International Standard

ISO 3845

Oil and gas industries including lower carbon energy — Full ring ovalization test method for the evaluation of the cracking resistance of steel line pipe in sour service

Industries du pétrole et du gaz, y compris les énergies à faible teneur en carbone — Méthode d'essai de déformation du diamètre d'une conduite en acier pour évaluer sa tenue mécanique en environnement corrosif

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Contents

Page

Foreword

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

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This document was prepared by Technical Committee ISO/TC 67, *Oil and gas industries including lower carbon energy*.

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

Introduction

Sour service cracking problems in susceptible steel line pipe are caused by the various forms of hydrogen damage due to the presence of wet hydrogen sulfide (H_2S). The main mechanisms are hydrogen-induced cracking (HIC) or stepwise cracking (SWC), sulfide stress cracking (SSC) and stress-oriented hydrogen-induced cracking (SOHIC). An industry-proven technique for assessing the cracking resistance of steel line pipe is to stress a full ring pipe specimen in a sour environment.

The advantages of the full ring test specified in this document are that it is not necessary to pressurize the line pipe full ring specimen to achieve the required stress, and residual stresses are retained. Equivalent internal stresses can be produced by ovalization of the pipe using mechanical means.

Additional advantages are more representative samples, when compared to machined four-point bend specimens and single-sided exposure can allow in-situ inspection during test exposure.

A known stress is exerted at two regions on a full ring section of steel pipe. The pipe specimen is then exposed internally to the sour test solution.

Ultrasonic testing can be conducted regularly on internally loaded test specimens during the exposure period to monitor crack initiation and propagation. Hydrogen permeation measurements may also be conducted. Both crack initiation and propagation can therefore be monitored. Finally, a metallurgical examination is undertaken to classify any indications found by non-destructive testing (NDT), such as visual inspection, magnetic particle testing (MT), penetrant testing (PT) or ultrasonic testing (UT).

The method has been in use since 1984, but in 1991 a Joint Industry Sponsored Project was set up with the aim of systematically developing, defining and validating the full ring test. The resultant test method designed to determine the susceptibility of steel line pipe, bends, flanges and fittings, including all associated welds to hydrogen damage caused by exposure to sour environments, was published by the UK HSE as OTI 95 635[1] and subsequently in 2016 as BS 8701, prior to adoption as ISO 3845.

Oil and gas industries including lower carbon energy — Full ring ovalization test method for the evaluation of the cracking resistance of steel line pipe in sour service

WARNING — The use of this document can involve hazardous materials, operations and equipment. It does not purport to address all the safety or environmental problems associated with its use. Attention is drawn to national and health safety practices and regulations regarding the use of hazardous materials prior to use, in particular for hydrogen sulfide.

1 Scope

This document gives a method for determining the resistance to cracking of steel pipes in sour service.

This test method employs a full-scale test specimen consisting of a short length of pipe (a ‘full ring’), sealed at each end to contain the sour test environment within. The test method applies to any pipe; seamless, longitudinally welded (with or without filler), helical welded, and to girth welds between pipes.

NOTE 1 The specimen is usually a pipe but can also consist of flange neck or section of a bend, or other tubular component or a combination of the above.

NOTE 2 This test method can also be used for corrosion resistant alloys (CRAs).

The method utilizes ovalization by mechanical loading to produce a circumferential stress, equal to the target hoop stress, at two diametrically opposite locations on the inside surface of the test specimen. The test specimen is then subjected to single sided exposure to the sour test environment.

NOTE 3 The test also allows measurement of hydrogen permeation rates.

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 2400, *Non-destructive testing — Ultrasonic testing — Specification for calibration block No. 1*

ISO 3059, *Non-destructive testing — Penetrant testing and magnetic particle testing — Viewing conditions*

ISO 3452 (all parts), *Non-destructive testing – Penetrant testing*

ISO 4787, *Laboratory glass and plastic ware — Volumetric instruments — Methods for testing of capacity and for use*

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

ISO 7963, *Non-destructive testing — Ultrasonic testing — Specification for calibration block No. 2*

ISO 8044, *Corrosion of metals and alloys — Vocabulary*

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

ISO 9934 (all parts), *Non-destructive testing — Magnetic particle testing*

ISO 11666, *Non-destructive testing of welds — Ultrasonic testing — Acceptance levels*

ISO 16810, *Non-destructive testing – Ultrasonic testing – General principles*

ISO 17635, *Non-destructive testing of welds — General rules for metallic materials*

ISO 17638, *Non-destructive testing of welds — Magnetic particle testing*

ISO 17640:2018, *Non-destructive testing of welds — Ultrasonic testing — Techniques, testing levels, and assessment*

ISO 22232 (all parts), *Non-destructive testing — Characterization and verification of ultrasonic test equipment*

ISO 23277, *Non-destructive testing of welds — Penetrant testing — Acceptance levels*

ASTM D1193, *Standard Specification for Reagent Water*

ASTM E1237, *Standard Guide for Installing Bonded Resistance Strain Gages*

ASTM F21, *Standard test method for hydrophobic surface films by the atomizer test*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8044 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
ancillary components
parts of the apparatus necessary for the test which are not the loading components to impart *stress* (3.26)

3.2
corrosion-resistant alloy
CRA
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]

3.3
imperfection
discontinuity or irregularity in the product wall or on the product surface that is detectable by inspection methods outlined in this document

3.4
indication
evidence obtained by non-destructive inspection

3.5
girth weld
butt weld joining one pipe to another (or bend or flange)

3.6
hardness
resistance of metal to *plastic deformation* (3.16), usually determined by indentation

3.7
heat-affected zone
HAZ
portion of base metal not melted during brazing, cutting or *welding* (3.31), but whose *microstructure* (3.14) and properties are altered by the thermal cycle of these processes

3.8
helical weld
DEPRECATED: spiral weld
weld running helically (spirally) around the circumference of a pipe formed from strip

3.9
hydrogen-induced cracking
HIC
planar cracking that occurs in carbon and *low alloy steels* (3.12) when atomic hydrogen diffuses into the steel and then combines to form molecular hydrogen at trap sites

[SOURCE: ISO 15156-1:2020, 3.12, modified — Note 1 to entry has been removed.]

3.10
hydrogen permeation
process of atomic hydrogen diffusion through a metal

3.11
longitudinal weld
straight weld running along the longitudinal axis of a pipe

3.12
low alloy steel
steel with a total alloying element content of less than about 5 % mass fraction, but more than specified for carbon steel

[SOURCE: ISO 15156-1:2020, 3.15]

3.13
measured strain
ε_1, ε_2, ε_3
surface *strain* (3.24) as measured by various techniques in one or more of three known directions at the surface

3.14
microstructure
structure of a metal as revealed by microscopic examination of a suitably prepared specimen

[SOURCE: ISO 15156-1:2020, 3.16]

3.15
modulus of elasticity
Young's modulus
E
ratio of tensile or compressive *stress* (3.26) to corresponding *strain* (3.24) below the elastic limit

3.16
plastic deformation
permanent deformation caused by straining beyond the elastic limit

3.17
Poisson's ratio
v
dimensionless material constant (approximately constant for steel) given by the ratio of contraction/expansion per unit length tangential to the direction of loading over the expansion/contraction per unit length in the direction of loading

3.18
principal strain
ε_p
maximum and minimum *strain* (3.24) levels existing at a point on the test surface acting at 90° to each other as calculated from *measured strain* (3.13) values

3.19
residual stress
σ_{res}
stress (3.26) present in a component free of external forces or thermal gradients

[SOURCE: ISO 15156-1:2020, 3.18, modified — The symbol σ_{res} has been added.]

3.20
sour environment
environment where hydrogen sulfide exists in the presence of water

3.21
specific service
conditions of application for the materials/components for which testing is defined to match the customer's requirements

Note 1 to entry: Fitness-for-purpose has also been historically used to define these same requirements.

3.22
specified minimum yield strength
SMYS
minimum *yield strength* (3.34) permitted for a given grade of material in product specifications

3.23
stepwise cracking
SWC
cracking that connects hydrogen-induced cracks on adjacent planes in a steel

Note 1 to entry: This term describes the crack appearance. The linking of hydrogen-induced cracks to produce stepwise cracking is dependent on the local *strain* (3.24) between the cracks and the embrittlement of the surrounding steel by dissolved hydrogen. HIC/SWC is usually associated with low-strength plate steels used in the production of pipes and vessels.

[SOURCE: ISO 15156-1:2020, 3.21]

3.24
strain
ε
dimensionless ratio of the change in length per unit length (e.g. mm/mm)

Note 1 to entry: It is normally expressed in parts per million ($\varepsilon \times 10^6$) of microstrain (με).

3.25
strain gauge
device using electrical resistance, which changes in proportion to applied *strain* (3.24)

3.26
stress
σ
applied force per unit area existing on any object as a result of external mechanical or thermal influences acting in that direction

3.27
stress-oriented hydrogen-induced cracking
SOHIC
staggered small cracks formed approximately perpendicular to the principal *stress* (3.26) (residual or applied) resulting in a “ladder-like” crack array linking (sometimes small) pre-existing HIC

Note 1 to entry: The mode of cracking can be categorized as *SSC* (3.28) caused by a combination of external stress and the local *strain* (3.24) around hydrogen-induced cracks. SOHIC is related to SSC and HIC/*SWC* (3.23). It has been observed in parent metal of longitudinally welded pipe and in the *heat-affected zone (HAZ)* (3.7) of welds in pressure vessels. SOHIC is a relatively uncommon phenomenon usually associated with low-strength ferritic pipe and pressure vessel steels.

[SOURCE: ISO 15156-1:2020, 3.23]

3.28
sulfide stress cracking
SSC
cracking of metal involving corrosion and *tensile stress* (3.29) (residual and/or applied) in the presence of water and H_2S

Note 1 to entry: SSC is a form of hydrogen stress cracking (HSC) and involves the embrittlement of the metal by atomic hydrogen that is produced by acid corrosion on the metal surface. Hydrogen uptake is promoted in the presence of sulfides. The atomic hydrogen can diffuse into the metal, reduce ductility, and increase susceptibility to cracking. High-strength metallic materials and hard weld zones are prone to SSC.

