International Standard

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Oil and gas industries including lower carbon energy — Factory bends, fittings and flanges for pipeline transportation systems —

Part 1: Induction bends

Industries du pétrole et du gaz, y compris les énergies à faible teneur en carbone — Coudes d'usine, raccords et brides pour systèmes de transport par conduites —

Partie 1: Coudes fabriqués par induction

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 67, *Oil and gas industries including lower carbon energy*, Subcommittee SC 2, *Pipeline transportation systems*.

This fourth edition cancels and replaces the third edition (ISO 15590-1:2018), which has been technically revised.

The main changes are as follows:

— changed the title to be consistent with the new title of ISO/TC 67 in response to the green and lower carbon development;

— classified the induction bending process into local heating process and global heating process according to the steel grade;

— removed the testing requirements of welds in transition zone;

— added a testing requirement for extracting samples from the bend neutral axis base metal;

— added the delaminated test pieces with reduced thickness for tensile testing;

— added requirements for retesting;

— added an additional condition for non-destructive testing in regards of copper pollution.

A list of all parts in the ISO 15590 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Oil and gas industries including lower carbon energy — Factory bends, fittings and flanges for pipeline transportation systems —

Part 1: Induction bends

1 Scope

This document specifies the technical delivery conditions for bends made by the induction bending process for use in pipeline transportation systems for the petroleum and natural gas industries as defined in ISO 13623.

This document is applicable to induction bends made from seamless and welded pipe of unalloyed or low-alloy steels.

NOTE These are typically C-Mn steels or low-alloy steels that are appropriate for the corresponding level and grade of line pipe in accordance with ISO 3183.

This document specifies the requirements for the manufacture of two product specification levels (PSLs) of induction bends corresponding to product specification levels given for pipe in ISO 3183.

This document is not applicable to the selection of the induction bend PSL.

This document is not applicable to pipeline bends made by other manufacturing processes.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 148-1, *Metallic materials — Charpy pendulum impact test — Part 1: Test method*

ISO 3183, *Petroleum and natural gas industries — Steel pipe for pipeline transportation systems*

ISO 6507 (all parts), *Metallic materials — Vickers hardness test*

ISO 6508 (all parts), *Metallic materials — Rockwell hardness test*

ISO 6892-1, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*

ISO 6892-2, *Metallic materials — Tensile testing — Part 2: Method of test at elevated temperature*

ISO 7438, *Metallic materials — Bend test*

ISO 7539-2, *Corrosion of metals and alloys — Stress corrosion testing — Part 2: Preparation and use of bent-beam specimens*

ISO 8501-1, *Preparation of steel substrates before application of paints and related products — Visual assessment of surface cleanliness — Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings*

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

ISO 10893-4, *Non-destructive testing of steel tubes — Part 4: Liquid penetrant inspection of seamless and welded steel tubes for the detection of surface imperfections*

ISO 10893-5, *Non-destructive testing of steel tubes — Part 5: Magnetic particle inspection of seamless and welded ferromagnetic steel tubes for the detection of surface imperfections*

ISO 10893-8, *Non-destructive testing of steel tubes — Part 8: Automated ultrasonic testing of seamless and welded steel tubes for the detection of laminar imperfections*

ISO 10893-9, *Non-destructive testing of steel tubes — Part 9: Automated ultrasonic testing for the detection of laminar imperfections in strip/plate used for the manufacture of welded steel tubes*

ISO 10893-10:2011, *Non-destructive testing of steel tubes — Part 10: Automated full peripheral ultrasonic testing of seamless and welded (except submerged arc-welded) steel tubes for the detection of longitudinal and/or transverse imperfections*

ISO 10893-11:2011, *Non-destructive testing of steel tubes — Part 11: Automated ultrasonic testing of the weld seam of welded steel tubes for the detection of longitudinal and/or transverse imperfections*

ISO 13623, *Petroleum and natural gas industries — Pipeline transportation systems*

ISO 17640, *Non-destructive testing of welds — Ultrasonic testing — Techniques, testing levels, and assessment*

ASTM E112, *Standard Test Methods for Determining Average Grain Size*

ASTM E214, *Standard Practice for Ultrasonic Pulse-Echo Straight-Beam Contact Testing*

ASTM E340, *Standard Test Method for Macroetching Metals and Alloys*

ASTM E797, *Standard Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method*

NACE TM0177:2016, *Standard Test Method — Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H_2S Environments*

NACE TM0284:2016, *Test Method — Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
arc
curved portion of a bend

3.2
bend angle
amount of directional change through the bend

3.3
bend qualification test
BQT
qualification test that produces a bend in accordance with the *MPS* (3.20) and demonstrates that bends that meet the specified requirements can be produced

Note 1 to entry: Clause 10 specifies requirements for bends.

3.4
bend radius
distance from the centre of curvature to the centreline axis of the bent pipe

3.5
by agreement
agreed between the *manufacturer* (3.19) and the *purchaser* (3.23)

[SOURCE: ISO 15590-2:2021, 3.1]

3.6
chord
line segment connecting start and stop points of the bend zone measured at the centreline axis

3.7
defect
imperfection (3.12) of a size and/or population density greater than the specified acceptance criteria

Note 1 to entry: 10.5 and Clause B.7 specify the acceptance criteria.

3.8
extrados
outer curved section of the bend *arc* (3.1)

3.9
global heating technology
induction bending (3.14) process in which the entire bend including *arc* (3.1) and *tangent* (3.27) sections is pushed through the induction heating coil and heated to the full bending temperature

3.10
heat
batch of steel prepared in one steel-making operation

3.11
if agreed
as prescribed, or more stringent than is prescribed, if achieved consensus by the *manufacturer* (3.19) and the *purchaser* (3.23) and specified in the purchase order

[SOURCE: ISO 24139-2:2023, 3.1.5]

3.12
imperfection
discontinuity or irregularity in the product wall or on the product surface that is detectable by *inspection* (3.15) methods outlined in this document

3.13
indication
evidence obtained by *non-destructive inspection* (3.22)

3.14
induction bending
continuous bending process that utilizes induction heating to create a narrow, circumferential, heated band around the material being bent

3.15
inspection
activities, such as measuring, examining, testing, weighing or gauging one or more characteristics of a product and comparing the results of such activities with the specified requirements in order to determine conformity

3.16
intrados
inner curved section of the bend *arc* (3.1)

3.17
lamination
internal metal separation that creates layers, generally parallel to the pipe/bend surface

3.18
local heating technology
induction bending (3.14) process in which only the *arc* (3.1) of a bend is pushed through the induction heating coil and heated to the full bending temperature

3.19
manufacturer
firm, company, or corporation responsible for making and marking the product in accordance with the specified requirements

Note 1 to entry: Clauses 9 and 10 specify requirements for manufacturers.

3.20
manufacturing procedure specification
MPS
document that specifies the properties and description of the *mother pipe* (3.21), the bending procedure, the post-bending heat treatment equipment and cycle (if needed), the qualification bend testing results, the non-destructive testing procedures and the weld end bevel details used for the manufacture of the bends

3.21
mother pipe
straight section of pipe from which an induction bend is made

3.22
non-destructive inspection
inspection (3.15) to reveal *imperfections* (3.12), using radiographic, ultrasonic or other methods specified in this document that do not involve disturbance, stressing or breaking of the materials

3.23
purchaser
party responsible for both the definition of requirements for a product order and for payment of that order

3.24
submerged-arc welding
SAW
welding process that produces melting and coalescence of metals by heating them with an arc or arcs between a bare metal consumable electrode or electrodes and the workpiece, wherein the arc and molten metal are shielded by a blanket of granular flux

[SOURCE: ISO 15590-4:2019, 3.22]

3.25
service condition
condition of use that is specified by the *purchaser* (3.23) in the purchase order

Note 1 to entry: In this document, the terms “sour service” and “offshore service” are service conditions.

