SAE Aerospace
An SAE International Group

AEROSPACE MATERIAL SPECIFICATION

SAE AMS2447 | REV. D

Issued 1998-05
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Superseding AMS2447C

Coating, Thermal Spray
High Velocity Oxygen/Fuel Process

RATIONALE

AMS2447D results from a Five Year Review and update of this specification.

1. SCOPE

1.1 Purpose

This specification covers the requirements for thermal spray coatings applied using the high velocity oxygen fuel (HVOF) combustion process. This specification is not intended to be used for duplex coatings, i.e., the application of the coating over a previously applied coating.

1.2 Application

This process has been used typically to provide coatings of lower porosity and higher adhesive, and/or cohesive, strength than generally attainable with typical plasma spray processes for applications requiring wear, heat, and corrosion resistance and for dimensional restoration, but usage is not limited to such applications.

1.3 Safety - Hazardous Materials

While the materials, methods, applications, and processes described or referenced in this specification may involve the use of hazardous materials, this specification does not address the hazards that may be involved in such use. It is the sole responsibility of the user to ensure familiarity with the safe and proper use of any hazardous materials and to take necessary precautionary measures to ensure the health and safety of all personnel involved.

1.4 Classification

Type 1 - Coatings with no residual stress requirements
Type 2 - Coatings where the residual stress state is specified

1.4.1 If no Type is specified, Type 1 shall be provided.

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http://www.sae.org/technical/standards/AMS2447D

2. APPLICABLE DOCUMENTS

The issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The supplier may work to a subsequent revision of a document unless a specific document issue is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AMS4027 Aluminum Alloy, Sheet, and Plate, 1.0Mg - 0.060Si - 0.28Cu - 0.2Cr (6061; -T6 Sheet, -T651 Plate), Solution and Precipitation Heat Treated

AMS4117 Aluminum Alloy, Rolled or Cold Finished Bars, Rods, and Wire and Flash Welded Rings, 1.0Mg - 0.60Si - 0.28Cu - 0.20Cr (6061; -T6, -T651), Solution and Precipitation Heat Treated

AMS4911 Titanium Alloy, Sheet, Strip, and Plate, 6Al - 4V, Annealed

AMS4928 Titanium Alloy Bars, Wire, Forgings, Rings, and Drawn Shapes, 6Al - 4V, Annealed

AMS5510 Steel, Corrosion and Heat-Resistant, Sheet, Strip and Plate, 18Cr - 10.5Ni - 0.40Ti (SAE 30321), Solution Heat Treated

AMS5596 Nickel Alloy, Corrosion and Heat-Resistant, Sheet, Strip, Foil and Plate, 52.5Ni - 19Cr - 3.0Mo - 5.1Cb (Nb) - 0.90Ti - 0.5Al - 18Fe, Consumable Electrode Remelted or Vacuum Induction Melted, 1775 °F (968 °C) Solution Heat Treated

AMS5645 Steel, Corrosion and Heat Resistant, Bars, Wire, Forgings, Tubing, and Rings, 18Cr - 10Ni - 0.40Ti (SAE 30321), Solution Heat Treated

AMS5662 Nickel Alloy, Corrosion and Heat-Resistant, Bars, Forgings, and Rings, 52.5Ni - 19Cr - 3.0Mo - 5.1Cb (Nb) - 0.90Ti - 0.50Al - 18Fe, Consumable Electrode or Vacuum Induction Melted, 1775 °F (968 °C) Solution Heat Treated, Precipitation-Hardenable

AMS7879 Tungsten Carbide-Cobalt Powder, Cast and Crushed

SAE J442 Test Strip, Holder, and Gage for Shot Peening

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2.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM C 633 Adhesion or Cohesive Strength of Flame-Sprayed Coatings

ASTM E 384 Microhardness of Materials

2.3 ASME Publications

Available from American Society of Mechanical Engineers, 22 Law Drive, P.O. Box 2900, Fairfield, NJ 07007-2900, Tel: 973-882-1170, www.asme.org.

ASME B46.1 Surface Texture (Surface Roughness, Waviness, and Lay)

3. TECHNICAL REQUIREMENTS

3.1 Equipment

3.1.1 Torch

A specially constructed gun that uses combustion products to generate a high velocity gas stream for heating the coating material to a molten or plasticized state and transfers the coating material to the work piece shall be used.

3.1.2 System

The system shall be fitted with controls for adjusting and monitoring the gas(es) and fuel(s) used to operate the torch.

3.1.2.1 Indicating devices used as a system controls, as applicable to the process gases and fuels, shall have a minimum accuracy as follows: pressure gauges ±1.5% of full scale; flow meters ±2% of full scale.