[SOURCE: ISO 15156-1:2020, 3.24]

3.29
tensile stress
ratio of load to original cross-sectional area

Note 1 to entry: These stresses include axial or longitudinal, circumferential or hoop and residual.

3.30
ultrasonic testing
testing of material by ultrasound for the presence of *imperfections* (3.3)

3.31
welding
joining of two metallic materials, usually by fusion techniques

3.32
weldment
portion of a component on which *welding* (3.31) has been performed, including the *weld metal* (3.33), the *heat-affected zone (HAZ)* (3.7), and the adjacent parent metal

[SOURCE: ISO 15156-2:2020, 3.24, modified — The abbreviated term for "heat-affected zone", HAZ, has been added.]

3.33
weld metal
portion of a *weldment* (3.32) that has been molten during *welding* (3.31)

3.34
yield strength
stress (3.26) at which a material exhibits a specified deviation from the proportionality of stress to *strain* (3.24)

Note 1 to entry: The deviation is expressed in terms of strain by either the offset method (usually at a strain of 0,2 %) or the total-extension-under-load method (usually at a strain of 0,5 %).

4 Symbols and abbreviated terms

AYS	actual yield strength
CAR	crack area ratio
CRA	corrosion-resistant alloy
DAC	distance-amplitude-corrected
E	modulus of elasticity
EPDM	ethylene propylene diene monomer
EPM	ethylene propylene copolymer
HAZ	heat-affected zone
HIC	hydrogen-induced cracking
MT	magnetic particle testing
NBR	nitrile butadiene rubber
NDT	non-destructive testing
PT	penetrant testing
PTFE	polytetrafluoroethylene
$R_{p0,2}$	0,2 % proof stress in accordance with ISO 6892-1
SOHIC	stress-oriented hydrogen-induced cracking
SMYS	specified minimum yield strength
SSC	sulfide stress cracking
SWC	step-wise cracking
SZC	soft-zone cracking
UT	ultrasonic testing
ε	strain
ε_p	principal strain
υ	Poisson's ratio
σ	stress
σ_p	principal stress
σ_{res}	residual stress

5 Principle

A short length of pipe (a ‘full ring’) is mechanically loaded to produce a circumferential stress equal to the target hoop stress at two diametrically opposite locations on the inside surface of the test specimen. The test specimen is subjected to a predetermined stress by ovalization and exposed to a sour environment. Testing is undertaken within an enclosure or in a restricted area.

The test specimen may be monitored throughout the test exposure to determine the extent of development of hydrogen damage due to the presence of wet hydrogen sulfide (H_2S). It is then subjected to post-test non-destructive testing and metallographic examination.

6 Reagents

6.1 The following reagent grade or higher-purity chemicals shall be used:

— sodium acetate, CH_3COONa;

— sodium chloride, NaCl;

— acetic acid, CH_3COOH;

— hydrochloric acid, HCl;

— sodium hydroxide, NaOH.

6.2 The following gases shall be used:

— hydrogen sulfide, 99,5 % minimum;

— carbon dioxide, 99,995 % minimum;

— inert gas used for the removal of oxygen, such as nitrogen, argon, or other non-reactive gas, 99,998 % minimum.

6.3 Water, distilled or deionized, conforming to the minimum purity requirements of Type IV of ASTM D1193 shall be used.

6.4 Test environment

6.4.1 General

The test solution used shall be reported for each test. All reagents added to the test solution shall be measured to ±1,0 % of the quantities specified.

The test solution shall be prepared in a separate sealed vessel followed by sparging with inert gas prior to transferring the test solution to the test cell, which has been subjected to inert gas purging in advance (see 9.5).

The test solution pH before transfer to the test cell shall be measured and verified to conform with requirements.

The H_2S concentration in the solution shall be measured using the iodometric titration method described in Annex C, or other equivalent method (e.g. photometric measurement).

6.4.2 Test solutions

The following test solutions shall be used depending on the specific test requirements:

a) NACE TM0284 Solution A: This test solution shall consist of a mass fraction of 5,0 % NaCl and 0,50 % CH_3COOH in distilled or deionized water (i.e. 50,0 g of NaCl and 5,00 g of CH_3COOH dissolved in 945 g of distilled or deionized water). The initial pH shall be 2,7 ± 0,1. Alteration of the test solution chemistry to adjust pH is not allowed. If the test solution pH is out of range the solution shall be discarded.

b) NACE TM0284 Solution C ('fitness for purpose' solution): This test solution shall consist of a mass fraction of 5,0 % NaCl and 0,40 % CH_3COONa in distilled or deionized water (i.e. 50,0 g of NaCl and 4,00 g of CH_3COONa dissolved in 946 g of distilled or deionized water).

   The target pH shall be defined by the customer. The initial pH shall be adjusted to the target pH ±0,2 by addition of HCl or NaOH before saturation with H_2S or the H_2S/CO_2 gas mixture.

c) Customer specified/field specific test solution.

NOTE a) and b) are equivalent to the test environments defined in ISO 15156-2:2020, Annex B.

6.4.3 Test gas composition

One of the following test gases shall be used depending on the specific test requirements:

a) NACE TM0284 Solution A: H_2S;

b) NACE TM0284 Solution C: H_2S or test gas mixtures consisting of H_2S and CO_2;

c) customer specified/field specific test solution: H_2S or test gas mixtures consisting of H_2S and CO_2 or H_2S and N_2.

The test gas or mixture composition shall be defined by the customer. Pre-mixed commercial test gas mixtures shall have a composition verified by analysis. Continuously-blended test gas mixtures shall have a composition verified by measurement. Each pure component gas used for continuously-blended test gas mixtures shall conform to the requirements of 6.2.

7 Apparatus

7.1 Containment materials

7.1.1 General

All materials employed in the test equipment shall be resistant to the test environment over the duration of the test.

7.1.2 Lid and base

Lid and base shall be made of:

a) polymethylmethacrylate (also known as acrylic) of appropriate thickness to avoid deformation with surfaces pre-treated with 50 % acetic acid solution for 1 h to 2 h;

b) PTFE coated/lined steel; or

c) other materials conforming to 7.1.1.

7.1.3 Seal rings

Seal rings shall be made from material conforming to 7.1.1

NOTE NBR, EPM/EPDM and PTFE have been found to be suitable seal materials.

7.2 Internal loading components

An example of the internal loading components that may be used to apply the stress to the specimen is shown in Figure 1.

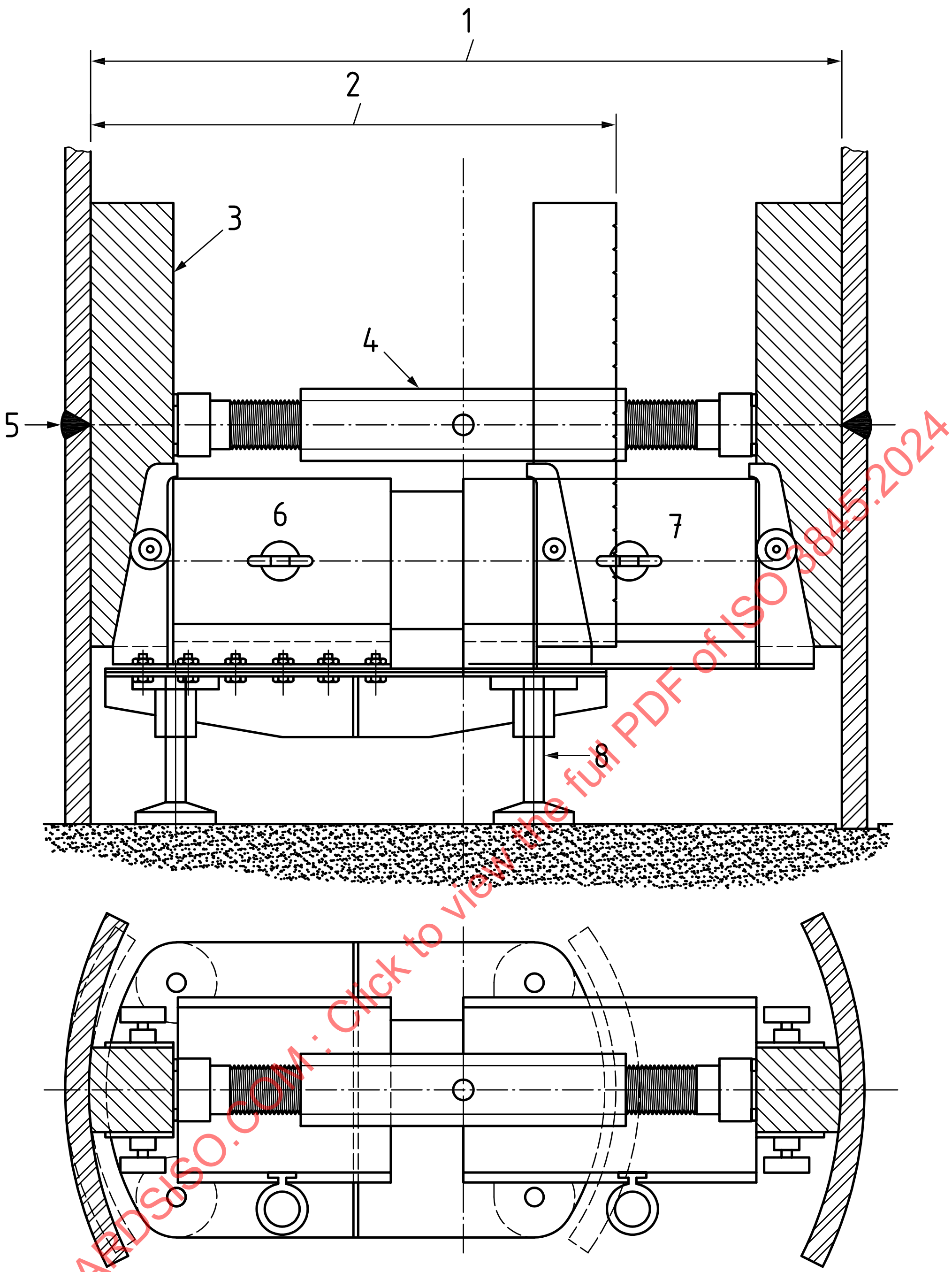
The turnbuckle consists of a barrel with a left- and right-handed thread bore, into which two sections screw with the appropriate thread.