3.26
end weld
weld that joins strip or plate ends together

3.27
tangent
straight section at the end of an induction bend

3.28
transition zone
area of the start and stop points of induction heating, which includes material that extends from the unheated *mother pipe* (3.21) to the material that has been heated to the full bending temperature

3.29
wall thinning
amount of reduction from the original wall thickness of the pipe to the wall thickness in the *extrados* (3.8) after bending

4 Symbols and abbreviated terms

4.1 Symbols

A	elongation of tensile test specimen after fracture, expressed as a percentage
L_{CVD}	crest to valley depth
D_2 and D_4	outside diameters of two adjacent crests
D_3	outside diameter of the intervening valley
D	specified outside diameter
D_a	manufacturer-designated outside diameter after sizing, expressed in millimeters
D_b	manufacturer-designated outside diameter before sizing, expressed in millimeters
D_{max}	maximum measured diameter, outside or inside
D_{min}	minimum measured diameter, outside or inside
l	distance between adjacent crests for waving
O	out-of-roundness
r_b	bend centreline radius
r_p	nominal mid-thickness radius of the mother pipe
R_m	ultimate tensile strength
$R_{t0,5}$	yield strength for 0,5 % total elongation
S_r	sizing ratio
T_{dmin}	minimum design temperature specified by the purchaser
t_i	minimum wall thickness at the bend intrados
t_{min}	minimum wall thickness required in accordance with ISO 13623, for the straight pipe adjacent to the bend, including any corrosion allowance

4.2 Abbreviated terms

CTOD	crack tip opening displacement testing
CVD	crest to valley depth
HAZ	heat-affected zone
HFW	high-frequency electric welding process for pipe during manufacturing
HIC	hydrogen-induced cracking
IB	induction bend
MT	magnetic particle testing
NDT	non-destructive testing
PSL	product specification level
PT	liquid-penetrant testing
RT	radiographic testing
SAWH	submerged arc helical welding process for pipe during manufacture
SAWL	submerged arc longitudinal welding process for pipe during manufacture
SI	International System of Units
SSC	sulfide stress-cracking
SWC	step-wise cracking
UT	ultrasonic testing
WPS	welding procedure specification

5 General requirements

5.1 Units of measurement

In this document, data are expressed in SI units. For a specific order item, unless otherwise stated, only one system of units shall be used, without combining data expressed in the other system.

5.2 Rounding

Unless otherwise stated in this document, to determine conformity with the specified requirements, observed or calculated values shall be rounded to the nearest unit in the last right-hand place of figures used in expressing the limiting value, in accordance with ISO 80000-1:2022, Annex B, Rule A.

NOTE See also ASTM E29-04.

5.3 Conformity to this document

A quality management system should be applied to assist conformity to the requirements of this document.

NOTE ISO 29001 gives sector-specific requirements on quality management systems.

A contract may specify that the manufacturer is responsible for conforming to all the applicable requirements of this document. It shall be permissible for the purchaser to make any investigation necessary to be assured of conformity by the manufacturer and to reject any material that does not conform.

6 Designation

Designation of induction bends shall take the form “IB xxx-PSL 1” or “IB xxx-PSL 2” or “IB xxx-PSL 2S”, where

— “xxx” is the specified minimum yield strength, expressed in megapascals (MPa);

— the letters “PSL 1” or “PSL 2” identify the technical delivery conditions class for induction bends in non-sour service;

— the letters “PSL 2S” identify PSL 2 bends for use in sour service conditions;

— the letters “PSL 2O” identify PSL 2 bends for use in offshore service conditions;

— the letters “PSL 2SO” identify PSL 2 bends for use in both offshore and sour service conditions.

7 Pressure rating and design

The hoop stress in the induction bend due to internal fluid pressure shall not exceed the hoop stress permitted in ISO 13623, for straight pipe in the location of the bend.

NOTE 1 The purchaser normally performs the pressure design and specifies the minimum wall thickness t_{min}.

The wall thickness of the bend extrados shall be at least t_{min}.

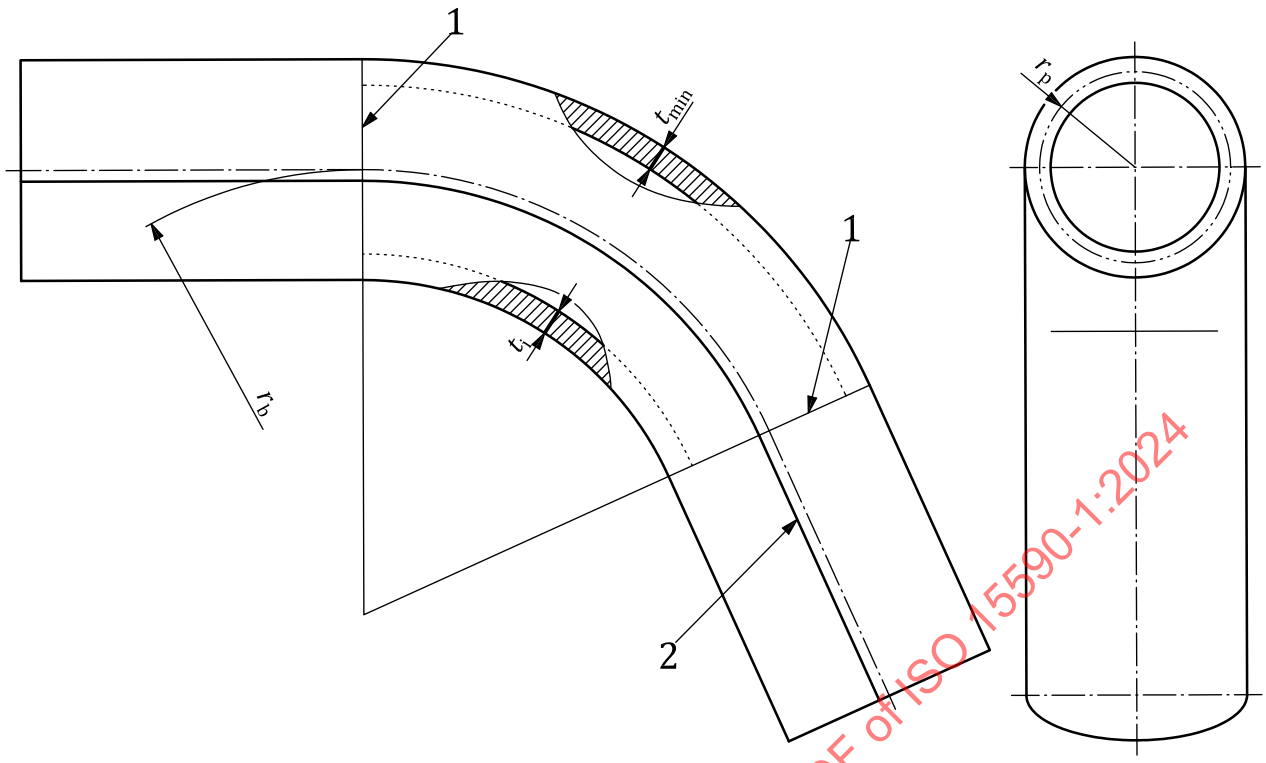
The wall thickness at the bend intrados shall be at least as given in Formula (1):

$$t_i = t_{min} \times \frac{2r_b - r_p}{2(r_b - r_p)} \quad (1)$$

NOTE 2 For pipelines not designed in accordance with ISO 13623, the minimum required wall thickness of the bend extrados can be less than t_{min}.

NOTE 3 The requirements in this clause address the design of a bend against internal pressure. The purchaser or designer can also consider other loads, both static and dynamic, and pipeline test conditions to demonstrate compliance with the strength requirements of ISO 13623.

NOTE 4 The geometric dimension of the bend is shown in Figure 1.



Key

1 transition zone

2 weld

Figure 1 — Geometric dimension of bend

8 Purchaser-supplied information

8.1 General information

The purchaser shall provide the following information:

a) number of this document and year of publication (i.e. ISO 15590-1:2024);

b) bend designation of each bend;

c) quantity of bends;

d) supply of mother pipe by the purchaser or the manufacturer;

e) required bend dimensions, including:

- diameter (inside or outside);
- minimum intrados and extrados wall thickness after bending;
- bend radius;
- bend angle;
- tangent lengths;

f) end preparation if different from square ends.

8.2 Additional information

The purchaser should specify the following additional information:

a) minimum design temperature;

b) maximum design temperature (and any requirement for high-temperature tensile testing);

c) maximum wall thickness;

d) special dimensional requirements;

e) requirements for supplementary inspection and testing;

f) requirements for gauging and other measurements of dimensions, if different from this document;

g) pipeline design standard or design factors, if different from ISO 13623;

h) pipeline operating conditions;

i) whether it is necessary to apply post-bending heat treatment;

j) mechanical-property requirements at the maximum design temperature;

k) Charpy impact test temperature;

l) requirements for proof, burst or hydrostatic testing;

m) hold-points for witness and approval by purchaser;

n) surface condition;

o) coating or painting requirements;

p) marking requirements, if different from this document;

q) requirements for ends or bevel protection (e.g. end caps or bevel protectors);

r) packaging and shipping instructions;

s) third-party inspection organization;

t) standard designation of inspection document that is required in accordance with ISO 10474;

u) requirements for format and additional content of the inspection document;

v) additional requirements for hardness testing;

w) constant outside or inside diameter;

x) other special requirements.

8.3 Information on the mother pipe

The following information on the mother pipe shall be provided to the manufacturer:

a) purchasing specification;

b) pipe diameter, inside or outside;

c) pipe wall thickness, nominal or minimum;

d) pipe lengths;

e) pipe manufacturer;

f) pipe material specification and pipe material certificates, including chemical composition, heat treatment, mechanical properties, dimensions and results of NDT;

g) welding procedure specification and weld metal chemical composition for SAWL and SAWH pipe;

h) weld-seam-repair welding-procedure specification for SAWL and SAWH pipe;

i) applicability of Annex B for sour service.

