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Petroleum and natural gas industries — Factory bends, fittings and flanges for pipeline transportation systems —

Part 4: Factory cold bends

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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 documents 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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 2, *Pipeline transportation systems*.

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.

Introduction

This document makes reference to line pipe and bends with delivery conditions based on ISO 3183.

This document contains additional requirements for special applications as follows:

— Manufacturing procedure specification (Annex A);

— PSL 2S cold bends ordered for sour service (Annex B).

The requirements of the annexes apply only where they are specified on the purchase order. This document does not provide guidance on when it is necessary to specify the above supplementary requirements defined in the annexes. It is the responsibility of the purchaser to specify, based upon the intended use and design requirements, the supplementary requirements that will apply for a particular purchase order.

Further or differing requirements can be needed for individual applications. This document is not intended to inhibit a manufacturer from offering, or the purchaser from accepting, alternative equipment or engineering solutions for the individual application. This can be particularly applicable where there is innovative or developing technology. Where an alternative is offered, it is the responsibility of the manufacturer to identify and provide details of any variations from this document.

Petroleum and natural gas industries — Factory bends, fittings and flanges for pipeline transportation systems —

Part 4: Factory cold bends

1 Scope

This document specifies the technical delivery conditions for bends made by the cold bending process for bend with radii 5xOD or higher for use in pipeline transportation systems for the petroleum and natural gas industries as defined in ISO 13623.

This document also specifies the requirements for the manufacture of two product specification levels (PSLs) of cold bends corresponding to product specification levels given for pipe in ISO 3183. This document is applicable to cold bends made from seamless and welded pipe of unalloyed or low-alloy steels.

NOTE 1 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 is not applicable to the selection of the cold bend product specification level. It is the responsibility of the purchaser to specify the PSL, based upon the intended use and design requirements.

NOTE 2 See also ISO 3183:2012, Introduction.

This document is not applicable to field cold bends and 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 80000-1:2009, *Quantities and units — Part 1: General*

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

ISO 3183:2012, *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 9712, *Non-destructive testing — Qualification and certification of NDT personnel*

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*

ASNT SNT-TC-1A, *Recommended Practice No. SNT-TC-1A: Personnel Qualification and Certification in Nondestructive Testing*

ASTM A370, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

ASTM A435, *Standard Specification for Straight-Beam Ultrasonic Examination of Steel Plates*

ASTM A578/ *A578M, Standard Specification for Straight-Beam Ultrasonic Examination of Rolled Steel Plates for Special Applications*

ASTM E18, *Standard Test Methods for Rockwell Hardness of Metallic Materials*

ASTM E92, *Standard Test Method for Vickers Hardness of Metallic Materials*

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

ASTM E165, *Standard Test Method for Liquid Penetrant Examination*

ASTM E213, *Standard Practice for Ultrasonic Testing of Metal Pipe and Tubing*

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

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

ASTM E709, *Standard Guide for Magnetic Particle Testing*

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

ASTM G39, *Standard Practice for Preparation and Use of Bent-Beam Stress-Corrosion Test Specimens*

NACE/TM 0177:2016, *Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking in Hydrogen Sulfide (H_2S) Environments*

NACE/TM 0284:2016, *Standard 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 terminological databases for use in standardization at the following addresses:

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

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

3.1
arc
curved portion of a bend

3.2
agreed
agreed upon by the *manufacturer* (3.17) and *purchaser* (3.21), and specified in the purchase order

3.3
bend angle
amount of directional change through the cold bend

3.4
bend qualification test
qualification test that produces a cold bend in accordance with the *MPS* (3.18) and demonstrates that bends that meet the specified requirements of this document can be produced

3.5
bend radius
distance from the centre of curvature to the centreline axis of the bent pipe

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

3.7
defect
imperfection (3.11) of a size and/or population density greater than specific acceptance criteria

Note 1 to entry: The specific acceptance criteria are specified in ISO 3183.

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

3.9
heat
batch of steel prepared in one steel-making operation

3.10
if agreed
required to be as prescribed, or more stringent than is prescribed, if agreed upon by the *manufacturer* (3.17) and the *purchaser* (3.21) and specified in the purchase order

3.11
imperfection
discontinuity or irregularity in the product wall or on the product surface that is detectable through inspection methods

3.12
indication
evidence obtained by *non-destructive inspection* (3.20)

3.13
cold bending
controlled bending process using presses at room temperature

3.14
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

3.15
intrados
inner curved section of the *arc* (3.1)

3.16
lamination
internal metal separation that creates layers, generally parallel to the pipe/bend surface

3.17
manufacturer
firm, company, or corporation responsible for making and marking the product