NOTE 1 ACME (ballistic) threading has been found to be suitable. Austenitic stainless steel has been found to be reusable and has not led to detrimental galvanic effects.

The face of the load distribution block which fits against the ring section is profiled to fit the ring section to ensure even load application.

The load distribution blocks shall consist of a galvanically compatible material to that of the internal surface of the specimen. Loading blocks shall be sufficiently rigid so that the applied load is maintained over the duration of the test.

NOTE 2 Low alloy steel has been found to be suitable.



Key

1 pipe inside diameter
2 closed jack position
3 load distribution blocks
4 turnbuckle
5 weldment
6 hydraulic jack
7 spacer block
8 height adjustable supports

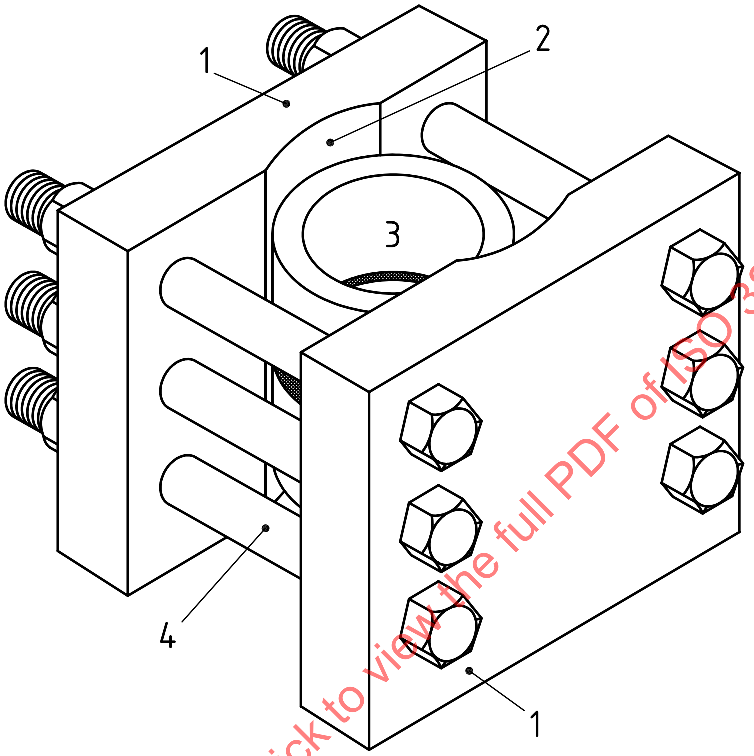
Figure 1 — Example of internal loading components

7.3 External loading components

External loading of the test specimen may be required, e.g. for pipe diameters <300 mm or with larger diameter pipe of thick wall/diameter combinations which preclude internal loading. Figure 2 shows a typical configuration of specimen and loading components. External loading imparts the target strain at the centre of the contact location on each block and, as such, precludes the in-test UT assessment. Internal strain gauging is used to monitor the load application.

Loading blocks shall be sufficiently rigid so that the applied load is maintained over the duration of the test.

The internal face (contact surface) in the centre of the block shall have a machined longitudinal slot with a minimum arc length of 75 mm or 5 % of the pipe circumference, whichever is greater, and should have a radius typically equivalent to 1,05 to 1,10 times the anticipated maximum external radius of the test specimen under loading.



Key

1 loading blocks with clearance holes

2 radius longitudinal slot

3 ring specimen

4 bolts with nuts/washers

Figure 2 — Example of external loading components

7.4 Loading component treatment

Both internal and external forms of loading components (see Figures 1 and 2) shall be designed for repeated use. At the conclusion of the full ring test, any loading components that have been submerged within the test solution shall be thoroughly wire brushed and, where practicable, submerged in oil until required for further use. On removal from the oil, the components shall be degreased. At no time shall loading components of either form come into contact with greases containing copper (Cu) or molybdenum disulfide (MoS_2).

7.5 Ancillary components

Ancillary components in contact with or exposed to the test environment, such as thermowells, shall conform to 7.1.1.

8 Sampling

8.1 General

The pipe sample(s) shall be representative of the commercial product and any weld shall be made using an appropriate welding procedure.

NOTE Additional material can be required to provide the tensile specimens for the determination of the AYS.

The pipe sample(s) to be tested shall be examined as described in 8.2 and 8.3 to ensure freedom from imperfections to permit specimen extraction.

8.2 Ultrasonic testing

The external surface of the sample shall be 100 % inspected using the ultrasonic test procedure detailed in Annex A. The sample shall be inspected using a compression probe and shear wave probes of angles 45°, 60° and 70°. All indications shall be recorded.

NOTE The purpose of this inspection is to confirm suitability of the sample for extraction of the test specimen(s) and to provide a “fingerprint” which will enable a quantitative comparison to be made with later inspections and to avoid misinterpretation of pre-existing indications.

8.3 Magnetic particle testing/penetrant testing

The entire internal surface of the sample shall be inspected using magnetic particle testing for carbon and low alloy steel, or penetrant testing for CRAs.

Magnetic particle testing shall be performed using a documented procedure conforming to the ISO 9934 series, ISO 3059, ISO 17635 and ISO 17638. Penetrant testing shall be performed using a documented procedure conforming to the ISO 3452 series, ISO 3059 and ISO 23277.

9 Procedure

9.1 General

Where the test specimen contains a girth weld, it shall be positioned at the mid-length. To retain the residual stress produced during manufacture and welding, the length of the test specimen shall be equal to or greater than the outer diameter.

Characterization of residual stress in the test specimen should be considered to aid post-test analysis.

If the test specimen contains a specific region for assessment (e.g. a repair weld or strained area), then this position shall be clearly marked on the external surface so that the applied load can be aligned accordingly.

NOTE 9.2.3.1 provides guidance on the alignment of seam welds, repair welds, etc. to optimize the data generated per test specimen.

The specimen shall be grit-blasted and the ends prepared so that they can later be fitted with gas-tight seals.

An illustrated summary of the procedure is given in Annex D.

9.2 Test specimen

9.2.1 Machining/Preparation

The length of the test specimen shall be equal to or greater than the outside diameter of the line pipe sample. The ends on the test specimen shall be machined to provide clean, flat surfaces. A groove may then be machined in the end faces to accommodate an o-ring seal.

9.2.2 Surface preparation

9.2.2.1 Carbon and low alloy steel

The internal surface shall be in one of two conditions:

a) prepared by grit blasting using grit with a nominal maximum diameter of 1,0 mm without re-circulation to a minimum grade Sa. 2,5 in accordance with ISO 8501-1.

NOTE 20-40 mesh (0,84 mm to 0,40 mm) garnet grit has been found to be suitable.

b) other surface conditions as specified by the customer specified, including as-received to retain surface features of interest.

To avoid flash rusting of the cleaned surface, after completion of grit blasting or other surface preparation, the ring specimen shall be stored in dry air or an inert gas atmosphere prior to strain gauging, loading and sealing.

9.2.2.2 Corrosion-resistant alloys

The internal surface shall be degreased and the adequacy of degreasing verified in accordance with ASTM F21 or equivalent. The surface shall not be abraded.

NOTE Other surface treatments can be used if specified by the customer.

9.2.3 Specimen loading

9.2.3.1 Position of maximum stress

The specimen shall be marked such that the maximum stress shall be applied at:

a) the area adjacent to the seam weld (if present);

b) any ultrasonic indications found in the girth weld or weld repair; or

c) any other customer specified location.

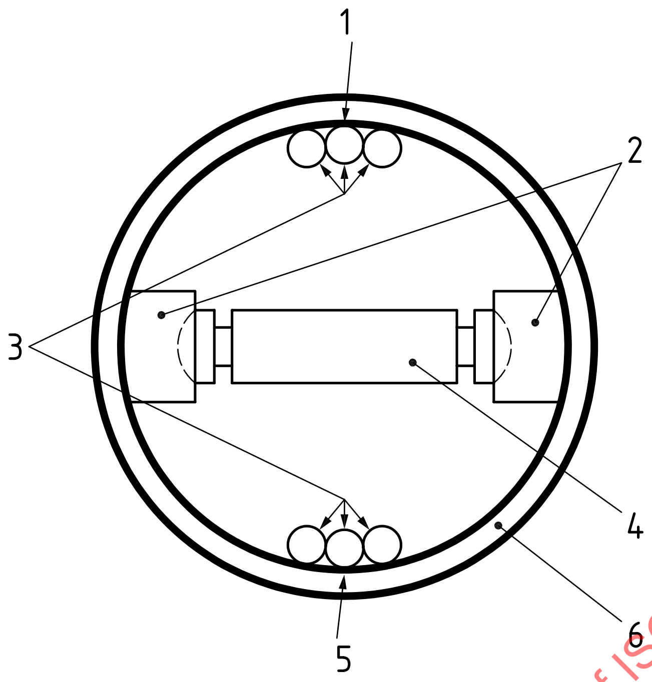
NOTE 1 It is therefore useful to consider these points prior to producing the test sample, as it is possible for the repair area in a girth weld to be positioned 180° from a seam weld, in which case both critical areas can be tested simultaneously at or above the minimum test stress.

NOTE 2 It is common industrial practice when lengths of seam welded pipe are welded together, that the two pipe seam welds are a minimum of 30° apart. For efficient testing, placing the seam welds 180° apart is useful as both seams can then be tested simultaneously at or above the minimum test stress.

NOTE 3 Annex B provides details of the strain gauging technique and also shows the various combinations of ring specimens that can be tested.

