—	0.08-0.15	1.30-1.80	0.30-0.80	0.020	0.020	0.80-1.00	0.15-0.40	0.30-0.65	0.03	0.10	0.10	0.10	0.30	—	
ER120S-M8	ER83S-M8	—	0.05-0.13	1.60-2.10	0.60-0.90	0.020	0.020	1.80-2.30	0.20-0.45	0.45-0.70	0.03	0.10	0.10	0.12	0.30	—	
ERXXS-G EXXS-G RXXS-G	ERXXS-G EXXS-G RXXS-G	—	Not Specified ⁱ														

a. The filler metal shall be analyzed for the specific elements for which values are shown in this table. In addition to that, analysis is required to be reported for boron (B) if intentionally added, or it is known to exceed 0.0010%. Additionally, if the presence of unspecified elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total (excluding iron) does not exceed 0.50%.

b. Single values are maximum.

c. The suffixes A1, B2, B2L, B2Si, etc., designate the chemical composition of the electrode or rod.

d. Refer to ASTM D5-56/SAE HS-1086, Metals & Alloys in the Unified Numbering System.

e. Copper due to any coating on the electrode or rod plus the copper content of the filler metal itself shall not exceed the stated maximum.

f. The B91 alloy type replaces the B9 alloy type.

g. The B91 and B92 designations require Mn + Ni ≤ 1.40% maximum. The B91 (1.2) and B92 (1.2) designations require Mn + Ni ≤ 1.20% maximum and also meet requirements for B91 or B92. The B91 (1.0) and B92 (1.0) designations require Mn + Ni ≤ 1.00% maximum and also meet requirements for B91 and B91 (1.2) or B92 and B92 (1.2). See 14.2, Annex A2, B7.18 and B7.21 for more information.

h. Analysis for Co is required to be reported if intentionally added, or if it is known to be present at levels greater than 0.20%.

i. In order to meet the requirement of the "G" classification, the electrode must have a minimum of one or more of the following: 0.50% Nickel, 0.30% Chromium, or 0.20% Molybdenum. The composition shall be reported. The requirements are those agreed to by the purchaser and supplier.

Table 2
Tension Test Requirements

AWS Classification A5.28 [A5.28M]	Tensile Strength (minimum) psi [MPa]	Yield Strength ^a (minimum) psi [MPa]	Percent Elongation ^a (minimum)	Shielding Gas ^{b, c, d}	Testing Condition ^e
ER70S-A1 [ER49S-A1] ER70S-B2L [ER49S-B2L] E70C-B2L [E49C-B2L]	75 000 [520] ^f	58 000 [400]	19	Argon/1-5% O ₂ (AWS M13 or M22)	PWHT
ER80S-B2 [ER55S-B2] E80C-B2 [E55C-B2]	80 000 [550]	68 000 [470]	19		
ER90S-B23 [ER62S-B23] ER90S-B3MnSi [ER62S-B3MnSi] ER90S-B3 [ER62S-B3] E90C-B3 [E62C-B3]	90 000 [620]	78 000 [540]	17		
ER80S-B3L [ER55S-B3L] E80C-B3L [E55C-B3L] ER80S-B6 [ER55S-B6] E80C-B6 [E55C-B6] ER80S-B8 [ER55S-B8] E80C-B8 [E55C-B8]	80 000 [550]	68 000 [470]	17		
ER80S-B23Mn [ER55S-B23Mn]	80 000 [550]	68 000 [470]	19	Argon/5% CO ₂ (AWS M12)	
ER90S-B91 [ER62S-B91] ER90S-B92 [ER62S-B92]	90 000 [620]	60 000 [410]	16		
ER90S-B91C [ER62S-B91C] ER90S-B91CMn [ER62S-B91CMn] ER90S-B92Co [ER62S-B92Co]	90 000 [620]	60 000 [410]	16	Argon/2% O ₂ (AWS M13)	
E90C-B91 [E62C-B91] E90C-B92, [E62C-B92] ER90S-B115 [ER62S-B115]	90 000 [620]	60 000 [410]	16	Argon/5-25% CO ₂ (AWS M12, M20 or M21)	
ER80S-B2Mn [ER55S-B2Mn] ER80S-B2Si [ER55S-B2Si]	80 000 [550]	68 000 [470]	19		
ER90S-B3Mn [ER62S-B3Mn] ER90S-B3Si [ER62S-B3Si]	90 000 [620]	78 000 [540]	17		
ER100S-M7 [ER69S-M7]	100 000 [690]	88 000 [610]	16		
E70C-Ni2 [E49C-Ni2]	70 000 [490]	58 000 [400]	24	Argon/1-5% O ₂ (AWS M13 or M22)	
ER80S-Ni2 [ER55S-Ni2] E80C-Ni2 [E55C-Ni2] ER80S-Ni3 [ER55S-Ni3] E80C-Ni3 [E55C-Ni3]	80 000 [550]	68 000 [470]	24		
R90S-F3 [R62S-F3] R90S-B24 [R62S-B24] R90S-B91C [R62S-B91C] R90S-B91CMn [R62S-B91CMn]	90 000 [620]	78 000 [540]	17		Argon (AWS I1)
ER80S-D2 [ER55S-D2]	80 000 [550]	68 000 [470]	17		CO ₂ (AWS C1)
ER90S-D2 [ER62S-D2] E90C-D2 [E62C-D2]	90 000 [620]	78 000 [540]	17	Argon/1-5% O ₂ (AWS M13 or M22)	As-Welded
ER80S-Ni1 [ER55S-Ni1] E80C-Ni1 [E55C-Ni1]	80 000 [550]	68 000 [470]	24		
ER100S-1 [ER69S-1]	100 000 [690]	88 000 [610]	16	Argon/2% O ₂ (AWS M13)	
ER110S-1 [ER76S-1]	110 000 [760]	95 000 [660]	15		
ER120S-1 [ER83S-1]	120 000 [830]	105 000 [730]	14		