NOTE Information f), g) and h) is necessary for the design of the bending procedure by the manufacturer.

9 Manufacturing

9.1 Mother pipe

The mother pipe shall be manufactured in accordance with ISO 3183 or by agreement.

The mother pipe for the manufacture of PSL 2 bends shall be made in accordance with ISO 3183 for PSL 2 pipes.

The mother pipe for the manufacture of PSL 2S bends shall be made in accordance with ISO 3183 for PSL 2S pipes ordered for sour service and the additional requirements specified in Annex B.

The mother pipe for the manufacture of PSL 2O bends shall be made in accordance with ISO 3183 for PSL 2O pipes ordered for offshore service.

The mother pipe for the manufacture of PSL 2SO bends shall be made in accordance with ISO 3183 for PSL 2SO pipes ordered for sour and offshore service and the additional requirements specified in Annex B.

The mother pipe may be supplied by either the purchaser or the manufacturer.

If the mother pipe is supplied by the purchaser, the manufacturer should be consulted as to the required chemical composition, properties and dimensions of the mother pipe, (including seam weld and seam repair weld) with regard to its suitability for induction bending.

The mother pipe shall not contain weld repairs to the pipe body.

The wall thickness of the mother pipe shall have adequate allowance for wall thinning at the extrados due to induction bending.

The surface of the mother pipe shall be free from contamination by low-melting-temperature metals, such as copper, zinc, brass and aluminium, and may be blast cleaned to ISO 8501-1, Sa 2.

9.2 Qualification test bend

The manufacture of all PSL-level test bends shall be carried out in accordance with an MPS qualified in accordance with Clause 9 before commencement of production, or at the beginning of production if agreed.

NOTE Annex A gives details of MPS.

A test bend with at least sufficient arc length to allow extraction of the necessary test specimens shall be manufactured in accordance with each preliminary MPS. The inspection and testing of the test bend shall include sufficient tangents and both stop and start transition zones if included in the produced bends.

The test bend shall be tested and inspected in accordance with Clause 10. The MPS being used for production shall, for each of the essential variables in Table 1, specify:

— the values recorded during the manufacturing of the test bend;

— the permissible range during production bending.

The variation in essential variables shall not exceed the permissible limits shown in Table 1.

9.3 Production bending

Bends shall be made by electric induction bending process, and the appropriate thermoplastic processing technology and cooling medium shall be used according to the hot working characteristics of the mother pipe material. Bends of IB 555 and below may be produced by either global heating technology or local heating technology.

Induction bending shall be carried out in accordance with a qualified MPS as specified in Annex A.

Interruption of the induction bending operation shall result in rejection of the bend.

9.4 Post-bending heat treatment

Post-bending heat treatment of bends is not mandatory for comformity with this document.

Post-bending heat treatment may be performed to achieve the required material properties, improve corrosion resistance, remove transition zones at the ends of the bend arc or to relieve residual stresses.

Post-bending heat treatment should be performed for PSL 2, PSL 2S, PSL 2O, and PSL 2SO bends with strength grades equal to or greater than 485 MPa.

The temperature of each furnace-load of bends shall be monitored by thermocouples connected directly to selected bends and shall be recorded. The type and location of the thermocouples shall be as specified in the MPS or in the dedicated drawings issued for heat treatment loading.

All testing and inspection shall be performed after post-bending heat treatment.

9.5 Forming and sizing after bending

Hot forming, including spot heating, or hot sizing after bending, shall not be performed unless followed by a subsequent full heat treatment above the upper critical temperature.

Cold forming or sizing without subsequent heat treatment is permitted for ovality and diameter corrections in the tangents provided the induced permanent strain does not exceed 1,5 %.

Unless otherwise agreed, the permanent strain shall be derived using Formula (2):

$$S_r = \frac{|D_a - D_b|}{D_b} \tag{2}$$

Table 1 — Essential variables and maximum permissible variations

Essential variable	Maximum permissible variations[a]
Heat of steel	None
Mother pipe seam weld WPS and welding consumables	None
Surface condition	By agreement
Nominal mother pipe diameter	None
Nominal mother pipe wall thickness	±3 mm or ±10 % whichever is the smallest
Bend radius	An approved MPS qualifies all larger radii (but not smaller) in the following ranges:

[a] The permissible variations apply to the values obtained in the approved bend qualification test (BQT) at steady state.

[b] The variation may be increased to ±20 % for test bends that will receive post-bend quench and temper heat treatment.

[c] The pipe long seam is normally placed on the neutral axis during bending.

Table 1 *(continued)*

Essential variable	Maximum permissible variations[a]
	a) Up to and including 3*D* b) 3*D* up to and including 5*D* c) 5*D* up to and including 10*D* d) 10*D* up
Forming speed	±2,5 mm/min
Forming temperature	±25 °C
Coil design	None
Coolant	None
Coolant flow rate or pressure	±10 %
Coolant temperature	±15 °C
Induction heating frequency	±10 %[b]
Weld seam location	±10° from the location in the test bend[c]
Post-bending heat treatment	Method: no change Soaking time: $^{+15}_{0}$ min Soaking temperature: ±15 °C Heating and cooling rates: by agreement

[a] The permissible variations apply to the values obtained in the approved bend qualification test (BQT) at steady state.

[b] The variation may be increased to ±20 % for test bends that will receive post-bend quench and temper heat treatment.

[c] The pipe long seam is normally placed on the neutral axis during bending.

9.6 Strip/plate end welds

Induction bends shall not contain coil-strip end welds or plate end welds.

9.7 Jointers and girth welds

Induction bends shall not contain girth welds.

9.8 End preparation

Bends shall be supplied with square ends unless otherwise specified by the purchaser.

10 Testing and inspection

10.1 General requirements

An MPS shall be approved or production bends accepted only after all testing and inspection activities required in this clause have been performed and all results meet the specified requirements.

Except where otherwise stated in this clause, the testing and inspection methods and acceptance criteria for induction bends shall be as required by ISO 3183 for pipes of the same steel grade and type.

The upper limit of yield stress for offshore service pipes (PSL 2) may be increased by agreement.

Testing and inspection shall be carried out on bends after final heat treatment.

Test results already available for the mother pipe may be used in place of testing and inspections where indicated in Table 2.

If the pipeline installation techniques require post-weld heat treatment of the bend, the purchaser may require additional testing to demonstrate that the mechanical properties of the bend are also achieved after post-weld heat treatment. The purchaser shall specify the details of the post-weld heat treatment cycle that shall be used during the pipeline installation. The test requirements and acceptance criteria shall be by agreement.

10.2 Extent of testing and inspection

10.2.1 Qualification test bend

The extent of testing and inspection that shall be performed on each test bend is as specified in Table 2 for each bend product specification level.

The location and type of tests shall be as specified in Table 3, with the locations for the extraction of samples as shown in Figure 2.

For SAWH pipe, the inspection and testing requirements shall be by agreement.

If a mechanical test specimen of a qualification test bend fails to conform to the requirements in this document and provided that $R_{t0,5}$ and R_m are not less than 95 % of the specified minimum values, then two additional specimens from the same test bend may be tested if agreed. The specimen shall be taken in the same manner as the failed specimen and from the area adjacent to the area from the failed specimens. The test requirements shall be considered to be met only if both retested specimens conform to the specified requirements.

10.2.2 Production bends

The extent of testing and inspection that shall be performed during production is as specified in Table 2 for each bend product specification level.

10.2.3 Production test bends

For large bend quantities, the production test bend frequency, extent of destructive testing and retesting shall be by agreement.

10.3 Chemical composition

The chemical composition of each bend shall conform to the requirements for pipes of the same grade and type as specified in ISO 3183.

NOTE In some instances, the aluminium and/or copper contents within the limits allowed by ISO 3183 can give rise to embrittlement and cracking during bending.

10.4 Physical testing

10.4.1 Test pieces — General

Test pieces shall be prepared in accordance with ISO 3183.

If thermal cutting has been used to remove samples, the full extent of the heat-affected region shall be removed during the preparation of the test pieces.

10.4.2 Tensile testing

10.4.2.1 Test pieces

Round-bar test pieces machined from unflattened samples may be used.

Welds shall be ground flush. Local imperfections and mill scale may be removed.

When the wall thickness of the bends is greater than 25 mm, strip test pieces with full-thickness or reduced thickness may be adopted.

When the reduced test pieces are adopted, the thickness of the test pieces shall be close to the maximum thickness that can be tested by the tensile testing machine; and the thickness of each single laminated piece shall be approximately equal. The thickness of laminated specimen group shall cover the full thickness of the bend (see Figure 3); and each piece of the group shall be tested.

