
**Petroleum and natural gas
industries — Corrosion resistant alloy
clad bends and fittings for pipeline
transportation system —**

**Part 1:
Clad bends**

*Industries du pétrole et du gaz naturel — Coudes et raccords
recouverts d'alliage résistant à la corrosion pour système de transport
par conduites —*

Partie 1: Coudes recouverts



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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).

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A list of all parts in the ISO 24139 series can be found on the ISO website.

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Petroleum and natural gas industries — Corrosion resistant alloy clad bends and fittings for pipeline transportation system —

Part 1: Clad bends

1 Scope

This document specifies the technical delivery conditions regarding design, geometric dimensions, materials, manufacturing procedures, inspection methods, non-destructive testing (NDT), marking, package and storage for corrosion resistant alloy (CRA) clad bends for use in pipeline transportation systems for the petroleum and natural gas industries.

This document is applicable to CRA clad bends for use in transportation or process pipelines transporting corrosive media-containing single-phase or multi-phase fluid such as oil, gas and water for the petroleum and natural gas industries. It can also be used as reference in other fields.

Two technical delivery conditions classes for clad bends are designated. Class B provides a standard quality level for clad bends and Class S provides technical requirements for sour-service conditions. It is the responsibility of the purchaser to specify the appropriated class, based upon the intended use and design requirements.

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

ISO 3183:2019, *Petroleum and natural gas industries — Steel pipe for pipeline transportation systems*

ISO 6507 (all parts), *Metallic materials — Vickers 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 8501-1:2007, *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 10893-6, *Non-destructive testing of steel tubes — Part 6: Radiographic testing of the weld seam of welded steel tubes for the detection of 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, *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, *Non-destructive testing of steel tubes — Part 11: Automated ultrasonic testing of the weld seam of welded steel tubes for the detection of longitudinal and/or transverse imperfections*

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

ISO 14732, *Welding personnel — Qualification testing of welding operators and weld setters for mechanized and automatic welding of metallic materials*

ISO 15156-1, *Petroleum and natural gas industries — Materials for use in H₂S-containing environments in oil and gas production — Part 1: General principles for selection of cracking-resistant materials*

ISO 15156-3:2020, *Petroleum and natural gas industries — Materials for use in H₂S-containing environments in oil and gas production — Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys*

ISO 15590-1:2018, *Petroleum and natural gas industries — Induction bends, fittings and flanges for pipeline transportation systems — Part 1: Induction bends*

ISO 15614-7, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 7: Overlay welding*

ISO 15614-8, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 8: Welding of tubes to tube-plate joints*

ISO 80000-1:2009, *Quantities and units — Part 1: General*

ASME BPVC Section II - Materials — Part C *Specifications for welding rods, electrodes, and filler metals*

ASME BPVC Section IX *Qualification standard for welding, brazing, and fusing procedures; welders; brazers; and welding, brazing, and fusing operators*

ASNT SNT-TC-1A, *Recommended practice No. SNT-TC-1A: Personnel qualification and certification in non-destructive testing*

ASTM A262-15, *Standard practices for detecting susceptibility to intergranular attack in austenitic stainless steels*

ASTM A263-12, *Standard specification for stainless Chromium steel-clad plate*

ASTM A264-12, *Standard specification for stainless Chromium-Nickel steel-clad plate*

ASTM A265-12, *Standard specification for Nickel and Nickel-base alloy-clad steel plate*

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-17, *Standard specification for straight-beam ultrasonic examination of rolled steel plates for special applications*

ASTM A751, *Standard test methods, practices, and terminology for chemical analysis of steel products*

ASTM A923-14, *Standard test methods for detecting detrimental intermetallic phase in duplex austenitic/ferritic stainless steels*

ASTM E3, *Standard guide for preparation of metallographic specimens*

ASTM E92, *Standard test methods for Vickers hardness and Knoop hardness of metallic materials*

ASTM E165, *Standard test method for liquid penetrant examination*

ASTM E273, *Standard practice for ultrasonic testing of the weld zone of welded pipe and tubing*

ASTM E340, *Standard practice for macroetching metals and alloys*

ASTM E353, *Standard test methods for chemical analysis of stainless, heat-resisting, maraging, and other similar Chromium-Nickel-Iron alloys*

ASTM E407, *Standard practice for microetching metals and alloys*

ASTM E562, *Standard test method for determining volume fraction by systematic manual point count*

ASTM E587, *Standard practice for ultrasonic angle-beam contact testing*

ASTM E709, *Standard guide for magnetic particle testing*

ASTM G1, *Standard practice for preparing, cleaning, and evaluating corrosion test specimens*

ASTM G28-02, *Standard test methods for detecting susceptibility to intergranular corrosion in wrought, Nickel-rich, Chromium-bearing alloys*

ASTM G39, *Standard practice for preparation and use of bent-beam stress-corrosion test specimens*

ASTM G48-11, *Standard test methods for pitting and crevice corrosion resistance of stainless steels and related alloys by use of ferric chloride solution*

ASTM G111, *Standard guide for corrosion tests in high temperature or high pressure environment, or both*

NACE TM0177, *Standard test method laboratory testing of metals for resistance to sulfide stress cracking and stress corrosion cracking in H₂S environments*

NACE TM0284, *Standard test method — Evaluation of pipeline and pressure vessel steels for resistance to hydrogen-induced cracking*

3 Terms, definitions, abbreviated terms and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 15590-1 and the following apply.

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

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1.1

backing steel

substrate of the clad plate, clad pipe or clad bends withstanding mechanical load or pressure, and made of carbon steel or low alloy steel

3.1.2

clad layer

layer of the corrosion resistant alloy metallurgically bonded to the surface of the backing steel of clad plate, clad pipe or clad bend

Note 1 to entry: Metallurgically bonded CRA layer is to be produced by hot roll bonding, weld overlaying, explosion cladding, coextruding or some other process that produces the atomic diffusion interface between CRA and carbon steel or low alloy steel.

3.1.3

corrosion resistant alloy

CRA

alloy such as stainless steel and nickel-based alloy intended to be resistant to general and localized corrosion of oilfield environments that are corrosive to carbon steel

[SOURCE: ISO 15156-1:2020, 3.6, modified — Examples of alloys have been added.]

3.1.4

manufacturer

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

Note 1 to entry: The requirements of this document.

[SOURCE: ISO 15590-1:2018, 3.17]

3.1.5

mother clad pipe

metallurgical straight clad pipe from which the corrosion resistant alloy clad bend is made

3.1.6

mother steel bend

carbon steel or low-alloy steel bend onto which the clad bend is made by weld overlay with corrosion resistant alloy

3.1.7

neutral axis

region of the bend that does not suffer the stress of traction or compression during manufacture and that separates the region of the intrados (compressed region) from the extrados (region pulled), where it is not considered a reduction in wall thickness

3.1.8

neutral zone

zone near the neutral axis of the bend arc

3.1.9

bond shear strength

tangential stress per unit contact area required to separate the clad layer from the backing steel of the metallurgically bonded clad plate, clad pipe or clad bend

3.1.10

sour environment

exposure to oilfield environments that contain sufficient H₂S to cause cracking of metallic materials by mechanisms

Note 1 to entry: The mechanisms addressed by ISO 15156-1:2020.

[SOURCE: ISO 15156-1:2020, 3.20, modified — Note 1 to entry has been added.]

3.2 Abbreviated terms

CLB	clad bend
CVN	Charpy V-notch
FPB	four-point bend beam
HAZ	heat-affected zone
HIC	hydrogen induced cracking
MPQT	manufacturing procedure qualification test
MPS	manufacturing procedure specification
MT	magnetic particle testing
NDT	non-destructive testing
PREN	pitting resistance equivalent number
PT	penetrant testing
RT	radiographic testing
SCC	stress corrosion cracking
SMYS	specified minimum yield strength
SSC	sulfide stress cracking
TIG	tungsten inert-gas arc welding
UT	ultrasonic testing
WPS	welding procedure specification
WT	wall thickness

3.3 Symbols

A	elongation of tensile test specimen after fracture, expressed as a percentage
D	nominal outside diameter of clad bend
d	specified inside diameter at the tangent ends of a clad bend
L	tangent length of a clad bend
t	specified minimum wall thickness of clad layer of a clad bend
t_B	nominal wall thickness of backing steel of clad bend
R_m	ultimate tensile strength
$R_{t0,5}$	yield strength for 0,5 % total elongation
r_b	radius of neutral axial of bends

4 General

4.1 Units of measurement

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

4.2 Rounding

Unless otherwise stated in this document, 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.

5 Information supplied by the purchaser

5.1 General requirements

The purchaser shall provide the following information:

- a) a reference to this document, i.e. ISO 24139-1:2022;
- b) designation of each clad bend;
- c) quantity of clad bends;
- d) grade of backing steel;
- e) CRA material type or identification of clad layer;
- f) manufacturing process: induction bending or weld overlay or other process as agreed;
- g) supply of mother clad pipes or mother steel bends by the purchaser or the manufacturer;
- h) required clad bend dimensions, including:
 - nominal outside diameter;
 - specified inside diameter at the tangent end;
 - minimum (or nominal) wall thickness of backing steel;
 - minimum (or nominal) wall thickness of clad layer;
 - bend radius;
 - bend angle;
 - tangent length.
- i) end preparation if different from square ends.