3.18
manufacturing procedure specification
MPS
document that specifies the properties and description of the *mother pipe* (3.19), the cold bending procedure, the post- bending heat treatment equipment and cycle, if applicable, the qualification bend testing results, the non-destructive testing procedures and the weld end bevel details used for the manufacture of the cold bends

3.19
mother pipe
straight section of pipe from which a cold bend is made

3.20
non-destructive inspection
inspection (3.14) to reveal *imperfections* (3.11), using radiographic, ultrasonic or other methods that do not involve disturbance, stressing or breaking of the materials

3.21
purchaser
party responsible for both the definition of the requirements for a product order and the payment of that order

3.22
submerged-arc welding
SAW
welding process that produces melting and coalescence of metals by heating them with an arc(s) between a bare metal consumable electrode(s) and the workpiece, wherein the *arc* (3.1) and molten metal are shielded by a blanket of granular flux

3.23
service condition
condition of use that is specified by the *purchaser* (3.21) in the purchase order

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

3.24
strip end weld
weld that joins strip ends together

3.25
plate end weld
weld that joins plate ends together

3.26
tangent
straight section at the ends of a cold bend

3.27
wall thinning
amount of reduction from the actual wall thickness of the pipe to the wall thickness in the *extrados* (3.8) after *cold bending* (3.13)

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 diameter, outside or inside
D_{max}	maximum measured diameter, outside or inside
D_{min}	minimum measured diameter, outside or inside
Dn	nominal pipe diameter
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
$R_{t,0,5}$	yield strength for 0,5 % total elongation
t_i	minimum wall thickness at the bend intrados
t_{min}	minimum wall thickness required in accordance with ISO 13623, or other applicable design code, for the straight pipe adjacent to the bend, including any corrosion allowance

4.2 Abbreviated terms

BQT	cold bend qualification test
CB	cold bending
CTOD	crack tip opening displacement testing
CVD	crest to valley depth

HAZ	heat-affected zone
HIC	hydrogen-induced cracking
HFW	high-frequency electric welding process for pipe during manufacturing
MT	magnetic particle testing
NDT	non-destructive testing
OD	outside diameter
PSL	product specification level
PT	liquid-penetrant testing
RT	radiographic testing
SAW	submerged arc welding process for pipe during manufacture
SAWH	submerged arc helical welding process for pipe during manufacture
SAWL	submerged arc longitudinal welding process for pipe during manufacture
SSC	sulfide stress-cracking
SWC	step-wise cracking
UT	ultrasonic testing
5D	5 xOD
10D	10 xOD

5 Conformance

5.1 Units of measurement

In this document, data are expressed in both SI units and USC 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.

For data expressed in SI units, a comma is used as the decimal separator and a space is used as the thousands separator. For data expressed in USC units, a dot (on the line) is used as the decimal separator and a space is used as the thousands separator.

5.2 Rounding

Unless otherwise stated in this document, to determine conformance 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 80000-1:2009, Annex B, Rule A.

NOTE For the purposes of this provision, the rounding method of ASTM E29-04[3] is equivalent to ISO 80000-1:2009, Annex B, Rule A.

5.3 Conformity to this document

A contract may specify that the manufacturer shall be responsible for conforming with 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 of cold bends

Designation of cold bends according to this document, i.e. ISO 15590-4, shall take one of the following forms:

ISO 15590-4-CB xxx-PSL 1;

ISO 15590-4-CB xxx-PSL 2;

ISO 15590-4-CB xxx-PSL 2S;

ISO 15590-4-CB xxx-PSL 2O;

ISO 15590-4-CB xxx-PSL 2SO

In this designation, the elements have the following meaning:

xxx: specified minimum yield strength, expressed in mega pascals (MPa);

PSL 1 or PSL 2: identifier for the technical delivery conditions class for cold bends in non-sour service;

PSL 2S: identifier for PSL 2 bends for use in sour service conditions;

PSL 2O: identifier for PSL 2 bends for use in offshore service conditions;

PSL 2SO: Identifier for PSL 2 bends for use in both offshore and sour service conditions.

7 Pressure rating and design

The hoop stress in the cold bend due to internal fluid pressure shall not exceed the hoop stress permitted in ISO 13623, or other applicable design code, for straight pipe in the location of the bend.

NOTE 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):

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

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

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

8 Information provided by the purchaser

8.1 General information

The purchaser shall provide the following information:

a) number of this document and year of publication (i.e. ISO 15590-4:2019);

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 cold bending,
- bend radius,
- bend angle and
- tangent lengths.

f) end preparation, if different from square ends;

g) equipment and method used for cold bend.

