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

**Part 2:  
Clad fittings**

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

*Partie 2: Raccords 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](http://www.iso.org/directives)).

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

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

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

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

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

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

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

## Part 2: Clad fittings

### 1 Scope

This document specifies the technical delivery conditions regarding design, geometric dimensions, materials, manufacturing procedures, inspection methods, non-destructive testing, marking, package and storage for factory-made, seamless and welded, corrosion resistant alloy (CRA) clad fittings for use in pipeline transportation systems for the petroleum and natural gas industries as defined in ISO 13623.

This document is applicable to CRA clad fittings 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.

The clad fittings specified in this document include clad elbows, clad reducers, clad tees and clad caps.

Two technical delivery conditions classes for clad fittings are designated. Class B provides a standard quality level for clad fittings and Class S provides technical requirements for sour-service conditions.

Fabricated laterals, fabricated lap joint stub ends and other fittings employing circumferential or intersection welds are considered as pipe fabrication and are outside the scope of this document.

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

ISO 3651-1:1998, *Determination of resistance to intergranular corrosion of stainless steels — Part 1: Austenitic and ferritic-austenitic (duplex) stainless steels — Corrosion test in nitric acid medium by measurement of loss in mass (Huey test)*

ISO 3651-2:1998, *Determination of resistance to intergranular corrosion of stainless steels — Part 2: Ferritic, austenitic and ferritic-austenitic (duplex) stainless steels — Corrosion test in media containing sulfuric acid*

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 8407, *Corrosion of metals and alloys — Removal of corrosion products from corrosion test 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 9400:1990, *Nickel-based alloys — Determination of resistance to intergranular corrosion*

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 14250, *Steel — Metallographic characterization of duplex grain size and distributions*

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 H<sub>2</sub>S-containing environments in oil and gas production — Part 1: General principles for selection of cracking-resistant materials*

ISO 15156-2, *Petroleum and natural gas industries — Materials for use in H<sub>2</sub>S-containing environments in oil and gas production — Part 2: Cracking-resistant carbon and low-alloy steels, and the use of cast irons*

ISO 15156-3:2020, *Petroleum and natural gas industries — Materials for use in H<sub>2</sub>S-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 15590-2:2021, *Petroleum and natural gas industries — Factory bends, fittings and flanges for pipeline transportation systems — Part 2: Fittings*

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 17405, *Non-destructive testing — Ultrasonic testing — Technique of testing claddings produced by welding, rolling and explosion*

ISO 17639, *Destructive tests on welds in metallic materials — Macroscopic and microscopic examination of welds*

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*

ASME B16.9, *Factory-made wrought butt welding fittings*

ASME B31.8, *Gas transmission and distribution piping systems*

ASME B31.4, *Pipeline transportation systems for liquids and NDT slurries*

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

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

MSS SP-75, *High-strength, wrought, butt-welding fittings*

NACE TM0177, *Standard test method — Laboratory testing of metals for resistance to sulfide stress cracking and stress corrosion cracking in H<sub>2</sub>S environments*

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

### 3 Terms, definitions, symbols and abbreviated terms

#### 3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 15590-2:2021 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

##### **as agreed**

as achieving consensus upon by the manufacturer and purchaser, and specified in the purchase order

##### 3.1.2

##### **backing steel**

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

##### 3.1.3

##### **clad layer**

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

Note 1 to entry: Metallurgically bonded corrosion resistant alloy (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.

##### 3.1.4

##### **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 steels

[SOURCE: ISO 15156-1:2020, 3.6, modified — "such as stainless steel and nickel-based alloy" has been added.]

##### 3.1.5

##### **if agreed**

as prescribed, or more stringent than is prescribed, if achieved consensus by the manufacturer and the purchaser and specified in the purchase order

##### 3.1.6

##### **manufacturer**

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

Note 1 to entry: The specific requirements are addressed in this document.

**3.1.7****mother clad pipe**

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

**3.1.8****mother steel fitting**

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

**3.1.9****neutral zone**

zone near the neutral axis of the elbow arc

**3.1.10****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 fittings

**3.1.11****sour environment**

exposure to oilfield environments that contain sufficient  $H_2S$  to cause cracking of metallic materials by specific mechanisms

Note 1 to entry: These mechanisms are addressed in ISO 15156-1.

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

**3.1.12****manufacturing procedure specification****MPS**

document that specifies the process control parameters and the acceptance criteria to apply for all manufacturing, inspection and testing activities performed during clad fitting manufacture

[SOURCE: ISO 15590-2:2021, 3.5, modified — "Fitting" has been replaced with "clad fitting".]

**3.2 Symbols**

|            |                                                                                                                 |
|------------|-----------------------------------------------------------------------------------------------------------------|
| $A$        | elongation of tensile test specimen after fracture, expressed as a percentage                                   |
| $D$        | nominal or calculated (from the specified inside diameter and wall thickness) outside diameter of clad fittings |
| $d$        | specified inside diameter at end of a clad fittings                                                             |
| $R_m$      | ultimate tensile strength                                                                                       |
| $R_{t0,5}$ | yield strength for 0,5 % total elongation                                                                       |
| $t$        | minimum wall thickness of clad layer for clad fitting                                                           |
| $t_B$      | nominal (minimum) wall thickness of backing steel for clad fitting                                              |

**3.3 Abbreviated terms**

|     |                              |
|-----|------------------------------|
| AUT | automatic ultrasonic testing |
| HAZ | heat-affected zone           |
| HIC | hydrogen induced cracking    |

|      |                                            |
|------|--------------------------------------------|
| MPQT | manufacturing procedure qualification test |
| MT   | magnetic 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                    |
| PWHT | post-welding heat treatment                |
| UT   | ultrasonic testing                         |
| WT   | wall thickness                             |
| WPS  | welding procedure specification            |

## 4 General requirements

### 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, 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 information

The purchaser shall provide the following information in the order given below:

- a) a reference to this document, i.e. ISO 24139-2:2023;
- b) clad fitting designation;
- c) quantity of clad fittings;
- d) CRA material type or identification (UNS or ASTM A240/A240M, see [Annex C](#)) of clad layer;
- e) clad fittings dimensions:
  - nominal diameter, DN (in accordance with MSS SP-75 or ASME B16.9);
  - specified inside diameter at ends;

- nominal (minimum) wall thickness of backing steel;
  - nominal (minimum) wall thickness of clad layer;
  - the angle (for special elbows).
- f) end preparation if different from square ends;
- g) seamless or with longitudinal weld(s);
- h) whether the purchaser wishes to approve the MPS prior to commencement of manufacturing.

## 5.2 Additional information

The purchaser should specify the following additional information if applicable, which will include but not limited to:

- a) pipeline operating conditions, including composition of transported fluid, temperature and pressure;
- b) design temperature (minimum and maximum);
- c) pipeline design standard or design factors;
- d) requirements for maximum wall thickness of both backing steel and clad layer;
- e) specifications and materials of matching pipes;
- f) special dimensional requirements;
- g) supply of mother clad pipes or mother steel fittings by the purchaser or the manufacturer;
- h) requirements for gauging and other measurements of dimensions, if different from this document;
- i) requirements for supplementary inspection and testing;
- j) mechanical property requirements for backing steel at high temperatures;
- k) requirements for proof burst testing or hydrostatic testing;
- l) whether verification of the capability to withstand internal pressure shall be done by calculation or by proof testing or both (see [Clause 7](#));
- m) requirements for corrosion resistance for both backing steel (such as HIC and SSC) and clad layer;
- n) whether approval of the MPS is to be by review of previous production data or by MPQT;
- o) coating or painting requirements;
- p) marking requirements, if different from this document;
- q) packaging and shipping instructions, if different from this document;
- r) third-party inspection organization;
- s) inspection documents which are required in accordance with ISO 10474;
- t) requirements for format and additional information of the inspection documents;
- u) PWHT (see [8.5](#)).

### 5.3 Information on the mother clad pipe

**5.3.1** If the mother clad pipe is supplied by the purchaser, the following information on the mother clad pipe 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.

**5.3.2** If the mother clad pipe is supplied by the purchaser, the following additional information should also be provided to the manufacturer if applicable:

- a) material specification and material certificates of clad pipe, including chemical composition, 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 WPS for welded clad pipe.

### 5.4 Information on the mother steel fitting

**5.4.1** If the mother steel fittings are supplied by the purchaser, the following information shall be provided to the manufacturer:

- a) purchasing specification;
- b) fitting designation;
- c) required fitting dimensions, including:
  - nominal diameter, DN,
  - specified inside diameter at ends,
  - nominal wall thickness,
  - radius and type of radius (if applicable), and
  - the angle (if applicable).

**5.4.2** If the mother steel fittings are supplied by the purchaser, the following additional information should also be provided to the manufacturer if applicable:

- a) material specification and material certificates of the steel fitting, including chemical composition, heat treatment, mechanical properties, and results of NDT;
- b) WPS for welded fittings;
- c) heat treatment status or PWHT for welded fittings.

## 6 Designation

Designation of clad fittings shall take the form of “XXX-YYY/CCC-Z”, where:

- the letters “XXX” represents the codes of clad fittings, which are shown in [Table 1](#);
- the letters “YYY” is the specified minimum yield strength (SMYS) of backing steel, expressed in megapascals (MPa);
- the letters “CCC” is the CRA type of clad layer (see [Annex C](#));
- the letter “Z” is the suffix B or S, B to identify the technical delivery conditions class for clad fittings in non-sour service, or the suffix S to identify the use in sour-service conditions.