5.2 Recommendations

The purchaser should specify additional information such as:

- a) pipeline operating conditions, including composition of transported fluid, temperature and pressure;
- b) minimum design temperature;
- c) maximum design temperature;

- d) maximum wall thickness for both backing steel and clad layer;
- e) special dimensional requirements;
- f) requirements for supplementary inspection and testing;
- g) requirements for gauging and other measurements of dimensions, if different from this document;
- h) pipeline design standard or design factors;
- i) whether post-bending heat treatment is used;
- j) whether ISO 15590-1:2018, Annex B is used for the backing layer of clad bends that are ordered for sour service;
- k) mechanical property requirements for backing steel at high temperatures;
- l) requirements for proof burst testing or hydrostatic testing;
- m) requirements for corrosion resistance for both backing steel and clad layer;
- n) surface condition requirements;
- o) coating or painting requirements;
- p) marking requirements, if different from this document;
- q) packaging and shipping instructions;
- r) third-party inspection organization;
- s) specifications and materials of matching pipes;
- t) other special requirements.

5.3 Requirements and recommendations on the mother clad pipe

5.3.1 If the mother clad pipe is supplied by the purchaser, the following shall be provided to the manufacturer:

- a) purchasing specification;
- b) pipe diameter, inside or outside;
- c) pipe wall thickness (nominal or minimum values for both backing steel and clad layer);
- d) pipe length;
- e) grade of backing steel;
- f) CRA type of clad layer;
- g) pipe manufacturer;
- h) mill certificate.

5.3.2 If the mother clad pipe is supplied by the purchaser, the following should be provided to the manufacturer:

- a) material specification of clad pipe, including chemical composition, carbon equivalent for the backing steel, heat treatment, mechanical properties, results of NDT and hydrostatic testing;
- b) WPS and weld metal chemical composition for welded clad pipe;

- c) weld repair record and weld-seam-repair welding procedure specification for welded clad pipe.

5.4 Requirements and recommendations on the mother steel bend

5.4.1 If the mother steel bends is supplied by the purchaser, the following shall be provided to the manufacturer:

- a) purchasing specification;
- b) bend designation of each bends;
- c) required bend dimensions, including
 - diameter (inside or outside),
 - minimum wall thickness,
 - bend radius,
 - bend angle, and
 - tangent lengths.
- d) mill certificate.

5.4.2 If the mother steel bends are supplied by the purchaser, the following should be provided to the manufacturer:

- a) material specification of the steel bend, including chemical composition, carbon equivalent, heat treatment, mechanical properties, and results of NDT;
- b) WPS and weld metal chemical composition for welded bends;
- c) weld repair record and weld-repair welding procedure specification for welded bends.

6 Designation

Designation of clad bends shall take the form of "CLB YYY-Z", where

- the letters "YYY" are the specified minimum yield strength (SMYS) of backing steel, expressed in megapascals (MPa);
- the letter "Z" is the suffix B or S, B to identify the technical delivery conditions class for clad bends in non-sour service, or the suffix S to identify the use in sour-service conditions.

7 Design

The design documents of clad bends shall at least include the bends design drawings and strength calculations. Design parameters including specified inside diameter at the tangent ends of clad bends shall be consistent with those of their matching pipes.

The strength design and material selection of clad bends shall follow the principle of the backing steel for withstanding of internal fluid pressure and external hydrostatic pressure (if any) while clad layer for corrosion resistance of conveying fluid.

Strength design for the backing steel of clad bends shall be based on the fluid transporting pressure and temperature. The hoop stress in the clad bends due to the internal fluid pressure shall not exceed the hoop stress for the tangent permitted in ISO 13623 or other applicable design code. The minimum wall thickness of the backing steel at extrados and at intrados shall conform to ISO 15590-1.

For materials selection for clad bends, the corrosivity of the transported fluid shall be taken into account, and the following principles shall apply:

- a) If the transported fluid contains several corrosive media such as H_2S , CO_2 or Cl^- , the clad layer shall be resistant to SCC, mass loss corrosion and pitting corrosion, and the clad layer material shall be in accordance with the requirements given in [Annex B](#).
- b) If the transported fluid contains H_2S and is defined as sour environment, the need for the backing steel to conform with ISO 15156-2 should be as agreed.

8 Manufacturing

8.1 Starting materials

8.1.1 Mother clad pipe

Mother clad pipe should be manufactured in accordance with API 5LD or other applicable standard as agreed.

The mother clad pipe is a clad bimetallic pipe composed of an internal CRA layer that is metallurgically bonded to the backing steel. The metallurgical clad layer may be bonded by hot-rolling, co-extrusion, weld overlaying, explosion bonding, or some other process that produces a metallurgical bond.

The mother clad pipe shall be either a seamless pipe or a welded pipe having only one longitudinal weld. The mother clad pipe shall not contain girth butt-welds. The wall thickness of backing steel and CRA clad layer of the mother clad pipe shall have adequate allowance for wall thinning at the extrados due to induction bending. The mother clad pipe shall not contain weld repairs on the backing steel pipe body, and repair of weld overlay should be accepted.

If the mother clad pipe is supplied by the purchaser, its suitability for induction bending through the following performance and tests shall be consulted with the manufacturer: chemical composition, mechanic properties, bond shear strength, hydrostatic test, workmanship, NDT and dimensions.

The backing steel of mother clad pipes for the manufacture of clad bends Class B and Class S shall conform with the applicable requirements for PSL2 in ISO 3183:2019.

If agreed, the backing steel of mother clad pipes for the manufacture of clad bends Class S should conform with the requirements for PSL2S in ISO 3183:2019.

The outer surface of the mother clad pipe shall be free from contamination by low-melting-temperature metals, such as copper, zinc, brass and aluminium.

8.1.2 Mother steel bend

Mother steel bends shall be manufactured in accordance with ISO 15590-1:2018, PSL2. If agreed, mother steel bends for the manufacture of clad bends Class S should be in accordance with ISO 15590-1:2018, PSL 2S.

The mother steel bends shall not contain weld repairs to the bend bodies. The surface of the mother steel bend shall be free from contamination by low-melting-temperature metals, such as copper, zinc, brass and aluminium.

8.1.3 Welding consumables

Unless otherwise agreed, all welding consumables shall conform with the requirements of ASME BPVC Section II, Part C.

8.1.4 Re-inspection of starting materials

The starting materials shall be re-inspected by the manufacturer after entering the manufacturing site. The mother clad pipes or mother steel bends produced by the same manufacturer as the clad bends with the same quality assurance system shall not be re-inspected.

The re-inspection of the starting materials shall conform with the following:

- a) The starting materials shall be provided with quality certificates;
- b) The appearance and geometric dimensions of each mother clad pipe and mother steel bend shall be examined;
- c) If agreed, for each lot of mother clad pipes or mother steel bends, one should be randomly tested for such items as the chemical composition, mechanical properties, non-destructive inspection and dimensions. The extent of re-inspection and acceptance criteria shall be as agreed.

8.2 Manufacturing procedure qualification

Before commencement of production, manufacturing procedure qualification about clad bends of different materials and different specifications shall be conducted in accordance with [Annex A](#), and the MPS for production clad bends shall be prepared.

If agreed, a formal MPS may be approved by performance of the MPQT at the beginning of production.

8.3 Clad bends manufacture

The following manufacturing procedures should be used to produce clad bends.

- a) Electric induction heating by using mother clad pipes;
- b) Weld overlaying with CRA onto the mother steel bends.

Manufacturing procedures shall ensure that the surface of clad bend has smooth transition after forming, and mechanical properties of the backing steel and corrosion resistance of the clad layer are not degraded, and without cracks or other defects that may impact safety are initiated.

8.4 Welding

All weld seams and weld overlay including weld repairs shall be performed by qualified welders in accordance with the qualified welding procedure. All WPS and welding procedure qualification used in the manufacture of clad bends shall meet the requirements specified in ISO 15614-7 and ISO 15614-8 or ASME BPVC Section IX. Welder qualification test shall be conducted in accordance with ISO 14732 or ASME BPVC Section IX.

At most one longitudinal weld seam is allowed for each clad bend, which shall be located in the area of 0° to 10° from neutral axis on extrados side or intrados side.

For weld overlay, cold-/hot- wire TIG welding or other welding processes with low heat input shall be used, and multi-layer weld overlaying shall be used. The lap length between adjacent weld overlay shall be 30 % to 50 % of the width of each layer, and the weld pass roughness and the concavity between adjacent passes shall not exceed 0,5 mm. The thickness of weld overlay shall meet the requirements of [9.6](#), and the chemical composition shall meet the requirements of [9.3](#).

