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

**Part 1:
Induction bends**

*Industries du pétrole et du gaz naturel — Coudes d'induction, raccords
et brides pour systèmes de transport par conduites —*

Partie 1: Coudes d'induction



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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 15590-1 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*.

This second edition cancels and replaces the first edition (ISO 15590-1:2001), which has been technically revised.

It is the intent of ISO/TC 67 that the first and second edition of ISO 15590-1 both be applicable, at the option of the purchaser (as defined in 4.20), for a period of six months from the first day of the calendar quarter immediately following the date of publication of this second edition, after which period ISO 15590-1:2001 will no longer be applicable.

ISO 15590 consists of the following parts, under the general title *Petroleum and natural gas industries — Induction bends, fittings and flanges for pipeline transportation systems*:

- *Part 1: Induction bends*
- *Part 2: Fittings*
- *Part 3: Flanges*

Introduction

This International Standard makes reference to line pipe and bends with delivery conditions based on ISO 3183. Following significant revision of ISO 3183 (ISO 3183:2007), ISO 15590-1 has been reviewed and redrafted taking cognizance of the changes to ISO 3183. In addition to general revision, and in common with ISO 3183:2007, the Technical Committee have introduced additional requirements for special applications as follows:

- Manufacturing procedure specification (Annex A);
- PSL 2 bends for sour service (Annex B).

The requirements of the annexe(s) apply only when it is (they are) specified on the purchase order.

This International Standard does not provide guidance on when it is necessary to specify the above supplementary requirements. Instead it is the responsibility of the purchaser to specify, based upon the intended use and design requirements, which, if any, of the supplementary requirements apply for a particular purchase order.

It is necessary that users of this part of ISO 15590 be aware that further or differing requirements can be needed for individual applications. This part of ISO 15590 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 any variations from this part of ISO 15590 and provide details.

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

Part 1: Induction bends

1 Scope

This part of ISO 15590 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 part of ISO 15590 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 part of ISO 15590 specifies the requirements for the manufacture of two product specification levels (PSLs) of induction bend corresponding to product specification levels given for pipe in ISO 3183.

This part of ISO 15590 is not applicable to the selection of the induction bend product specification level. It is the responsibility of the purchaser to specify the PSL, based upon the intended use and design requirements; see also ISO 3183:2007, Introduction.

This part of ISO 15590 is not applicable to pipeline bends made by other manufacturing processes.

2 Conformance

2.1 Units of measurement

In this International Standard, 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.

2.2 Rounding

Unless otherwise stated in this International Standard, 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 31-0:1992, Annex B, Rule A.

NOTE For the purposes of this provision, the rounding method of ASTM E29-04^[2] is equivalent to ISO 31-0:1992, Annex B, Rule A.

2.3 Compliance to standard

A quality management system should be applied to assist compliance with the requirements of this International Standard.

NOTE ISO/TS 29001^[1] gives sector-specific guidance on quality management systems.

A contract may specify that the manufacturer shall be responsible for complying with all of the applicable requirements of this International Standard. It shall be permissible for the purchaser to make any investigation necessary in order to be assured of compliance by the manufacturer and to reject any material that does not comply.

3 Normative references

The following referenced documents are indispensable for the application 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 31-0:1992, *Quantities and units — Part 0: General principles*

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

ISO 783, *Metallic materials — Tensile testing at elevated temperature*

ISO 3183:2007, *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, *Metallic materials — Tensile testing at ambient 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 9303:1989, *Seamless and welded (except submerged arc-welded) steel tubes for pressure purposes — Full peripheral ultrasonic testing for the detection of longitudinal imperfections*

ISO 9305, *Seamless steel tubes for pressure purposes — Full peripheral ultrasonic testing for the detection of transverse imperfections*

ISO 9712, *Non-destructive testing — Qualification and certification of personnel*

ISO 9764:1989, *Electric resistance and induction welded steel tubes for pressure purposes — Ultrasonic testing of the weld seam for the detection of longitudinal imperfections*

ISO 10124, *Seamless and welded (except submerged arc-welded) steel tubes for pressure purposes — Ultrasonic testing for the detection of laminar imperfections*

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

ISO 11496, *Seamless and welded steel tubes for pressure purposes — Ultrasonic testing of tube ends for the detection of laminar imperfections*