9.2.3.2 Strain gauge locations

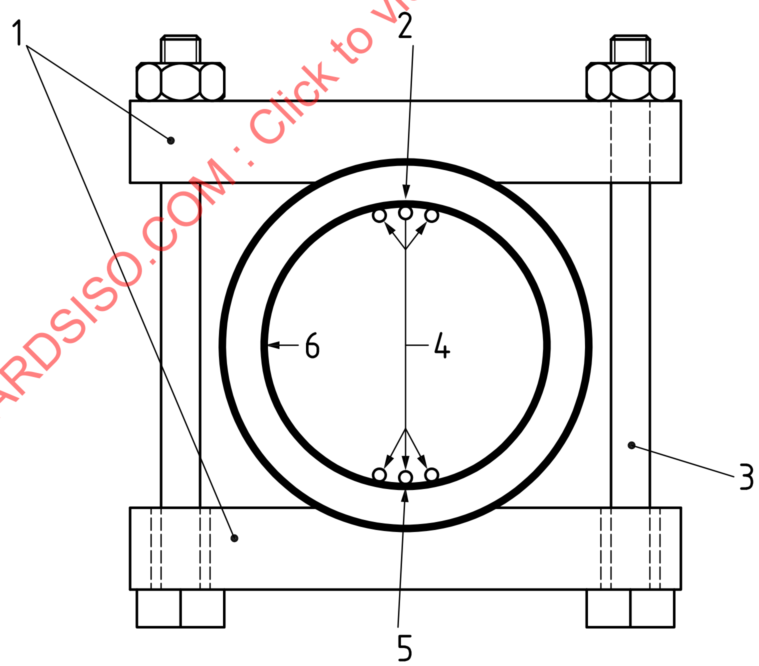
The ring specimen shall be loaded by internal or external loading as illustrated in Figure 3 and Figure 4. To monitor the load and determine the stress during application of the load, strain gauges shall be attached to the internal surface in accordance with Annex B.



Key

1 0° position for maximum target stress
2 load distribution blocks
3 strain gauges
4 turnbuckle
5 180° position for maximum target stress
6 ring specimen

Figure 3 — Example of full ring test configuration using internal loading technique



Key

1 loading blocks with clearance holes
2 0° position for maximum target stress
3 bolts with nuts/washers
4 strain gauges
5 180° position for maximum target stress
6 ring specimen

Figure 4 — Example of full ring test configuration using external loading technique

9.2.3.3 Dimensional checks pre-loading

Measure and record:

— the specimen length;

— the wall thickness of the pipe at 0° and 180° positions;

— the outer diameter across 0° to 180° positions;

— the outer diameter across 90° to 270° positions;

— the position of any welds.

9.2.3.4 Strain gauge installation

Strain gauges shall be installed in accordance with Annex B.

9.2.3.5 Required stress

The required stress to be applied shall be specified by the customer.

9.2.3.6 Calculation of applied stress/strain

The principal circumferential stress to be applied is calculated as follows.

If the AYS value is used, it shall be taken from the average of two or more uniaxial tensile tests.

In the absence of an appropriate definition of the AYS in the manufacturing specification, the stress-percentage extension curve determined at the test temperature shall be used to derive the 0,2 % proof strength, plastic extension, $R_{p0,2}$, as defined in ISO 6892-1.

For testing at stresses up to the elastic limit, the applied principal stress, σ_p, is determined from the circumferential, ε_c and longitudinal, ε_l strain gauge readings using Formula (1):

$$\sigma_p = \frac{E}{1-v^2}(\varepsilon_c + v\varepsilon_l) \quad (1)$$

where

E is the modulus of elasticity;

v is the Poisson's ratio;

ε_c is the strain measured in circumferential direction;

ε_l is the strain measured in longitudinal direction.

For testing CRAs at stresses between the elastic limit and $R_{p0,2}$, the principal strain value required shall be taken from the average of two or more stress-percentage extension curves determined at the test temperature.

NOTE In the elastic part of the stress-percentage extension curve, the value of the slope does not necessarily represent the modulus of elasticity (and the abscissa of the stress-percentage extension plot does not therefore necessarily represent strain). This value can closely agree with the value of the modulus of elasticity if optimal conditions (high resolution, double sided, averaging extensometers, perfect alignment of the test piece, etc.) are used.

The applied principal strain, ε_p is determined from the circumferential, ε_c and longitudinal, ε_l strain gauge readings using Formula (2):

$$\varepsilon_p = \frac{1}{1-\nu^2}(\varepsilon_c + \nu\varepsilon_l) \quad (2)$$

where

ν is the Poisson's ratio;

ε_c is the strain measured in circumferential direction;

ε_l is the strain measured in longitudinal direction.

The principal stress is usually considered to be aligned exactly along the circumferential axis, however in the presence of a helical weld seam, the direction of the principal stress might not coincide exactly with the circumferential direction. In this case, three-element stacked rosette strain gauges can be used to capture additional information at the 45-degree orientation which may be of use in subsequent evaluation of shear stresses. For loading Formulae (1) and (2) shall apply.

The values calculated shall be recorded in the test report (see Annex F).

9.2.3.7 Stress application

Stress application shall be accomplished by one of two methods, dependent on the internal diameter, wall thickness, pipe AYS and the % SMYS or % AYS required.

It is desirable to stress pipes internally using the typical form of rig shown in Figure 1, since on-line ultrasonic monitoring can be performed. In this rig, loading is typically applied internally using a turnbuckle via two loading blocks. Loading shall be applied 90° and 270° remote from the position of peak internal stress. Due to ring specimen size, initial loading shall be applied through a hydraulic jack, situated below the turnbuckle. The turnbuckle shall then be tightened before removing the hydraulic jack.

Internal loading is normally undertaken using an internal turnbuckle/hydraulic jack and two load distribution blocks, as shown in Figure 1. A combination of internal hydraulic jacks and external loading blocks can also be used; either the internal hydraulic jacks or the external loading blocks are removed after a stable load has been achieved. Loading shall not be started until once the two internal loading blocks and turnbuckle/hydraulic jack are in position and the strain gauges are zeroed.

NOTE 1 For thin-walled ring sections, the load can be applied manually by turning the centre section of the turnbuckle.

NOTE 2 For thicker sections, a hydraulic jack positioned under but as near to the turnbuckle as possible can be used. In this case, the turnbuckle is tightened as the load is applied and locked when the required stress level is reached. The hydraulic jack is then released.

NOTE 3 When using a hydraulic jack the stress level can drop when the jack is released. Therefore, a higher stress level will be attained before release, so that the final relaxed stress level is achieved.

In cases where internal loading is not feasible or practical, the specimen shall be loaded externally, using the form of loading rig shown in Figure 2. The specimen ring shall be placed between the loading blocks to achieve peak tensile stress internally at the two points of contact in line with the blocks.

External loading is normally undertaken using two load distribution blocks, as shown in Figure 2.

Loading shall not commence until the two external loading blocks are in position and the strain gauges are zeroed.

Care should be taken to avoid overstressing. When approaching the target stress small loading increments should be applied, e.g. increments corresponding to 5 % of SMYS or AYS.

Once the load has been applied, data collected from all the strain gauges shall be recorded and converted into a stress value, expressed as % SMYS or % AYS.

The loaded ring specimen shall be left for an initial minimum of 60 min and the strain monitored to ensure no load relaxation takes place. If relaxation does occur, the load shall be adjusted back to the target strain value and left for a further minimum time of 30 min. This 30 min adjustment procedure shall be repeated until a stable strain has been achieved. The time required for loading and relaxation is dependent on the diameter/wall thickness of the pipe, the applied stress and the loading technique (i.e. internal or external loading). When the stable target stress has been achieved, the strain gauges shall be removed, taking care not to damage or score the surface, and the gauge areas cleaned and degreased. Any other contaminated areas shall also be cleaned and degreased.

NOTE 4 The potential for significant local variation in applied stress is expected. This arises from small variations in pipe or clamp geometry, leading to local point contact between the sample and loading mechanism. This can lead to stress level variations of many tens of percent, to where areas of the sample can be yielded (i.e. over 100 % AYS) or significantly under loaded (e.g. less than 50 %). These variations are not an indication of poor pipe quality, just a fact of the nature of loading. Pipe dimensional changes much smaller than those tolerances allowed in all major line pipe standards can lead to these applied stress variations.

9.2.3.8 Dimensional checks (post-loading)

Measure and record:

— the outer diameter across 0° to 180° positions;

— the outer diameter across 90° to 270° positions.

9.3 Preparation of the test cell

The loaded ring specimen shall be converted into the test cell by fitting gas tight lids/seals to each end. There are various methods to achieve this and any method meeting the following criteria shall be used:

a) the materials used for the lids and seals shall conform to 7.1.1;

b) the lids and fittings shall not be so rigid as to contribute to the pipe rigidity, for instance, a welded steel plate shall not be used.

NOTE The lid and base can be attached by drilling and tapping the ring specimen and bolting the lids to the pipe.

After the test specimen has been made into the test cell, it shall be moved into the safety enclosure or restricted area where the exposure test shall be undertaken.

9.4 Test duration and solution parameters

The full ring test exposure duration shall be a minimum of 30 days.

NOTE 1 If the test environment has been reduced in severity from those given in 6.4, an extended test duration can be considered.

NOTE 2 On-line monitoring by ultrasonic and hydrogen permeation measurements can be used to indicate if an extended test duration is required.

The H_2S concentration in solution shall be maintained at a minimum value of 2,300 mg/l for a test conducted at 100 kPa pH_2S, or pro-rata for tests conducted at less than or greater than 100 kPa pH_2S.

The pH shall be maintained within the specified limits for the respective solution, as detailed in 6.4, i.e.

a) NACE TM0284 – Solution A.

The pH at the start of the test shall be measured immediately after H_2S saturation and shall be within the range of 2,7 to 3,3.

The pH at the end of the test shall not exceed 4,0 for the test to be valid.

b) NACE TM0284 – Solution C.

The target pH shall be defined by the customer.

The initial pH shall be adjusted to the target pH ±0,2 by addition of HCl or NaOH before saturation with H_2S or the H_2S/CO_2 gas mixture.

During the test, the pH may alter, but shall not be allowed to change by more than ±0,2 pH units. This shall be achieved by periodically regenerating the buffering power of the test solution with HCl or NaOH.

c) Specific service test solution.

The test solution shall be maintained at a temperature of (24 ± 3) °C unless otherwise specified by the customer. For corrosion resistant alloys the temperature shall be stipulated by the customer.

The minimum test solution volume to exposed test specimen surface area shall be 5 ml/cm^2: For small diameter line pipe, this ratio might not be achieved within the test specimen. To achieve the required minimum solution volume to area ratio of 5 ml/cm^2, a glass/acrylic extension can be attached to the pipe section or a separate reservoir containing the test solution can be used, and the solution circulated between the reservoir and the test cell.