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, i.e. 15590-4;

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

h) pipeline operating conditions;

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

j) Charpy impact test temperature;

k) requirements for proof, burst or hydrostatic testing;

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

m) surface condition;

n) coating or painting requirements;

o) marking requirements, if different from this document, i.e. 15590-4;

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

q) packaging and shipping instructions;

r) third-party inspection organization;

s) inspection document required in accordance with ISO 10474;

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

u) additional requirements for hardness testing;

v) 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 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.

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

9 Manufacturing

9.1 Mother pipe

Mother pipe shall be manufactured in accordance with ISO 3183.

Mother pipe for the manufacture of PSL 2 bends shall be in accordance with ISO 3183 PSL 2.

Mother pipe for the manufacture of PSL 2S bends shall be made in accordance with ISO 3183:2012, Annex H, with the additional requirements specified in Annex B of this document.

Mother pipe for the manufacture of PSL 2O bends shall be made in accordance with ISO 3183:2012, Annex J.

Mother pipe for the manufacture of PSL 2SO bends shall be made in accordance with ISO 3183:2012, Annex H; ISO 3183:2012, Annex J; and the additional requirements specified in Annex B of this document.

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 on the required properties and dimensions of the mother pipe (including seam weld and seam repair weld) regarding its suitability for cold bending.

The body of the mother pipe shall have no weld repairs.

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

9.2 Qualification test bend

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

NOTE Annex A gives details on MPS.

A test bend with at least sufficient arc length to conform to Table 1 shall be manufactured in accordance with each preliminary MPS. The inspection and testing of the test bend shall include sufficient tangents, if included in the produced bends.

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

— the values recorded during the manufacturing of the test bend, and

— the permissible range during production bending.

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

9.3 Production cold bending

Cold bending shall be carried out in accordance with an MPS as specified in Annex A.

9.4 Post-bending heat treatment

Post-bending heat treatment may be performed to achieve the required material properties, improve corrosion resistance or to relieve residual stresses due to cold bending process.

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.

Heat treatment of stress relieving after cold bending is required for up to a 10D radius, irrespectively of the service.

Heat treatment of stress relieving after cold bending is required for any radius for sour or offshore service.

The heat treatment of stress relieving will be carried out between 480 °C and 675 °C, with holding time 30 minutes for 25,4 mm (1 in), but never less than 30 minutes and cooling in the furnace or in still air. The maximum cooling rate shall be 200 °C/h.

Due to the inherent characteristics of the TMCP method, plates manufactured to this specification cannot be formed or post-weld heat treated at a temperature above 595 °C, without some risk of sustaining irreversible and significant losses in strength and toughness.

9.5 Forming and sizing after bending

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 %.

Table 1 — Essential variables and maximum permissible variations

Essential variable	Maximum permissible variations[a]
Pipe grade	None
Pipe manufacturer	None
[a] The permissible variations apply to the values obtained in the approved to BQT.	
[b] The pipe long seam shall be placed on the neutral axis during bending. It does not apply to SAWH pipes.	

Table 1 *(continued)*

Essential variable	Maximum permissible variations[a]
Mother pipe seam weld WPS and welding consumables	None
Cold bending machine tools	None
Mother pipe process of manufacture	None
Cold bending machine	None
Nominal mother pipe diameter	None
Nominal mother pipe wall thickness	±3 mm (0.118 in) or ±10 % whichever is the smallest
Bend radius	An approved MPS qualifies all larger radii (but not smaller) in the following ranges: a) 5*D* up to and including 7*D* b) >7*D* up
Longitudinal weld seam location	±15° from the location in the test bend[b]
Post-bending heat treatment	Method: no change Soaking time: $^{+15}_{0}$ min Soaking temperature: ±15 °C (±27 °F) Heating and cooling rates by agreement

[a] The permissible variations apply to the values obtained in the approved to BQT.

[b] The pipe long seam shall be placed on the neutral axis during bending. It does not apply to SAWH pipes.

9.6 Strip/plate end welds

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

9.7 Jointers and girth welds

Whenever possible, the girth weld should be at least 1 m far from the bend section. When girth welds are within 1 m from the bend area or in the bend section, it shall be subjected to radiography examination after bending.

9.8 End preparation

Cold 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 required in Clause 10 have been performed and all results meet the specified requirements.

Except where otherwise stated in Clause 10, the testing and inspection methods and acceptance criteria for cold bend shall be as required by ISO 3183 for pipe of the same steel grade and type.

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

Testing and inspection shall be carried out on cold bends after final heat treatment of stress relieving, when applicable.

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 1.

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 with the requirements for pipe of the same grade and type as specified in ISO 3183.