3.1.3 Powder Feeder

The powder feed system shall supply a metered flow of material.

3.2 Materials

3.2.1 Gases and Fuels

Specifications chosen by the processor to procure these materials shall be acceptable to purchaser.

3.2.2 Coating material shall conform to the specification referenced by the drawing or otherwise specified by purchaser. All powders shall be dry, free flowing and uniformly blended.

3.2.2.1 Coating Designation

Coating specification number and appropriate suffix number designate the material composition to be applied in accordance with Table 1, e.g., AMS2447-7 means the part shall be coated with 78W - 16Co - 5.1C powder.

3.3 Preparation

3.3.1 Cleaning

Surfaces to be coated shall be thoroughly cleaned to remove moisture, oil, grease, dirt, scale, paint and other foreign material. Final cleaning shall take place no more than 4 hours prior to coating. Cleaning procedures shall not cause hydrogen embrittlement or cause other detrimental effects to materials to be coated.

3.3.2 Masking

Parts shall be masked to protect surfaces that are not to be coated.

3.3.3 Surface Conditioning

Surfaces to be coated may be grit blasted with clean, dry, oil free grit. After grit blasting loose particles shall be removed from the surface by a dry filtered air blast, brushing with a clean nylon brush, or other applicable methods that do not contaminate the prepared surface. A maximum average surface roughness of 150 microinches (3.81 microns) shall not be exceeded for Type 2 coatings. Surface finish measurements shall be made in accordance with ASME B46.1.

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3.4 Application

3.4.1 Preheating

Surfaces to be coated shall be preheated as necessary to remove moisture. Preheating may be accomplished by use of the torch or by other suitable means. Maximum substrate temperature during preheating shall not exceed limits shown in 3.4.3.

TABLE 1 - POWDER SPECIFICATION

Coating Designation	Typical Composition	Recommended Method of Manufacture	Recommended Particle Size, Microns
AMS2447-1	57Co - 25Cr - 10Ni - 7W	Gas Atomized	-45/+5
AMS2447-2	60Co - 29Mo - 8Cr - 3Si	Gas Atomized	-45/+10
AMS2447-3	69Cr - 20Ni - 11C ($75Cr_3C_2$ - 25 Ni Cr)	Sintered	-53/+10
AMS2447-4	95Ni - 5Al (Alloyed Ni-Al)	Gas Atomized	-45/+15
AMS2447-5	76Ni - 18Cr - 6Al (Alloyed Ni-Cr-Al)	Gas Atomized	-45/+15
AMS2447-6	60Ni - 19Cr - 18Fe - 3Mo	Gas Atomized	-53/+15
AMS2447-7	78W - 16Co - 5.1C (83WC - 17Co)	Agglomerated Sintered	-53/+10
AMS2447-8	82W - 11Co - 4.1C (88WC - 12Co, AMS7879)	Cast	-45/+5
AMS2447-9	82W - 10Co - 4Cr - 3.5C (86WC - 10Co - 4Cr)	Sintered	-53/+10
AMS2447-10	86W - 10Ni - 3.5C (90WC - 10Ni)	Cast	-53/+10

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3.4.2 Coating

Coating material shall be deposited on the designated surface to a sufficient thickness to permit finishing to specified dimensions. Coating thickness requirements do not apply to areas designated as optional coating areas.

3.4.2.1 Areas on which coating is optional shall, if coated, be prepared and handled in the same manner as the area on which coating is required.

3.4.2.2 Spray deposition shall be continuous, except for interruptions to measure coating thickness and/or for cooling cycles to maintain part below maximum allowable temperature.

3.4.3 Substrate Temperature

Unless otherwise specified, maximum temperature of the substrate during preheating and coating application shall not exceed the temperatures shown in Table 2.

TABLE 2 - MAXIMUM SUBSTRATE TEMPERATURE

Part Basis Material	Temperature
Aluminum Alloys	250 °F (121 °C)
Magnesium Alloys	350 °F (176 °C)
Steel, Including Corrosion Resistant Alloys	350 °F (177 °C)
Nickel and Cobalt Alloys	400 °F (204 °C)
Titanium Alloys	350 °F (177 °C)

3.4.3.1 Temperature Measurement

Temperature measurement shall be made utilizing equipment with a response time of less than 1 second, a resolution of 1 °C minimum, and capable of monitoring part temperature during the coating process. Paragraph 8.2 provides one suggested type of equipment. The measurement location shall be within the coated area of the part and may be following the plume of the torch or may be at a fixed location. If the measurement technique or measurement locations are not possible or practical on the subject part, then an appropriate method shall be agreed upon by the purchaser and processor.