Table 2 — Summary of testing and inspection requirements

Test		PSL 1[a]	PSL 2[a]	Acceptance
Chemical analysis	Chemical composition	M	M	In accordance with ISO 3183
Physical tests	Tensile	T[b]	T[b]	In accordance with ISO 3183
	Impact	N	T	In accordance with ISO 3183
	Through-thickness hardness	O	T	In accordance with 10.4.4.2
	Surface hardness	T and P	T and P	In accordance with 10.4.5.2
	Metallography	T	T	In accordance with 10.4.6.2
	HIC	N	T[c]	In accordance with B.4.3
	SSC	N	T[c]	In accordance with B.4.4
	CTOD	N	O	By agreement
	Guided bend (weld seam of SAW)	M	M	In accordance with ISO 3183
	Flattening (HFW)	M	M	In accordance with ISO 3183
NDT	Visual inspection	T and P	T and P	In accordance with ISO 3183 and 10.5.1
	Weld seam (UT or RT)	M	T and P	In accordance with ISO 3183
	Bend ends (laminations)	P	P	In accordance with 10.5.4
	Bend body (MT or PT)	T and P	T and P	In accordance with 10.5.5
	Bend body (UT) transverse defects	N	T and P	In accordance with 10.5.6
	Bend body (UT) laminations	N	M	In accordance with 10.5.6
	Residual magnetism ends	P	P	In accordance with 10.5.7
	Repairs	P	P	In accordance with ISO 3183 and 10.5.8
Dimensions	Wall thickness	T and P	T and P	In accordance with 10.6
	D bend body	P	P	In accordance with 10.6
	D at ends	P	P	In accordance with 10.6
	Out-of-roundness ends	P	P	In accordance with 10.6
	Out-of-roundness body	P	P	In accordance with 10.6

[a] M – Testing of the induction bend shall not be required if acceptable test results are available for the mother pipe. If acceptable test results for the mother pipe are not available then the test shall be performed on either the mother pipe or the bend. When applicable, chemical and physical tests shall be conduction on only one mother pipe or bend per test unit, while NDT and dimensional testing shall be conducted on each pipe or bend.

N – Not required.

O – Performance of the test or inspection on a production induction bend may be required by agreement.

P – Required for each production bend.

T – Required for each test bend.

[b] The tensile test orientation for the tangent, extrados and intrados shall be as per the orientation for tensile testing for mother pipe in ISO 3183. The orientation of the tensile testing of the transition zones shall be as per the orientation for tensile testing for mother pipe in ISO 3183 or, if agreed, in the longitudinal direction with the transition zone located in the gauge section of the tensile test specimens.

[c] Required only for PSL 2S and PSL 2SO bends.

Table 2 *(continued)*

Test		PSL 1[a]	PSL 2[a]	Acceptance
	Linear dimensions	P	P	In accordance with 10.6
	Angle	P	P	In accordance with 10.6
	Radius	T and P	T and P	In accordance with 10.6
	End squareness	P	P	In accordance with 10.6
	Out of plane	P	P	In accordance with 10.6
	End preparation	By agreement		By agreement
Gauging		By agreement		By agreement
Hydrostatic test		By agreement		By agreement

[a] M – Testing of the induction bend shall not be required if acceptable test results are available for the mother pipe. If acceptable test results for the mother pipe are not available then the test shall be performed on either the mother pipe or the bend. When applicable, chemical and physical tests shall be conduction on only one mother pipe or bend per test unit, while NDT and dimensional testing shall be conducted on each pipe or bend.

N – Not required.

O – Performance of the test or inspection on a production induction bend may be required by agreement.

P – Required for each production bend.

T – Required for each test bend.

[b] The tensile test orientation for the tangent, extrados and intrados shall be as per the orientation for tensile testing for mother pipe in ISO 3183. The orientation of the tensile testing of the transition zones shall be as per the orientation for tensile testing for mother pipe in ISO 3183 or, if agreed, in the longitudinal direction with the transition zone located in the gauge section of the tensile test specimens.

[c] Required only for PSL 2S and PSL 2SO bends.

Table 3 — Location of test pieces and type of test for destructive testing of test bends

Location	Test
Tangent base metal[a]	Tensile Impact Through-thickness hardness
Tangent weld[a]	Tensile transverse Impact Flattening (HFW) Through-thickness hardness Metallography Guided bend(SAW)
Transition zones base metal extrados, start and stop [b]	Tensile[c] Impact[c] Through-thickness hardness[c] Metallography[c]

[a] Testing after bending is not necessary if test results are available for the mother pipe and the tangent is not heat-treated during induction bending or subsequent heat treatment.

[b] Where the entire bend, including tangents, is subject to the same off-line quenching and tempering heat treatment after bending, then unless otherwise specified by the purchaser, these induction bends are not considered to have transitions for testing purposes

[c] Where the entire length of the mother pipe, including tangents, is subject to the same continuous induction heating, cooling and speed parameters as the bent portion during the induction bending process then, unless specified otherwise by the purchaser, these induction bends are not considered to have transitions for testing purposes.

[d] Required only for PSL 2S bends.

[e] By agreement; requirement for HIC testing of seamless pipe bends may be waived.

[f] For SAWH bends, additional testing shall be by agreement.

Table 3 *(continued)*

Location	Test
Bend extrados base metal	Tensile Impact Through-thickness hardness Metallography HIC and SSC[de]
Bend intrados base metal	Tensile Impact Through-thickness hardness
Bend weld[f]	Tensile transverse Impact Through-thickness hardness Metallography for PSL-2 only Guided bend HIC and SSC[d]
Bend neutral axis base metal	Tensile
	Impact
	Through-thickness hardness

[a] Testing after bending is not necessary if test results are available for the mother pipe and the tangent is not heat-treated during induction bending or subsequent heat treatment.

[b] Where the entire bend, including tangents, is subject to the same off-line quenching and tempering heat treatment after bending, then unless otherwise specified by the purchaser, these induction bends are not considered to have transitions for testing purposes

[c] Where the entire length of the mother pipe, including tangents, is subject to the same continuous induction heating, cooling and speed parameters as the bent portion during the induction bending process then, unless specified otherwise by the purchaser, these induction bends are not considered to have transitions for testing purposes.

[d] Required only for PSL 2S bends.

[e] By agreement; requirement for HIC testing of seamless pipe bends may be waived.

[f] For SAWH bends, additional testing shall be by agreement.