8.5 Heat treatment

For the clad bends made from induction mother steel bends by weld overlaying with CRA, before weld-overlaying, post-bending heat treatment should be applied to the mother steel bends to achieve the required material properties or to relieve residual stresses.

Post-bending heat treatment need not be applied to clad bends made by hot forming from mother clad pipes. However, this shall depend on manufacturing procedure qualification tests (MPQT).

For clad bends made by hot-forming from weld overlaid mother clad pipe, pre-bending heat treatment may be applied to the weld overlaid clad mother pipes to prevent of cracks during the bending process. This heat treatment shall be as agreed.

The temperature of each furnace shall be monitored by thermocouples connected directly to the selected bends and shall be recorded. The furnace and thermocouples for heat treatment shall be evaluated at least once a year.

8.6 Forming and sizing after bending

Hot-forming, including spot-heating, or hot-sizing after bending, shall not be performed.

Cold-forming or sizing without subsequent heat treatment is permitted for ovality and diameter corrections in the tangents. If $D \leq 600$ mm, the permanent radial deformation shall not exceed 1,5 % D or 8 mm, whichever is smaller. If $D > 600$ mm, the permanent radial deformation shall not exceed 1,5 % D or 17 mm, whichever is smaller. Cold-expanding shall not be used to adjust the inside diameter at the ends.

If the ovality and inside diameter at the ends cannot meet the tolerance requirements of [Table 6](#), weld overlaying and machining of the ends may be performed.

8.7 Joints and girth welds

Clad bends shall not contain joints or girth welds.

8.8 End preparation

Clad bends shall be supplied with prepared bevel ends in accordance to purchaser specifications unless otherwise specified by the purchaser.

The type of welded bevel shall be consistent with that of the matching pipe. Unless otherwise agreed, the weld ends should be machined into bevels as V-shape, or double-V-shape or U-shape.

8.9 Surface treatment

The surfaces of the clad bends shall be cleaned before the final inspection and testing. The outer surfaces should be derusted by steel shot blasting to the grade Sa2 of ISO 8501-1:2007.

The inner surface of the CRA layer of a clad bend after forming or weld overlay shall be cleaned by shot blasting or/and pickling followed by passivation. The cleaning shall be able to remove the oxides and other contaminants that can affect the corrosion resistance of the CRA. Glass bead, garnet, chopped CRA wire or other suitable materials are proposed for shot blasting. Blasting of inner surface is not mandatory if CRA layer is machined. After pickling, the inner surface of the CRA shall be finally cleaned with tap water until the chloride ion content is less than 50 mg/l. The inner and outer surface, upon cleaned, shall be completely dry.

Effective measures shall be taken during the process of manufacturing to prevent the surface of the CRA layer from being polluted by iron ions. If polluted, effective measures shall be taken for inspection and elimination.

Some CRAs are self-passivation, pickling after weld overlay or forming might be not necessary. Pickling and passivation for the self-passivated CRA should be waived as agreed.

9 Testing and inspection

9.1 General requirements

MPS shall be approved or production clad bends shall be accepted only after all testing and inspection required in [Clause 9](#) have been performed and all results meet the specified requirements. Testing and inspection shall be carried out on clad bends after final heat treatment.

If agreed, test results already available for the mother clad pipe or mother steel bend may be used in place of testing and inspections where indicated in [Table 1](#).

The number and location for the extraction of specimens shall be in accordance with [Annex C](#).

9.2 Extent of testing and inspection

At the stage of manufacturing procedure qualification, the extent of testing and inspection that shall be performed on each test clad bends is as specified in [Table 1](#).

During production, the extent of testing and inspection shall be performed as specified in [Table 1](#), and the frequency of testing shall be performed as specified in [Table 2](#). The inspection frequency can also be as agreed.

For the batch inspection during production, retesting is permitted if the failed results are from chemical composition testing, or physical testing. At the option of the purchaser, double specimens shall be taken from the same test sample and re-tested for the failed items, or double-sampled and re-tested separately for the failed items in the same batch, or subject this batch of clad bends to another heat treatment and then carry out all testing and inspections as indicated in [Table 1](#). Repeated heat treatment shall be permitted only once. However, if the only nonconforming item is tensile strength, with the consent from the designer, this batch of clad bends may be used for applications with reduced pressure ratings.

Table 1 — Summary of testing and inspection

Type of test and inspection		Class B ^a	Class S ^a	Subclause number
Chemical analysis	Chemical composition of backing steel	M	M	9.3
	Chemical composition of CRA ^b	M	M	
Physical tests	Tensile	T and O	T and O	9.4.1
	Impact	T and O	T and O	9.4.2
	Guided bend of weld seam	T and O	T and O	9.4.3
	Through-thickness hardness	T and O	T and O	9.4.4
	Surface hardness	T and P	T and P	9.4.5
	Flattening tests	M	M	9.4.6
	Shear bond strength	T and O	T and O	9.4.7
	Macrographic examination	T	T	9.4.8
	Metallography	T	T	9.4.9
Corrosion tests	Intergranular corrosion	T	T	9.5.1
	HIC and SSC testing	N	T and O	9.5.2
	Corrosion testing of clad layer for service condition	T	T	9.5.3
Dimensions	Wall thickness of backing steel layer	T and P	T and P	9.6
	Wall thickness of clad layer	T and P	T and P	9.6
	Outside diameter of bend body	N	N	9.6
	Inside diameter of bend ends	P	P	9.6
	Out-of-roundness	P	P	9.6
	Bend angle	P	P	9.6
	Radius	O	O	9.6
	End out-of-squareness	P	P	9.6
	Out-of-planeness	P	P	9.6
	Linear dimensions	P	P	9.6
	End preparation	P	P	9.6
NDT	Visual inspection	T and P	T and P	9.7.3
	Surface of clad bend (PT or MT)	T and P	T and P	9.7.4
	Weld seam (RT or UT)	T and P	T and P	9.7.5
	Clad bend end (PT and UT)	T and P	T and P	9.7.6
	Clad bend body (UT)	T and P	T and P	9.7.7
	Residual magnetism	P	P	9.7.8
Hydrostatic test		By agreement	By agreement	9.8

^a M: Testing of the induction clad bend shall not be required if acceptable test results are available for the mother clad pipe or the mother steel bend. If acceptable test results for the mother clad pipe or the mother steel bend are not available, then the test shall be performed on either the mother clad pipe or the mother steel pipe or the clad bend.

N: Not required.

O: Requirement for each batch of production clad bend at the purchaser's option.

P: Required for each production clad bends.

T: Required for each test clad bends.

^b Chemical analysis of clad layer is required for weld overlayer with CRA onto mother steel bend.

Table 2 — Extent of testing and inspection during production

Type of test and inspection	Minimum frequency of tests ^a	
	Class B	Class S
Chemical composition of backing steel	b	b
Chemical composition of CRA	c	c
Tensile-backing steel layer	One per test batch	One per test batch
Charpy V-notch impact -backing steel layer	One per test batch	One per test batch
Guided bend (weld seam)	One per test batch	One per test batch
Through-thickness hardness	One per test batch	One per test batch
Surface hardness	Each clad bend	Each clad bend
Flattening tests	b	b
Shear bond strength	One per test batch	One per test batch
Macrographic examination	Not required	Not required
Metallography	Not required	Not required
Intergranular corrosion	Not required	Not required
HIC and SSC testing	Not required	as agreed
Corrosion testing of clad layer material for service condition	Not required	Not required
Dimensional inspection	Each clad bend	Each clad bend
NDT	Each clad bend	Each clad bend
Hydrostatic test	as agreed	as agreed

^a For clad bends with same material type and same heat of steel number, same manufacturing procedure, same heat treatment procedure, same bend radius and same nominal wall thickness, at most 100 bends are considered as one test batch in the case of $D < 600$ mm, or at most 50 bends are considered as one test batch in the case of $D \geq 600$ mm.

^b Testing of the induction clad bend shall not be required if acceptable test results are available for the mother clad pipe or mother steel bend.

^c Chemical analysis of clad layer is required only for weld overlay with CRA onto mother steel bend. The chemical analysis of weld overlay is conducted on only one per test batch.

9.3 Chemical composition

9.3.1 Requirements

The chemical composition of the backing steel shall be in accordance with the requirements for PSL2 of the same grade as specified in ISO 3183:2019. If agreed, carbon steel or low alloy steel other than as specified in ISO 3183:2019 may also be used.

The clad layer of the clad bends should be made of austenitic stainless steel or duplex stainless steel or nickel base alloy (see [Annex D](#)). For weld overlay with CRA onto the mother steel bend, the chemical composition of CRA shall be determined in accordance with ISO 15614-7. Other CRA conforming with relevant standards may be selected for the clad layer if agreed.

Chemical composition of the as deposited overlay of the seam or weld overlay shall be within the tolerances of the clad layer or as agreed.

The chemical composition of the cladding weld shall be within the allowable deviation of CRA. The product analysis results of the clad layer shall meet the minimum PREN value for the CRA if given by the purchaser.