10.4 Physical testing

10.4.1 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

Test specimens shall be taken from cold bend in final condition, after heat treatment of stress relieving (if any) and NDT testing. Test specimens shall be in accordance with ASTM A370 or ISO 6892-1, using rectangular full-size specimens or the largest sub-size specimens allowed. Flattening of test pieces shall be carried out according to ISO 3183:2012, 10.2.3.2.

Table 2 — Summary of testing and inspection requirements

Test		PSL 1	PSL 2	Acceptance
Physical tests	Tensile	T[c]	T[c]	In accordance with ISO 3183 and with 10.4.2.1 and 10.4.2.2
	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[a]	In accordance with B.4.2
	SSC	N	T[ab]	In accordance with B.4.3
	CTOD	N	O	By agreement
	Guided bend (weld seam)	[e]	[e]	In accordance with ISO 3183
	Flattening	[e]	[e]	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)[d]	[e]	T and P	In accordance with 10.5.2 or B.7.3
	Bend ends (laminations)[d]	P	P	In accordance with 10.5.3 or B.7.1
	Bend body (MT or PT)[d]	T and P	T and P	In accordance with 10.5.4
	Bend body (UT) transverse defects[d]	N	T and P	In accordance with 10.5.5 or B.7.2
	Bend body (UT) laminations[e]	N	[e]	In accordance with 10.5.5 or B.7.2
	Residual magnetism ends	P	P	In accordance with 10.5.6
	Repairs	P	P	In accordance with ISO 3183 and 10.5.7
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	T and P	T and P	In accordance with 10.6
	Out-of-roundness body	T and P	T and P	In accordance with 10.6
	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		In accordance with 10.7
Hydrostatic test		By agreement		In accordance with 10.8

Table 2 *(continued)*

Test	PSL 1	PSL 2	Acceptance
key N: Not required. O: Performance of the test or inspection on a production cold bend might be required by agreement. P: Required for each production cold bend. T: Required for each test cold bend. [a] Required only for PSL 2S bends. [b] By agreement; requirement for SSC testing of seamless pipe bends may be waived. [c] 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. [d] By agreement, may be waived when bend radii is above 20D (for D up to 200 mm), 30D (for D over 200 mm to 400 mm) and 40D (for D over 400 mm). If heat treatment is applied, all prescribed tests shall be done [e] Testing of the cold bend are not 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 manufacturing procedure specification, while NDT and dimensional testing shall be conducted on each pipe or bend.			

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 Through-thickness hardness Metallography Guided bend
Bend extrados base metal	Tensile Impact Through-thickness hardness Metallography HIC and SSC
Bend intrados base metal	Tensile Impact Through-thickness hardness
Bend weld	Tensile transverse Impact Through-thickness hardness Metallography for PSL-2 only Guided bend HIC and SSC
[a] Testing after bending is not necessary if test results are available for mother pipe and the tangent and the bend are not heat-treated during cold bending or subsequent heat treatment of stress relieving.	

10.4.2.2 Test method

Tensile testing at ambient temperature shall be carried out in accordance with ISO 6892-1 or ASTM A370.

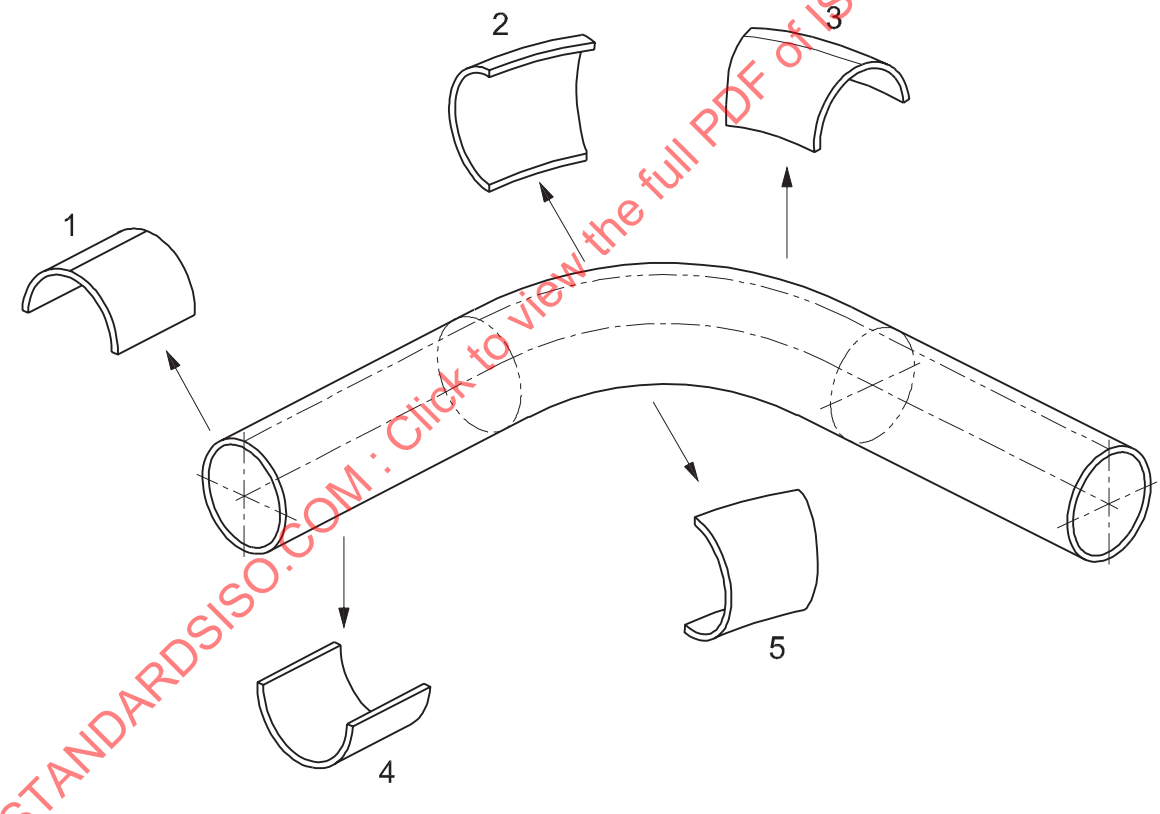
Number, orientation and location of test pieces per sample for mechanical tests in accordance with ISO 3183:2012, Table 20.