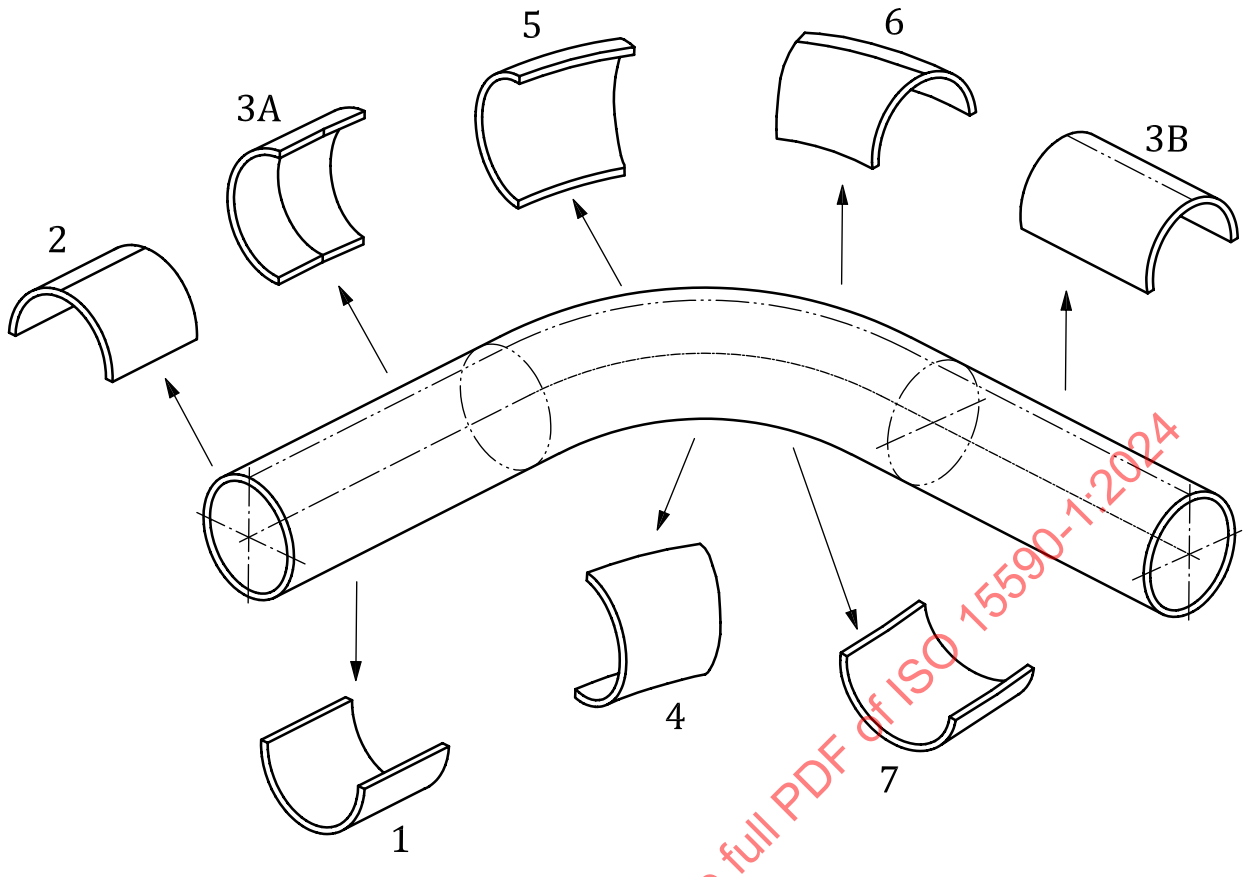
10.4.2.2 Test method

Tensile testing at ambient temperature shall be carried out in accordance with ISO 6892-1 (see also ASTM A370). Additional elevated-temperature tensile testing should be performed if the maximum design temperature exceeds 50 °C. Tensile testing at elevated temperatures shall be carried out in accordance with ISO 6892-2 and the test location and the acceptance criteria shall be by agreement.

R_m, $R_{t0,5}$ and A shall be determined using test pieces from the base metal in the bend arc, tangent and transition zones.

The percentage elongation after fracture shall be reported with reference to ISO 3183.

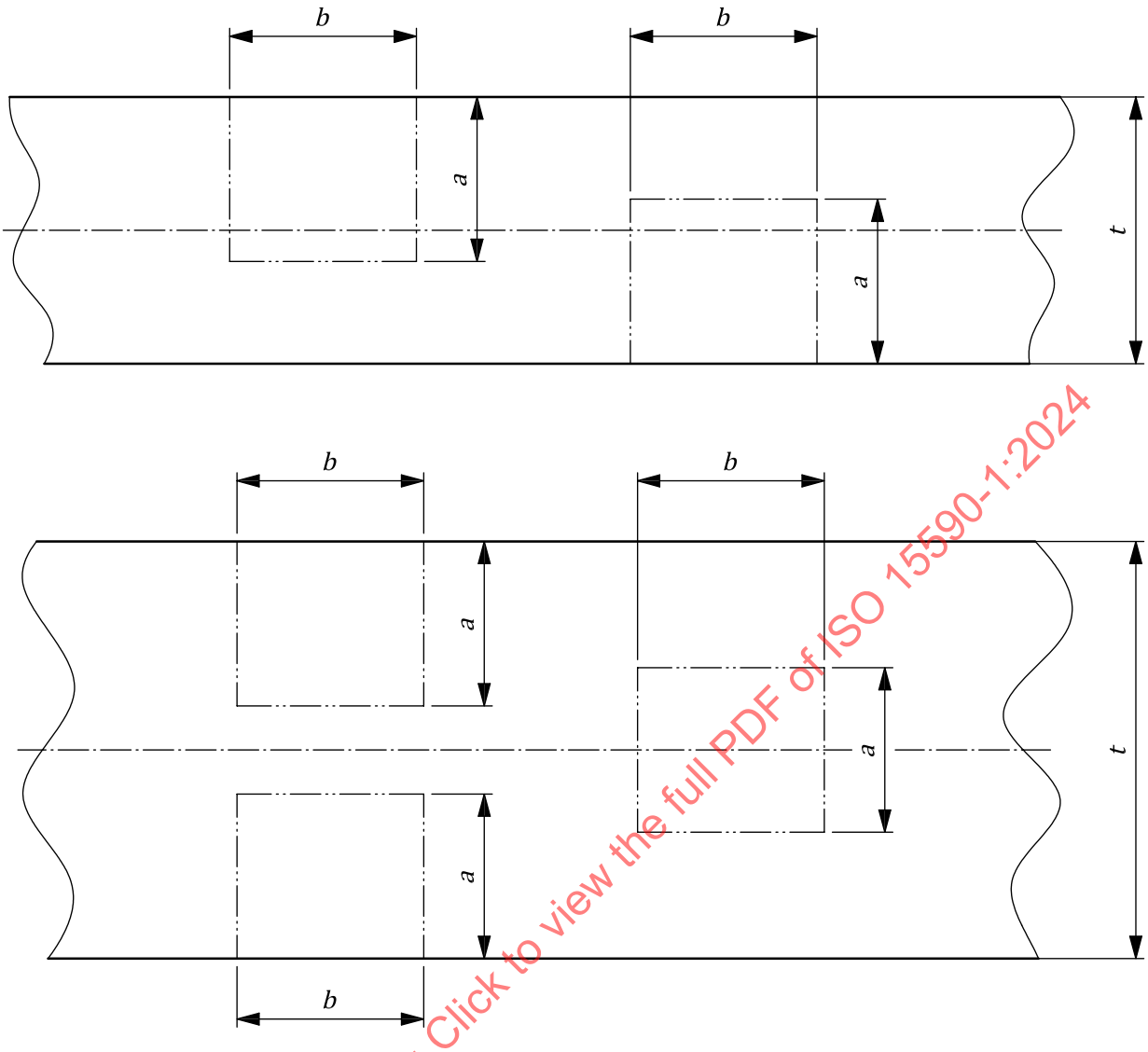
For weld transverse tensile tests, only R_m shall be required.



Key

1 tangent base metal
2 tangent weld
3A transition zone base metal (start transitions)
3B transition zone base metal (stop transitions)
4 bend intrados base metal
5 bend extrados base metal
6 bend weld
7 bend neutral axis base metal

Figure 2 — Location for extraction of samples for testing



Key

a thickness of the reduced test piece

b width of the reduced test piece

t actual wall thickness of the test bend

Figure 3 — Schematic diagrams of typical reduced test pieces

10.4.3 Charpy V-notch impact testing

10.4.3.1 Test pieces

Charpy V-notch test pieces shall be prepared in accordance with ISO 148-1 (see also ASTM A370), with the axis of the notch perpendicular to the bend surface. The orientation and size of the test pieces shall be transverse with the greatest possible width between 10 mm and 5 mm. If transverse test pieces with a minimum width of 5 mm, are not possible, longitudinal test pieces with the greatest possible width between 10 mm and 5 mm shall be used.

Impact testing is not required if the bend dimensions are insufficient to produce longitudinal test pieces with a minimum width of 5 mm.

All Charpy V-notch test pieces shall be taken from the sample at a depth of no more than 2 mm below the outer surface as illustrated in Figure 4.

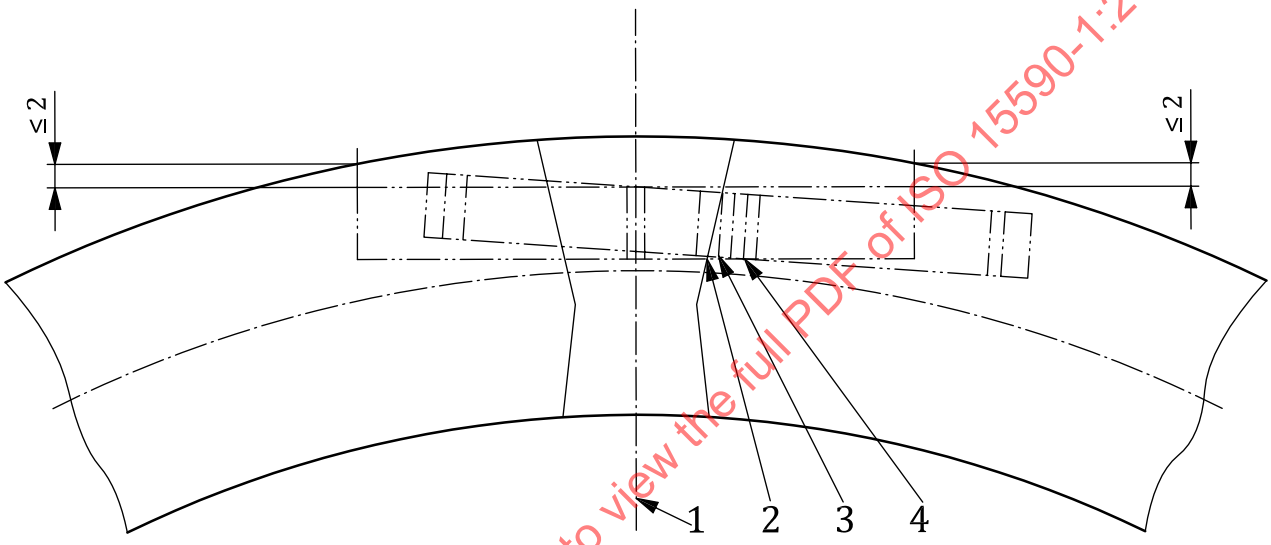
Test pieces from welds in SAW pipe with a mother pipe nominal wall thickness not exceeding 25 mm shall be taken across the weld with the notch at the four locations indicated in Figure 4. The distance of notch location from the fusion line shall be determined with reference to the centreline of the test piece. The orientation of the weld test piece shall be transverse to either the longitudinal or helical weld.