9.5 Test commencement

Following the solution preparation and pH verification given in 9.4, the solution shall be de-aerated by sparging with inert gas to ensure a maximum dissolved oxygen level of 50 ppb for carbon and low alloy steels and 10 ppb for CRA's is achieved, before transfer to the de-aerated full ring test cell.

Before filling with the test solution, the test cell shall be purged with inert gas and checked for leaks. If the test cell is gas-tight, the prepared de-aerated solution shall be transferred from the mixing tank to the test cell under a blanket of inert gas.

Following the transfer of the test solution, the solution in the test cell shall be tested to confirm de-aeration and if necessary be sparged again with inert gas.

The test gas shall then be introduced into the cell at a flow rate sufficient to achieve the required H_2S concentration in solution.

NOTE 1 The required H_2S concentration in solution is generally reached within 24 h for up to 1 016 mm (40 inch) outer diameter pipes.

Continuous bubbling is required throughout the test duration using an open-ended gas inlet tube with a diameter which allows the test conditions to be maintained.

NOTE 2 Fritted end tubes have been found to be liable to blockage by corrosion product during testing.

The pH of the solution shall be measured.

The H_2S concentration in the solution shall be measured using the iodometric titration method described in Annex C, or other equivalent method (e.g. photometric measurement). When the H_2S concentration reaches or exceeds the target value in accordance with 9.4, the test shall be deemed to have commenced.

9.6 Monitoring

9.6.1 Test solution

The test solution (see 9.4) shall be monitored during the test, as follows:

a) continuous monitoring of the test solution temperature;

b) measurement of the H_2S concentration in solution using the iodometric titration method described in Annex C, or other equivalent method (e.g. photometric measurement), at a frequency of every (7 ± 2) days;

c) measurement of the solution pH, at a frequency of every (7 ± 2) days.

NOTE For tests where pH control is required, more frequent pH measurements can be necessary.

9.6.2 Ultrasonic testing

When specified by the customer, ultrasonic testing shall be undertaken for internally loaded test specimens in accordance with Annex A at a frequency of every (7 ± 2) days.

NOTE Ultrasonic testing of the high stressed regions of externally loaded pipes cannot be undertaken due to the presence of the loading blocks.

9.6.3 Hydrogen permeation

If hydrogen cells are to be fitted, they shall be attached after loading and cell containment. For single material ring tests, a single cell attachment can be sufficient. Girth welded full rings of differing materials can require two or more cells to measure each material.

9.6.4 Galvanic coupling

A galvanic couple can be produced when two sections of pipe from different sources are welded together to form the test piece, for example pipe/bend, pipe/flange, pipe A/pipe B. Therefore, it can be useful to record the relevant corrosion potentials of each section by inserting a luggin probe through the lid.

9.7 Test completion

After completion of the exposure period, the solution pH and H_2S concentration shall be measured and the solution sparged with inert gas. When the H_2S concentration is below safe limits, the solution shall be drained and the exposed surfaces washed with water and dried. The specimen shall then be unloaded in preparation for evaluation unless secondary testing is required (see 9.8).

9.8 Secondary testing

Secondary testing is applicable to carbon and low alloy steels only.

On completion of a 30-day test, secondary testing of the same ring specimen may be specified by the customer, either at a higher load level or at the original load level using a different region of a circumferential girth weld. If secondary testing is undertaken, the original test can only be evaluated by ultrasonic testing and magnetic particle testing. Therefore, since the metallographic examination cannot be performed, this limitation in the evaluation of the initial test shall be agreed with the customer. If secondary testing is undertaken any residual stresses shall be evaluated by measuring the strain during the unloading operation.

9.9 Evaluation of test specimen

9.9.1 General

The cleaned tested specimen is evaluated using ultrasonic testing (UT), magnetic particle testing (MT) / penetrant testing (PT) and metallographic examination. The size, location and type of any indications / cracks are characterised and reported, and a visual observation of corrosion or other notable features is recorded.

If SSC indications occur outside a region of quantified applied stress, they should be investigated. If no metallurgical reason can be found for cracking (e.g. localized high hardness or susceptible microstructure), the indication may be considered invalid as it could have occurred due to overstressing.

The inspection does not include the region occluded by the loading blocks for internally loaded specimens.

9.9.2 Post-test non-destructive testing

9.9.2.1 Ultrasonic testing

The external surface of the test specimen shall be 100 % inspected using the ultrasonic test procedure detailed in Annex A.

The orientation relative to the areas of maximum stress (see Figures 3 and 4), distance from the specimen mid-length, area and depth of all indications shall be recorded, and the locations marked on the test specimen.

9.9.2.2 Magnetic particle testing/penetrant testing

Except for any areas covered by internal loading blocks, the internal surface of the test specimen shall be 100 % inspected using magnetic particle testing for carbon steel, or penetrant testing for CRAs.

The orientation relative to the areas of maximum stress (see Figures 3 and 4), distance from the specimen mid-length and length of all indications shall be recorded, and the locations marked on the test specimen.

9.9.3 Metallographic examination

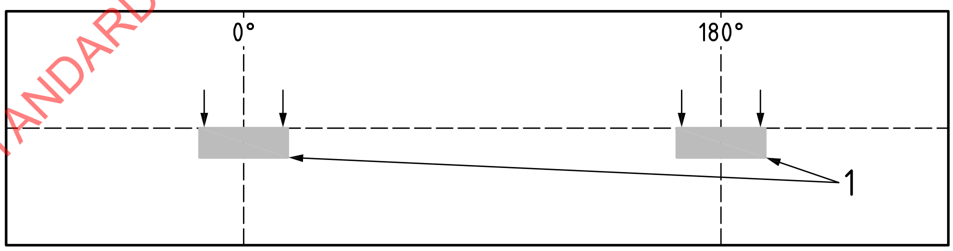
Indications detected by NDT shall be sectioned and the cut faces metallographically prepared and examined in the un-etched and etched condition at a minimum magnification of 100×.

For pipes with a large number of indications, a representative sampling may be sectioned for metallographic analysis.

Sectioning at the two highly stressed target zones (see Figures 5 to 10) shall be undertaken, regardless of the presence or absence of NDT indications. For girth welds, two sections from each location shall be prepared; one through the fusion-line/HAZ region and one through the weld centre-line. For seam and helical welds transverse, weld sections shall be taken in order to examine the weld, fusion-line/HAZ and adjacent parent regions. The cut faces shall be metallographically prepared and examined in the un-etched and etched condition at a minimum magnification of 100×.

The type, extent, size and location of any cracking shall be characterised and reported (examples of cracking are given in Annex E, see Figures E.1 to E.4).

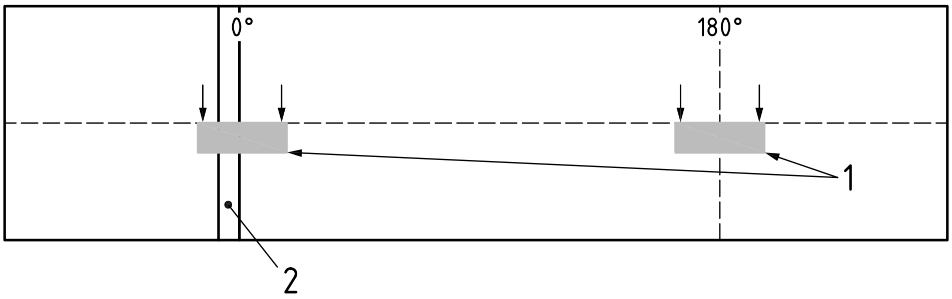
NOTE Guidance on SSC evaluation for interpretation of features and giving a procedure for distinguishing cracks or pits is given in Reference [2].



Key

1 metallographic sections

Figure 5 — Expanded view of the pipe specimen showing the location of the two metallographic sections to be taken from a parent pipe

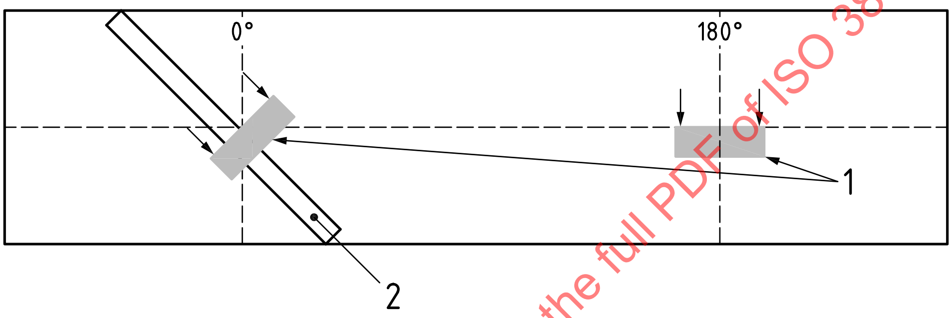


Key

1 metallographic sections

2 seam weld

Figure 6 — Expanded view of the pipe specimen showing the location of the two metallographic sections to be taken from a seam welded pipe

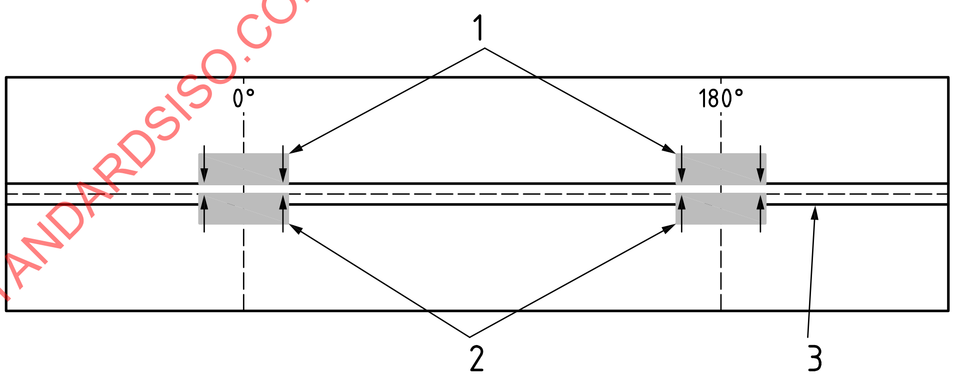


Key

1 metallographic sections

2 helical weld

Figure 7 — Expanded view of the pipe specimen showing the location of the two metallographic sections to be taken from a helically welded pipe