ISO 12094, *Welded steel tubes for pressure purposes — Ultrasonic testing for the detection of laminar imperfections in strips/plates used in the manufacture of welded tubes*

ISO 12095, *Seamless and welded steel tubes for pressure purposes — Liquid penetrant testing*

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

ISO 13663, *Welded steel tubes for pressure purposes — Ultrasonic testing of the area adjacent to the weld seam for the detection of laminar imperfections*

ISO 13664, *Seamless and welded steel tubes for pressure purposes — Magnetic particle inspection of the tube ends for the detection of laminar imperfections*

ISO 13665, *Seamless and welded steel tubes for pressure purposes — Magnetic particle inspection of the tube body for the detection of surface imperfections*

ASNT SNT-TC-1A¹⁾, *Recommended Practice No. SNT-TC-1A: Personnel Qualification and Certification in Nondestructive Testing*

ASTM A370²⁾, *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 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 TM0177-2005³⁾, *Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking in Hydrogen Sulfide (H₂S) Environments*

NACE TM0284-2003, *Standard Test Method — Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking*

1) American Society for Nondestructive Testing, 1711 Arlingate Lane, Columbus, OH 43228-0518, USA.

2) American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA.

3) NACE International, 1440 South Creek Drive, P.O. Box 201009, Houston, TX 77084-4906, USA.

4 Terms and definitions

For the purposes of this part of ISO 15590, the following terms and definitions apply.

4.1

arc

curved portion of a bend

4.2

as agreed

requirement that shall be as agreed upon by the manufacturer and purchaser, and specified in the purchase order

Modified from ISO 3183:2007, 4.1.

4.3

bend angle

amount of directional change through the bend

4.4

bend qualification test

qualification test that produces a bend in accordance with the MPS and demonstrates that bends that meet the specified requirements of this part of ISO 15590 can be produced

4.5

bend radius

distance from the centre of curvature to the centreline axis of the bent pipe

4.6

defect

imperfection of a size and/or population density greater than the acceptance criteria specified in this part of ISO 15590

4.7

extrados

outer curved section of the bend arc

4.8

heat

batch of steel prepared in one steel-making operation

4.9

if agreed

requirement that shall be as prescribed, or more stringent than is prescribed, if agreed upon by the manufacturer and the purchaser and specified in the purchase order

Modified from ISO 3183:2007, 4.19.

4.10

imperfection

discontinuity or irregularity in the product wall or on the product surface that is detectable by inspection methods outlined in this International Standard

4.11

indication

evidence obtained by non-destructive inspection

4.12**induction bending**

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

4.13**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

[ISO 3183:2007, 4.22]

4.14**intrados**

inner curved section of the bend arc

4.15**lamination**

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

4.16**manufacturer**

firm, company, or corporation responsible for making and marking the product in accordance with the requirements of this International Standard

4.17**manufacturing procedure specification****MPS**

document that specifies the properties and description of the mother pipe, the bending procedure, the post-bending heat treatment equipment and cycle, the qualification bend testing results, the non-destructive testing procedures and the weld end bevel details used for the manufacture of the bends

4.18**mother pipe**

straight section of pipe from which an induction bend is made

4.19**non-destructive inspection**

inspection to reveal imperfections, using radiographic, ultrasonic or other methods specified in this International Standard that do not involve disturbance, stressing or breaking of the materials

[ISO 3183:2007, 4.30]

4.20**purchaser**

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

[ISO 3183:2007, 4.38]

4.21**service condition**

condition of use that is specified by the purchaser in the purchase order

NOTE In this International Standard, the terms “sour service” and “offshore service” are service conditions.

[ISO 3183:2007, 4.45]

4.22

strip/plate end weld

weld that joins strip or plate ends together

4.23

tangent

straight section at the ends of an induction bend

4.24

transition zone

areas of the start and stop points of induction heating, which include material that extends from the unheated mother pipe to the material that has been heated to the full bending temperature

4.25

wall thinning

amount of reduction from the original wall thickness of the pipe to the wall thickness in the extrados after bending

5 Symbols and abbreviated terms

5.1 Symbols

A	elongation of tensile test specimen after fracture, expressed as a percentage
CVD, 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
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
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, or other applicable design code, for the straight pipe adjacent to the bend, including any corrosion allowance

5.2 Abbreviated terms

BQT	bend qualification test
CTOD	crack tip opening displacement testing
DWT	drop-weight tear testing
HAZ	heat-affected zone
HIC	hydrogen-induced cracking
HFW	high-frequency electric welding process for pipe during manufacturing

MPS	manufacturing procedure specification
MT	magnetic particle testing
NDT	non-destructive testing
PSL	product specification level
PT	liquid-penetrant testing
RT	radiographic testing
SAWL	submerged arc longitudinal welding process for pipe during manufacture
SAWH	submerged arc helical welding process for pipe during manufacture
SSC	sulfide stress-cracking
SWC	step-wise cracking
UT	ultrasonic testing
WPS	welding procedure specification

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.