9.3.2 Test specimens

At the option of the manufacturer, specimens can be extracted either from finished clad bends or mother clad pipes. For the welded clad bend or mother clad pipe with longitudinal weld seam, location

to extract specimens of base metal from the backing layer and the clad layer shall be at least 90° away from the weld seam. The specimens for chemical composition analysis should be extracted with reference to [Annex C](#).

9.3.3 Test method

Methods and practices relating to chemical analysis shall be performed in accordance with ASTM A751 or ASTM E353.

9.4 Physical testing

9.4.1 Tensile testing

9.4.1.1 Requirements

The tensile property of the backing steel shall conform with the requirements for PSL2 of the same grade as specified in ISO 3183:2019.

Additional elevated-temperature tensile testing shall be performed for the backing steel material if the maximum design temperature exceeds 50 °C. The criteria shall be as agreed.

9.4.1.2 Test specimens

Round-bar specimens from unflattened samples or strip specimens as specified in ISO 3183:2019 may be used as the specimens. The CRA layer on the specimens shall be removed, and the weld seam shall be ground flush. Specimens are extracted from the base metal of backing steel in locations defined in [Annex C](#) for R_m , $R_{t0,5}$ and A . For weld transverse tensile tests, only R_m shall be required.

9.4.1.3 Test method

Tensile testing at ambient temperature shall be carried out in accordance with ISO 6892-1 or ASTM A370. Tensile testing at elevated temperatures shall be carried out in accordance with ISO 6892-2.

9.4.2 Charpy V-notch impact testing

9.4.2.1 Requirements

Unless otherwise agreed, impact absorbed energy of the backing steel materials (base metal and weld seam) at the test temperature shall meet the following requirements:

- For the transverse full-size standard specimens, the minimum average value shall be not less than 40 J. For a single specimen, the minimum value shall be not less than 30 J, and the shear area data shall be reported.
- For the longitudinal specimens, the minimum average value and the minimum value of a single specimen shall be not less than 1,5 times the specified values of a corresponding transverse specimen.
- For a smaller specimen with the size of 10 mm × 7,5 mm or 10 mm × 5,0 mm, the required impact absorbed energy value is respectively 0,75 and 0,5 times the specified value of a full-size specimen.

9.4.2.2 Test specimens

Each set of impact tests shall consist of three adjacent test specimens taken from a single non-flattened backing steel sample. Charpy V-notch specimens shall be prepared in accordance with ISO 148-1 or ASTM A370 with reference to ISO 15590-1.

9.4.2.3 Test method

Charpy V-notch impact testing shall be in accordance with ISO 148-1 or ASTM A370. Impact test specimens shall be tested at the lower of 0 °C or the minimum design temperature.

9.4.3 Guided bend testing

9.4.3.1 Requirements

Welds with-filler metal shall be tested by the guided-bend test. Unless otherwise agreed, the results of guided bend testing shall meet the following requirements: No cracks whose length is greater than 3,2 mm shall be present in weld seams, HAZ and base metal. For cracks originated from the edge of a specimen, the length of crack in any direction shall be not greater than 6,4 mm. However, a specimen with edge cracking due to slag inclusion or defects shall be regarded as nonconforming, and a new specimen shall be extracted for testing.

For welded clad bends with smaller diameter, as an alternate to the guided-bend test and as agreed a flattening test may be conducted, and acceptance criteria of crack length shall be specified as agreed.

9.4.3.2 Test specimens

Specimens shall be prepared in accordance with ISO 7438 or ASTM A370. Both specimens shall be extracted from the bend tangent and arc respectively. For clad bends with a wall thickness >20 mm, the specimens should be machined to provide a rectangular cross section having a thickness of 19 mm. Full-thickness specimens shall be processed for clad bends with a wall thickness ≤20 mm. Welds shall be ground flush at both faces. The clad layer shall be removed on the weld seam for weld overlay with CRA onto the mother steel bends, and the clad layer shall remain on the weld seam for other manufacturing process. No repaired weld seam shall be allowed on the specimens.

9.4.3.3 Test method

The diameter of the mandrel used for guided-bend tests shall be a maximum of six times the thickness of the specimen. The weld seam shall be located in the middle of the specimen. One face bend and one root bend specimen shall be bent approximately 180° in a jig.

9.4.4 Through-thickness hardness testing

9.4.4.1 Requirements

Through-thickness Vickers hardness values of the backing steel and the CRA layer shall meet the requirements of [Table 3](#).

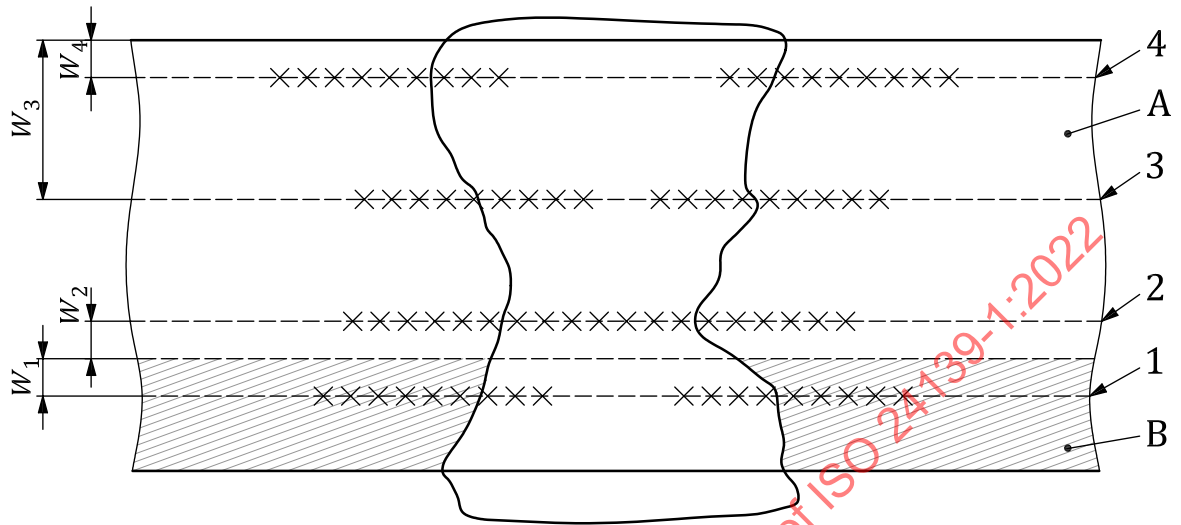
9.4.4.2 Test specimens

For clad bend with longitudinal weld seam made from clad plate, the testing locations shall include the base metal and weld seam of the bend tangent, the transition zone, the extrados, intrados and neutral zone of the bend arc. The indent locations for weld seam cross-section hardness testing are as shown in [Figure 1 a\)](#). Unless otherwise agreed, for base metal not affected by heat, the hardness indents shall have a spacing of 1 mm. For HAZ and weld seams, the hardness indents shall have a spacing of 0,75 mm, and the high temperature hardness point with the nearest distance from the fusion line shall have the distance not exceeding 0,5 mm.

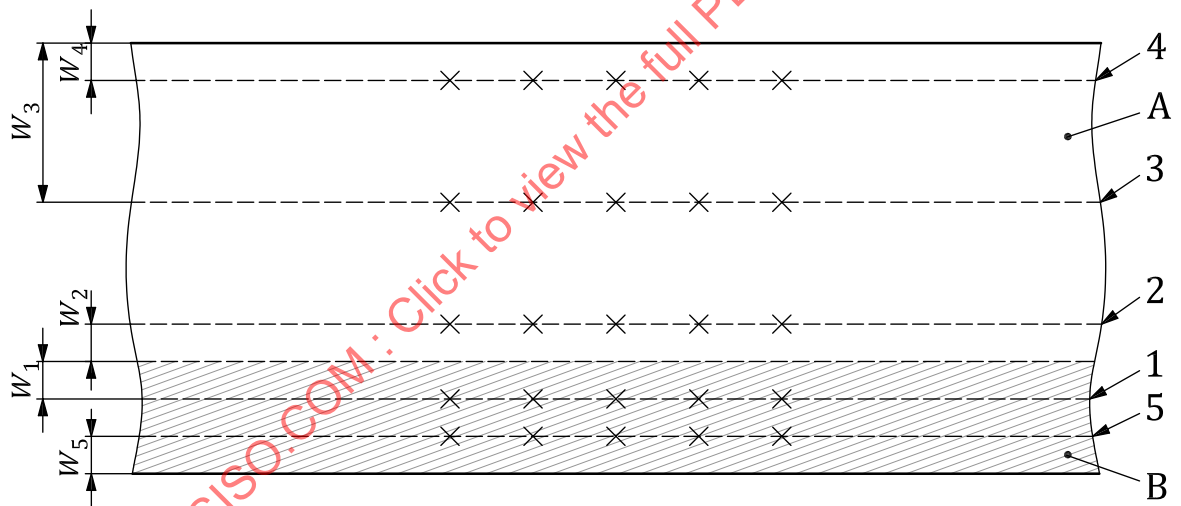
For seamless clad bend made from weld overlaying procedure, the locations for through-thickness hardness testing shall include the intrados, extrados and neutral zone of the bend arc and the extrados at the transition zone. The testing points at each location are as shown in [Figure 1 b\)](#) and [Figure 1 c\)](#) for seamless clad bend and welded clad bend respectively. Unless otherwise agreed, the hardness indents shall have a spacing of 1 mm.