(Continued)

Table 2 (Continued)
Tension Test Requirements

AWS Classification A5.28 [A5.28M]	Tensile Strength (minimum) psi [MPa]	Yield Strength ^a (minimum) psi [MPa]	Percent Elongation ^a (minimum)	Shielding Gas ^{b, c, d}	Testing Condition ^e		
ER70S-Ni4 [ER49S-Ni4]	70 000 [490]	58 000 [400]	22	Argon/5-25% CO ₂ (AWS M12, M20 or M21)	As-Welded		
ER80S-Ni5 [ER55S-Ni5]	80 000 [550]	68 000 [470]	19				
E90C-K3 [E62C-K3]	90 000 [620]	78 000 [540]	18				
E100C-K3 [E69C-K3]	100 000 [690]	88,000 [610]	16				
E110C-K3 [E76C-K3]	110 000 [760]	98 000 [680]	15				
E110C-K4 [E76C-K4]							
E120C-K4 [E83C-K4]	120 000 [830]	108 000 [750]	15				
<i>E90C-K14 [E62C-K14]</i>	<i>90 000 [620]</i>	<i>78 000 [540]</i>	<i>18</i>				
ER110S-M6 [E76S-M6]	110 000 [760]	95 000 [660]	15				
ER120S-M8 [ER83S-M8]	120 000 [830]	105 000 [730]	14				
E80C-W2 [E55C-W2]	80 000 [550]	68 000 [470]	22	Argon (AWS I1)			
R70S-Ni4 [R49S-Ni4]	70 000 [490]	58 000 [400]	22				
R70S-Ni5 [R49S-Ni5]							
R80S-D3 [R55S-D3]	80 000 [550]	68 000 [470]	19				
R80S-M1 [R55S-M1]							
R90C-Mn1 [R62C-Mn1]	90 000 [620]	<i>52 000 [360]</i>	22				
R100C-Mn2 [R69C-Mn2]	100 000 [690]	<i>58 000 [400]</i>	22	See Note (g)			
R110S-M5 [R76S-M5]	110 000 [760]	98 000 [680]	15				
ER70S-G [ER49S-G]	70 000 [490]						
ER70C-G [ER49C-G]							
E70S-G [E49S-G]							
E70C-G [E49C-G]							
R70S-G [R49S-G]							
R70C-G [R49C-G]							
ER80S-G [ER55S-G]	80 000 [550]						
ER80C-G [ER55C-G]							
E80S-G [E55S-G]							
E80C-G [E55C-G]							
R80S-G [R55S-G]							
R80C-G [R55C-G]							
ER90S-G [ER62S-G]	90 000 [620]						
ER90C-G [ER62C-G]							
E90S-G [E62S-G]							
E90C-G [E62C-G]							
R90S-G [R62S-G]							
R90C-G [R62C-G]							
ER100S-G [ER69S-G]	100 000 [690]						
ER100C-G [ER69C-G]							
E100S-G [E69S-G]							
E100C-G [E69C-G]							
R100S-G [R69S-G]							
R100C-G [R69C-G]							
ER110S-G [ER76S-G]	110 000 [760]						
ER110C-G [ER76C-G]							
E110S-G [E76S-G]							
E110C-G [E76C-G]							
R110S-G [R76S-G]							
R110C-G [R76C-G]							
ER120S-G [ER83S-G]	120 000 [830]						
ER120C-G [ER83C-G]							
E120S-G [E83S-G]							
E120C-G [E83C-G]							
R120S-G [R83S-G]							
R120C-G [R83C-G]							

a. Yield strength at 0.2% offset and elongation in 2 in [50 mm] gage length for 0.500 in [12.5 mm] tension test specimen or elongation in 1.4 in [36 mm] gage length for 0.350 in [9 mm] tension test specimen.