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, or other applicable design code, for straight pipe in the location of the bend.

Compliance with this requirement shall be demonstrated either by calculations or by satisfying both of the following requirements.

- a) The wall thickness of the bend extrados shall be at least $t_{\min}$.
- b) The wall thickness at the bend intrados shall be at least as given in Equation (1):

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

For pipelines not designed in accordance with ISO 13623, the wall thickness of the bend extrados may 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 compliance with the strength requirements of ISO 13623.

8 Information that shall be supplied by the purchaser

8.1 General information

The purchaser shall provide the following information:

- a) number of this part of ISO 15590 and year of publication (i.e. ISO 15590-1:2009);
- 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 wall thickness,
 - 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 part of ISO 15590;
- 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 part of ISO 15590;
- q) packaging and shipping instructions;
- r) third-party inspection organization;
- s) standard designation of inspection document that is required in accordance with ISO 10474;
- t) requirements for format and additional content of the inspection document;
- u) requirements for hardness testing;
- v) other special requirements.

8.3 Information on the mother pipe

8.3.1 If the mother pipe is supplied by the purchaser, 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.

8.3.2 If available, the following additional information shall also be provided:

- a) pipe material specification and pipe material certificates, including chemical composition, heat treatment, mechanical properties, dimensions and results of NDT;
- b) welding procedure specification and weld metal chemical composition for SAWL and SAWH pipe;
- c) weld-seam-repair welding-procedure specification for SAWL and SAWH pipe.

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 3183:2007 PSL 2.

Mother pipe for the manufacture of PSL 2S bends shall be made in accordance with ISO 3183:2007, Annex H with the additional requirements specified in Annex B of this part of ISO 15590.

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 should 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.

9.2 Qualification test bend

The manufacture of all PSL-level test bends shall be carried out in accordance with an MPS that shall be 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 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

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 compliance with this part of ISO 15590.

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.

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.

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 provided the induced permanent strain does not exceed 1,5 %.

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 (0.118 in)
Bend radius	For $r_b \leq 5D$: $\begin{matrix} +25 \\ 0 \end{matrix} \%$ For $5D < r_b \leq 10D$: $\begin{matrix} +100 \\ 0 \end{matrix} \%$ For $r_b > 10D$: $\begin{matrix} +\infty \\ 0 \end{matrix} \%$
Forming speed	±2,5 mm/min (0.098 in/min)
Forming temperature	±25 °C (±45 °F)
Coil design	None
Coolant	None
Coolant flow rate or pressure	±10 %
Coolant temperature	±15 °C (± 27 °F)
Power	±5 % in steady conditions (except for seamless pipe, which is subject to agreement)
Induction heating frequency	±20 %
Weld seam location	±15° from the location in the test bend
Post-bending heat treatment	Method: no change Soaking time: $\begin{matrix} +15 \\ 0 \end{matrix} \text{ min}$ Soaking temperature: ±15 °C (±27 °F) Heating and cooling rates: by agreement
^a The permissible variations apply to the values obtained in the approved bend qualification test (BQT).	

9.6 Strip/plate end welds

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

9.7 Joints 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 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 induction bends 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 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 1.

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

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 and the extent of destructive testing shall be by agreement.

10.3 Chemical composition

The chemical composition of each bend shall comply with the requirements for pipe 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 by agreement.