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 and tangent.

The percentage elongation after fracture shall be reported with reference to a gauge length of 50 mm (2 in). For test pieces having a gauge length less than 50 mm (2 in), the measured elongation after fracture shall be converted to a percentage elongation in 50 mm (2 in) in accordance with ISO 3183:2012, 10.2.4.2.

For weld transverse tensile tests, only R_m is required.



Key

1 tangent weld
2 bend extrados base metal
3 bend weld
4 tangent base metal
5 bend intrados base metal

Figure 1 — Location for extraction of samples for testing

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 or 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 (0.394 in) and 5 mm (0.197 in). If transverse test pieces with a minimum width of 5 mm (0.197 in) are not possible, longitudinal test pieces with the greatest possible width between 10 mm (0.394 in) and 5 mm (0.197 in) 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 (0.197 in).

All Charpy V-notch test pieces shall be taken from the sample at a depth of no more than 2 mm (0.079 in) below the outer surface as illustrated in Figure 2.

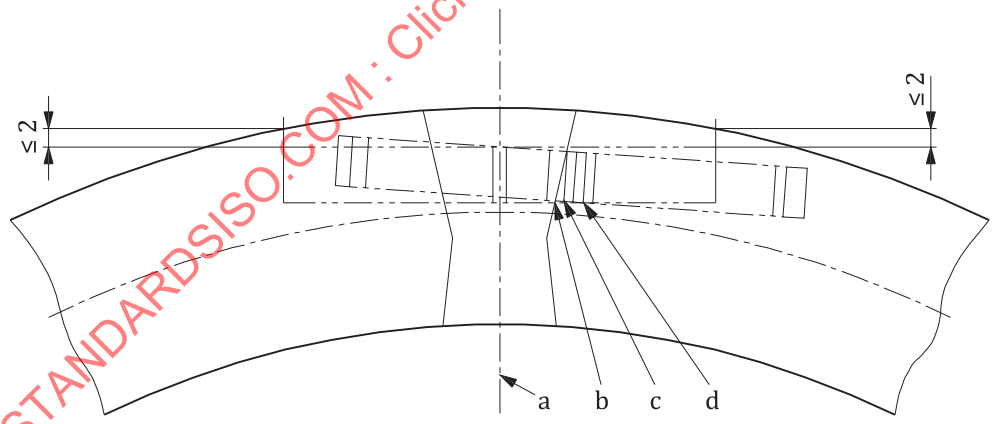
Test pieces from welds in SAW pipe with a mother pipe nominal wall thickness not exceeding 25 mm (0.984 in) shall be taken across the weld with the notch at the four locations indicated in Figure 2. The distance of notch location from the fusion line shall be determined with reference to the centreline 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 and one set with the notch located 2 mm (0.079 in) 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 (0.984 in), the locations of test pieces shall be by agreement.

Dimensions in millimetres



a Weld centreline.

b Fusion line.

c Fusion line plus 2 mm (0.079 in).

d Fusion line plus 5 mm (0.197 in).

Figure 2 — 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 or 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 (32 °F) or the minimum design temperature. A lower test temperature may be used by agreement.