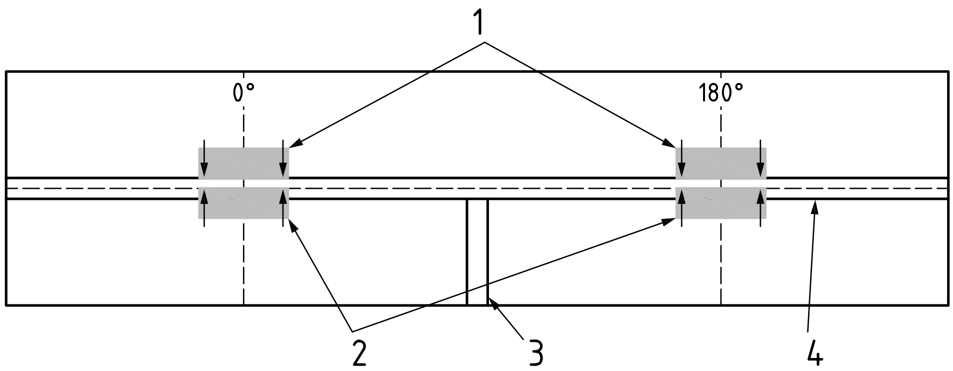
Key

1 metallographic sections through fusion line/HAZ region

2 metallographic sections through weld centre line

3 girth weld

Figure 8 — Expanded view of the pipe specimen showing the location of the four metallographic sections to be taken from a girth welded pipe



Key

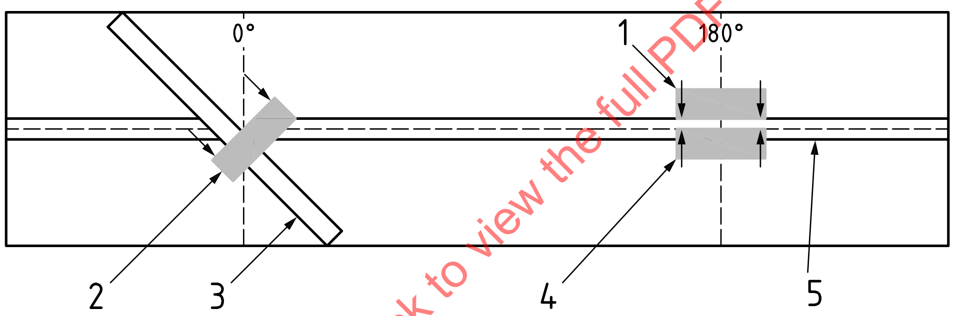
1 metallographic sections through fusion line/HAZ region

2 metallographic sections through weld centre line

3 seam weld

4 girth weld

Figure 9 — Expanded view of the pipe specimen showing the location of the four metallographic sections to be taken from a seam-girth welded pipe



Key

1 metallographic sections through fusion line/HAZ region

2 metallographic section through helical weld

3 helical weld

4 metallographic section through weld centre line

5 girth weld

Figure 10 — Expanded view of the pipe specimen showing the location of the three metallographic sections to be taken from a helical-girth welded pipe

10 Test report

A test report shall include the following:

a) all information necessary for the identification of the sample tested, including:

  1) material specification;

  2) pipe identification;

  3) pipe dimensions pre and post loading (9.2.3.3 and 9.2.3.8) and product form (e.g. seamless or type of welding);

b) reference to this document, ISO 3845:2024;

c) any variations or options in the test method;

d) any deviations from the test method;

e) date of the test;

f) identification of the test laboratory;

g) loading details (9.2.3);

h) applied stress;

i) strain gauge locations and values;

j) solution type, gas composition, pH, H_2S concentrations and temperature (6.4.2, 6.4.3 and 9.6);

k) results of ultrasonic testing and magnetic particle/penetrant testing (8.2 and 8.3);

l) results of metallographic examination (9.9.3);

m) results of any hydrogen permeation measurements (9.6.3);

n) pass/fail test result against agreed acceptance criteria (see Annex G for guidance on acceptance criteria for carbon steels);

o) any unusual features observed.

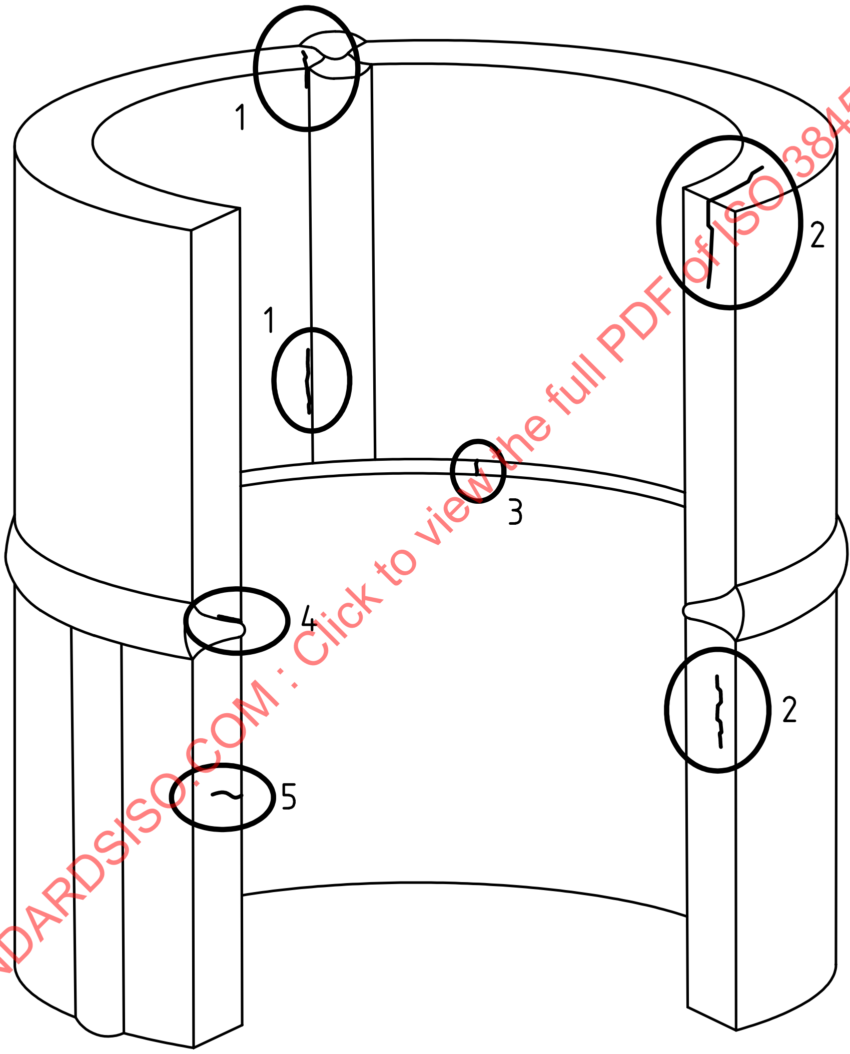
An example of a full ring test report and of a loading report is given in Annex F.

Annex A
(normative)

Ultrasonic testing (UT)

A.1 General

Common cracking locations and orientations for carbon and low alloy steel line-pipe are shown in Figure A.1.



Key

1 SSC or SOHIC at longitudinal seam weld fusion line/HAZ
2 HIC in parent material
3 SSC at girth weld root (longitudinal)
4 SSC or SOHIC at girth weld fusion line/HAZ (circumferential)
5 SSC or SOHIC in parent material

Figure A.1 — Most common crack locations for carbon and low alloy steel line-pipe

NOTE 1 Pipelines transporting hydrocarbon fluids can be prone to develop hydrogen-induced cracks (HIC) / stepwise cracking (SWC). This normally occurs in the mid-wall section of the pipe plate, and through a series of steps, cracking can become surface emerging.

NOTE 2 Cracking can occur in the girth weld, either in a longitudinal orientation, through the weld root or in a circumferential orientation at the weld root fusion-line/HAZ.

NOTE 3 The longitudinal seam weld can develop cracking at the weld root fusion-line/HAZ which usually originate from the internal surface.

NOTE 4 Cracking within the material can be fully embedded.

A.2 General requirements

A.2.1 Personnel

Ultrasonic testing shall be performed by personnel qualified in accordance with ISO 9712.

A.2.2 Equipment

A.2.2.1 Ultrasonic examination equipment, in accordance with the ISO 22232 series.

A.2.2.2 Ultrasonic probes, in accordance with ISO 22232-2 and ISO 22232-3.

A.2.2.3 Zero-degree compression probes, single and/or combined double crystal compression wave probes with a crystal size ranging from 10 mm to 20 mm and a frequency in the range of 4 MHz to 10 MHz shall be used.

Exact probe details shall be specified in the individual report sheets and technique sheets.

A.2.2.4 Angle shear wave probes, single and/or combined double crystal 45°, 60° and 70° shear probes shall be used. They shall have a crystal size of 10 mm and a frequency in the range of 4 MHz to 5 MHz.

Exact probe details shall be specified in individual report sheets and technique.

A.2.2.5 Calibration reference blocks, calibration and reference blocks shall be prepared in accordance with ISO 2400, Block No.1 (IIW-V1) and ISO 7963, Block No.2 (IIW-V2).

A.2.2.6 Imperfection location aids, suitable imperfection location equipment such as slides shall be available and used at the time of testing.

A.2.2.7 Couplant, the couplant used shall be silicone-free and shall not adversely affect the strain gauge adhesion. The coupling media shall be in accordance with ISO 16810. The coupling medium used for range and sensitivity setting and for the test shall be the same.

NOTE Couplants containing silicone have been found to adversely affect adhesion, leading to inaccurate strain response.

A.2.3 Surface condition

Scanning surfaces shall be even and free from foreign matter in accordance with ISO 17640:2018, Clause 9.

All surfaces from which scanning is to be carried out shall be prepared such that satisfactory acoustic coupling can be achieved for the full scan distance. To achieve this, the scanning surface shall be free from loose oxide scale, weld spatter and other surface irregularities.

The entry and back surfaces of the specimen shall be sufficiently smooth to maintain a first back wall echo amplitude of greater than 50 % full screen height while scanning an area which does not contain significant reflectors.