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

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	T	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 ^b	In accordance with B.4.3
	SSC	N	T ^b	In accordance with B.4.4
	DWT	N	O	By agreement
	CTOD	N	O	By agreement
	Guided bend (weld seam)	M	M	In accordance with ISO 3183
	Flattening	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 10.5.3
	Bend body (MT or PT)	T and P	T and P	In accordance with 10.5.4
	Bend body (UT) transverse defects	N	T and P	In accordance with 10.5.5
	Bend body (UT) laminations	N	M	In accordance with 10.5.5
	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	P	P	In accordance with 10.6
	Out-of-roundness body	P	P	In accordance with 10.6
	Linear dimensions	P	P	In accordance with 10.6
	Angle	P	P	In accordance with 10.6
	Radius	O	O	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.
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 Required only for PSL 2S 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 Through-thickness hardness Metallography Guided bend
Transition zones base metal extrados, start and stop	Tensile ^c Impact ^c Through-thickness hardness ^c Metallography ^c
Transition zones welds, start and stop	Tensile transverse ^c Impact ^c
Bend extrados base metal	Tensile Impact Through-thickness hardness HIC and SSC ^{de}
Bend intrados base metal	Tensile Impact Through-thickness hardness
Bend weld ^b	Tensile transverse Impact Through-thickness hardness Metallography Guided bend HIC and SSC ^d

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

^b For SAWH bends, additional testing shall be by agreement.

^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.

10.4.2.2 Test method

Tensile testing at ambient temperature shall be carried out in accordance with ISO 6892 or 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 783 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 3183:2007, 10.2.4.2.

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

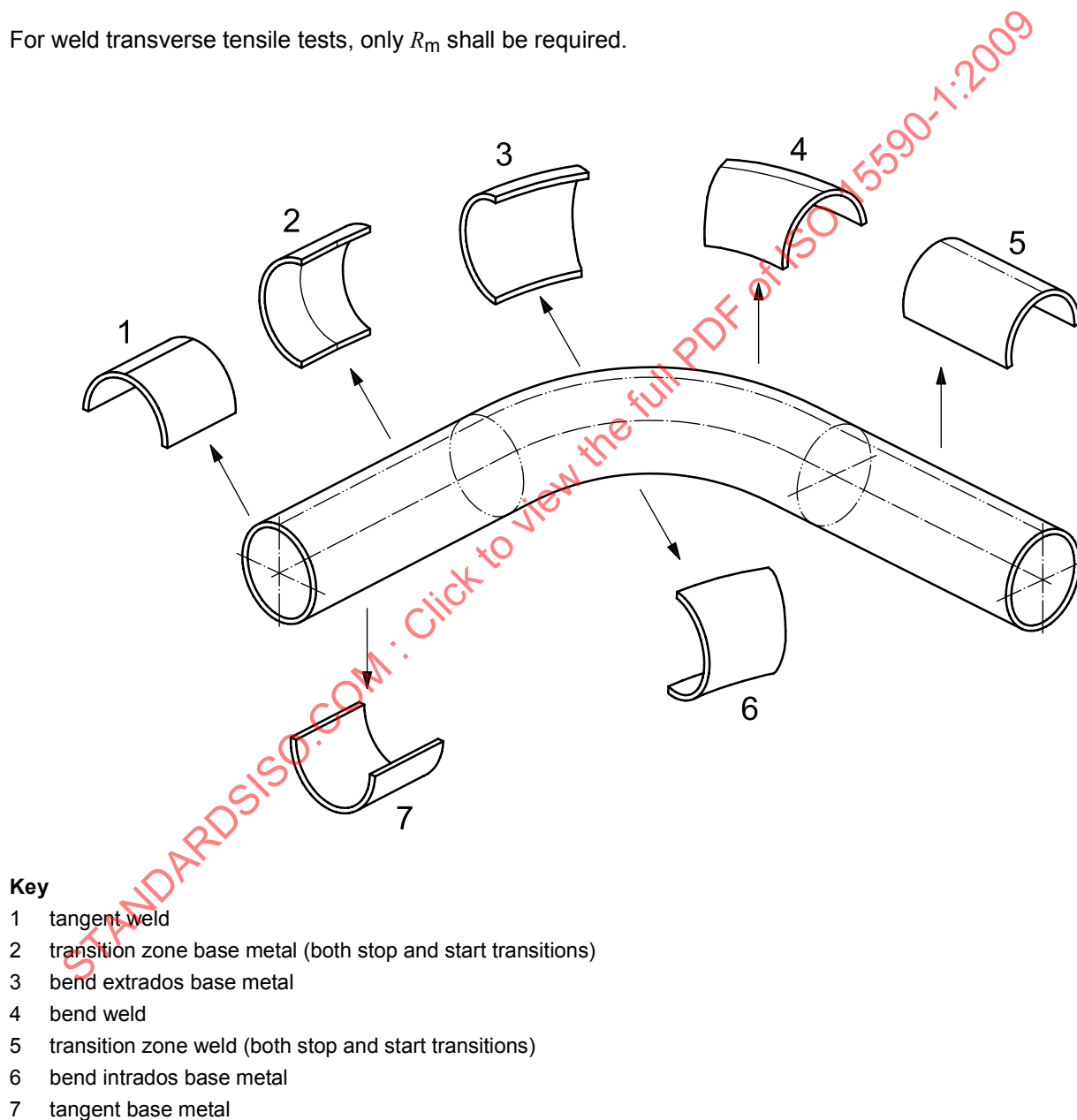
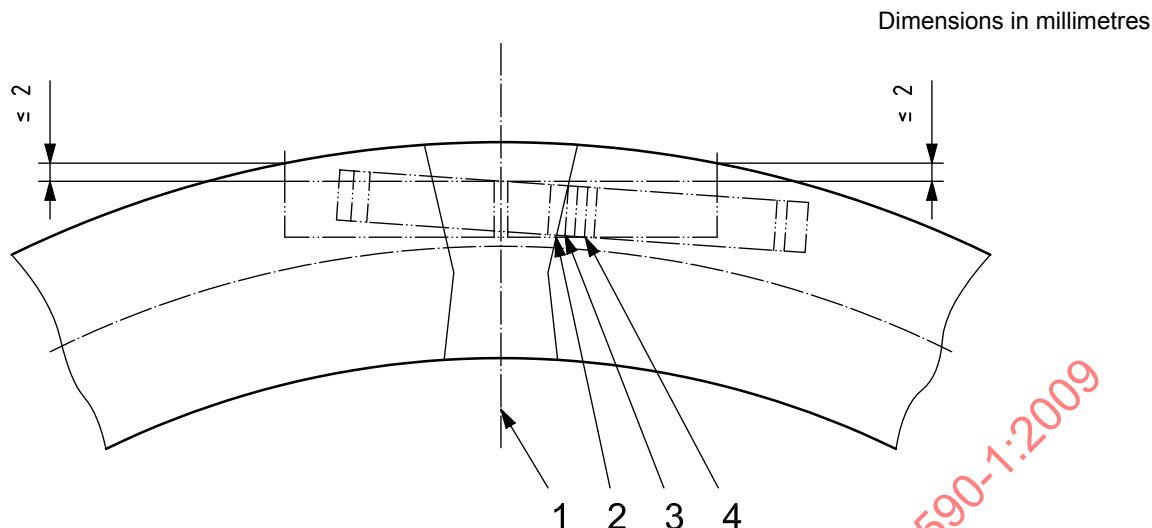