Test pieces from welds in HFW pipe shall be taken across the weld: one set with the notch located in the weld centreline with a tolerance of ±0,5 mm and one set with the notch located 2 mm from the weld centreline. The weld centreline shall be located by using metallographic etching techniques.

For bend weld and HAZ tests, each test piece shall be etched prior to notching in order to enable proper placement of the notch.

For all bends with a mother pipe nominal wall thickness greater than 25 mm, additional Charpy V-notch testing shall be performed during MPS qualification testing at 2 mm below the inner surface.

Dimensions in millimetres



Key

1 weld centreline
2 fusion line
3 fusion line plus 2 mm
4 fusion line plus 5 mm

Figure 4 — Location of Charpy V-notch test pieces in the weld region of SAW pipe

10.4.3.2 Test method

Each set of impact tests shall consist of three adjacent test pieces taken from a single non-flattened sample.

Charpy V-notch impact testing shall be in accordance with ISO 148-1 (see also ASTM A370) with an additional requirement to report the shear area of the fracture surface for all test pieces except those for the weld centreline.

Impact test specimens shall be tested at the lower of 0 °C or the minimum design temperature. A lower test temperature may be used by agreement.

10.4.3.3 Requirements

For bends from mother pipes with a nominal wall thickness up to and including 25 mm, the results of the Charpy V-notch impact tests shall meet the requirements of ISO 3183.

10.4.4 Through-thickness hardness testing

10.4.4.1 Test method

For PSL 2 bends, through-thickness hardness testing shall be performed with the Vickers method in accordance with the ISO 6507 series (see also ASTM E92), or with the Rockwell test using Rockwell test HR 15N in accordance with the ISO 6508 series (see also ASTM E18). In case of dispute, the Vickers method shall apply. Hardness indent locations shall be in accordance with ISO 3183 for PSL2 pipe ordered for onshore service (see also API Spec 5L:2018, annex J).

10.4.4.2 Requirements

Hardness readings shall not exceed 300 HV_{10}, or equivalent (see also ASTM E140) for PSL 2 bends.

Bends for sour service (PSL 2S) shall meet the hardness requirements of Annex B.

10.4.5 Surface hardness testing

10.4.5.1 Test method

Three surface-hardness readings at each location shall be taken across two circumferential locations in the arc and across one circumferential location in each tangent.

Readings in the arc shall be obtained at the four main locations:

a) top neutral axis;

b) bottom neutral axis;

c) intrados;

d) extrados.

Readings in the tangent shall be taken at one of the above locations.

The same type of testing device shall be used both for qualification test and production bends. The selection of the testing device shall be at the manufacturer's discretion unless otherwise agreed.

10.4.5.2 Requirements

The average value of the three readings at each location of the test bend should be used for production test guidance.

The average value of the three hardness readings at each location of a production bend should not vary by more than the equivalent of 30 HV 10, or 30 HV 5 by agreement, hardness points from the average value measured in the same location of the test bend. Single hardness values shall meet the requirements of 10.4.4.2.

10.4.6 Metallographic examination

10.4.6.1 Test method

The test pieces for metallographic examination shall be examined at a magnification of not less than 100 ×. Test piece preparation shall be in accordance with ASTM E340.

Photomicrographs of the microstructures of the test bend arc, transition and tangent weld after completion of all post-bend heat treatment shall be prepared at magnifications of 100 × and 400 × or 500 ×.

Unless otherwise agreed, the micrographic examination shall be made at a distance of 2,0 mm from the external and internal surfaces and at a mid-wall position. For a wall thickness of 10 mm and smaller, the micrographic examination should be made at the mid-wall position only.

The photomicrographs shall be representative of the full wall thickness and shall include the extrados of the arc of the bend and the transition zones. Grain-size measurement shall be performed in accordance with ASTM E112, where appropriate for the microstructure.

10.4.6.2 Requirements

The photomicrographs shall demonstrate that the induction bending and any subsequent heat treatment have produced a consistent microstructure without separations in the base metal and, for welded pipe, in the weld and the HAZ. The type of microstructure and actual grain size shall be recorded on the bending-procedure qualification test report.

10.4.7 Crack tip opening displacement testing

CTOD testing is not mandatory for any bend product specification level.

Test methods and requirements shall be by agreement.

10.4.8 Guided bend testing

10.4.8.1 Test pieces

Test pieces shall be prepared in accordance with ISO 7438 (see also ASTM A370).

For induction bends with a wall thickness >20 mm the test pieces may be machined to provide a rectangular cross section having a thickness of 19 mm. Full-thickness, curved section test pieces are mandatory for a pipe wall thickness ≤20 mm. Welds shall be ground flush at both faces.

10.4.8.2 Test method

The mandrel dimensions shall be as defined in ISO 3183 for pipes of the same grade as the production bend and made by the same process as the mother pipe.

Both test pieces shall be bent through approximately 180°, one with the root of the weld and the other with the face of the weld directly under the mandrel.

10.4.9 Flattening tests

If required, flattening tests shall be carried out in accordance with ISO 3183 for pipes of the same grade and type.

10.4.10 Retesting

If the test specimen representing the batch of bends fails to conform to the specified requirements, the manufacturer may:

a) carry out two retests for only the rejecting type(s) of test from the same sacrificial bend at a location close to the failed sample;

b) carry out two retests for only the rejecting type(s) of test on one additional bend from the same batch.

If the retested specimens conform to the specified requirements, each of the remaining bends in the batch shall be accepted.

If one or both of the retested specimens fail to conform to the specified requirements, the manufacturer may elect to conduct re-heat treatment for the remaining bends. All the types of tests shall be carried out on one sampling bend after re-heat treatment. The re-heat treatment shall not carry out more than once. If

the retested specimens taken from the re-heat-treated bend fail to conform to the specified requirements, unless otherwise agreed, the batch shall be rejected.

10.5 Non-destructive testing

10.5.1 General

Where necessary, after final heat treatment and prior to visual or other non-destructive inspection, the entire outside surface of all bends shall be cleaned to a cleanliness grade of ISO 8501-1 Sa 2.

10.5.2 Visual inspection

Visual inspection for laminations, cracks, notches, gouges and other imperfections shall be performed on the complete outer and, if practical, the inner surface of the bend in accordance with ISO 3183.

Waving, as shown in Figure 5, is acceptable provided that the following conditions are met.

— The wave shapes blend into the pipe surface in a gradual manner with a maximum crest-to-valley depth, CVD, of 1 % of the actual outside diameter.

— The ratio of the distance between adjacent crests, l, to the CVD is a minimum of 25.

The CVD, designated by the symbol L_{CVD}, shall be determined as given in Formula (3):

$$L_{CVD} = \frac{D_2 + D_4}{2} - D_3 \tag{3}$$

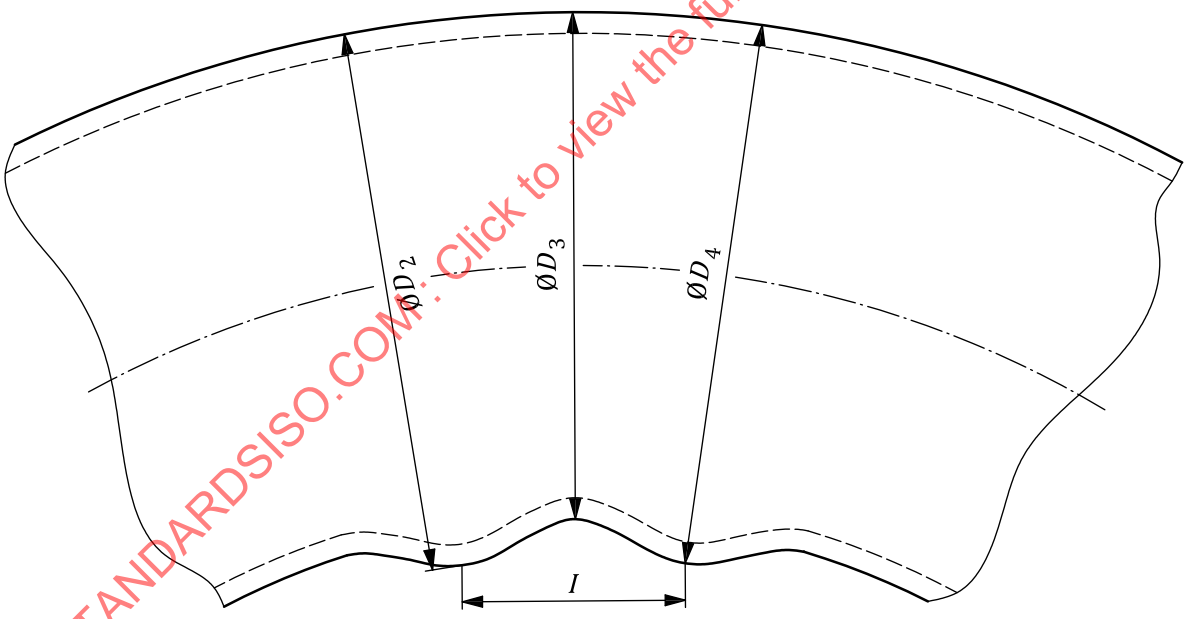


Figure 5 — Schematic diagram for measurement of waving

10.5.3 Weld seam testing

RT or UT of the weld seam shall be required for:

— the complete weld seam in the arc and transition zones;

— the end 250 mm of the tangent for local heating bends, if not examined already on the mother pipe prior to bending. For global heating bends, the complete weld seam of the tangent shall be examined.