9.4.4.3 Test method

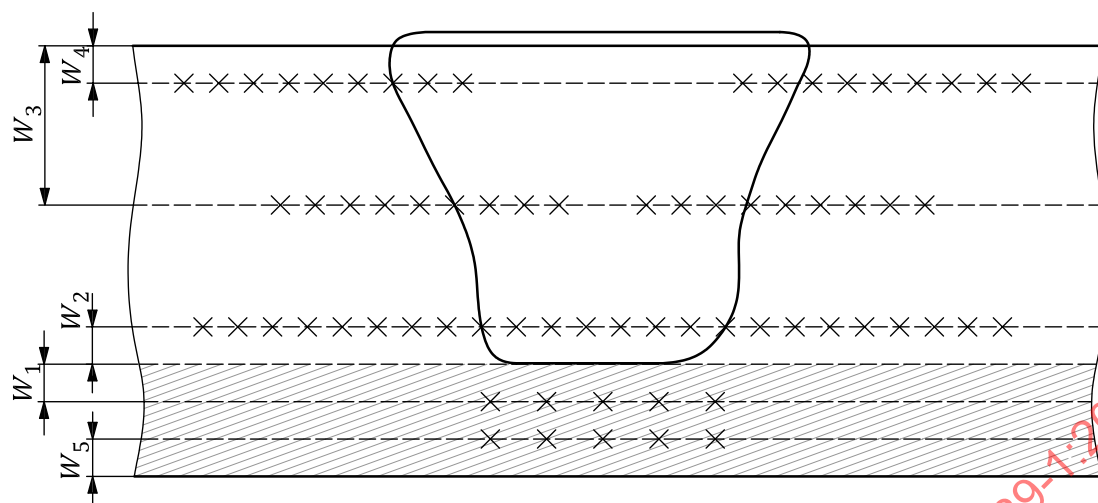
Through-thickness hardness testing shall be performed with the Vickers method in accordance with the ISO 6507 series or ASTM E92.



a) Welded clad bend



b) Seamless clad bend with weld overlay



c) Welded clad bend with weld overlay

Key

- A backing layer
 B clad layer
 1 — distance to the backing steel/clad layer interface fusion line on the clad layer side
 $W_1 = 1,0 \text{ mm}, +0,0, -0,5 \text{ mm}$
 2 — distance to the backing steel/clad layer interface fusion line on the backing steel side
 $W_2 = 1,0 \text{ mm}, +0,0, -0,5 \text{ mm}$
 3 — at the mid-wall position of the backing steel, W_3 , which is half the backing steel wall thickness
 4 — distance to the external surface of the backing steel $W_4 = 1,5 \text{ mm}, +0,5 \text{ mm}, -0,0$
 5 — distance to the internal surface of the surfaced clad layer $W_5 = 1,5 \text{ mm}, +0,0, -0,5 \text{ mm}$

Figure 1 — Indent locations for through-thickness hardness testing**Table 3 — Hardness testing requirements**

Type of materials	Hardness requirements
Base metal and weld seam of the backing steel (carbon steel or low alloy steel)	Hardness readings shall not exceed 300 HV10, or equivalent (see ASTM E140) for non- sour service (Class B). Clad bends for sour service (Class S) shall meet the hardness requirements of ISO 15590-1:2018 Annex B.
Base metal and weld seam of the clad layer (austenitic stainless steel)	Not exceeding 300 HV10
Base metal and weld seam of the clad layer (duplex stainless steel)	Not exceeding 300 HV10 in the parent material and 334 HV10 in the weld and HAZ for 22 Cr. Not exceeding 300 HV10 in the parent material and 378 HV10 in the weld and HAZ for 25 Cr.
Base metal and weld seam of the clad layer (nickel base alloy, such as 825 alloy (LC2242) and 625 alloy (LC2262))	Not exceeding 350 HV10
NOTE The conversion factors between Vickers hardness and other hardness for stainless steel and nonferrous metal are different from those for carbon steel. Refer to ASTM E140 as a reference for hardness conversion.	

9.4.5 Surface hardness testing

9.4.5.1 Requirements

The conformance acceptance indicators shall be as agreed. For test clad bends used for manufacturing procedure qualification, the average value of the readings obtained from the three equidistant points at each testing location is taken as the testing result, which can be used as the basis for establishing conformance acceptance indicators for the mass production of clad bends.

Single hardness values shall meet the requirements of [Table 3](#).

9.4.5.2 Test method

A portable hardness tester shall be used to test the macro hardness of the external surface of backing steel. The same type of testing device shall be used both for qualification test and production test. The selection of the testing device shall be at the manufacturer's discretion unless otherwise agreed.

Three surface-hardness readings at each location shall be taken across one circumferential location 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 only at one of the above locations.

9.4.6 Flattening tests

Seamless and welded clad bends shall be tested by flattening. A section of pipe not less than 63,5 mm in length with the CRA layer left on the test specimen shall be flattened cold between parallel plates in two steps as follows.

Step 1. This is a test for ductility. No disbonding of the cladding and no cracks or breaks on the inside or outside or end surfaces shall occur in the backing steel or the CRA until the distance between the plates is less than the value of H , which is calculated using [Formula \(1\)](#):

$$H = \frac{1,09(t+t_B)}{0,09+(t+t_B)/D} \quad (1)$$

Step 2. This is a test for cladding bond strength. The flattening shall be continued until either the specimen breaks or the opposite walls of the pipe meet. During this second step of the flattening test, no disbonding between the CRA layer and the backing steel shall occur.

If agreed, flattening test is not required for clad bends with larger diameter (such as $D \geq 600$ mm) due to the capacity of the test machine.

9.4.7 CRA cladding bond strength testing

9.4.7.1 Requirements

For induction clad bends made from mother clad pipes which are produced from clad plates, the minimum acceptable bonding shear strength shall be not less than 140 MPa. The testing of the induction clad bends shall not be required if acceptable test results are available for the mother clad pipe. For clad bends made by weld overlay process, the testing of bonding shear strength is not necessary.

9.4.7.2 Test specimens

Longitudinal specimens shall be extracted from the bend arc, tangent and transition zone for tests.

9.4.7.3 Test method

Methods and practices relating to bond shear strength tests shall be performed in accordance with ASTM A264-12 or ASTM A265-12.

9.4.8 Macrographic examination

9.4.8.1 Requirements

The tangent and arc of clad bends with weld seam shall be subjected to cross-section macroscopic examination. No defects shall be allowed in the weld seam zone. The internal and external weld passes shall be completely fused. Geometric dimensions of the weld seams and defects in workmanship shall meet the requirements of [Table 4](#).

9.4.8.2 Test specimens

Specimen preparation shall be in accordance with ASTM E3.

9.4.8.3 Test method

Geometric dimensions of the weld seams and defects of the welded clad bends shall be examined by macrographic testing. The specimens for through-thickness hardness testing shall be examined, prior to hardness testing, at a magnification of not less than 10×. Macroetching shall be in accordance with ASTM E340.

Table 4 — Acceptance criteria for macrographic examination of weld

Type of defects ^a	Longitudinal weld seam ^b	Weld overlayer of CRA
Weld seam fusion	Complete fusion	Complete fusion
Weld undercut of mother pipe	≤0,4 mm	
Weld undercut of clad layer ^c	≤0,4 mm	≤0,4 mm
Longitudinal weld misalignment of backing steel	≤1,5 mm	
Longitudinal weld misalignment of corrosion resistant alloy layer	≤0,5 mm	
Weld continuity of corrosion resistant alloy layer	100 % continuous	
Crack	Not allowed	Not allowed
Weld deviation	≤0,15 t_B , and ≤3,0 mm ≤0,15 t_B , and ≤3,0 mm	
Mutual penetration	≤2 mm	≤2 mm
Height of external weld seam	≤3 mm	
Weld reinforcement of clad layer	≤0,5 mm	
^a The types of weld imperfections are based on the ISO 6520 series. ^b It shall not be required if acceptable test results are available for mother clad pipes. ^c Weld undercut of clad layer is not applicable for the weld overlay process.		

9.4.9 Metallographic examination

9.4.9.1 Requirements

As part of the MPQT, results of the metallographic examination shall demonstrate that the microstructure of the base metal, weld seam and HAZ for different locations of the clad bend tangent, transition zone and arc (including the intrados, extrados and neutral zone) is basically consistent, and there is no detrimental phase present. Acceptance criteria of the weld seams shall meet the requirements of [Table 5](#).