Figure 1 — Location for extraction of samples for testing



Key

- 1 weld centreline
- 2 fusion line
- 3 fusion line plus 2 mm (0.079 in)
- 4 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 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.

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 ISO 6507 or ASTM E92, or with the Rockwell test using Rockwell test HR 15N in accordance with ISO 6508 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.

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 shall be obtained at the four main locations:

- a) top neutral axis;
- b) bottom neutral axis;
- c) intrados;
- d) extrados.

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 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, transition and tangent materials 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 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 external surface of 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. The minimum average grain-size number shall be 7.

10.4.7 Drop-weight tear testing

DWT is not mandatory for any bend product specification level.

Test methods, test piece locations and acceptance criteria shall be by agreement.

10.4.8 Crack tip opening displacement testing

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

Test methods and requirements shall be by agreement.

10.4.9 Guided bend testing

10.4.9.1 Test pieces

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

For induction 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 mandatory for a pipe wall thickness ≤ 20 mm (0.787 in). Welds shall be ground flush at both faces.

10.4.9.2 Test method

The mandrel dimensions shall be as defined in ISO 3183 for pipe 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.

10.4.10 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 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} for the purposes of its inclusion in a mathematical expression, shall be determined as given in Equation (2):

$$L_{CVD} = \frac{D_2 + D_4}{2} - D_3 \quad (2)$$

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 transition zones;
- the end 250 mm (9.843 in) of the tangent, if not examined already on the mother pipe prior to bending.