EXAMPLE “45CEL(L)-245/UNS S31603-B” is a 45 deg. long radius clad elbow, the SMYS of backing steel is 245 MPa, and the CRA type of clad layer is UNS S31603, and identifies the use in non-sour service.

**Table 1 — Types and codes of clad fittings**

| Types               | Category             | Codes     |
|---------------------|----------------------|-----------|
| 45 deg. clad elbows | Long radius (1.5D)   | 45CEL(L)  |
|                     | 3D                   | 45CEL(3D) |
| 90 deg. clad elbows | Long radius          | 90CEL(L)  |
|                     | Long radius reducing | 90CEL(LR) |
|                     | Short radius (1D)    | 90CEL(S)  |
|                     | 3D                   | 90CEL(3D) |
| Clad reducers       | Concentric           | CCR       |
|                     | Eccentric            | CER       |
|                     | Conical              | CNR       |
| Clad tees           | Straight             | CTE(S)    |
|                     | Reducing outlet      | CTE(R)    |
| Clad caps           | -                    | CCA       |

## 7 Design

The design documents of clad fittings shall at least include design drawings and strength calculations or proof test report. The design parameters of clad fittings shall be consistent with those of their matching pipes.

The strength design and material selection of clad fittings shall follow the principle of the backing steel for withstanding of internal fluid pressure and additional special load and clad layer for corrosion resistance of conveying fluid.

The capability of the clad fitting to withstand internal pressure shall equal or exceed that of the matching pipe. The verification of the capability shall be made by design calculation or proof testing or both.

The calculations of the minimum wall thickness (or design thickness) of the backing steel shall be made in accordance with ISO 15590-2:2021, Annex A. The calculations of the nominal wall thickness ( $t_B$ ) of the backing steel shall be made by Barlow's formula. The hoop stress in the clad fitting 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 proof test procedure shall be as defined in ISO 15590-2:2021, Annex B. The pressure design thickness (or equivalent pipe wall or schedule rating) for critical areas of each type of clad fitting shall be determined and recorded. Critical areas are normally the extrados and intrados of elbows, the crotch of tees, the knuckle of caps, and the large end of reducers.

Additional requirements on strength design verification or different method of calculation, such as resistance to internal pressure under special load cases in accordance with ISO 13623, ASME B31.8, ASME B31.4 or other recognized documents shall be indicated at the time of enquiry or purchase order.

The design calculations and/or results of successful proof testing shall be available for review at the manufacturer's facility.

If the SMYS of the backing steel of clad fitting is less than that of the matching pipe, the minimum thickness of the fitting end shall be increased such that the product of its thickness times its SMYS shall at least equal the product of the specified wall thickness and the SMYS of the matching pipe.

For materials selection for clad fittings, 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 [9.5.4](#);
- 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 shall be as agreed.

## 8 Manufacturing

### 8.1 Starting materials

#### 8.1.1 General requirement

The starting material for clad fittings shall be fusion-welded with filler metal or seamless clad pipe, clad plate, unalloyed or low-alloy steel seamless and welded fittings.

#### 8.1.2 Mother clad pipe

Mother clad pipe should be manufactured in accordance with API Spec 5LD or other applicable document 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, coextrusion, weld overlay, 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 or other forming. The mother clad pipe shall not contain weld repairs on the backing steel pipe body, and repair of weld overlay should be accepted.

The mother clad pipe may be supplied by either the purchaser or the manufacturer. If the mother clad pipe is supplied by the purchaser, with regard to its suitability for manufacturing of fitting, the following performance 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 pipe shall conform with the applicable requirements for PSL2 in ISO 3183:2019.

If agreed, the backing steel of mother clad pipe for the manufacture of clad fittings 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.

### 8.1.3 Clad plate

The stainless chromium steel-clad plate or stainless chromium-nickel steel-clad plate used to manufacture clad fittings shall conform to ASTM A263-12 or ASTM A264-12 respectively, and the nickel-base alloy-clad plate shall conform to ASTM A265-12.

The CRA layer of the clad plate may be bonded by hot rolling, explosion bonding or other metallurgical bonding processes as agreed.

The wall thickness of backing steel and CRA clad layer of the clad plate shall have adequate allowance for wall thinning at the extrados due to bending.

The minimum acceptable bond shear strength of clad plate shall be not less than 210 MPa.

The clad plate shall be inspected by UT with 100 % coverage for bond integrity prior to shipment in accordance with ISO 17405 or ASTM A578/A578M-17. The acceptance criteria for bond quality shall fulfil the requirements of Class 1 in ASTM A263-12 or ASTM A264-12 or ASTM A265-12. The bond integrity of the clad plate may also be tested by AUT technique.

The clad plate shall not contain weld repairs on the backing steel. The repair of defects in CRA layer, except for within 50 mm any of the edges of the clad plate, should be accepted. The disbonded defects in CRA layer may be repaired with a procedure and welders or welding operators that are qualified in accordance with ISO 14732 or ASME BPVC Section IX. Butt weld seam shall not be present in the finished clad plate.

### 8.1.4 Mother steel fitting

Mother steel fitting shall be manufactured in accordance with ISO 15590-2:2021. If agreed, mother steel fitting for the manufacture of clad fittings Class S should conform with the requirements for Class S in ISO 15590-2:2021. If agreed, carbon steel or low alloy steel in accordance with MSS SP-75 or ASME B16.9 or other recognized documents may also be used.

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

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

### 8.1.5 Welding consumables

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

NOTE ISO/TC 44/SC 3 develops many relevant standards, which can be referenced according to the application.

### 8.1.6 Re-inspection of starting materials

The starting materials shall be re-inspected by the manufacturer after it has entered the manufactory. The mother clad pipe or mother steel fitting produced by the same manufacturer as the clad fittings with the same quality assurance system shall not be re-inspected.

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

- a) the starting materials shall be provided with quality certificates;
- b) the appearance and geometric dimensions of each mother clad pipes, mother steel fittings and clad plate shall be examined;

- c) if agreed, for each lot of mother clad pipes, mother steel fittings and clad plate, one should be randomly tested for such items as the chemical composition, mechanical properties, and non-destructive inspection. The extent of re-inspection and acceptance criteria shall be as agreed.

## 8.2 Manufacturing procedure specification (MPS)

### 8.2.1 General requirements

Clad fittings shall be manufactured in accordance with a documented MPS. If specified by the purchaser, manufacturing shall not proceed until the MPS has been accepted by the purchaser.

An approval of the MPS shall be required, either by review of the manufacturer's previous production data or by the report of MPQT.

Unless otherwise agreed, before commencement of the mass production, MPQT listed in [Table 2](#) shall be conducted as specified in [Clause 9](#).

During the production of clad fittings, 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.

### 8.2.2 MPS development procedure

MPS development procedure includes the following steps:

- a) prepare a preliminary MPS;
- b) start production of the test clad fittings per the preliminary MPS;
- c) conduct testing and inspection in accordance with [Clause 9](#);
- d) revise the preliminary MPS according to the report of manufacture and MPQT for the test clad fitting, and finalize the MPS;
- e) submit the MPS to the purchaser for approval.

### 8.2.3 Required information in MPS

MPS shall specify the following information (as appropriate):

- a) for the starting material:
  - 1) name of manufacturer;
  - 2) material type or steel grade (including backing steel and clad layer);
  - 3) manufacturing procedure;
  - 4) product form (such as seamless or welded mother clad pipe, or clad plate, or seamless or welded mother steel fitting), specifications and dimensions;
  - 5) chemical composition (including backing steel, clad layer and that of the weld seam);
  - 6) mechanical properties of backing steel;
  - 7) WPS and weld repair report;
  - 8) NDT report;
  - 9) heat treatment status;

- 10) re-testing requirements;
- b) for clad fitting manufacture:
  - 1) cleaning method and preparation requirements of starting materials prior to manufacturing;
  - 2) inspection and evaluation of the forming machine;
  - 3) forming procedure;
  - 4) WPS and approval record;
  - 5) heat treatment procedure;
  - 6) machining requirements;
- c) dimensions and rounding procedures;
- d) testing and inspection requirements for:
  - 1) qualification of the test clad fitting;
  - 2) production of the clad fittings;
- e) traceability;
- f) additional requirements (e.g. end preparation, coating and marking).

### 8.3 Clad fitting manufacture

All manufacturing processes shall be performed in accordance with the MPS. The following manufacturing processes should be used to produce the clad fittings.

- a) electric induction heating and forming by using mother clad pipe;
- b) butt-welding following cold- or hot- forming by using CRA steel-clad plate;
- c) weld overlay with CRA onto the mother steel fittings.

Cold- or hot- forming processes used in the manufacturing the clad fittings include bending, extruding, pressing, expanding, rolling, drawing, upsetting or by a combination of these operations or other processes as agreed.

Manufacturing procedures shall ensure that the surface of clad fittings has smooth transition after forming, and mechanical properties of the backing steel and corrosion resistance of the clad layer are not degraded, and no cracks or other defects that may impact safety initiated.

## 8.4 Welding

### 8.4.1 General requirements

All welds 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 fittings 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.