10.4.3.3 Requirements

For bends from mother pipe with a nominal wall thickness up to and including 25 mm (0.984 in), 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 or ASTM E92, or with the Rockwell test using Rockwell test HR 15N in accordance with the ISO 6508 series or ASTM E18. In case of dispute, the Vickers method shall apply. Hardness indent locations shall be in accordance with ISO 3183.

10.4.4.2 Requirements

Hardness readings shall not exceed 300 HV10, or equivalent (see ASTM E140[4]) for PSL 2 bends.

Cold 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 testing device shall be at the manufacturer's option 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 through-thickness hardness testing (see 10.4.4) shall be examined, prior to hardness testing, 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 and tangent weld after completion of all post-bend heat treatment shall be prepared at magnifications of 100× and 400×.

Unless otherwise agreed, the micrographic examination shall be made at a distance of 2,0 mm (0.079 in) from the external and internal surfaces and at a mid-wall position. For a wall thickness of 10 mm (0.39 in) 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 external surface of the extrados of the arc of the bend. 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 cold bending and any subsequent heat treatment of stress relieving 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 Guided bend testing

10.4.7.1 Test pieces

Test pieces shall be prepared in accordance with ISO 7438 or ASTM A370.

For bends with a wall thickness >20 mm (0.787 in), the test pieces may be machined to provide a rectangular cross section having a thickness of 19 mm (0.748 in). Full-thickness, curved section test pieces are required for a pipe wall thickness ≤20 mm (0.787 in). Welds shall be ground flush at both faces.

10.4.7.2 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.

10.4.8 Flattening tests

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

10.5 Non-destructive testing

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.

10.5.1 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 3, is acceptable provided that the following requirements are met.

— The wave shapes blend into the pipe surface in a gradual manner with a maximum 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} for the purposes of its inclusion in a mathematical expression, shall be determined as given in Formula (2):

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

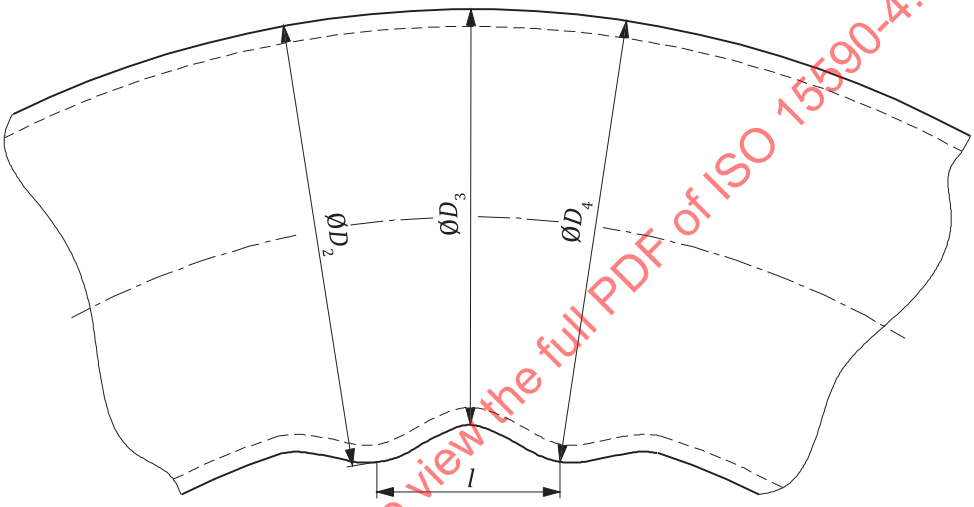


Figure 3 — Schematic diagram for measurement of waving

10.5.2 Weld seam testing

RT or UT of the weld seam shall be required for

— the complete weld seam in the arc, and

— the end 250 mm (9.843 in) of the tangent.

The acceptance criteria shall be as stated in ISO 3183.

10.5.3 Inspection of bend ends

After end preparation, the complete end preparation and 100 mm (3.937 in) of the weld seam shall be inspected by MT or PT.

MT of bend ends shall be performed in accordance with ISO 10893-5 or ASTM E709. PT shall be performed in accordance with ISO 10893-4 or ASTM E165. Laminar imperfections greater than 6,4 mm (0.250 in) in the circumferential direction shall be classified as defects.

For PSL 2 bends, a 50 mm (1.968 in) wide band at each end shall be inspected for laminar imperfections by UT in accordance with ISO 10893-8, ASTM A435 or ASTM A578/A578M. Laminar imperfections shall not exceed 6,4 mm (0.250 in) in the circumferential direction or have an area in excess of 100 mm^2 (0.16 in^2).

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

For all cold 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 or ASTM E709, or PT in accordance with ISO 10893-4.

All cracks, laps, laminations and all rounded indications greater than 3 mm (0.118 in) in any direction shall be classed as defects and shall be repaired in accordance with 10.5.7.