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 13664 or ASTM E709. PT shall be performed in accordance with ISO 12095 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 11496, 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 mm² (0.16 in²).

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

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 13665 or ASTM E709, or PT in accordance with ISO 12095.

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 9305 or 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 12094, ISO 10124, ASTM A435, or ASTM A578/A578M 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.

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

All ground repair areas shall be examined by MT in accordance with ISO 13665, or by PT in accordance with ISO 12095, to confirm the complete removal of the defects.

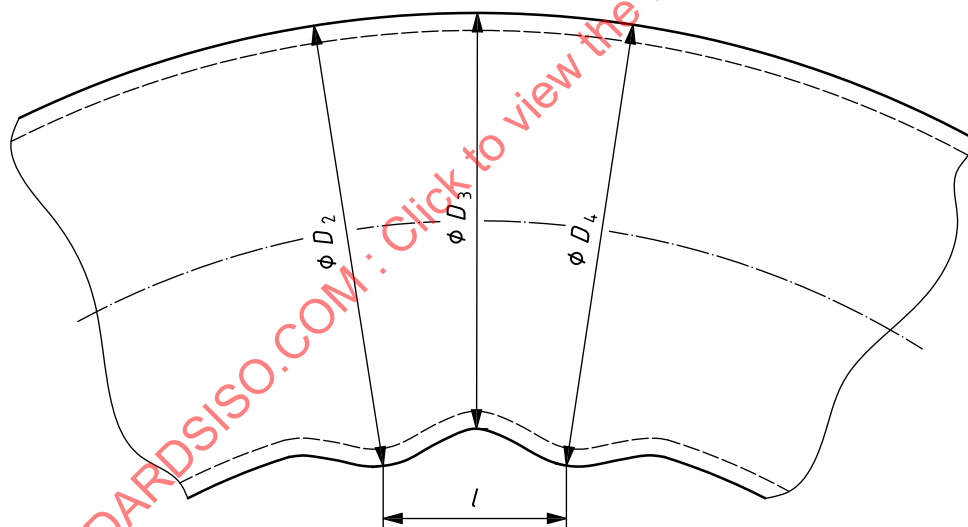


Figure 3 — Schematic diagram for measurement of waving

10.5.8 NDT personnel

All NDT personnel shall be qualified and certified in accordance with ISO 9712, ASNT SNT-TC-1A or equivalent to the appropriate 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 a sufficient number of locations by ultrasonic methods in accordance with ASTM E797.

The bend angle may be determined as follows; see Figure 4.

- Extend the centreline axis of each tangent to the “centre of bend” where the two axes cross.
- Measure and mark the distance from the “centre of bend” to each of the “centre of ends”.
- 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 4 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 5.

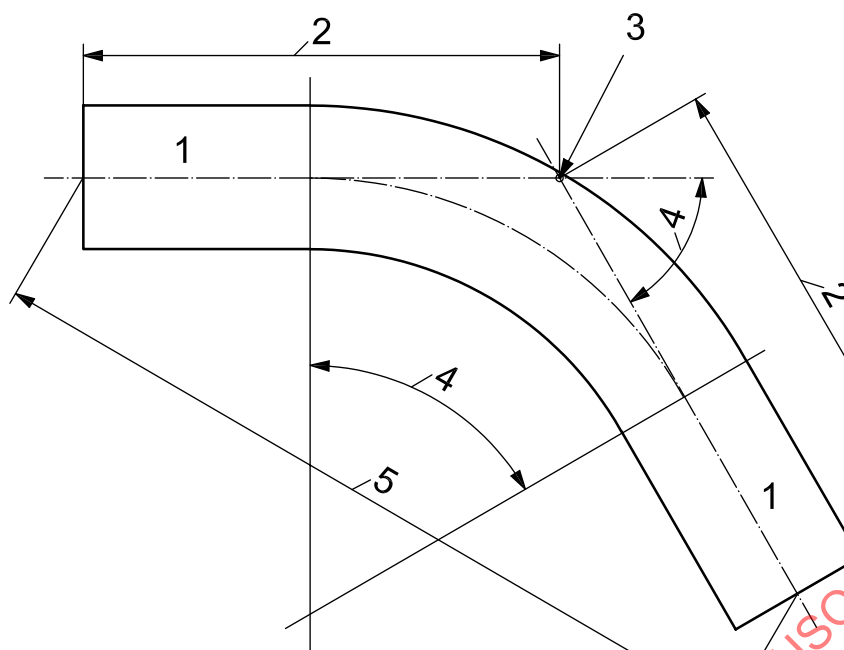
Out-of-planeness is measured by levelling the centrelines of both bend tangent ends and measuring the difference in height of the two end centrelines from the level surface, as shown in Figure 6. Practical measurement methods shall be by agreement.