### 8.4.2 Weld overlay

For weld overlay, cold/hot wire TIG welding or other welding processes with low heat input shall be used. Multi-layer weld overlay shall be used. The lap length between adjacent weld over layer 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 overlayer shall meet the requirements of 9.6.2, and the chemical composition shall meet the requirements of 9.3.

### 8.4.3 Weld metal

Weld metal used in the manufacturing of clad fittings shall be suitable to meet the chemical composition, mechanical properties and corrosion resistance properties requirements of Clause 9.

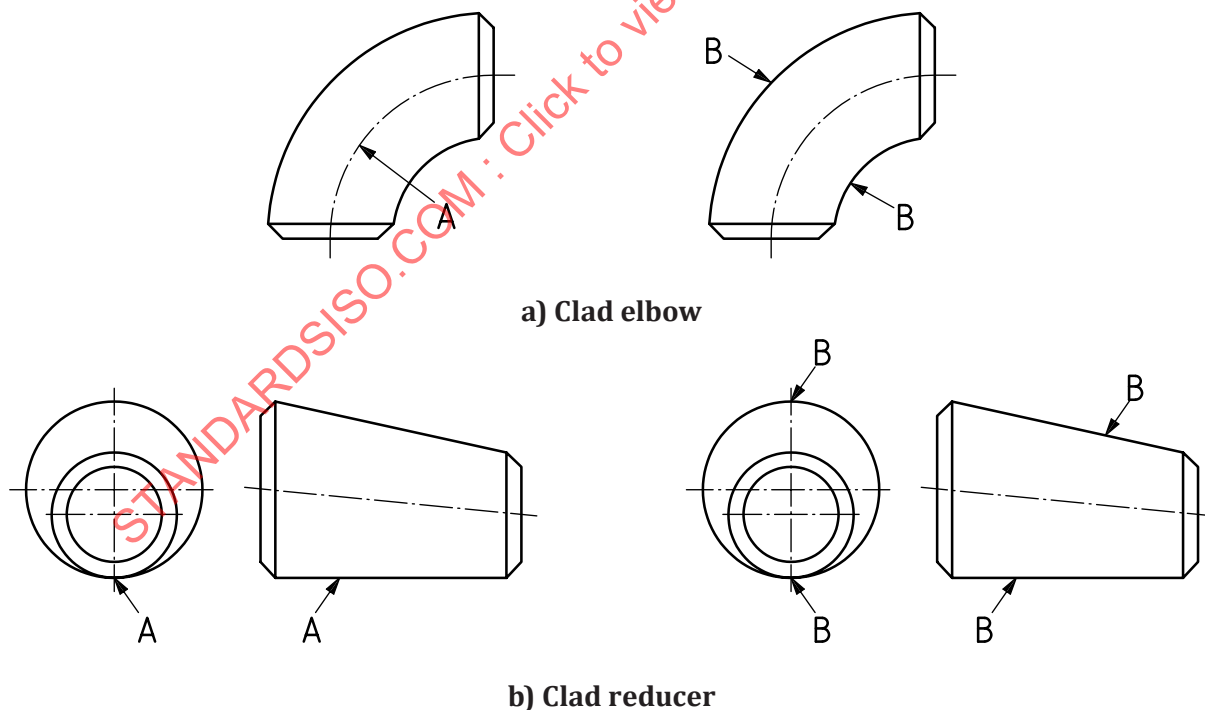
### 8.4.4 Welds and position

All butt-welds shall have full penetration and be done with at least one pass from the inside. Backing rings shall not be used.

The weld number and position of welded clad fittings shall meet the following requirements:

- at most one longitudinal weld is allowed for each clad tee, and the branch outlet in clad tee shall be positioned diametrically opposite the longitudinal weld;
- at most double longitudinal welds are allowed for each clad elbow and clad reducer, and double welds shall be located 180 degrees apart. For the clad elbow with one longitudinal weld, the seam shall be located in the area of  $0^{\circ}$  to  $10^{\circ}$  from neutral axis of elbow on extrados side or intrados side. Weld position diagrams are shown in Figure 1;
- if agreed, the clad cap may be made by butt-welding from CRA steel-clad plate, and the weld seam length should be less than  $1/4$  of the outer diameter of the cap.

When the above requirements for the weld position of welded clad fittings is not possible, the position shall be decided as agreed.



#### Key

- A one longitudinal weld  
B double seam

**Figure 1 — Weld position diagrams for welded clad elbows and reducers**

## 8.5 Heat treatment

For the clad fittings made by weld overlay with CRA onto the mother steel fittings [see 8.3 c)], before weld-overlaying, post-forming heat treatment should be applied to the mother steel fittings to achieve the required material properties or to relieve residual stresses.

For clad fittings made by hot- or cold-forming from weld overlay mother clad pipe [see 8.3 a)], pre-forming heat treatment may be applied to the weld overlay clad mother pipes to prevent of cracks during the forming process.

For the clad fittings made by cold-forming or by overlay welding process, stress relieving of the clad fitting by heating subcritically is permitted.

Post-forming or post-welding heat treatment need not be applied to clad fittings made by hot-forming from mother clad pipe or by butt-welding from CRA steel-clad plate. However, this shall be determined by manufacturing procedure qualification tests.

## 8.6 Cold forming and sizing

Cold-forming or sizing without subsequent heat treatment is permitted for ovality and diameter corrections in the tangents or ends (about within 100 mm from the end bevel). If  $DN \leq 600$  mm, the permanent radial deformation shall not exceed 1,5 %  $D$  or 8 mm, whichever is smaller. If  $DN > 600$  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 7, weld overlaying and machining of the ends may be performed.

## 8.7 Joints and girth welds

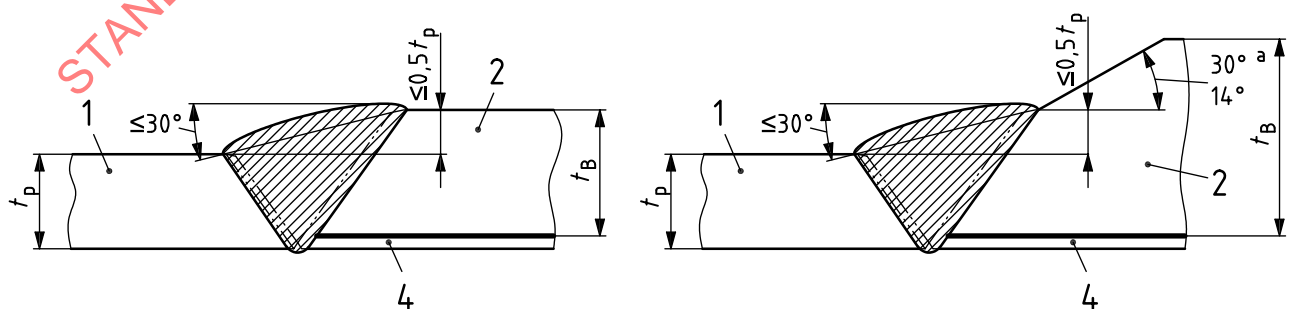
Clad fittings shall not contain jointers or girth welds.

## 8.8 End preparation

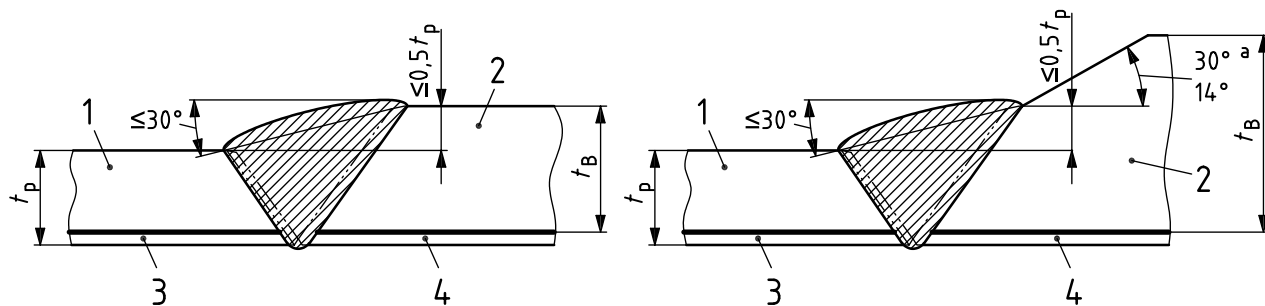
Clad fittings should be supplied with square ends unless otherwise specified by the purchaser.

The type of welded bevel shall be consistent with that of the matching pipes. Unless otherwise agreed, the weld ends should be machined into bevels as V-shape, or double-V-shape or U-shape. The root face of the clad fitting shall be machined flat and shall not vary from the plane by more than 0,76 mm at any point.

Where the wall thickness of the clad fittings exceeds that of matching pipe, the transition design of the joints shall be external offset as shown in Figure 2.



a) the matching pipe is CRA solid pipe



b) the matching pipe is CRA clad or lined steel pipe

#### Key

- 1 backing steel of matching pipe (clad/lined pipe) or the matching pipe (solid pipe)
- 2 backing steel of the clad fitting
- 3 CRA layer of the matching pipe (clad/lined pipe)
- 4 CRA layer of the clad fitting
- $t_B$  nominal wall thickness of the backing steel of clad fitting
- $t_p$  nominal wall thickness of matching solid pipe or that of the backing steel of matching clad pipe
- <sup>a</sup> There is no restriction on the minimum angle if the materials joined have equal SMYS (only for backing steel).