b. Electrodes may also be classified with different shielding gases by using the optional supplemental OE H/L designator. See Clauses 14.4, B8.4, and Table A.2.

c. AWS classifications per AWS A5.32M/A5.32. The reference to the AWS classification only indicates what classification(s) that the specified gas(es) fall into and does not necessarily indicate that the full range of any given classification(s) may be used for the filler metal classification requirements and testing procedures.

d. The use of a particular gas for classification purposes shall not be construed to restrict the use of other gas mixtures. A filler metal tested with other gas blends shall be as agreed upon between the purchaser and supplier.

e. Postweld heat treated condition in accordance with Table 7.

f. The minimum tensile strength of these classification is 75 000 psi [520 MPa] and is higher than indicated by the tensile strength designators using the multipliers in Figure 1

g. Not specified (as agreed upon between the purchaser and supplier).

Table 3
Impact Test Requirements

AWS Classification A5.28 [A5.28M]		Average Impact Energy Absorbed ^{a,b} (Minimum)		Testing Condition ^c
		A5.28	A5.28M	
ER70S-A1 [ER49S-A1] ER70S-B2L [ER49S-B2L] E70C-B2L [E49C-B2L] ER80S-B2 [ER55S-B2] E80C-B2 [E55C-B2] ER80S-B2Mn [ER55S-B2Mn] ER80S-B2Si [ER55S-B2Si] ER90S-B3Si [ER62S-B3Si] ER90S-B23 [ER62S-B23] ER80S-B23Mn [ER55S-B23Mn] R90S-B24 [R62S-B24] ER90S-B3 [ER62S-B3] E90C-B3 [E62C-B3] ER80S-B3L [ER55S-B3L] ER90S-B3Mn [ER62S-B3Mn] ER90S-B3MnSi [ER62S-B3MnSi]	E80C-B3L [E55C-B3L] ER80S-B6 [ER55S-B6] E80C-B6 [E55C-B6] ER80S-B8 [ER55S-B8] E80C-B8 [E55C-B8] ER90S-B91 [ER62S-B91] E90C-B91 [E62C-B91] ER90S-B91C [ER62S-B91C] ER90S-B91CMn [ER62S-B91CMn] ER90S-B92 [ER62S-B92] E90C-B92 [E62C-B92] ER90S-B92Co [ER62S-B92Co] <i>ER90S-B115 [ER62S-B115]</i>	Not Specified	Not Specified	PWHT
R80S-D3 [R55S-D3]		20 ft•lbf at -4 °F	27 J at -20 °C	As-Welded
ER80S-Ni1 [ER55S-Ni1] E80C-Ni1 [E55C-Ni1]	ER80S-Ni5 [ER55S-Ni5]	20 ft•lbf at -50 °F	27 J at -45 °C	
ER70S-Ni4 [ER49S-Ni4] R70S-Ni5 [R49S-Ni5]	R80S-M1 [R55S-M1] R110S-M5 [R76S-M5]	20 ft•lbf at -76 °F	27 J at -60 °C	
R90S-F3 [R62S-F3]		50 ft•lbf at -40 °F	68 J at -40 °C	PWHT
E70C-Ni2 [E49C-Ni2], ER80S-Ni2 [ER55S-Ni2]	E80C-Ni2 [E55C-Ni2]	20 ft•lbf at -80 °F	27 J at -60 °C	
ER80S-Ni3 [ER55S-Ni3]	E80C-Ni3 [E55C-Ni3]	20 ft•lbf at -100 °F	27 J at -75 °C	
ER80S-D2 [ER55S-D2] ER90S-D2 [ER62S-D2] <i>E90C-K14 [E62C-K14]</i>	E90C-D2 [E62C-D2]	20 ft•lbf at -20 °F	27 J at -30 °C	As-Welded
ER100S-1 [ER69S-1] ER110S-1 [ER76S-1]	ER120S-1 [ER83S-1]	50 ft•lbf at -60 °F	68 J at -50 °C	As-Welded
ER100S-M7 [ER69S-M7]		20 ft•lbf at -60 °F	27 J at -50 °C	PWHT
E90C-K3 [E62C-K3] E100C-K3 [E69C-K3] E110C-K3 [E76C-K3] E110C-K4 [E76C-K4]	E120C-K4 [E83C-K4] ER120S-M8 [ER83S-M8] ER110S-M6 [ER76S-M6]	20 ft•lbf at -60 °F	27 J at -50 °C	As-Welded
E80C-W2 [E55C-W2]		20 ft•lbf at -20 °F	27 J at -30 °C	As-Welded
R90C-Mn1 [R62C-Mn1] R100C-Mn2 [R69C-Mn2]		0.015 in ^d at -320 °F	0.38 mm ^d at -196 °C	
ERXXS-G [ERXXS-G] EXXS-G [EXXS-G] RXXS-G [RXXS-G]	ERXXC-G [ERXXC-G] EXXC-G [EXXC-G] RXXC-G [RXXC-G]	As agreed between supplier and purchaser		