9.4.9.2 Test specimens

Specimen preparation shall be in accordance with ASTM E3.

9.4.9.3 Test method

Specimens shall be examined, at a magnification of not less than 100×. Microetching shall be in accordance with ASTM E407.

Table 5 — Acceptance criteria for metallographic examination of weld

Type of defects	Longitudinal weld seam	Weld overlayer of CRA
Detrimental intermetallic phase	Not allowed	Not allowed
After-welding ferrite content of S31603 austenitic stainless steel, point count procedure in accordance with ASTM E562	5 % to 13 %	5 % to 13 %
When intermetallic phases are present, the detriment of the intermetallic phases shall be validated through a corrosion test.		

9.5 Corrosion testing

9.5.1 Intergranular corrosion testing

9.5.1.1 Requirements

As part of the MPQT, intergranular corrosion test shall be carried out on the CRA layers of the clad bends. If ASTM A262-15, Practice E is adopted, the specimen should be checked for cracks in the curved specimen under the condition of no less than 10× magnification after corrosion. If there is any doubt about the result, the specimen shall be examined by the metallographic examination at magnification of 150× to 500×, and no cracks are considered as qualified.

If ASTM A262-15, Practice B, Practice C or ASTM G28-02 Method A is used, the corrosion rate calculated from mass loss shall be reported and the acceptance criteria shall be as agreed.

NOTE 1 The following criteria are as reference:

- For austenitic steel (such as 316L), no ditch as ASTM A262-15, Practice A and no cracking and no intergranular attack as A262-15 Practice E.
- For nickel-based alloy (such as UNS N06625), the corrosion rate of base metal is no more than 0,8 mm/year and that of the weld seam and HAZ or weld-overlay is no more than 1,0 mm/y by ASTM G28-02, Method A.
- For iron-nickel-based alloy (such as UNS N08825), the corrosion rate is no more than 0,8 mm/y and no intergranular attack by ASTM A262-15, Practice C.

Unless otherwise specified, the maximum acceptable corrosion rate calculated from mass loss shall not exceed 10 mdd for ASTM A923-14 method C and 4 g/m² for ASTM G48-11, Method A.

NOTE 2 corrosion rate mdd = weight loss (mg)/[specimen area (dm²) × time (days)]

9.5.1.2 Test specimens

One specimen shall be taken from the CRA layer of as manufactured bend in the same condition as bends to be delivered. For welded clad bend, an additional specimen shall be taken from across the longitudinal weld. The specimen axis shall be transverse to the bend axis. The specific sampling location should be performed in accordance with [Annex C](#). The cutting edges of the specimens shall be machined or ground if flame cutting is used for specimens. Unless flattening is required, the specimen shall be tested in its original state. Any scale or steel on the specimen shall be removed mechanically using an iron-free alumina abrasive with a particle size of 120, or chemically method. Copper sulfate test or ferroxyl test as specified in ISO 10309 may be used for inspection the iron contamination at the discretion of the tester.

9.5.1.3 Test method

If the clad layer is austenitic stainless steel, intergranular corrosion test shall be conducted by ASTM A262-15, Practice A & (Practice B or Practice E).

If the clad layer is iron-nickel-based alloy (such as UNS N08825) or nickel-based alloy (such as UNS N06625), intergranular corrosion test shall be conducted by ASTM A262-15, Practice C or ASTM G28-02, Method A, respectively. If agreed, ASTM G48-11, Method A may also be applied in intergranular corrosion testing for iron-nickel-based or nickel-based alloy.

ASTM G48-11, Method A or ASTM A923-14, Method C shall be used to detect the detrimental intermetallic phase in duplex austenitic/ferritic stainless steel to the extent that corrosion resistance is affected.

9.5.2 HIC and SSC testing of backing steel material

9.5.2.1 Requirements

If agreed, for the clad bend class S, as part of the MPQT, HIC and SSC testing of backing steel material shall meet the requirements of ISO 15590-1:2018, Annex B.

9.5.2.2 Test specimens

One sample shall be taken from the backing layer of the extrados of the clad bend body in the longitudinal direction. For welded clad bend, an additional sample shall be extracted transverse to the weld seam and contain a section of the longitudinal seam at its centre. Three specimens shall be taken from each sample and shall not be flattened. Unless otherwise specified, samples may be flattened prior to machining SSC test specimens. Any scale or CRA on the specimens shall be removed mechanically.

If a transverse sample with weld seam cannot be taken from the finished welded clad bend because of its smaller diameter, a longitudinal sample is advisable, or taken from the mother clad pipe or exempt the test under the agreement.

9.5.2.3 Test method

HIC and SSC testing shall be carried out in accordance with NACE TM0284 and NACE TM0177 or ASTM G39, respectively, with a reference to ISO 15590-1.

9.5.3 Corrosion testing of clad layer material for service condition

If corrosion testing of CRA clad layer material for intended service condition is specified by the purchaser, the test methods, specimen locations and acceptance criteria shall be performed in accordance with [Annex B](#) and [Annex C](#).

9.6 Dimensions and tolerances

9.6.1 General

The dimensions of the clad bends shall be measured to confirm that the dimensions specified by the purchaser have been achieved within the permissible tolerances of [Table 6](#).

9.6.2 Wall thickness

9.6.2.1 Requirements

The WT of the backing steel of clad bends shall be in accordance with [Clause 7](#). The minimum WT of the clad layer shall be not less than 2,5 mm unless otherwise agreed.

9.6.2.2 Test method

For clad bends produced by bending a mother clad pipe, the WT of backing steel and of the clad layer shall be examined by metallographic method in MPQT. The examined location shall include at least the tangent, the extrados and intrados of the bend arc.

The values of WT of backing steel obtained at the extrados and intrados together with the values of backing steel WT previously measured on the mother clad pipe should be used to determine the thinning/thickening ratio of backing steel.

The thinning/thickening ratio, T , expressed as a per cent, is given in [Formula \(2\)](#):

$$T = \frac{t_a - t_t}{t_t} \times 100 \quad (2)$$

where

- t_a WT of backing steel measured by metallographic method at the extrados or intrados of the bend arc;
- t_t WT of backing steel at tangent section by metallographic method or WT of backing steel previously measured on the mother clad pipe.

During production of clad bends, WT measurements shall be made with a properly calibrated non-destructive inspection device of appropriate accuracy. The total WT of the clad bend should be measured by manual ultrasonic pulse-echo contact method in accordance with ASTM E797, and the WT of clad layer should be measured by electromagnetic method in accordance with ASTM B499.

The measured location of total WT shall include at least the tangent section, and the extrados and intrados of the bend arc, at least 3 points shall be measured evenly for each location. The WT of clad layer shall be measured by electromagnetic method at 4 quadrants of clad bend ends. The WT of backing steel at tangent section can be calculated as difference between the total WT and the WT of clad layer measured at bend ends.

Where the measurement by electromagnetic method is not possible due to inaccessibility of the area, the WT of backing steel at the extrados and intrados of the bend arc should be assumed to be the WT of backing steel measured before bending or the WT of backing steel at tangent section, applying the thinning/thickening ratio determined by metallographic method. The WT of clad layer at the extrados and intrados of the bend arc can be determined as difference between total WT and the calculated WT of backing steel.

For weld overlay with CRA onto the mother steel bends, the WT of CRA can be measured by electromagnetic method in accordance with ASTM B499 or calculated as difference between total WT and that of mother steel bend prior to welding measured by manual ultrasonic pulse-echo contact

method in accordance with ASTM E797. The measured location shall include at least tangent, and the extrados and intrados of the bend arc, at least 3 points shall be measured evenly for each location.

9.6.3 Diameter

The outside diameter and inside diameter at bend ends of clad bend shall be measured using circumferential tape, mechanical callipers or an optical gauge with appropriate accuracy.

9.6.4 Bend angle, bend radius, end out-of-squareness, out-of-planeness and tangent length

Unless otherwise agreed, tangent lengths for both ends of a clad bend should be equal. The tangent length, L , shall meet the following requirements: If $D \leq 300$ mm, L shall be not less than D ; If $D > 300$ mm, L shall be not less than 500 mm.

The bend angle, bend radius, end out-of-squareness, out-of-planeness and tangent length of clad bends should be measured in accordance with ISO 15590-1.