Figure 2 — Welding ends transition designs for unequal wall thicknesses

## 8.9 Surface treatment

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

The inner surface of the CRA layer of the clad fitting 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. After pickling, the inner surface of the CRA shall be finally cleaned with tap water until the chloride content is less than 50 mg/l. The inner and outer surfaces, upon cleaned, shall be completely dry.

Effective measures shall be taken during the process of manufacturing to prevent the surface of the CRA layer 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 not be necessary. Pickling and passivation for the self-passivated CRA should be waived as agreed.

## 9 Testing and inspection

### 9.1 General requirements

Production clad fittings 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 fittings after final heat treatment (if applicable).

If agreed, test results already available for the mother clad pipe or mother steel fitting or clad plate may be used in place of testing and inspections where indicated in [Table 2](#).

The detailed extraction of test specimens is defined in [Annex B](#).

If the orientation or quantity is restricted by dimensions, and it is impossible to extract the defined specimens, test specimens should be taken from one or more of the following or the requirement for the testing may be waived:

- a) other appropriate locations of the clad fitting;
- b) extension lengths formed and heat-treated as part of the clad fitting and/or test piece attached to the clad fitting;
- c) starting material that has been subjected to the same heat treatment as the proposed clad fitting.

## 9.2 Extent of testing and inspection

At the stage of manufacturing procedure qualification, the extent of testing and inspection on each test clad fittings shall be performed in accordance with [Table 2](#).

During production, the extent of testing and inspection that shall be performed is as specified in [Table 2](#), and the frequency of testing shall be performed as specified in [Table 3](#). 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 unqualified items, or double-sampled and re-tested separately for the unqualified items in the same batch, or subject this batch of clad fittings to another heat treatment and then carry out all testing and inspections as indicated in [Table 1](#). Repeated heat treatment is permitted only once. However, if the only nonconforming item is tensile strength, with the consent from the designer, this batch of clad fittings may be used for applications with reduced pressure ratings.

**Table 2 — Summary of testing and inspection**

| Type of test and inspection                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                          | Class B | Class S | Acceptance            |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|---------|---------|-----------------------|
| Chemical analysis                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Chemical composition of backing steel    | M       | M       | <a href="#">9.3</a>   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Chemical composition of CRA <sup>a</sup> | M       | M       |                       |
| Physical tests                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Tensile                                  | T and O | T and O | <a href="#">9.4.1</a> |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Charpy V-notch impact                    | T and O | T and O | <a href="#">9.4.2</a> |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Guided fitting of weld seam              | T and O | T and O | <a href="#">9.4.3</a> |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Through-thickness hardness               | T and O | T and O | <a href="#">9.4.4</a> |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Surface hardness                         | T and P | T and P | <a href="#">9.4.5</a> |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Flattening tests                         | M       | M       | <a href="#">9.4.6</a> |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | CRA cladding bond strength               | T and O | T and O | <a href="#">9.4.7</a> |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Macrographic examination                 | T       | T       | <a href="#">9.4.8</a> |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Metallography                            | T       | T       | <a href="#">9.4.9</a> |
| <p>M: Testing of the clad fitting shall not be required if acceptable test results are available for the mother clad pipe or the mother steel fitting. If acceptable test results for the mother clad pipe or the mother steel fitting are not available, then the test shall be performed on either the mother clad pipe or the mother steel fitting or the clad fitting</p> <p>N: Not required</p> <p>O: Requirement for each batch of production clad fitting at the purchaser's option</p> <p>P: Required for each production clad fittings</p> <p>T: Required for each test clad fittings</p> <p><sup>a</sup> Chemical analysis of clad layer is required only for weld overlay with CRA onto mother steel fitting.</p> |                                          |         |         |                       |

**Table 2 (continued)**

| Type of test and inspection |                                                       | Class B        | Class S        | Acceptance            |
|-----------------------------|-------------------------------------------------------|----------------|----------------|-----------------------|
| Corrosion tests             | Intergranular corrosion                               | T              | T              | <a href="#">9.5.1</a> |
|                             | HIC testing                                           | N              | T and O        | <a href="#">9.5.2</a> |
|                             | SSC testing                                           | N              | T and O        | <a href="#">9.5.3</a> |
|                             | Corrosion testing of clad layer for service condition | T              | T              | <a href="#">9.5.4</a> |
| Dimensions                  | Wall thickness of backing steel and clad layer        | T and P        | T and P        | <a href="#">9.6.2</a> |
|                             | Outside diameter at ends(bevel)                       | N or as agreed | N or as agreed | <a href="#">9.6.3</a> |
|                             | Inside diameter at ends                               | P              | P              | <a href="#">9.6.3</a> |
|                             | Out-of-roundness at ends                              | P              | P              | <a href="#">9.6.3</a> |
|                             | Fitting angle                                         | P              | P              | <a href="#">9.6.4</a> |
|                             | Radius                                                | O              | O              | <a href="#">9.6.4</a> |
|                             | Angularity off angle (End out-of-square-ness)         | P              | P              | <a href="#">9.6.4</a> |
|                             | Out-of-planeness                                      | P              | P              | <a href="#">9.6.4</a> |
|                             | Overall structural dimensions                         | P              | P              | <a href="#">9.6.4</a> |
| NDT                         | Visual inspection                                     | T and P        | T and P        | <a href="#">9.7.3</a> |
|                             | Surface of clad fitting (PT or MT)                    | T and P        | T and P        | <a href="#">9.7.4</a> |
|                             | Weld seam (RT or UT)                                  | T and P        | T and P        | <a href="#">9.7.5</a> |
|                             | Clad fitting end (PT and UT)                          | T and P        | T and P        | <a href="#">9.7.6</a> |
|                             | Clad fitting body (UT)                                | T and P        | T and P        | <a href="#">9.7.7</a> |
|                             | Residual magnetism                                    | P              | P              | <a href="#">9.7.8</a> |
| Hydrostatic test            |                                                       | As agreed      | As agreed      | <a href="#">9.8</a>   |

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

N: Not required

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

P: Required for each production clad fittings

T: Required for each test clad fittings

<sup>a</sup> Chemical analysis of clad layer is required only for weld overlay with CRA onto mother steel fitting.

**Table 3 — Extent of testing and inspection during production**

| Type of test and inspection                | Minimum frequency of tests <sup>a</sup> |                    |
|--------------------------------------------|-----------------------------------------|--------------------|
|                                            | 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 |

<sup>a</sup> For clad fittings with same material type and same heat of steel number, same manufacturing procedure, same heat treatment procedure, same fitting radius and same nominal wall thickness, at most 100 samples are considered as one test batch in the case of DN < 600, or at most 50 samples are considered as one test batch in the case of DN ≥ 600.

<sup>b</sup> Testing of the clad fitting shall not be required if acceptable test results are available for the mother clad pipe or mother steel fitting.

<sup>c</sup> Chemical analysis of clad layer is required only for weld overlay with CRA onto mother steel fitting. The chemical analysis of weld overlay is conducted on only one per test batch.

Table 3 (continued)

| Type of test and inspection                                                                                                                                                                                                                                                                                                                                           | Minimum frequency of tests <sup>a</sup> |                    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|--------------------|
|                                                                                                                                                                                                                                                                                                                                                                       | Class B                                 | Class S            |
| Guided fitting (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 fitting                       | Each clad fitting  |
| Flattening tests                                                                                                                                                                                                                                                                                                                                                      | b                                       | b                  |
| CRA cladding 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 fitting                       | Each clad fitting  |
| NDT                                                                                                                                                                                                                                                                                                                                                                   | Each clad fitting                       | Each clad fitting  |
| Hydrostatic test                                                                                                                                                                                                                                                                                                                                                      | As agreed                               | As agreed          |
| <sup>a</sup> For clad fittings with same material type and same heat of steel number, same manufacturing procedure, same heat treatment procedure, same fitting radius and same nominal wall thickness, at most 100 samples are considered as one test batch in the case of DN < 600, or at most 50 samples are considered as one test batch in the case of DN ≥ 600. |                                         |                    |
| <sup>b</sup> Testing of the clad fitting shall not be required if acceptable test results are available for the mother clad pipe or mother steel fitting.                                                                                                                                                                                                             |                                         |                    |
| <sup>c</sup> Chemical analysis of clad layer is required only for weld overlay with CRA onto mother steel fitting. 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 ISO 15590-2:2021. If agreed, carbon steel or low alloy steel in accordance with MSS SP-75 or ASME B16.9 or other recognized documents may also be used.

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

Chemical composition of the as deposited overlay of the seam or weld overlay should 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, samples can be extracted either from finished clad fittings or mother clad pipe or clad plate. For welded clad fittings or clad pipe, location to extract samples shall be at least 90° away from the longitudinal seam.

### 9.3.3 Test method

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

NOTE ISO/TR 9769 also provides some related information.

## 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 or MSS SP-75 or other document as agreed.

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 or rectangular specimens as specified in ISO 3183:2019 shall be used. Rectangular specimens shall be from cold-flattened samples, whereas round-bar specimens shall be machined from unflattened samples.

The CRA layer, local imperfections and mill scale on the test specimens shall be removed, and the weld seam shall be ground flush.

For base metal,  $R_{t0.5}$ ,  $R_m$  and percentage elongation  $A$  after fracture shall be determined. For weld transverse tensile tests, only  $R_m$  shall be required.