10.5.4 Inspection of bend ends

After end preparation, the complete end preparation and 100 mm of the weld seam shall be inspected by MT or PT.

MT of bend ends shall be performed in accordance with ISO 10893-5 (see also ASTM E709). PT shall be performed in accordance with ISO 10893-4 (see also ASTM E165). Laminar imperfections greater than 6,4 mm in the circumferential direction shall be classified as defects.

For PSL 2 bends, a 50 mm wide band at each end shall be inspected for laminar imperfections by UT in accordance with ISO 10893-8 (see also ASTM A435 or ASTM A578/A578M). Laminar imperfections shall not exceed 6,4 mm in the circumferential direction or have an area in excess of 100 mm^2.

10.5.5 Magnetic particle testing or liquid-penetrant testing on the bend body

Unless otherwise agreed by the purchaser, for all bends, the bend body shall be inspected over an arc of 180°, 90° each side of the extrados by MT in accordance with ISO 10893-5 (see also ASTM E709) or PT in accordance with ISO 10893-4. In case of the risk of copper pollution, the whole bend body shall be inspected by MT or PT.

All cracks, laps, laminations and all rounded indications greater than 3 mm in any direction shall be classed as defects and shall be repaired in accordance with 10.5.8.

10.5.6 Ultrasonic testing on the bend body

Unless otherwise agreed by the purchaser, ultrasonic testing in accordance with ISO 10893-10 shall be performed over an arc of 180°, 90° each side of the extrados to verify that the bend is free from transverse defects. In case of the risk of copper pollution, the whole bend body shall be inspected by UT.

If required, ultrasonic testing in accordance with ISO 10893-8 or ISO 10893-9 shall be performed on the bend to detect laminar imperfections (see also ASTM A435, ASTM A578/A578M or ASTM E213.). The extent and coverage of inspection shall be by agreement. The acceptance criteria shall be as stated in ISO 3183.

10.5.7 Level of residual magnetism

The level of residual magnetism shall not exceed 2 mT.

10.5.8 Repairs

Unless otherwise agreed by the purchaser, no repair by welding shall be performed on any part of the bend or tangents. If repair by welding is agreed, weld repairs should be examined by UT and/or RT.

Provided that a smooth curved surface is maintained and the required minimum wall thickness is maintained, surface defects may be removed by grinding. Thickness measurement by UT shall be in accordance with ASTM E797.

All ground repair areas shall be examined by MT in accordance with ISO 10893-5 or by PT in accordance with ISO 10893-4, to confirm the complete removal of the defects.

10.5.9 NDT personnel

All NDT personnel shall have the appropriate level of competence.

NOTE One way of showing competence is by being certified to ISO 9712, ASNT SNT-TC-1A or equivalent.

10.6 Dimensions

The dimensions of the bends shall be measured to confirm that the dimensions specified by the purchaser have been achieved within the permissible tolerances of Table 4.

Wall thickness measurements shall be made at a sufficient number of locations by ultrasonic methods in accordance with ASTM E797 or ASTM E214.

The bend angle may be determined as follows; see Figure 6.

a) Extend the centreline axis of each tangent to the “centre of bend” where the two axes cross.

b) Measure and mark the distance from the “centre of bend” to each of the “centre of ends”.

c) Calculate the bend angle from the two “centre of bend” to “centre of end” dimensions and the chord length.

For angles less than 15°, the angle may be determined by measuring a triangle established by the two centreline axes and the offset at the end of the bend, as shown in Figure 6 b).

End out-of-squareness shall be measured from lines constructed at the specified bend angle and lines perpendicular to the plane of the bend, as shown in Figure 7.

Out-of-planeness is measured by levelling the centrelines of both bend tangent ends and measuring the difference in height of the two end centrelines from the level surface, as shown in Figure 8. Practical measurement methods shall be by agreement.

Out-of-roundness, O, expressed as a percent, is as given in Formula (4):

$$O = \frac{D_{\max} - D_{\min}}{D} \times 100 \tag{4}$$

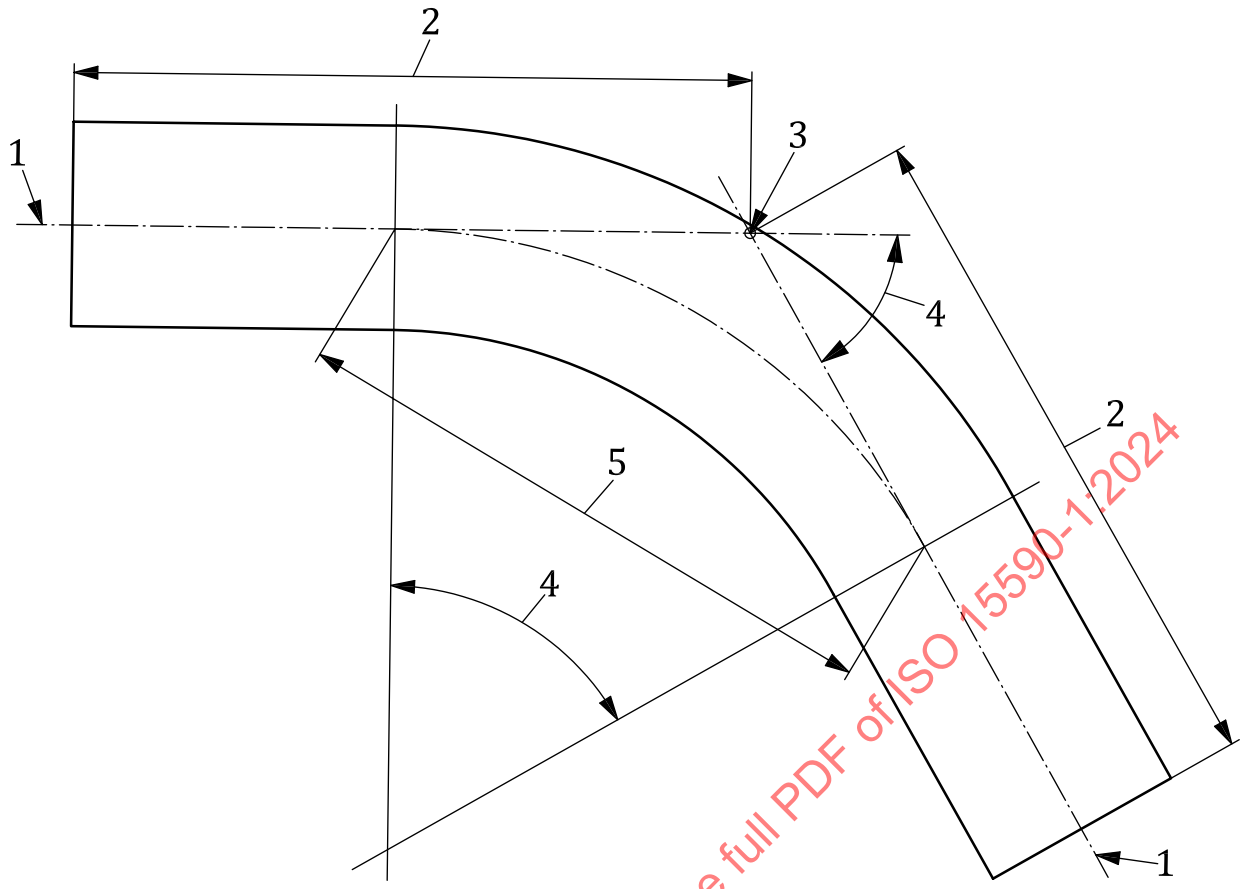
Table 4 — Permissible dimensional tolerances