10.5.5 Ultrasonic testing on the bend body

If required, ultrasonic testing in accordance with ISO 10893-10 and shall be performed over an arc of 180°, 90° each side of the extrados to verify that the bend is free from transverse defects.

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

10.5.6 Level of residual magnetism

The level of residual magnetism shall not exceed 2 mT.

10.5.7 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.

10.5.8 NDT personnel

All NDT personnel shall be qualified in accordance with ISO 9712, ASNT SNT-TC-1A or equivalent level of competence.

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 three locations at the intrados and three locations at the extrados by ultrasonic methods in accordance with ASTM E797 or ASTM E214.

The bend angle may be determined either using a clinometer or as follows; see Figure 4.

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.

The radius may be determined by trigometric formula using cord and height of the arced portion: see Figure 4.

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 5.

If the tangent end keeps the original mother pipe end, the end out-of-squareness measurement may be waived.

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 6. Practical measurement methods shall be by agreement.

Out-of-roundness, O, expressed as a percent, is as given in Formula (3):

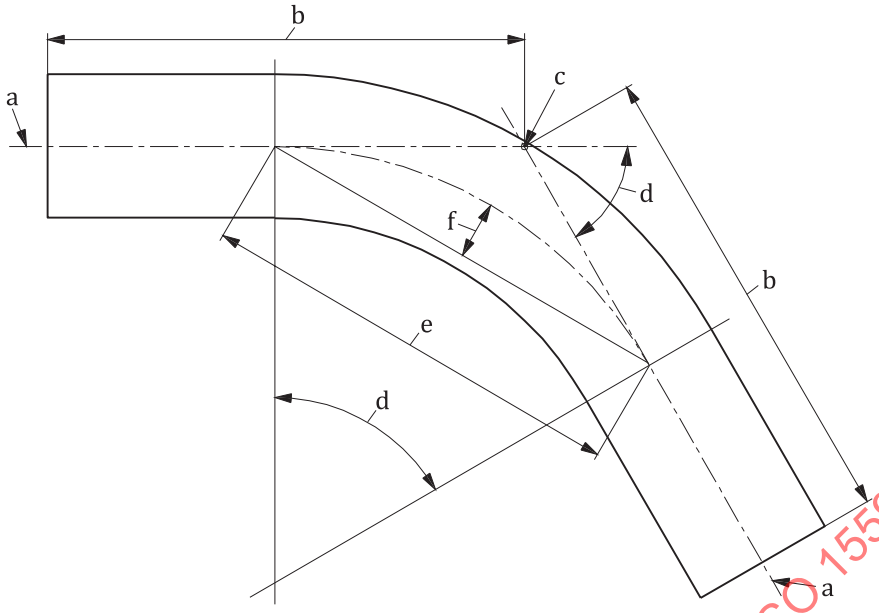
$$O = \frac{D_{\max} - D_{\min}}{D} \times 100 \tag{3}$$

Table 4 — Permissible dimensional tolerances

Dimension	Permissible tolerance
Linear dimensions[a]	±30 mm (1.18 in)
Minimum wall thickness	Zero
Maximum wall thickness	By agreement
Inside or outside diameter[b] of bend ends	ISO 3183:2012, Table 10 or J.3, 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 (0.394 in)
End out-of-squareness	1,6 mm (0.063 in) max.
Out-of-planeness	± bend angle × 10 /90 mm or 5 mm, whichever is greater
Out-of-roundness at ends	ISO 3183:2012, Table 10 or J.3, as specified in the purchase order
Out-of-roundness in bend body	$r_b \geq 5D$; 2,5 % max.

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

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



a Centreline axis.
b Centre to end.
c Centre of bend.
d Bend angle.
e Chord.
f Height of the arced portion.

Figure 4 — Dimensions for determination of bend angle

10.7 Gauging

All bends shall be tested with a gauging device. The gauging device shall consist of two rigidly joined plates separated by at least 1 × D. For pipelines that will be pigged, the plates shall be separated by at least 1,5 × D. For determining the diameter of the gauging plate, the following formula shall be used:

$$D_p = 0{,}975D_n - 2t$$

where

D_p Gauging plate diameter expressed in mm;

D_n Nominal pipe diameter expressed in mm;

t Wall thickness expressed in mm.

10.8 Hydrostatic testing

If hydrostatic testing is specified by the purchaser, the methods and requirements shall be by agreement.

NOTE Hydrostatic testing of bends is not required for any bend product specification level.

11 Inspection document

The purchaser shall specify the required ISO 10474 designation of inspection document and any specific requirements for format and content of the document. MPS qualification test results shall be included in the inspection documents.