The testing location shall include at least the following: the extrados or neutral zone of the elbow, the large end or the conical shell section of the reducer, the branch outlet and run of tee, the straight skirt of the cap. The detailed extraction of test specimens from the backing steel is defined in [Annex B](#).

#### 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 test

Test procedures and acceptance criteria shall be in accordance with ISO 15590-2:2021.

The testing location shall include at least the following: the extrados or neutral zone of the elbow, the large end or the conical shell section of the reducer, the branch outlet and run of tee, the straight skirt of the cap. The detailed extraction of test specimens from the backing steel is defined in [Annex B](#).

### 9.4.3 Guided bending testing

#### 9.4.3.1 Requirements

Clad fittings with filler-metal welds shall be tested by the guided-bending test. Unless otherwise specified, the acceptance criteria of guided bending testing shall be in accordance with in ISO 15590-2:2021, 9.4.10.

If agreed, flattening test may be conducted as an alternate to the guided-bending test for clad fittings with smaller diameter (DN200 and smaller).

### 9.4.3.2 Test specimens

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

The locations of both test specimens shall be in accordance with [Annex B](#).

For clad fittings with a wall thickness more than 20 mm, the test specimens should be machined to provide a rectangular cross-section having a thickness of 19 mm. Full-thickness test specimens shall be processed by cold flattening for clad fittings with a wall thickness of 20 mm and smaller. No repair weld seam shall be allowed on the test specimens, and welds shall be ground flush at both faces.

The clad layer on the specimens shall be removed for clad fitting manufactured by weld overlay with CRA onto the mother steel fittings, and the clad layer shall remain on the weld seam for other manufacturing process.

### 9.4.3.3 Test method

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

## 9.4.4 Through-thickness hardness testing

### 9.4.4.1 Requirements

As part of the MPQT, through-thickness Vickers hardness values of the backing steel and CRA clad layer and their welds shall meet the requirements of [Table 4](#).

### 9.4.4.2 Test specimens

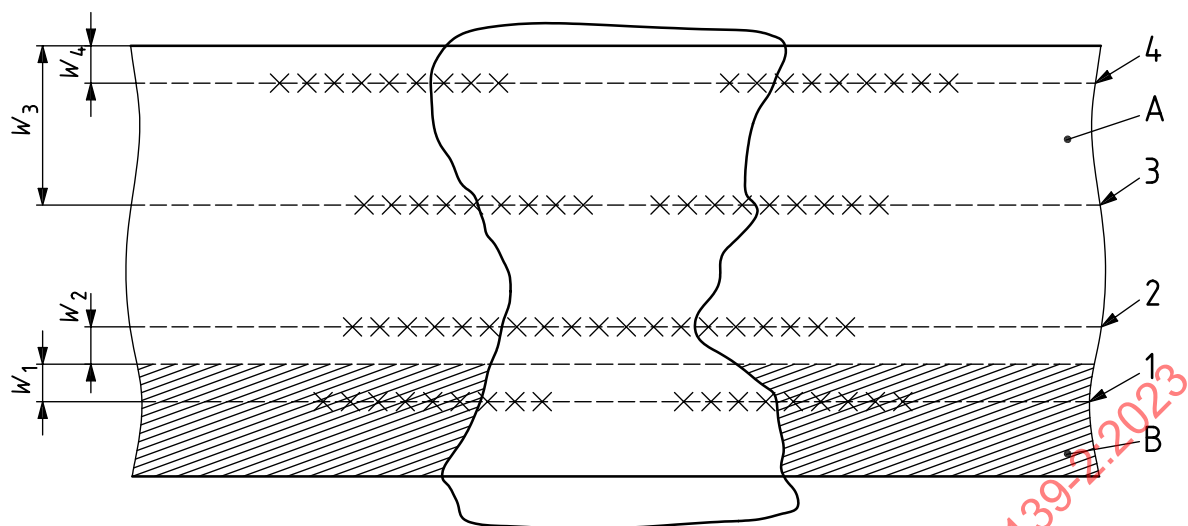
The testing location shall include at least the following: the extrados and intrados of the elbow, the large end and/or the conical shell section of the reducer, the branch outlet and run and crotch of tee, the knuckle and the straight skirt of the cap. The locations test specimens shall be in accordance with [Annex B](#).

For butt-welding fittings, the hardness indent locations shall be in accordance with [Figure 3 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 area hardness point with the nearest distance from the fusion line shall have the distance not exceeding 0,5 mm.

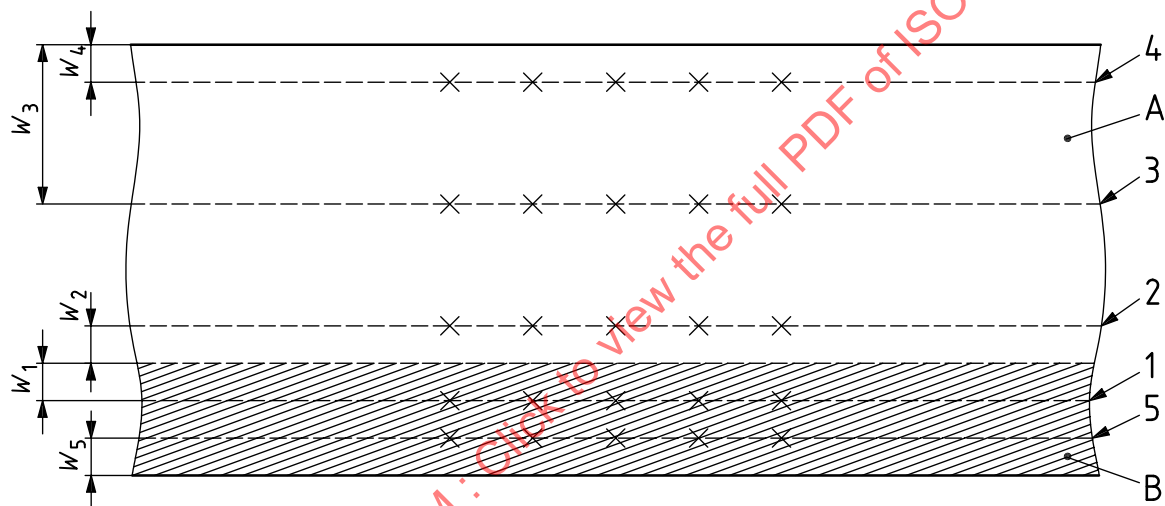
For seamless clad fitting and welded clad fitting manufactured by weld overlay process, the testing points at each location are as shown in [Figure 3 b\)](#) and [Figure 3 c\)](#) respectively. Unless otherwise agreed, the hardness indents shall have a spacing of 1 mm.

### 9.4.4.3 Test method

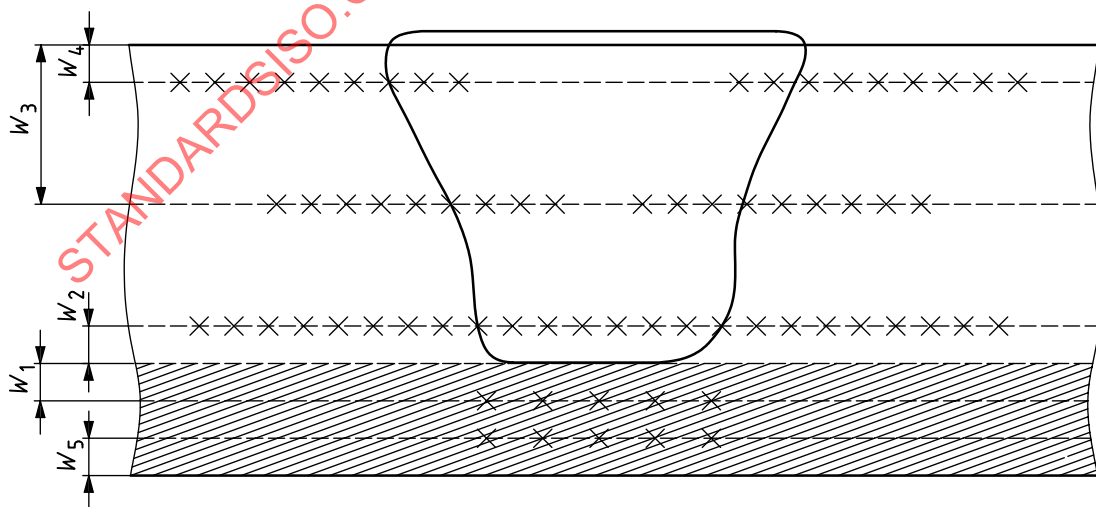
Through-thickness hardness testing shall be performed with the Vickers method (HV10) in accordance with the ISO 6507 series or ASTM E92.



a) welded clad fitting



b) seamless clad fitting with weld overlay



## c) welded clad fitting with weld overlay

## Key

A backing layer

B clad layer

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

Figure 3 — Indent locations for through-thickness hardness testing

Table 4 — 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).<br>Clad fittings for sour service (Class S) shall not exceed 250 HV10  |
| 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 22Cr. Not exceeding 300 HV10 in the parent material and 378 HV10 in the weld and HAZ for 25Cr. |
| 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 fittings used for manufacturing procedure qualification, the average value of the readings obtained from the 3 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 fittings.