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

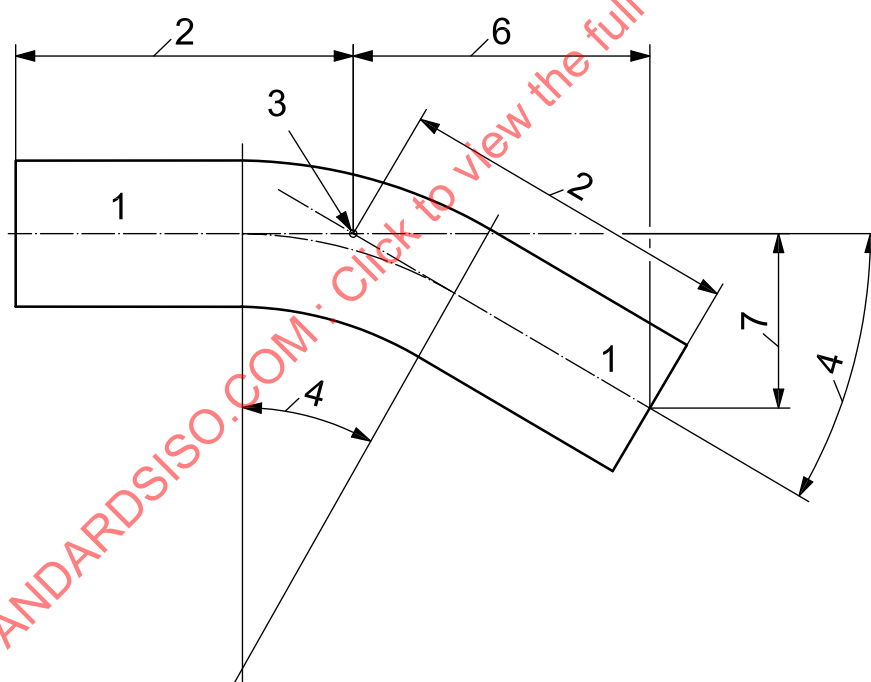
$$O = \frac{D_{\max} - D_{\min}}{D} \times 100 \quad (3)$$

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	By agreement
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	3 mm (0.118 in) max.
Out-of-planeness	By agreement
Out-of-roundness at ends	By agreement
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
^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 4 — Dimensions for determination of bend angle

10.7 Gauging

The requirements for gauging shall be by agreement.

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 mandatory 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.