Table 6 — Permissible dimensional tolerances of clad bend

Dimension	Permissible tolerance
Linear dimensions ^a	± 30 mm
Outside diameter of clad bend arc and tangents, D	Not required or as agreed
Inside diameter of clad bend ends, $d^{b,c}$	$d \leq 200$ mm, $\pm 0,5$ mm $200 < d \leq 600$ mm, $\pm 1,0$ mm $d > 600$ mm, as agreed
Minimum wall thickness of backing steel layer	0
Maximum wall thickness of backing steel layer	as agreed
Minimum wall thickness of clad layer	0
Maximum wall thickness of clad layer	as agreed
Bend angle	$\pm 1^\circ$
Bend radius for clad bends with $r_b \geq 1\,000$ mm	± 1 %
Bend radius for clad bends with $r_b < 1\,000$ mm	± 10 mm
End out-of-squareness	$\leq 1,6$ mm from true 90°
Out-of-planeness	as agreed
Out-of-roundness of inside diameter at ends ^{b,c,d}	0,5 % max and the maximum difference of inside diameter shall not exceed 2,0 mm
Out-of-roundness of outside diameter in clad bend body ^e	$r_b \geq 5D$; 2,5 % max. $3D \leq r_b < 5D$; 3 % max, unless otherwise agreed as agreed for a smaller bend radius

^a Such as centre-to-end, offsets, chord lengths, tangent length.

^b Within 100 mm from the end.

^c The requirements may be agreed by the manufacturer and purchaser.

^d Out-of-roundness of inside diameter at ends, O_i , expressed as a per cent, is given in Formula (3):

$$O_i = \frac{d_{\max} - d_{\min}}{d} \times 100 \quad (3)$$

^e Out-of-roundness of outside diameter in clad bend body, O_o , expressed as a per cent, is given in Formula (4):

$$O_o = \frac{D_{\max} - D_{\min}}{D} \times 100 \quad (4)$$

9.7 Non-destructive testing

9.7.1 General

Where necessary, after final heat treatment and prior to visual or other non-destructive inspection, the entire outside and inside surface of all clad bends shall be cleaned to a cleanliness grade of ISO 8501-1:2007, Sa 2.

9.7.2 NDT personnel

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

9.7.3 Visual inspection

All finished clad bends shall be visually examined. An endoscope or other computer-aided imaging technique shall be used to detect the inner surface which is not convenient for direct vision.

The acceptance criteria for laminations, cracks, notches, gouges and other imperfections on the outer surface of backing steel shall be in accordance with ISO 3183:2019. The CRA clad layer shall be free of cracks, undercut, incomplete fusion, arc burns, overheating and over burning.

The wave shapes shall be blend into the bend surface in a gradual manner with a maximum crest-to-valley depth (CVD), of 1 % of the measured outside diameter at the intrados surface. The ratio of the distance between adjacent crests, f , to the CVD is a minimum of 25. The schematic diagram for measurement of waving is shown in [Figure 2](#).

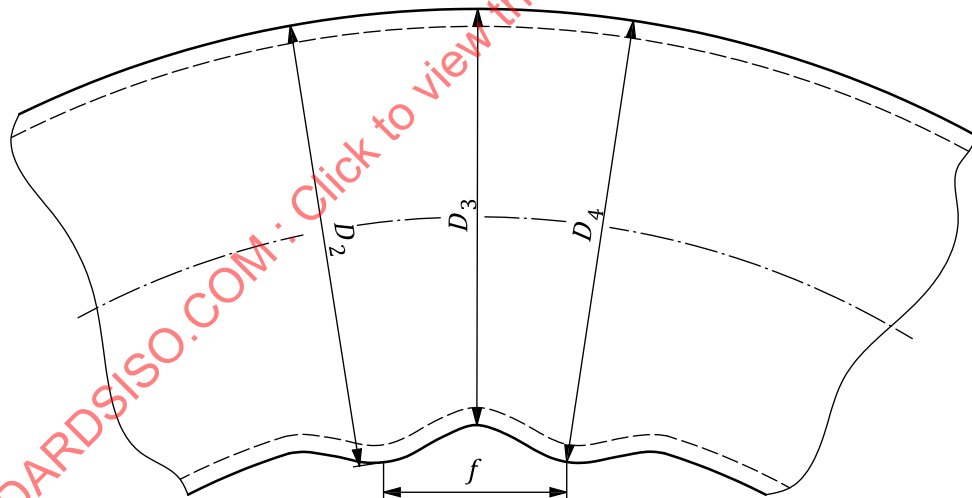


Figure 2 — Schematic diagram for measurement of waving

The CVD, designated by the symbol L_{CVD} , shall be determined as given in [Formula \(5\)](#):

$$L_{CVD} = \frac{D_2 + D_4}{2} - D_3 \quad (5)$$

where

D_2, D_4 outside diameters of two adjacent crests of clad bend in millimetres;

D_3 outside diameter of the intervening valley of clad bend in millimetres.

NOTE When there is only one crest occurred, the dimensional criteria is based on the outside diameter tolerance at that crest.

9.7.4 Inspection of surfaces of clad bend

For all clad bends, the outer surfaces of backing steel 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 by PT in accordance with ISO 10893-4.

For induction clad bend produced by mother clad pipe, PT shall cover as much of the internal surface as is practical. For weld overlay with CRA onto the mother steel bends, the entire CRA overlay of the internal surface shall be inspected by PT.

All cracks, laps, laminations and all rounded indications greater than 3 mm in any direction in the backing steel shall be classed as defects and shall be repaired in accordance with 9.7.9.

Defects in the CRA layer detected by PT shall be repaired in accordance with 9.7.9, and the required minimum WT of clad layer shall be maintained

9.7.5 Inspection of weld seam

The longitudinal weld seam of the clad bend shall be inspected full length (100 %) by radiological testing (RT) in accordance with ISO 10893-6 or by manual or automatic ultrasonic testing (UT) procedures in accordance with ISO 10893-11, ASTM E273 or ASTM E587 or as agreed.

If not carried out on the starting material already, an ultrasonic inspection shall be performed for disbondment of the cladding, as defined in ASTM A263-12, ASTM A264-12, and ASTM A265-12, Clause 13, along the zone 50 mm on each side of the weld seam. Disbonded areas are not permitted within 50 mm of any of the edges to be longitudinally welded.

9.7.6 Inspection of clad bend ends

After end preparation, the complete end preparation shall be inspected for laminar imperfections by PT. PT shall be performed in accordance with ISO 10893-4 or ASTM E165.

A 50 mm wide band at each end shall be inspected for laminar imperfections and disbonding by UT in accordance with ISO 10893-8, ASTM A435 or ASTM A578/A578M-17. Laminar imperfections shall not exceed 6,4 mm in the circumferential direction or have an area in excess of 100 mm². Disbonded areas are not permitted within 100 mm of both ends. The acceptance criteria for the disbonded areas shall not exceed the limits of ASTM A578/A578M-17, Level C.

9.7.7 Inspection of clad bend body

Ultrasonic testing (UT) in accordance with ISO 10893-10 shall be performed over an arc of 180°, 90° each side of the extrados to verify that the clad bend is free from transverse defects. The acceptance criteria for transverse defects shall be as stated in ISO 3183:2019.

If not carried out on the starting material already, ultrasonic testing (UT) in accordance with ISO 10893-8, ISO 10893-9, ASTM A435, or ASTM A578/A578M-17 as applicable shall be performed on the clad bend to detect laminar imperfections and disbonding. The acceptance criteria for backing steel shall be in accordance with ISO 15590-1. The acceptance criteria for the disbonded areas shall not exceed the limits of ASTM A578/A578M-17, Level C.

9.7.8 Level of residual magnetism

The residual magnetism at both ends of each finished clad bend shall not exceed 15 Gauss. Magnetism levels higher than this value shall require the clad bend end to be demagnetized until the level is reduced below 15 Gauss.

9.7.9 Imperfection and defect treatment

Defects shall be repaired as follows:

a) Surface defects.

The weld repair of surface defects on backing steel is prohibited. Except for surface defects of weld overlay, any other surface defects on the clad layer are not allowed to be repaired by welding.

Surface defects (such as upset, crest, peak at the start/stop transition zone) should be removed by grinding, provided that a smooth curved surface is maintained and the required minimum wall thickness is maintained. The grinding of cladding layer should be made of special grinding wheel to prevent CRA from being contaminated.

All ground repair areas shall be examined by using the same NDT method that originally detected the defect to confirm the complete removal of the defects. After grinding, the WT of the backing steel and of clad layer shall be measured in accordance with [9.6.2](#).

b) Weld seam.

The defects on weld seam, except for the distance 100 mm from the ends of the clad bend, may be repaired at the discretion of the manufacturer in accordance with a qualified and accepted welding procedure specification. UT and/or RT in accordance with [9.7.5](#) as applicable shall be performed on the repaired weld seam to verify the complete removal of the defects.

There shall be no more than 3 welding repair points for longitudinal weld seam of CRA layer for each clad bend. The length of individual welding repair for longitudinal weld seam of CRA layer shall not be less than 50 mm, and the adjacent spacing of the welding repair shall not be less than 100 mm.

c) Disbonded areas.

The repair of disbonded defects within 50 mm of any of the edges to be longitudinally welded and within 100 mm of any end of the clad bend is prohibited. Except the aforementioned areas of the clad bend, the disbonded defects may be repaired as agreed.