The average value of the 3 equidistant points readings at each location of a production clad fitting should not vary by more than the equivalent of 30 HV10 or 30 HV5 hardness points from the average value measured in the same location of the test fitting. Single hardness values shall meet the requirements of [Table 4](#).

## 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.

The testing location shall include at least the following: the extrados and intrados of the elbow, the large end and/or the conical shell section of the reducer, the branch outlet and crotch of tee, the knuckle of the cap.

#### 9.4.6 CRA cladding bond strength test

##### 9.4.6.1 Requirements

For induction clad fittings made from mother clad pipe or clad plate, the minimum acceptable bond shear strength shall be not less than 140 MPa. For clad fittings made by weld overlay process, the testing of bond shear strength is not necessary.

##### 9.4.6.2 Test specimens

The testing location shall include at least the following: the extrados or neutral zone of the elbow, the large end or the conical shell section of the reducer, the branch outlet and run of tee, the straight skirt of the cap. The detailed extraction of test specimens from the backing steel is defined in [Annex B](#).

Curved samples shall be cold-flattened prior to machining the test specimens.

##### 9.4.6.3 Test method

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

#### 9.4.7 Flattening Tests

A section of pipe not less than 63,5 mm in length with the CRA layer left on the test specimen shall be extracted from the end of clad fittings (unnecessary for the outlet of tee). For the reducing elbow and reducer, samples shall be extracted from the larger end.

If agreed, flattening test is not required for clad fittings with larger diameter (such as DN400 and larger) due to the capacity of the test machine.

Specimens shall be cold-flattened 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 \(1\)](#):

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

Where  $H$  the distance between flattening plates, millimetres.

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.

#### 9.4.8 Macrographic examination

##### 9.4.8.1 Requirements

A cross weld macrographic sample shall be taken from the longitudinal weld seam and weld overlay of CRA. The section shall be examined with an optical microscope and shall show that the weld area is free from defects, that proper fusion has been obtained throughout the full thickness of butt-weld, and shall confirm that the geometry and workmanship falls within the requirements of [Table 5](#).

### 9.4.8.2 Test specimens

Specimens preparation shall be in accordance with ISO 17639 or ASTM E3.

The testing location shall include at least the following: the extrados and intrados of the elbow, the large end and/or the conical shell section of the reducer, the branch outlet and run and crotch of tee, the knuckle and the straight skirt of the cap. The detailed extraction of test specimens is defined in [Annex B](#).

### 9.4.8.3 Test method

The macrographic examination shall be conducted in accordance with ISO 17639, prior to through-thickness hardness testing, at a magnification of not less than 10 ×. Macroetching shall be in accordance with ASTM E340. The cross-section shall include the weld fusion line, heat-affected zone (HAZ), and parent metal on both sides of the weld and shall be polished to a 1 µm finish and then etched to show the macrostructure.

NOTE ISO/TR 16060 also provides some related information for reference.

**Table 5 — Acceptance criteria for macrographic examination of weld**

| Type of defects <sup>a</sup>                                                                         | Longitudinal weld seam <sup>c</sup>                    | Weld overlayer of CRA |
|------------------------------------------------------------------------------------------------------|--------------------------------------------------------|-----------------------|
| Weld seam fusion                                                                                     | Complete fusion                                        | Complete fusion       |
| Weld undercut of mother pipe                                                                         | ≤0,4 mm                                                | -                     |
| Weld undercut of clad layer <sup>b</sup>                                                             | ≤0,4 mm                                                | ≤0,4 mm               |
| Longitudinal weld misalignment of backing steel                                                      | ≤1,5 mm                                                | -                     |
| Longitudinal weld misalignment of CRA layer                                                          | ≤0,5 mm                                                | -                     |
| Weld continuity of CRA layer                                                                         | 100 % continuous                                       | -                     |
| Crack                                                                                                | Not allowed                                            | Not allowed           |
| Weld deviation                                                                                       | ≤0,15 $t_B$ , and ≤3,0 mm<br>≤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                                                | -                     |
| Weld porosity of CRA layer                                                                           | Not allowed                                            | Not allowed           |
| Longitudinal weld porosity of backing steel                                                          | As agreed                                              | -                     |
| <sup>a</sup> For further information on weld imperfections, see the ISO 6520 series.                 |                                                        |                       |
| <sup>b</sup> Weld undercut of clad layer is not applicable for the weld overlay process.             |                                                        |                       |
| <sup>c</sup> It shall not be required if acceptable test results are available for mother clad pipe. |                                                        |                       |

## 9.4.9 Metallographic examination

### 9.4.9.1 Requirements

As part of the MPQT, results of the metallographic examination shall demonstrate that there is no detrimental phase and phase content is acceptable in the longitudinal weld and weld overlayer of CRA for critical locations of clad fittings. Critical locations are normally the extrados and intrados of elbows, the branch outlet and the crotch of tees, the knuckle of caps, and the large end and knuckle of reducers.

Acceptance criteria of the weld seams shall meet the requirements of [Table 6](#).

### 9.4.9.2 Test specimens

Specimen preparation shall be in accordance with ISO 17639 or ASTM E3. The detailed extraction of test specimens is defined in [Annex B](#).

### 9.4.9.3 Test method

The specimens for through-thickness hardness testing shall be inspected by metallographic examination, prior to hardness testing, at a magnification of not less than 100 ×.

**Table 6 — Acceptance criteria for metallographic examination of weld**

| Type of defects                                                                                                                          | Longitudinal weld seam | Weld overlay of CRA |
|------------------------------------------------------------------------------------------------------------------------------------------|------------------------|---------------------|
| Detrimental intermetallic phase                                                                                                          | Not allowed            | Not allowed         |
| Ferrite content of austenitic weld deposit for S31603 stainless steel by point count procedure in accordance with ISO 14250 or 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 clad layer. If the boiling copper-copper sulfate-sulfuric acid test specified by ISO 9400:1990, Method B or ISO 3651-2:1998, Method A or 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 the boiling ferric sulfate-sulfuric acid test specified by ISO 9400:1990, Method A, ASTM G28-02, Method A or ASTM A262-15, Practice B, or the boiling nitric acid test (Huey test) specified by ISO 3651-1:1998, ISO 9400:1990, Method D or ASTM A262-15, Practice C is used, the corrosion rate calculated from mass loss shall be reported and the acceptance criteria shall be as agreed.

NOTE The following criteria are given for reference:

- for austenitic steel (such as 316L), no ditch as ASTM A262-15, Practice A and no cracking and no intergranular attack as ISO 3651-2, Method A or 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/y and that of the weld seam and HAZ 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 ISO 3651-1, ISO 9400:1990, Method D or 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.

NOTE corrosion rate mdd = weight loss (mg)/[specimen area (dm<sup>2</sup>) × time (days)]

#### 9.5.1.2 Test specimens

The sampling location shall include at least the following: the extrados, intrados and neutral zone of the elbow, the large end or the conical shell section of the reducer, the branch outlet and run of tee,

the straight skirt of the cap. The detailed extraction of test specimens from the clad layer is defined in [Annex B](#).

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

The samples shall be cold-flattened prior to machining the test specimens. The cutting edges of the specimens shall be machined or ground if flame cutting is used for specimens. 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 ferroxy test as specified in ISO 10309 may be used for inspecting the iron contamination, at the discretion of the tester.

### 9.5.1.3 Test method

If the clad layer is austenitic stainless steel, oxalic acid etch test specified by ASTM A262-15, Practice A shall be conducted and the ferric sulfate-sulfuric acid test specified by ISO 9400:1990, Method A, ASTM G28-02, Method A or ASTM A262-15, Practice B, or the copper-copper sulfate-sulfuric acid test specified by ISO 9400:1990, Method B or ISO 3651-2:1998, Method A or ASTM A262-15, Practice E shall be conducted.

If the clad layer is iron-nickel-based alloy (such as UNS N08825), the nitric acid test (Huey test) shall be conducted in according with ISO 3651-1:1998, ISO 9400:1990, Method D or ASTM A262-15, Practice C.

If the clad layer is nickel-based alloy (such as UNS N06625), the ferric sulfate-sulfuric acid test specified by ISO 9400:1990, Method A, ASTM G28-02, Method A or ASTM A262-15, Practice B shall be carried out.

The ferric chloride corrosion test in according with 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 testing of backing steel

### 9.5.2.1 Requirements

If agreed, for the clad fitting class S, as part of the MPQT, HIC testing of backing steel should meet the requirements of ISO 15590-1:2018, Annex B.

### 9.5.2.2 Test specimens

The sampling location shall include at least the following: the extrados, intrados and neutral zone of the elbow, the large end or the conical shell section of the reducer, the branch outlet and run of tee, the straight skirt of the cap. The detailed extraction of test specimens from backing steel is defined in [Annex B](#).

The preparation of test specimens shall be carried out in accordance with NACE TM0284. Any scale or CRA on the specimens shall be removed mechanically. The test specimens shall be machined from unflattened samples.

### 9.5.2.3 Test method

HIC testing shall be carried out in accordance with NACE TM0284 and ISO 15590-1:2018, Annex B.

## 9.5.3 SSC testing of backing steel

### 9.5.3.1 Requirements

If agreed, for the clad fitting class S, as part of the MPQT, SSC testing of backing steel should meet the requirements of ISO 15590-1:2018, Annex B.