3.4.4 Test Specimens

Specimens shall be coated using the process procedures identified on the Coating Process Control Factors Sheet, Figure 1, for the parts they represent. For Type 2 coatings temperature of all test specimens shall be maintained within 50 °F (28 °C) of the temperature maintained during the spraying of the parts represented unless otherwise specified by the purchaser.

3.4.4.1 Specimen Material

Unless otherwise specified by purchaser, test specimens shall be made from the materials as listed in Table 3.

TABLE 3 - TEST SPECIMEN MATERIAL

Part Basis Material	Bond Strength Specimen	Metallographic and Bend Specimen
Aluminum and Magnesium Alloys	AMS4117	AMS4027
Nickel and Cobalt Alloys	AMS5662	AMS5596
All Steels	AMS5645	AMS5510
Titanium and Titanium Alloys	AMS4928	AMS4911

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3.5 Surface Finishing

Procedures for finishing shall be as agreed upon by purchaser and processor.

3.6 Properties

3.6.1 Adhesion

3.6.1.1 Bend Test

Specimens prepared and tested in accordance with 3.7.1 shall not show separation of the coating from the substrate, when examined visually without magnification. Cracking of the coating and minimal separation at the edges of the specimen shall be considered acceptable.

PROCESSOR:_____ COATING SPECIFICATION:_____
PURCHASER:_____

APPLICATION:
PART NAME:_____
PART NUMBER: _____ BASIS MATERIAL:_____

PREPARATION:
PRE-BLAST CLEANING:_____
BLASTING GRIT TYPE:_____GRIT SIZE:_____PRESSURE:_____
BLASTING TIME, INTENSITY, COVERAGE: _____

SPRAY EQUIPMENT & ACCESSORY EQUIPMENT:
MANUFACTURER: _____ TORCH: _____
POWDER PORT: _____ HEAD: _____ NOZZLE: _____
INJECTOR: OXYGEN: _____ FUEL: _____ POWDER: _____
ADAPTORS:_____

CONSOLE PARAMETERS:
OXYGEN: SUPPLY PRESSURE: _____
TORCH PRESSURE: _____FLOW RATE: _____
FUEL: TYPE: _____ SUPPLY PRESSURE: _____
TORCH PRESSURE: _____ FLOW RATE: _____

POWDER FEEDER:
FEEDER TYPE: _____
CARRIER GAS: _____SUPPLY PRESSURE:_____
FEEDER PRESSURE:_____FLOW RATE: _____DIAL: _____
VIBRATOR USED: [ ]YES [ ]NO AMPLITUDE: _____
FEEDER HOSE: DIAMETER:_____LENGTH:_____

COATING PROCESS DATA:
PREHEAT TEMPERATURE: _____ MAXIMUM PART TEMPERATURE: _____
COOLING, METHOD: _____ POSITION: _____
COOLING, CYCLE TIME: _____ SPRAY, CYCLE TIME:_____
SPRAY, NO. OF CYCLES:_____ SPRAY, COATING THICKNESS:_____

WORK HANDLING:
PART MOTION: _____ SPEED: _____
GUN MOTION: _____SPEED: _____
GUN-TO-WORK: DISTANCE: _____ ANGLE: _____
SPRAY MASKING/FIXTURES: _____

METALLOGRAPHY:
MICROSTRUCTURE: _____ HARDNESS: _____
BOND STRENGTH: _____ BEND TEST: _____
COATING MATERIAL: _____ LOT/BATCH NO:_____

OPERATOR: _____ CERTIFICATION NO: _____
APPROVAL: _____ DATE: _____

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FIGURE 1 - COATING PROCESS CONTROL FACTORS SHEET

3.6.1.2 Bond Strength

Specimens, prepared and tested in accordance with 3.7.2, shall comply with the requirements shown in Table 4.

TABLE 4 - COATING PROPERTIES

Coating Designation	Minimum Hardness	Oxides Max%	Voids Max%	Quantity of Unmelts Max	Bond Strength Min, ksi (MPa)
AMS2447-1	400 (HV100)	5	1	5	8 (56)
AMS2447-2	500 (HV300)	2	1	2	9 (64)
AMS2447-3	800 (HV300)	2	1	-	10 (70)
AMS2447-4	275 (HV100)	2	1	3	8 (70)
AMS2447-5	350 (HV100)	2	1	3	8 (56)
AMS2447-6	375 (HV300)	5	1	3	9 (64)
AMS2447-7	1050 (HV300)	1	1	-	10 (70)
AMS2447-8	1000 (HV300)	1	1	-	10 (70)
AMS2447-9	1050 (HV300)	1	1	-	10 (70)
AMS2447-10	1000 (HV300)	1	1	-	10 (70)

3.6.2 Coating Hardness

Specimens, prepared and tested in accordance with 3.7.3 shall comply with the requirements shown in Table 4.