12 Marking

Both ends of each bend shall be marked with the following information:

— manufacturer's name or trade mark;

— cold bending ISO 15590-4;

— diameter, outside or inside;

— minimum wall thickness;

— bend designation, as defined in Clause 6;

— bend angle;

— bend radius;

— purchase order and item number;

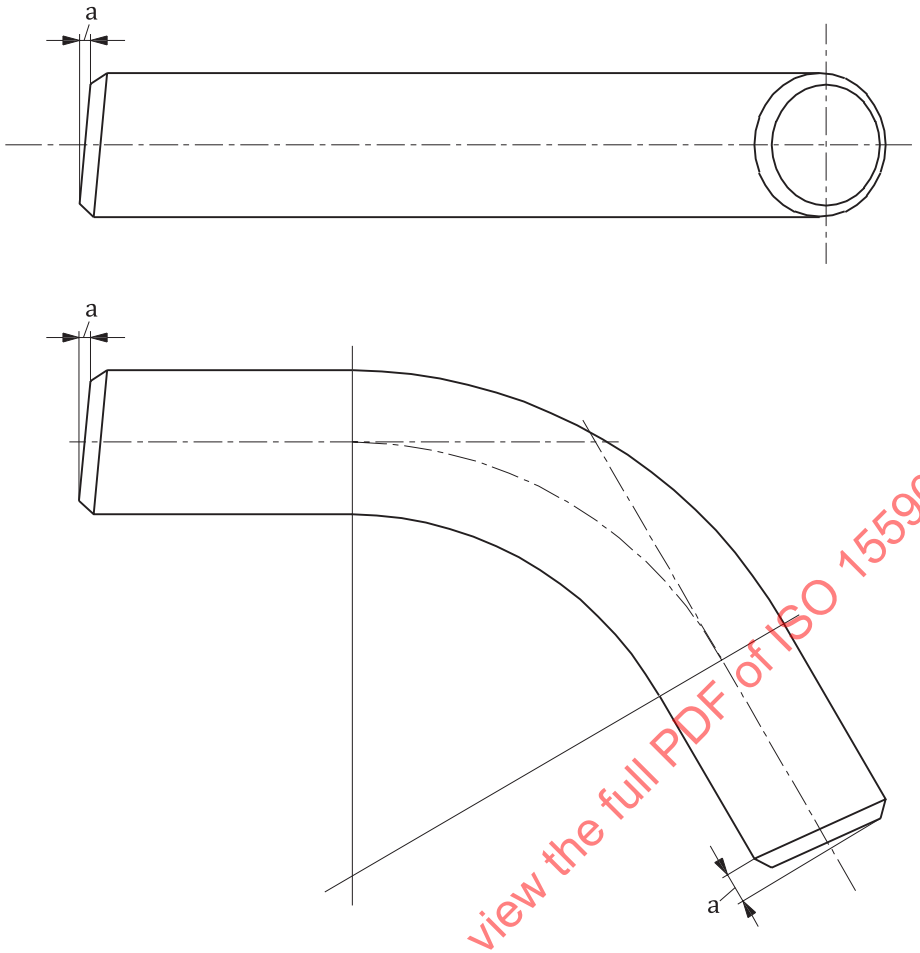
— heat number or manufacturer's heat identification;

— unique bend number;

— any additional marking specified in the purchase order.

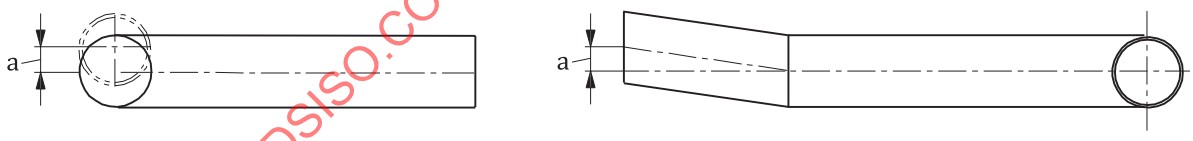
Markings shall be in block capitals with indelible paint on the inside surface or, if it is not possible to mark on the inside surface, on the outside for smaller diameter bends. Metal labels shall be used for bends with a diameter not exceeding 90 mm (3.500 in).

For bends with a nominal outside diameter of above 90 mm (3.500 in) and not exceeding 219,1 mm (8.625 in) markings shall be with a minimum height of 10 mm (0.397 in). For larger diameter bends, the height of the marking shall be a minimum of 19 mm (0.748 in). Identification markings shall not be stencilled or painted on the weld preparation.



[a] Out-of-squareness.

Figure 5 — Determination of end out-of-squareness



[a] Out-of-planeness.

Figure 6 — Determination of out-of-planeness