External weld dressing shall not be permitted, except seam/girth/helical weld regions at the site of the loading blocks.

A.2.4 Scope of examination

A.2.4.1 The ultrasonic examination shall be performed on the pipe prior to test commencement and after the test in all cases and additionally during the test at regular intervals for internally loaded pipe.

A.2.4.2 The weld metal, heat-affected zone and adjacent parent metal shall be scanned using zero-degree compression wave techniques where possible.

A.2.4.3 The weld metal, heat-affected zone and any regions in the parent pipe where indications have been detected by the zero-degree compression wave technique shall be examined using angle shear wave technique.

A.3 Examination procedure

A.3.1 Weldment examination

Examine the weldment in accordance with ISO 17640:2018, Clause 8.

A.3.2 Parent metal

Examine the parent metal in accordance with ISO 17640:2018, Clause 10.

A.3.3 Determination of scanning sensitivity – zero-degree compressional wave

A.3.3.1 The scanning sensitivity shall be defined by the reference level plus 6 dB.

A.3.3.2 The reference level shall be set on an area of the parent metal, free from imperfections such that the second backwall echo is displayed at full screen height.

A.3.3.3 An alternative method can be used with a standard reference block containing flat bottomed/side drilled holes at a depth nominally equal to or greater than the product thickness, at one half and one quarter of the product thickness.

The standard reference blocks shall be made from the same metal as the test sample or from a metal with the same acoustic properties.

A.3.3.4 A distance-amplitude-corrected (DAC) curve shall be constructed using the standard reference block. The reference level shall be based on the DAC curve.

A.3.3.5 When the reference block is different from the test specimen, a transfer correction shall be considered. This shall be carried out in accordance with ISO 17640.

A.3.4 Determination of scanning sensitivity – angle shear wave

A.3.4.1 The scanning sensitivity shall be determined using the reference blocks as described in A.3.3.3 containing side drilled holes at a depth nominally equal to or greater than the specimen thickness.

A.3.4.2 The scanning sensitivity shall be set such as the maximized signal echo from the side drilled hole at a depth of specimen thickness is set at full screen height plus 6 dB.

A.3.4.3 Alternatively a reference level based on a DAC curve can be used; the construction of the DAC curve shall be carried out in accordance with ISO 17640.

A.3.4.4 When the reference block is different from the test component, a transfer correction shall be considered. This shall be carried out in accordance with ISO 17640.

A.3.4.5 The scanning sensitivity shall be set at DAC curve reference level plus 6 dB.

A.4 Scanning

A.4.1 Zero-degree compression wave – weldment examination

The weldment shall be examined using zero-degree compression wave techniques where access, surface condition and weld configuration ensure complete coverage.

A.4.2 Angle shear wave – weldment examination

Scanning of welds shall be carried out in accordance with ISO 16810 and ISO 17640.

A.4.3 Zero-degree compression wave – parent metal examination

The entire external surface of the pipe shall be examined in two directions using compression wave techniques to detect imperfections and also to ascertain the exact wall thickness of the material.

Any imperfections within the volume of parent metal, through which angle shear wave examinations are to be carried out, i.e. an area of 5,5 times the material thickness plus 30 mm on each side of the weld, shall be recorded.

A.4.4 Angle shear wave – parent metal examination

Angle shear wave scanning of the parent metal shall be carried out where indications were found by zero-degree compression wave technique and shall be carried out using angle beam search units of at least two different refracted angles. The difference between the angles shall be at least 15°, normally 45° and 60°and 70° angles being used.

The scanning shall be carried out to determine whether the indications are laminar or stepwise.

For parent metal full ring tests or where the parent metal is also of interest on welded full ring tests, angle shear wave scanning shall also be conducted, irrespective of the results from the zero-degree compression wave scanning.

A.5 Evaluation of indications

A.5.1 Zero-degree compression wave

Evaluation of indications shall be performed at reference level.

Maximum signal amplitude exceeding 15 % full screen height at reference level shall be evaluated.

A.5.2 Angle shear wave

Indications presenting maximum signal amplitude greater than or equal to the evaluation level defined in ISO 11666 shall be evaluated in accordance with ISO 17640.

In addition, any indications in the base material or welds (including HAZ regions) shall be monitored and characterized at the end of the test.

A.6 Acceptance and recording standards

A report detailing all indications having a response in excess of the recording level defined in ISO 11666 shall be produced in accordance with ISO 17640.

A.7 Reporting

The examination report shall contain at least the information specified in ISO 16810 and ISO 17640.

Any deviations from this procedure shall be recorded in the test report.

Annex B
(normative)

Strain gauge installation

B.1 General

This annex incorporates a strain gauging technique as a means of loading full ring specimens. The limitation is the access to the bore surface in the case of small diameter pipes.

NOTE Guidance on the selection, installation and checking of bonded resistance strain gauges is given in ASTM E1237.

B.2 Ring specimens

Neglecting ring diameters; specimens fall into 8 categories which shall be designated as:

a) seamless specimens;

b) specimens containing a longitudinal weld seam only;

c) specimens containing a helical weld seam only;

d) specimens containing a girth weld seam only;

e) specimens having either longitudinal or helical weld seams connected by a girth weld seam, wall thicknesses either side of the girth weld seam being equal;

f) as in e) but with wall thicknesses either side of the girth weld seam being unequal;

g) seamless specimens girth welded to specimens containing a longitudinal weld seam, wall thickness either side of the girth weld being equal;

h) as in g) but with wall thicknesses either side of the girth weld seam being unequal.

Each of these cases shall be treated separately with regard not just to strain gauging but also the mode of loading.

B.3 Surface preparation of ring specimens

Persons responsible for conducting surface processes on any ring subject to subsequent strain gauge testing shall ensure that all products used in such processes are free from silicone compounds.

All areas intended for subsequent strain gauge application shall be thoroughly degreased using Propan-2-ol or similar degreasing agent.

Gauge positions shall initially be marked out, for example using French chalk, with the markings extending approximately 100 mm beyond the gauge position in all directions.

An area approximately (25 x 25) mm centred on each gauge position shall be lightly ground using a P180 / P220 grade (ANSI 180 / 240 grit) wheel and then hand polished using P360 / P800 grade (ANSI 320 / 400 grit). This polishing shall be conducted using an orbital motion and light pressure to eliminate linear stress raisers and to minimize residual stresses.

Where ground areas encroach on weld seams, it shall be ensured that the grinding and polishing extends across the toe of the weld and on to the weld metal.

Each gauge position shall then be finally marked and the positions additionally treated in the manner described by the gauge manufacturer.

B.4 Strain gauges

Strain gauges of the adhesively bonded electrical foil type shall be used. Such gauges shall be of a minimum of 350 Ω nominal resistance and shall have nominal gauge lengths of 1 mm for outer ring diameters of 150 mm or less and 2 mm for ring diameters greater than 150 mm.

NOTE 1 Other strain gauge lengths can be used where specified by the customer.

The following types of gauge are recommended:

a) T gauge (also called biaxial or 90° stacked rosette);

b) 45° stacked rosette.

The strain gauges shall be self-temperature compensated appropriate to the ring test material and shall have stability within the range −10 °C to +30 °C.

Strain gauges shall be applied with one element orientated in the circumferential axis of the ring specimen.

The centres of gauge grids shall normally be positioned at a nominal distance of 3 mm to 5 mm from the toe positions of any welds seams where encountered.

B.5 Strain gauge adhesives

The adhesive used in strain gauge boding shall be compatible with the applied strain gauges and capable of maintaining a satisfactory bond up to strain levels of 2 % (20 000 με).

NOTE A cyano-acrylate adhesive with suitable strain capacity has been found to provide the easiest option for gauge bonding.

B.6 Strain gauge wiring

Each strain gauge shall be monitored in quarter bridge configuration by a 3 wire or 4 wire method. If using a 3 wire method, then correction to the strain gauge readings shall be applied if the resistance of a single lead wire exceeds 0,5 % of the gauge resistance. All gauge connection wires shall be of the same material and of similar length.

Principal output wiring shall be connected to composite gauge wiring via suitable tab terminals.

Solders utilized shall be compatible with the applied strain gauges. All soldering shall be free of solder spikes and cold joints and be cleared of any residual flux on completion.

B.7 Post installation verification

Following installation, each strain gauge shall be inspected and verified as described in the manufacturer's data sheet and ASTM E1237.

B.8 Strain gauge data acquisition

After acceptance of strain gauge installation tests, the fitted gauges shall be connected to a calibrated strain gauge test instrument with a measurement resolution of ±1 με.

B.9 Potential sources of loading errors

There are a number of factors that can introduce errors into the loading system including the following:

a) misalignment of the loading blocks along the 90°/270° longitudinal axes of the ring specimen;

b) misalignment of the turnbuckle across the centre line of the girth weld where present;

c) off-centre guide cups in the loading blocks for location of the turnbuckle screw heads;

d) the loading blocks should be radiused to match the ring internal diameter to reduce the tendency for blocks to dig into the ring wall and thereby redistribute the overall stresses over the test period;

e) where internal ring wall mismatch occurs, it is essential to produce accurate shimming between the ring wall and loading blocks to prevent redistribution of stresses with time as in d);

f) misalignment of strain gauges in respect to the ring longitudinal and circumferential axes;

g) use of incorrect instrument gauge factor settings and the gauge factors of the strain gauges used; this includes the use of strain gauges where the gauge factor is only quoted as 'nominal' and it is recommended that such gauges are not used in full ring testing;

h) not allowing sufficient time for settlement of load following loading.