3.6.3 Microstructure

The coating on a suitably prepared cross-sectioned specimen shall be free from cracks and free from coating-to-substrate separation. Microstructural properties shall be evaluated in accordance with the following:

3.6.3.1 Voids and oxides shall not be greater than as specified in Table 4 in any field of view (approximately 0.02 inch (0.51 mm) in length) when examined at 400X minimum magnification on the cross-sectioned specimen.

3.6.3.2 Quantities of unmelted particles shall be not greater than as specified in Table 4 in any field of view (approximately 0.04 inch (1.0 mm) in length) when viewed at 200X minimum magnification on the cross-sectioned specimen. Unmelted particles shall have a minor diameter greater than or equal to 0.002 inch (0.051 mm) and have an aspect ratio less than 1.5 to 1 unless a larger ratio is acceptable to the cognizant engineering organization.

3.6.3.3 Interface

Contamination of the coating/substrate interface with surface preparation media shall not exceed 10% in any field of view (approximately 0.04 inch (1.0 mm) in length) when viewed at 200X minimum magnification on the cross-sectioned specimen.

3.6.4 Residual Stress

For Type 2 coatings, Almen strip arc height requirements shall be as defined on the engineering drawing.

3.7 Test Methods

3.7.1 Bend Test

Test panels (Table 3) approximately 0.05 x 1.0 x 3.0 inches (1.3 x 25 x 76 mm) shall be coated on one side to a thickness of 0.001 to 0.003 inch (0.025 to 0.076 mm). Panels shall be tested by being bent around a 0.5 inch (12.7 mm) diameter bar, with the coated surface on the outside of the bend, at a rate of approximately 10 degrees per second. Panels shall be bent to obtain a minimum 90 degree permanent set. For tungsten carbide coating applied to titanium basis material specimens, the coupon can be prone to fracture during bend test. Such a result will not be considered a failure.

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3.7.2 Bond Strength

Test specimens (Table 3) approximately 1.0 inch (25 mm) in diameter by 2.0 inches (51 mm) long, shall be coated to a thickness of 0.008 to 0.012 inch (0.2 to 0.3 mm). Specimens shall be prepared and tested in accordance with ASTM C 633.

3.7.3 Microhardness

Test specimens, approximately 0.05 x 1.0 x 3.0 inches (1.3 x 25 x 76 mm) shall be coated on one side to a minimum thickness of 0.008 inch (0.20 mm). The hardness shall be the average of a minimum of ten evenly spaced Vickers indentations determined in accordance with ASTM E 384.

3.7.4 Residual Stress

Residual Stress measurement applies only to Type 2 coatings. Almen strip specimen shall be made to the requirements of the Almen N strip defined in SAE J442. If grit blasting is performed, both the surface to be coated and the uncoated surface of the Almen strip shall be blasted. The curvature of the Almen strip after grit blasting shall not exceed 0.0015 inch (38 micrometers). If the strip is not flat the coating shall be applied to the convex side. The Almen strip shall be secured in a standard screw type Almen strip holder as specified in SAE J442 or any flat steel fixture with the same screw spacing. The coating shall be applied to the strip spraying across the 0.5 inch dimension and indexing along the 3 inch dimension. Coating shall be applied to a thickness of 0.005 inch ± 0.001 (127 µm ± 25). Readings shall be made with a standard Almen gage in accordance with SAE J442. The reported arc height shall be the arc height after coating (second reading) minus the arc height before coating (first reading). If grit blasting is performed the first reading shall be made after grit blasting and prior to coating. The reported arc height shall be normalized for the actual applied coating thickness by multiplying the measured arc height by the Arc Height Multiplication Factor (AHMF). See 8.5.

3.8 Quality

Coating, as received by purchaser, shall be adherent to the basis material and shall have a uniform, continuous surface free from spalling, chipping, flaking, and other imperfections detrimental to usage of the coating.

3.9 Tolerances

Unless otherwise specified by the purchaser, a tolerance of -0 to +0.125 inch (3.2 mm) is allowed on the boundaries of the area designated to be coated.

3.10 Geometric Sample

When specified by the purchaser, a sample shall be coated that approximates the geometry of the part being represented. This sample shall be sectioned and subjected to visual examinations, examinations of masking performance, or any coating property tests required in 3.6. The appropriate sample geometry shall be agreed to by the processor and purchaser, and shall be supplied by the purchaser.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

Processor shall supply all test specimens for processor's tests and shall be responsible for the performance of all required tests. Purchaser reserves the right to sample and to perform any conformity testing deemed necessary to ensure that the coating conforms to specified requirements.

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