### 9.5.3.2 Test specimens

One sample shall be taken from the backing steel of the major axis of the clad fitting body in the longitudinal direction. For the welded clad fitting, additionally, a sample or double samples (for double welds) 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. Samples may be flattened prior to machining SSC specimens. Any scale or CRA on the specimens shall be removed mechanically.

Unless agreed otherwise, test specimens for four-point bending SSC tests shall be equal to or larger than 115 mm long × 15 mm wide × 5 mm thick.

If a transverse sample with weld seam cannot be taken from the finished welded clad fitting because of its smaller diameter,

- a longitudinal sample may be used,
- a transverse sample may be taken from the mother clad pipe or clad plate, or
- exempt the test as agreed.

### 9.5.3.3 Test method

SSC testing shall be carried out in accordance with NACE TM0177 or ASTM G39 and ISO 15590-1:2018.

### 9.5.4 Corrosion evaluation of clad layer material for service condition

If specified by the purchaser, corrosion evaluation of CRA clad layer material for intended service condition shall be conducted.

Except the extraction of specimens, the test methods and acceptance criteria shall be performed in accordance with [Annex A](#). The extraction of specimens for corrosion testing is same as that of intergranular corrosion testing defined in [9.5.1](#).

## 9.6 Dimensions and tolerances

### 9.6.1 General

One of the principles of this document is the maintenance of a fixed position for the welding ends with reference to the centre line or the overall structural dimensions of the clad fittings.

Unless otherwise agreed, except the outside diameter at bevel, overall structural dimensions of clad fitting, such as centre-to-end, end-to-end and overall length of reducers and caps, shall be in accordance with MSS SP-75 and ASME B16.9 for nominal sizes less than DN 400 (NPS16).

Another principle is to ensure that circumferential (girth) weld seam between the clad fittings and matching pipes does not produce obvious weld misalignment and discontinuity of CRA layer, by specifying the inside diameter and their more stringent tolerance at ends and the WT of clad layer of clad fitting, which shall be specified by purchaser.

The dimensions of the clad fittings shall be measured to confirm that the dimensions have been achieved within the permissible tolerances of [Table 7](#).

### 9.6.2 Wall thickness

#### 9.6.2.1 Requirements

The minimum WT of the clad layer shall be not less than 2,5 mm unless otherwise agreed.

The WT of the backing steel of clad fittings shall be in accordance with [Clause 7](#).

When surface defects of the fittings require grinding, the isolated non-continuous reductions are permitted provided the remaining WT is not diminished to less than 93,5 % of the specified nominal. In no case can the total area of isolated non-continuous reduction exceed 10 % of the outside surface area of the clad fitting.

### 9.6.2.2 Test method

The WT measured location of the clad fittings shall include at least the following: the extrados and intrados of the elbow, the tangents at each end and the conical shell section of the reducer, the branch outlet and run and crotch of tee, the knuckle and the straight skirt and the body of the cap.

At least 3 points shall be measured evenly for each examined location.

In MPQT stage, the WT of backing steel and of the clad layer shall be examined by metallographic method.

During production of clad fittings, WT measurements shall be made with a properly calibrated non-destructive inspection device of appropriate accuracy. The total WT of the clad fitting 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.

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 elbow arc should be assumed to be the WT of backing steel measured before forming 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 elbow arc can be determined as difference between total WT and the calculated WT of backing steel.

The thinning/thickening ratio,  $T$ , expressed in percent, is as 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 and intrados of the elbow or other inaccessible areas of clad fitting;
- $t_t$  WT of backing steel measured by metallographic method at tangent of clad fittings or backing steel of the mother clad pipe or clad plate.

The WT of clad layer shall be measured by electromagnetic method at 4 quadrants of clad fitting 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 fitting ends.

For the clad fittings made by weld overlay with CRA onto the mother steel fittings, 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 fitting prior to welding measured by manual ultrasonic pulse-echo contact method in accordance with ASTM E797.

### 9.6.3 Diameter

The inside diameter at ends of clad fitting shall be consistent with (match) that of the mating pipes. The inside diameter at ends of clad fitting shall be specified by purchaser.

The outside diameter of clad fitting is specified by purchaser or calculated from the specified inside diameter and wall thickness.

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

Unless otherwise agreed, bore diameters away from the ends (within 100 mm) are not specified. If special flow path requirements are needed, the bore dimensions shall be specified by the purchaser.

#### 9.6.4 Radius, end out-of-squareness, out-of-planeness and tangent length

The fitting angle, fitting radius, out-of-roundness, angularity off angle, off plane and overall structural dimensions of clad fittings should be measured in a way in accordance with MSS SP-75 and ASME B16.9.

#### 9.6.5 Tolerances

The dimensions of the clad fittings shall be measured to confirm that the dimensions have been achieved within the permissible tolerances of [Table 7](#).

#### 9.6.6 Special dimensions

Clad fittings may be made to special dimensions, sizes, shapes, and tolerances as agreed.

When factory-made clad elbows are intended for segmenting in field to meet customer angle requirements, the dimensions should be in accordance with MSS SP-75 or ASME B16.9.

**Table 7 — Permissible dimensional tolerances of clad fitting**

| Dimension                                                                                                                                                                                                                                                                                                                                                                                                                                           | Permissible tolerance                                                                             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| Outside diameter at ends (bevel), $D$                                                                                                                                                                                                                                                                                                                                                                                                               | Not required or as agreed                                                                         |
| Inside diameter at ends <sup>a</sup> , $d$                                                                                                                                                                                                                                                                                                                                                                                                          | $d \leq 200$ mm, $\pm 0,5$ mm;<br>$200 < d \leq 600$ mm, $\pm 1,0$ mm;<br>$d > 600$ mm, as agreed |
| Minimum wall thickness of backing steel layer <sup>b</sup>                                                                                                                                                                                                                                                                                                                                                                                          | 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                                                                                         |
| Out-of-roundness at ends <sup>a,c</sup>                                                                                                                                                                                                                                                                                                                                                                                                             | 0,5 % max and the maximum difference of inside diameter shall not exceed 2,0 mm                   |
| Out-of-roundness of elbow body                                                                                                                                                                                                                                                                                                                                                                                                                      | Not required or as agreed                                                                         |
| Centre-to-end dimensions of elbows and tees                                                                                                                                                                                                                                                                                                                                                                                                         | $d$                                                                                               |
| Overall length of reducers and caps                                                                                                                                                                                                                                                                                                                                                                                                                 | $d$                                                                                               |
| Angularity off angle (End out-of-squareness)                                                                                                                                                                                                                                                                                                                                                                                                        | $d$                                                                                               |
| Off plane of elbows, eccentric and concentric                                                                                                                                                                                                                                                                                                                                                                                                       | $d$                                                                                               |
| <sup>a</sup> Within 100 mm from the end.<br><sup>b</sup> Does not include isolated non-continuous reduction areas permitted by <a href="#">9.6.2</a> .<br><sup>c</sup> Out-of-roundness, $O$ , expressed as a percent, is as given in Formula (3):<br>$O = \frac{d_{\max} - d_{\min}}{d} \times 100 \% \quad (3)$ <sup>d</sup> Tolerances shall be in accordance with MSS SP-75 and, for nominal sizes less than DN 400 as specified in ASME B16.9. |                                                                                                   |

### 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 fittings shall be cleaned to a cleanliness grade of ISO 8501-1:2007 Sa 2.

The surface to be examined shall be dry and free of all dirt, grease, lint, scale, welding flux and spatter, oil or other extraneous matter that could interfere with NDT. Fitting surfaces shall be finished so that surface imperfections can be detected by visual inspection.

### 9.7.2 NDT personnel

All NDT personnel shall be competent 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 fittings shall be visually examined. An endoscope or other computer-aided imaging technique shall be used to detect the inner surface that 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 15590-2:2021, 9.5.3.1. The CRA clad layer shall be free of cracks, arc burns, porosity, lack of fusion, overheating and over burning.

### 9.7.4 Inspection of surfaces of clad fitting

All finished clad fittings shall be examined by MT in accordance with ISO 10893-5 or ASTM E709, or by PT in accordance with ISO 10893-4.

The examined areas of the outer surface of each clad fitting shall include at least: an arc of 180°, 90° each side of the extrados for the elbow, conical shell section of the reducer, the area from the weld bevel of the branch outlet to the centre line of the body or run for the tee, and the body of the cap.

For all clad fitting, PT shall cover as much of the internal surface as is practical. For weld overlay with CRA onto the mother steel fittings, 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 fitting shall be inspected full length (100 %) by RT in accordance with ISO 10893-6 or by manual UT or AUT procedures in accordance with ISO 10893-11, ASTM E273 or ASTM E578 or as agreed.

If not carried out on the starting material already, UT shall be performed for disbondment of the cladding, as defined in ISO 17405 or 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 fitting 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.

This 50 mm band shall extend from the intersection of the weld bevel and fitting outside diameter back along the body of the fitting.

Laminar imperfections shall not exceed 6,4 mm in the circumferential direction or have an area in excess of 100 mm<sup>2</sup>. 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 fitting body

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 elbow 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, UT in accordance with ISO 10893-8 or ISO 10893-9 or ASTM A435 or ASTM A578/A578M-17 as applicable shall be performed on the clad fitting body to detect laminar imperfections and disbonding. The acceptance criteria for laminar imperfections of backing steel shall be according to ISO 15590-1:2018. 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 magnetic flux density at both ends of each finished clad fitting shall not exceed 1,5 mT. Magnetism levels higher than this value shall require the ends to be demagnetized until the level is reduced below 1,5 mT.