9.8 Hydrostatic testing

If hydrostatic testing is specified by the purchaser, the test method shall be as agreed. The requirements for hydrostatic testing shall be: At the option of the purchaser, the testing pressure is 150 % of the design pressure or calculated pressure based on Barlow's formula, minimum allowable carbon steel wall thickness after bending and 90 % SMYS of the backing steel (CRA is not part of strength design), whichever lesser. The test clad bend shall be free of cracking, leakage or other damages affecting service.

10 Marking

Clad bends manufactured according to this document shall be marked as follows:

- a) manufacturer name or trade mark;
- b) a reference to this document, i.e. 24139-1;
- c) nominal outside diameter, specified inside diameter at the tangent end;
- d) minimum wall thickness of backing steel and clad layer;
- e) clad bend designation as defined in [Clause 6](#);
- f) CRA type of clad layer;
- g) bend angle;

- h) bend radius;
- i) purchase order and item number;
- j) unique number of each clad bend;
- k) any additional marking specified in the purchase order.

Markings shall be made with indelible paint on the outside surface. If the dimensions of the clad bends are insufficient to mark all the aforementioned information, additional label can be used for marking. Cold-die stamping shall be only allowed on the bend bevel. If agreed, other marking methods can be performed.

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

11 Packaging, handling and storage

Packaging, handling and transportation of clad bends shall be carried out in such a way that they are protected from deformation or damage caused by external force.

The ends of bends shall be effectively protected by protective covers such as bevel end protectors so as to prevent mechanical damage and pollution to the prepared bevel ends and interior surfaces of bends during handling and transportation.

During handling and transportation, devices containing iron, copper or copper alloy are not allowed to contact the internal surface of CRA or the groove of clad bend ends.

The manufacturer shall submit its packaging, handling, storage and transportation procedures in writing for inspection by the purchaser. The shipment shall at least conform with the requirements of road, rail or sea transport.

12 Documents

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.

All tests and inspections to be carried out as prescribed shall be completed before delivery and testing, and inspection documents shall be provided to the purchaser. Quality certificates of clad bends shall include at least:

- a) Manufacturer's name and date of manufacture;
- b) Product name, specification, this standard number;
- c) Starting material inspection report;
- d) Inspection report on product dimensions;
- e) Report on chemical composition and physical tests of the products;
- f) Report on corrosion of cladding materials;
- g) Product NDT report;
- h) Heat treatment report;
- i) Other documents designated by the purchaser.

Annex A (normative)

Manufacturing procedure qualification

A.1 Introduction

In one of the following cases, manufacturing procedure qualification shall be carried out:

- a) New production evaluation;
- b) Major changes to material, structure or procedure that may affect the product performance (i.e. mechanical, corrosion resistance and dimensions, etc);
- c) Production restoration after more than one year of continuous suspension.

Manufacturing procedure qualification consists of the following two parts:

- Manufacturing procedure specification (MPS);
- Manufacturing procedure qualification tests (MPQT)

A.2 MPS requirements

A.2.1 MPS development procedure

MPS development procedure includes the following steps:

- a) Prepare a preliminary MPS;
- b) Start production of test bends per the preliminary MPS;
- c) Conduct testing and inspection in accordance with [Clause 9](#);
- d) Revise the preliminary MPS according to the test bend production report, and finalize the MPS;
- e) Submit the MPS to the purchaser for approval.

A.2.2 Required information in MPS

MPS shall contain, as a minimum, the following information:

- a) Starting material
 - 1) Name of manufacturer;
 - 2) Material type or steel grade (including backing steel and clad layer);
 - 3) Manufacturing procedure;
 - 4) Specifications and dimensions;
 - 5) Chemical composition (including backing steel and clad layer);
 - 6) Mechanical properties of backing steel layer;
 - 7) Welding procedure of welded steel pipes and chemical composition of weld metal;

- 8) Weld seam testing methods and report;
 - 9) Weld repair procedure and report;
 - 10) Specifications, dimensions, steel grade, chemical composition, mechanical properties, welding procedure, weld metal chemical composition and bending procedure of mother steel bends, if the clad bends are made by weld overlay with CRA onto the mother steel bends;
 - 11) Weld overlay procedure;
 - 12) Heat treatment and status of supply;
 - 13) Re-testing requirements.
- b) Bending procedure
- 1) Cleaning method and requirements of mother clad pipe prior to bending;
 - 2) Inspection and evaluation of the bending machine;
 - 3) Method of temperature control and measurement during bending;
 - 4) Heating and quenching of tangent where the bending starts and stops. The upper limit temperature of cooling water.
- c) If post-bending or post-weld overlay heat treatment is to be performed, the following information shall be included:
- 1) Type of heat treatment;
 - 2) Values of heat treatment parameters (heating rate, soaking time and temperature, cooling rate);
 - 3) Type of temperature control instrument and location of thermocouples.
- d) Dimensions and rounding procedures;
- e) Testing and inspection requirements for:
- 1) Qualification test clad bend;
 - 2) Production clad bends.
- f) Additional purchaser requirements (e.g. end preparation, coating and marking).

The bending parameters (Induction heating frequency, bending speed, bending temperature, coolant type, coolant temperature, and coolant flow rate or pressure) (see [Table A.1](#)) should not be included in the MPS, but shall be made available in the mill for review by the purchaser.

A.3 MPQT requirements

A.3.1 MPQT shall be performed in accordance with the following provisions:

- a) Qualified MPS may be applied to the manufacturing of same bends except for bend radii (i.e. bends with smaller bend radii may cover those with bigger bend radii but not the other way round).
- b) Test clad bend shall ensure sufficient arc length to allow extraction of the test specimens.
- c) Testing and inspection of test bends shall include geometric dimensions, chemical composition, physical testing, corrosion testing, and NDT. Specific testing and inspection items are as shown in [Table 1](#), and testing and inspection results shall meet the requirements of this document.

A.3.2 During the production of bends, the manufacturer shall conform with the MPS approved by the purchaser. The manufacturer's any revision to the MPS shall be approved by the purchaser.

Table A.1 — Essential variables and maximum permissible variations

Essential variable	Maximum permissible variations ^a
Heat of backing steel	None
CRA type of clad layer	None
PREN of clad layer (if specified on the purchase order or data-sheet)	-0,5 %
Mother clad pipe seam weld WPS and welding consumables	None
Surface condition	as agreed
Diameter of mother clad pipe (inside or outside)	None
Wall thickness (nominal or minimum values for both backing steel and clad layer)	±3 mm or ±10 % whichever is the smallest for backing steel; ±0,5 mm for CRA layer
Bend radius	For $r_b \leq 5D$, from 0 % to +25 % For $5D < r_b \leq 10D$, from 0 % to +100 % For $r_b > 10D$, None
Forming speed	±2,5 mm/min
Forming temperature	±25 °C
Induction heating frequency	±20 %
Coil design	None
Coolant	None
Coolant flow rate or pressure	±10 %
Coolant temperature	±15 °C
Weld seam location	±15° from the location in the test clad bend
Weld overlay	According to ASME Section IX or ISO 15614-7 Weld overlay WPS and welding consumables: None Nominal diameter of mother steel bend
Post-bending or post-weld overlay heat treatment	Method: no change Soaking time: from 0 min to +15 min Soaking temperature: ±15 °C Heating and cooling rates: as agreed
^a The permissible variations apply to the values obtained in the approved bend qualification test (BQT).	

Annex B (normative)

Corrosion qualification of CRA clad layer for intended service condition

B.1 General

If specified by the purchaser, corrosion qualification for the clad layer material shall include SCC (see [B.2](#)) or mass loss corrosion and pitting corrosion tests (see [B.3](#)).

If mass loss corrosion and pitting corrosion tests (see [B.3](#)) is adopted, SCC test (see [B.2](#)) shall be conducted additionally when pitting appears and is within the acceptance criteria.

B.2 SCC qualification

B.2.1 General requirements

SCC performance of the clad layer material shall be evaluated by one of the following three methods.

- a) Evaluation based on ISO 15156-3:2020, Annex A without testing. Acceptable metallurgical conditions and environmental limits are given for which alloys are expected to resist cracking. Environmental limits are given for H₂S partial pressure, pH, temperature, chloride concentration, and elemental sulfur.
- b) Evaluation based on satisfactory field application experience is also acceptable, which shall conform to ISO 15156-1.
- c) If a) and b) above cannot meet the requirements, the test shall be carried out in accordance with the methods specified in [B.2.2](#) to [B.2.6](#).

B.2.2 Test method

Four-point bend (FPB) tests should be performed to evaluate the SCC of the CRA clad layer. FPB tests shall be conducted in accordance with ISO 7539-2.

Specimens for FPB tests shall be loaded to a stress level of the CRA material as agreed with the purchaser.

B.2.3 Test environment

SCC tests shall be conducted in the simulated environment of clad bend conveying medium. An autoclave is generally used to simulate the high-pressure and/or high-temperature. The test method should be conducted in accordance with ASTM G111 or other specification as agreed.

The following factors shall be controlled and recorded for the simulation of test conditions:

- Total pressure;
- H₂S partial pressure;
- CO₂ partial pressure;
- Temperature;