Dimension	Permissible tolerance
Linear dimensions[a]	±30 mm
Minimum wall thickness	0 mm min.
Maximum wall thickness	By agreement
Inside or outside diameter[b] of bend ends	ISO 3183, this as specified in the purchase order
Inside diameter of bend arc and tangents	By agreement (see 10.7)
Bend angle	±1°
Bend radius for bends with $r_b \geq 1\,000$ mm	±1 %
Bend radius for bends with $r_b < 1\,000$ mm	±10 mm
End out-of-squareness	3 mm max.
Out-of-planeness	± bend angle × 10 /90 mm or 5 mm, whichever is greater
Out-of-roundness at ends	ISO 3183, this as specified in the purchase order
Out-of-roundness in bend body	$r_b \geq 5D$; 2,5 % max. $3D \leq r_b < 5D$; 3 % max. By agreement for a smaller bend radius

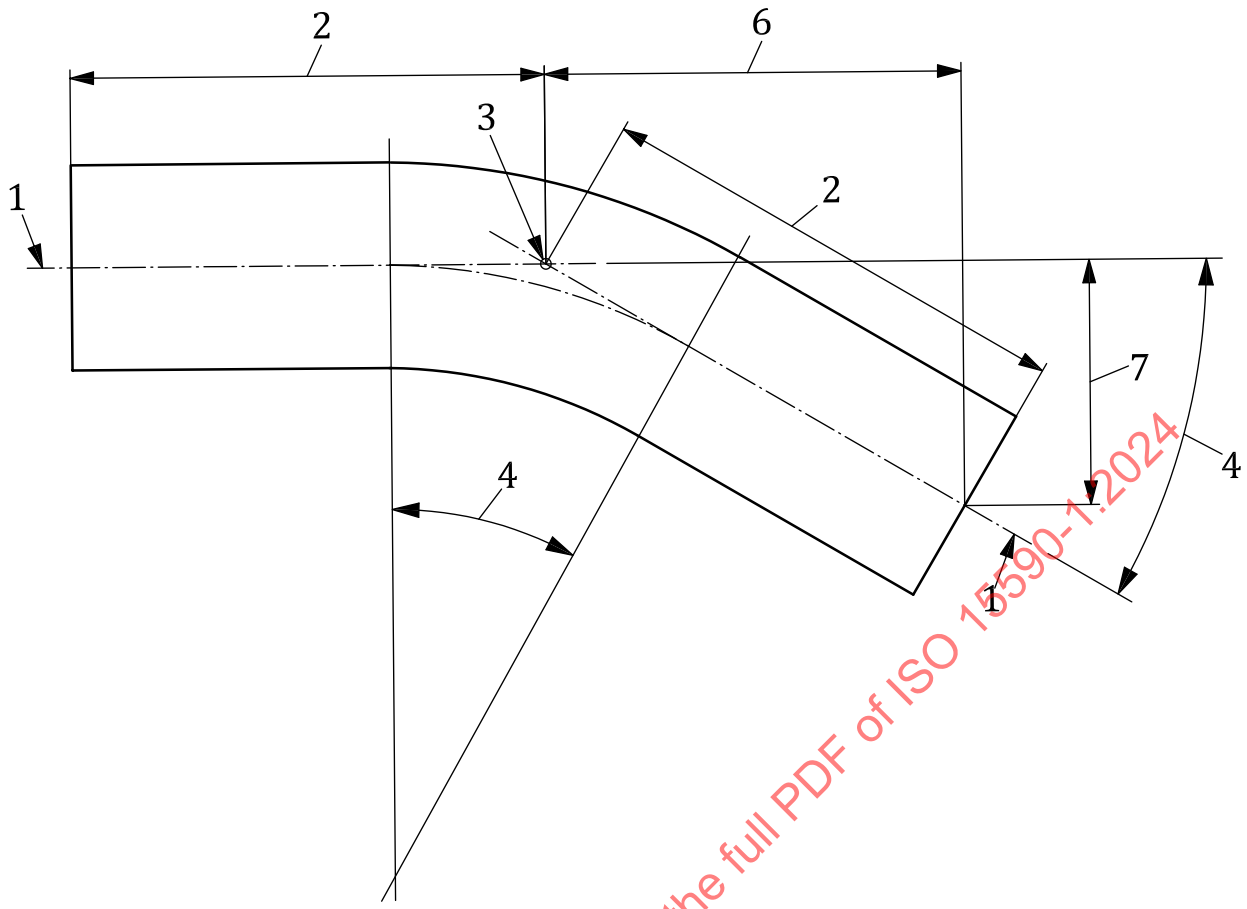
When measuring the bends dimensions and geometrical features it is reasonable to consider that each parameter (e.g. angle, radius, linear tolerances, etc) is fully independent of the others. This means that the bend should be considered to have nominal values for all parameters, except the one parameter being measured.

[a] Such as centre-to-end, offsets, chord lengths.

[b] Purchaser shall specify whether tolerance applies to inside or outside diameter.



a) Bends with angles of 15° and greater

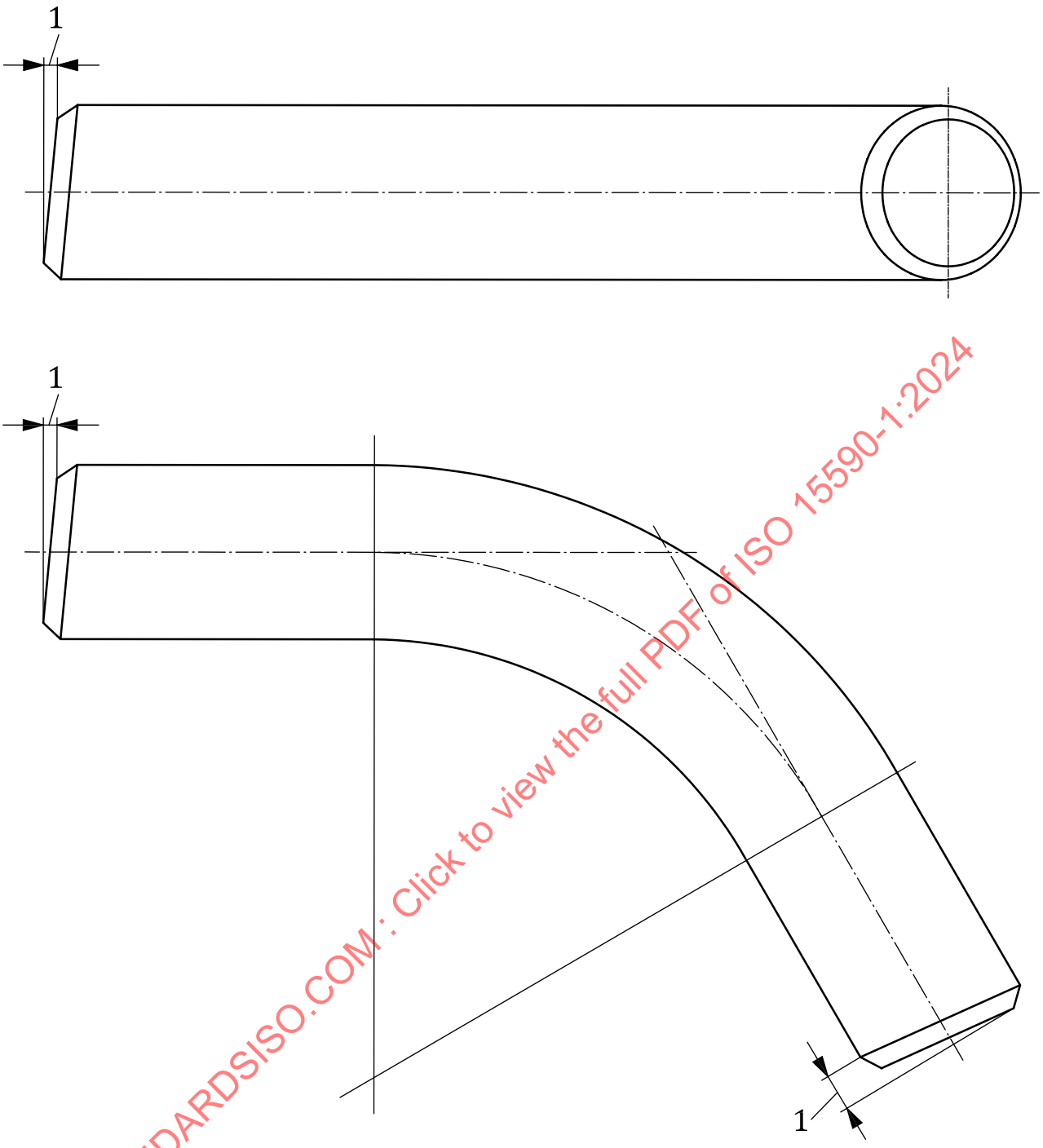


b) Bends with angles of less than 15°

Key

1	centreline axis	5	chord
2	centre to end	6	extension
3	centre of bend	7	offset
4	bend angle		

Figure 6 — Dimensions for determination of bend angle



Key

1 out-of-squareness

Figure 7 — Determination of end out-of-squareness