#### 9.7.9 Imperfection and defect treatment

##### 9.7.9.1 Surface

Imperfections not classified as defects may remain in the clad fitting without repair. Localized grinding, however, may be performed.

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

Surface defects (sharp defects such as notches, scratches, upset, crest, seams, laps, tears, or slivers that result in a wall thickness not less than permitted by [9.6.2](#)) should be removed by grinding, provided that a smooth curved surface is maintained and the required minimum WT 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 PT in accordance with ISO 10893-4 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](#).

##### 9.7.9.2 Weld seam

Repair by welding on weld seams may be performed only by the following processes:

- manual metal-arc welding;
- metal inert gas/metal active gas welding;
- tungsten inert gas welding;
- or other welding methods as agreed.

The defects on weld seam, except for the distance 100 mm from the ends of the clad fitting, 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 fitting. Each individual welding repair for longitudinal weld seam of CRA layer shall be carried out

with a minimum of two weld passes over a minimum length of 50 mm, and the adjacent spacing of the welding repair shall not be less than 100 mm.

### 9.7.9.3 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 fitting is not allowed. Except the aforementioned areas of the clad fitting, the disbonded defects may be repaired as agreed.

### 9.7.9.4 Treatment of non-repairable defects

Clad fittings containing non-repairable defects shall be rejected.

## 9.8 Hydrostatic testing

Hydrostatic testing of clad fittings is not mandatory. The manufacturer shall confirm that the clad fitting will withstand an internal pressure at least as high as that specified for the matching pipe or the design pressure.

If hydrostatic testing is specified by the purchaser, the test method shall be as agreed. The requirements for hydrostatic testing shall be as follows: 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 forming and 90 % SMYS of the backing steel (CRA is not part of strength design), whichever lesser. The test sample shall be free of cracking, leakage or other damages affecting service.

## 10 Marking

### 10.1 General requirements

Markings shall be made with indelible paint on the outside surface. If the dimensions of the clad fittings are insufficient to mark all the information in [10.2](#), additional label can be used for marking. Cold die stamping shall be only allowed on the bevel. If agreed, other marking methods can be performed.

For clad fittings 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 fittings, 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.

### 10.2 Marking information

Clad fittings manufactured in accordance with this document shall be marked as follows:

- a) manufacturer name or trade mark;
- b) a reference to this document, i.e. ISO 24139-2:2023;
- c) nominal diameter (DN) in millimetres of clad fittings;
- d) and specified inside diameter at the welding end;
- e) minimum (nominal) wall thickness of backing steel and clad layer;
- f) clad fitting designation as defined in [Clause 6](#);
- g) CRA type of clad layer; material identification, either the ASTM or ASME grade designation (see [Annex C](#));
- h) purchase order and item number;

- i) unique number of each clad fitting;
- j) any additional marking specified in the purchase order.

EXAMPLE 1

45 deg. long radius clad elbow, DN 600, the specified inside diameter at the welding end is 585 mm, the nominal wall thickness of backing steel is 9,5 mm, and the specified minimum wall thickness of CRA layer is 3,0 mm, the SMYS of backing steel is 245 MPa, the clad layer is austenitic stainless steel UNS S31603 and identifies the use in non-sour service, manufactured in ABCO, the clad elbow can be stenciled as follows:

ABCO ISO 24139-2 DN 600-ID585-9,5/3,0  
45CEL(L)-245/UNS S31603-B Purchase order and unique number

EXAMPLE 2

Reducing outlet clad tee, DN550 × 550 × 400 (NPS22 × 22 × 16), the specified inside diameter at the end of run and outlet is 530 mm and 378 mm, respectively; the nominal wall thickness of backing steel is 11,5 mm, and the specified minimum wall thickness of CRA layer is 2,5 mm, the SMYS of backing steel is 360 MPa, the clad layer is Ni base alloy UNS N08825, and identifies the use in sour service, manufactured in ABCO, the reducing outlet clad tee can be stenciled as follows:

ABCO ISO 24139-2 DN550 × 550 × 400 -ID530 × 530 × 378-11,5/2,5  
CTE(R)-360/ UNS N08825-S Purchase order and unique number

## 11 Packaging, handling and storage

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

The ends of fittings shall be effectively protected by protective covers such as pipe cap so as to prevent mechanical damage and pollution to ends and interior of formed grooves 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 fitting 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 fittings shall include at least:

- a) manufacturer's name and date of manufacture;
- b) product name, specification, this document 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.

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## Annex A (normative)

### Corrosion qualification of CRA clad layer for intended service condition

#### A.1 General

At the option of the purchaser, corrosion qualification for the clad layer material shall include SCC (see [A.2](#)) or mass loss corrosion and pitting corrosion tests (see [A.3](#)).

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

#### A.2 SCC qualification

##### A.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 H<sub>2</sub>S partial pressure, pH, temperature, chloride concentration, and elemental sulfur;
- b) evaluation based on satisfactory field application experience is also acceptable, which shall conform with ISO 15156-1;
- c) if a) and b) in [A.2.1](#) cannot meet the requirements, the test shall be carried out in accordance with the methods specified in [A.2.2](#) to [A.2.6](#).

##### A.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.

##### A.2.3 Test environment

SCC tests shall be conducted in the simulated environment with similar composition as the 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;
- H<sub>2</sub>S partial pressure;
- CO<sub>2</sub> partial pressure;
- temperature;
- if possible, pH of test solution.

- composition of test solution;
- elemental sulfur ( $S^0$ ).

In all cases,  $H_2S$  partial pressure,  $CO_2$  partial pressure, concentrations of chloride and elemental sulfur  $S^0$  in the test environment shall be at least as severe as those expected. When intended applications are insufficiently defined, one or more test environments listed in ISO 15156-3:2020, Table D.1 should be selected. It can be necessary to use more than one test environment to achieve qualification for a particular service.

#### A.2.4 Test period

The test shall last for at least 720h without interruption. The test period shall not be shortened unless otherwise agreed and documentation is available.

#### A.2.5 Sampling

One sample of CRA clad layer shall be taken from the extrados of the clad fitting body in the longitudinal direction. For welded clad fitting, an additional sample shall be extracted transverse to the weld seam and contain a section of the longitudinal seam at its centre. Three test specimens shall be taken from each sample and prepared in accordance with ISO 7539-2. The specimen shall be tested in the as-received condition except that it may be flattened, if desired. If the specimen is obtained by thermal cutting, all heat-affected areas shall be removed by mechanical processing, and the backing steel shall be cleared.

If the specimen cannot be extracted because of smaller diameter, the specimen's dimensions can be modified to suit the SCC test's needs but the approximate dimensional proportions shall be preserved. The specimen can be also taken from the mother clad pipes, or its clad plates with the same heat treatment as the clad fittings.

#### A.2.6 Acceptance criteria

The test results shall be considered acceptable if no fracture is visually found or no crack is found with a 10 times magnifying glass in the tensile stressed region between the inner loading rollers of the three specimens taken from each sample. If any crack is found in this region, a metallographic microscopy shall be used to determine whether the crack is caused by an environmentally-assisted cracking mechanism.

In all cases, any signs of corrosion leading to metal loss, including pitting or crevice corrosion, shall be reported.

### A.3 Mass loss corrosion and pitting corrosion tests

#### A.3.1 Test specimen

A sample of CRA clad layer shall be taken from the extrados of the clad fitting in the longitudinal direction. For welded clad fitting, an additional sample shall be extracted transverse to the weld seam and contain a section of the longitudinal seam at its centre. Three test specimens shall be taken from each sample. The preparation of specimens and cleaning after the test shall be in accordance with ISO 8407 and/or ASTM G1.

#### A.3.2 Test method

The mass loss corrosion and pitting corrosion tests shall be conducted with high temperature and high-pressure mounting coupons, in accordance with ASTM G111.

If agreed, the mass loss corrosion and pitting corrosion results can be obtained by examined the mass change of the specimens during the SCC tests.

The average corrosion rate of a single specimen is determined by the metal mass loss per unit area and test duration. The rate can be calculated by [Formula \(A.1\)](#):

$$v_{\text{corr}} = \frac{365\,000 \cdot \Delta W}{\rho \cdot T_{\text{corr}} \cdot S} \quad (\text{A.1})$$

where

$v_{\text{corr}}$  is the average corrosion rate (mm/a);

$\Delta W$  is the mass loss of specimen (g);

$\rho$  is the density of specimen material (g/cm<sup>3</sup>);

$T_{\text{corr}}$  is the corrosion test duration (d);

$S$  is the specimen area (mm<sup>2</sup>).

Calculate the mathematical average of three parallel specimens in a group as the average mass loss corrosion rate of the material, and report each value of the three parallel specimens.

After the test, the specimen surface shall be magnified (5 times to 10 times) for observation. If any corrosion pits exist, the size, distribution density, distribution uniformity and depth (average depth and maximum depth) of the pits shall be detected and reported.

### A.3.3 Test period

Conducted according to [A.2.4](#).

### A.3.4 Test environment

Conducted according to [A.2.3](#).

### A.3.5 Acceptance criteria

The mass loss corrosion test and pitting corrosion test should be conducted, and the corrosion rate should be as agreed.