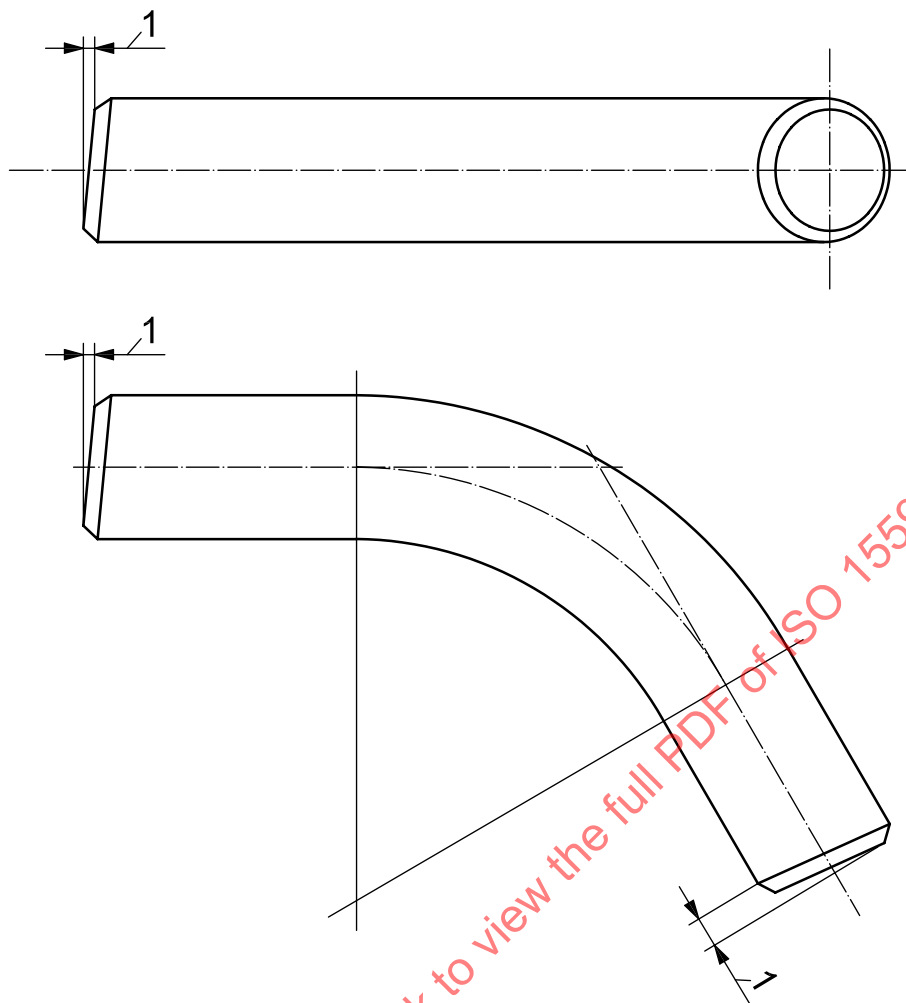
12 Marking

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

- manufacturer's name or trade mark;
- number of this part of ISO 15590;
- 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.

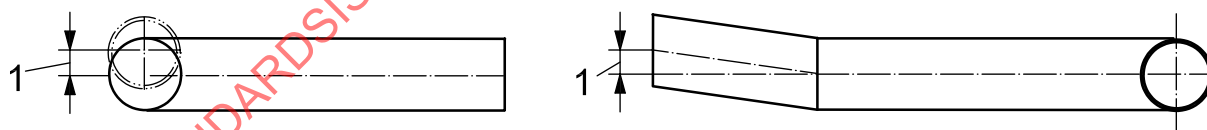
Markings shall be made with indelible paint on the inside surface or, if it is not possible to mark on the inside surface, on the outside for smaller diameter bends.

For bends with a nominal outside diameter of 100 mm (4 in) and larger, markings shall be executed in block capitals with a minimum height of 19 mm (0.748 in). For smaller bends, the height of the stencil marking shall be a minimum of 10 mm (0.397 in). Identification markings shall not be stencilled or painted on the weld preparation.



Key
1 out-of-squareness

Figure 5 — Determination of end out-of-squareness



Key
1 out-of-planeness

Figure 6 — Determination of out-of-planeness

Annex A (normative)

Manufacturing procedure specification

A.1 Introduction

This annex specifies the requirements for the manufacturing procedure specification for all PSL level bends.

A.2 Manufacturing procedure specification

A manufacturing procedure specification shall be produced for all bends. Test bends shall be manufactured in accordance with a preliminary MPS documented before commencement of test bending. The preliminary MPS shall be modified as necessary, based on the parameters recorded during test bending, prior to commencing production bending. If specified by the purchaser, manufacturing shall not proceed until the MPS has been accepted by the purchaser.

The MPS shall specify the following details:

a) information on the mother pipe:

- name of manufacturer,
- pipe grade,
- type of pipe,
- pipe forming process,
- pipe dimensions,
- chemical composition,
- mechanical properties;

b) welding procedure and weld metal chemical composition for welded pipe:

- inspection technique and reports for weld seam,
- weld seam repair procedures,
- heat treatment conditions;

c) Testing and inspection requirements for

- qualification test bend,
- production bends;

- d) Bending process details:
 - pipe cleaning method prior to bending,
 - identification of the bending machine,
 - method of temperature measurement and control during bending,
 - values of bending parameters (see Table 1),
 - heating and quenching of tangent ends;
- e) Details of post-bending heat treatment:
 - type of post-bending heat treatment,
 - heating rate, soaking time and temperature, cooling rate,
 - type and location of thermocouples;
- f) Sizing and rounding processes;
- g) Additional purchaser requirements (such as end preparation, coating and marking).

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