- a. Both the highest and lowest of the five test values obtained shall be disregarded in computing the average impact energy absorbed or lateral expansion measurement. See 13.3.1 for acceptance criteria for classifications requiring 20 ft•lbf [27J]. See 13.3.2 for acceptance criteria for classifications requiring 50 ft•lbf [68J]. See 13.3.3 for acceptance criteria for classifications requiring lateral expansion measurement.
- b. The test temperature shall be that specified in this table or lower for the classification under test. The actual test temperature shall be shown on test reports.
- c. Postweld heat treated in accordance with Table 7.
- d. Measurement of lateral expansion.

Table 4
Chemical Composition Requirements for Weld Metal from Composite Electrodes and Rods^{a,b,c}

AWS Classification ^d A5.28 [A5.28M]	UNS ^e Number	Weight Percent											Other Specified Elements
		C	Mn	Si	P	S	Ni	Cr	Mo	V	Al	Cu	
Chromium-Molybdenum Steel Electrodes and Rods													
E80C-B2 [E55C-B2]	W52030	0.05-0.12	0.40-1.00	0.25-0.60	0.025	0.030	0.20	1.00-1.50	0.40-0.65	0.03	—	0.35	—
E70C-B2L [E49C-B2L]	W52130	0.05	0.40-1.00	0.25-0.60	0.025	0.030	0.20	1.00-1.50	0.40-0.65	0.03	—	0.35	—
E90C-B3 [E62C-B3]	W53030	0.05-0.12	0.40-1.00	0.25-0.60	0.025	0.030	0.20	2.00-2.50	0.90-1.20	0.03	—	0.35	—
E80C-B3L [E55C-B3L]	W53130	0.05	0.40-1.00	0.25-0.60	0.025	0.030	0.20	2.00-2.50	0.90-1.20	0.03	—	0.35	—
E80C-B6 [E55C-B6]	—	0.10	0.40-1.00	0.25-0.60	0.025	0.025	0.60	4.50-6.00	0.45-0.65	0.03	—	0.35	—
E80C-B8 [E55C-B8]	—	0.10	0.40-1.00	0.25-0.60	0.025	0.025	0.20	8.00-10.50	0.80-1.20	0.03	—	0.35	—
E90C-B91 [E62C-B91] ^{f, g, h}	—	0.08–0.13	1.20 ^g	0.50	0.020	0.015	0.80 ^g	8.00–10.50	0.85–1.20	0.15-0.30	0.04	0.20	Nb: 0.02-0.10 N: 0.03-0.07 ^h
E90C-B92 [E62C-B92] ^{g, h}	—	0.08–0.15	1.20 ^g	0.50	0.020	0.015	0.80 ^g	8.00–10.50	0.20–0.70	0.15-0.30	0.04	0.25	Nb: 0.04-0.08 N: 0.03-0.08 W: 1.50-2.50 B: 0.006 ^h
Nickel Steel Electrodes and Rods													
E80C-Ni1 [E55C-Ni1]	W21030	0.12	1.75	0.90	0.025	0.030	0.80-1.10	—	0.30	0.03	—	0.35	—
E70C-Ni2 [E49C-Ni2]	W22030	0.08	1.25	0.90	0.025	0.030	0.75-2.75	—	—	0.03	—	0.35	—
E80C-Ni2 [E55C-Ni2]	W22030	0.12	1.50	0.90	0.025	0.030	1.75-2.75	—	—	0.03	—	0.35	—
E80C-Ni3 [E55C-Ni3]	W23030	0.12	1.50	0.90	0.025	0.030	2.75-3.75	—	—	0.03	—	0.35	—
Manganese-Molybdenum Steel Electrodes and Rods													
E90C-D2 [E62C-D2]	W19230	0.12	1.00-1.90	0.90	0.025	0.030	—	—	0.40-0.60	0.03	—	0.35	—
Other Low-Alloy Steel Electrodes and Rods													
E90C-K3 [E62C-K3]	—	0.15	0.75-2.25	0.80	0.025	0.025	0.50-2.50	0.15	0.25-0.65	0.03	—	0.35	—
E100C-K3 [E69C-K3]	—	0.15	0.75-2.25	0.80	0.025	0.025	0.50-2.50	0.15	0.25-0.65	0.03	—	0.35	—

(Continued)