B.10 Strain gauge positions on full ring specimens (internal)

B.10.1 General

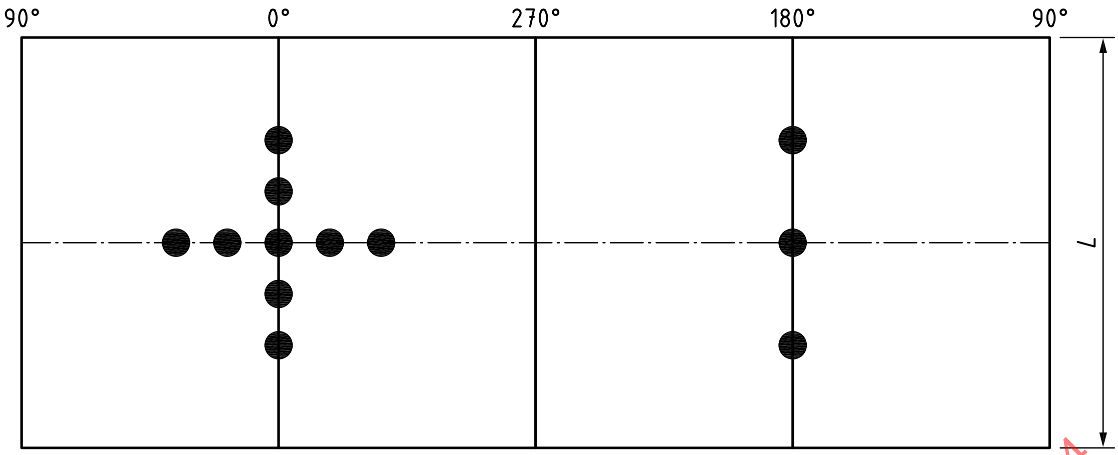
Eight forms of ring specimen are described in this clause. The minimum number of gauges which shall be used to achieve the required loading are specified. The positions of strain gauges should be recorded and numbered in the test report.

When specified by the customer other strain gauge positions may be used. This shall be recorded in the test report.

NOTE Additional strain gauges can be applied to the external surface to monitor stress-strain state during the test.

B.10.2 Seamless specimens

Biaxial gauges shall be located as shown in Figure B.1, along the central circumference of the ring as well as longitudinally at the 0° and 180° positions. Gauges at these locations allow a more complete assessment of applied stress variation radially and applied stress consistency longitudinally in the ring.



Key

● T gauge

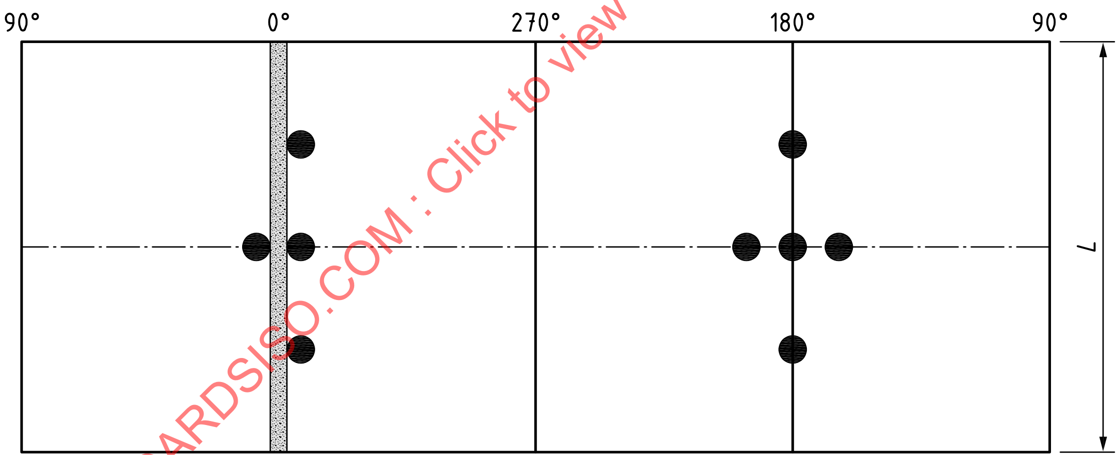
L length of pipe specimen

NOTE See 9.2.3.4

Figure B.1 — Gauge positions for seamless ring specimens (expanded view of internal surface)

B.11 Longitudinal weld seam specimens

T gauges shall be positioned as shown in Figure B.2, on the central circumference of the ring.



Key

● T gauge

L length of pipe specimen

NOTE See 9.2.3.4.

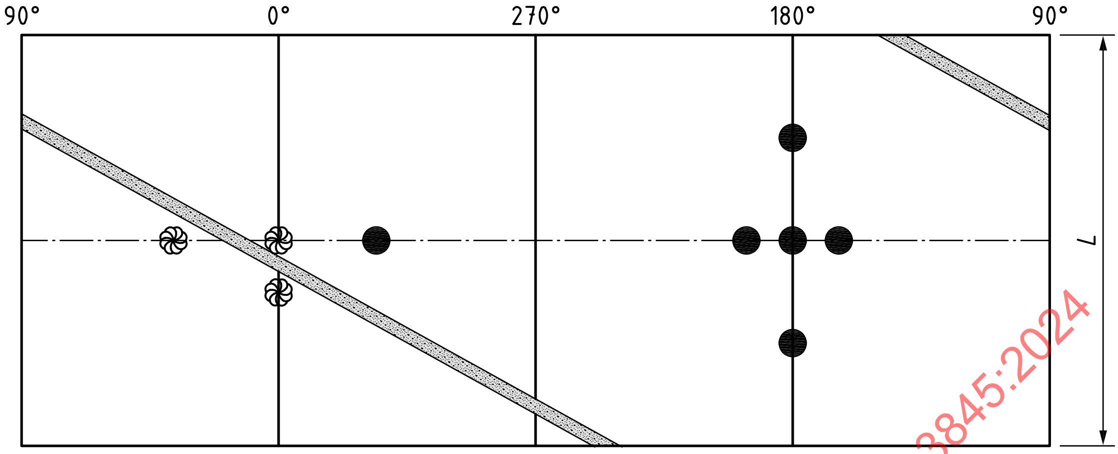
Figure B.2 — Gauge positions for ring specimens that contain only a longitudinal seam weld

NOTE In this form of ring specimen, gauges are again located in the central circumferential axis.

The alignment of the target maximum stress (0°) shall lie immediately to one side of the longitudinal seam toe of weld.

B.12 Helical weld seam specimens

Ring specimens of the helical form might still be encountered and here a combination of T gauge and 45° stacked rosette type gauges shall be used as shown in Figure B.3.



Key

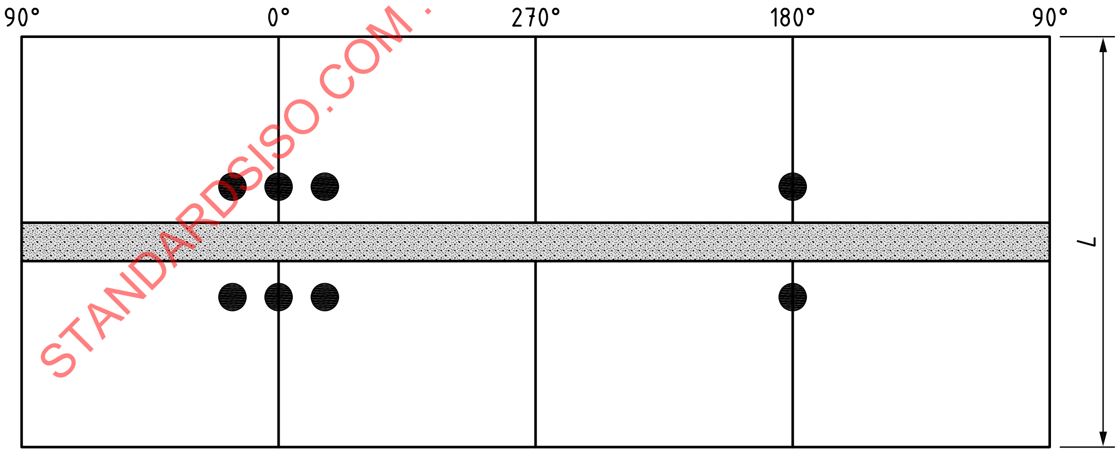
- ● T gauge
- 45° stacked rosette gauge
- *L* length of pipe specimen

NOTE See 9.2.3.4.

Figure B.3 — Gauge positions on specimens having a helical weld seam only

B.13 Girth weld seam specimens

For seamless specimens containing a girth weld, T gauges shall be used at positions shown in Figure B.4.



Key

- ● T gauge
- *L* length of pipe specimen

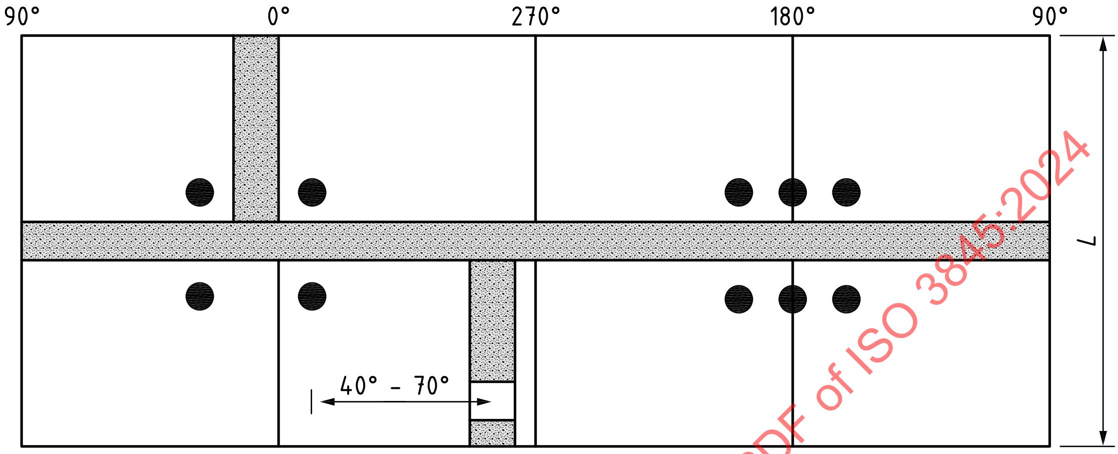
NOTE See 9.2.3.4.

Figure B.4 — Gauge positions for ring specimens that contain only a girth weld seam

B.14 Girth weld specimens combined with longitudinal or helical welds – all plates of identical wall thickness

This form of ring specimen has a wide variety of geometries as shown in Figure B.5, Figure B.6, Figure B.7 and Figure B.8. In general, the longitudinal weld seams can be displaced by between 30° and 180°.

In some cases, the secondary weld seam might come into contact with one of the loading beams. In such cases it is necessary to grind back the weld cap of the longitudinal weld seam flush with the internal ring surface.



Key

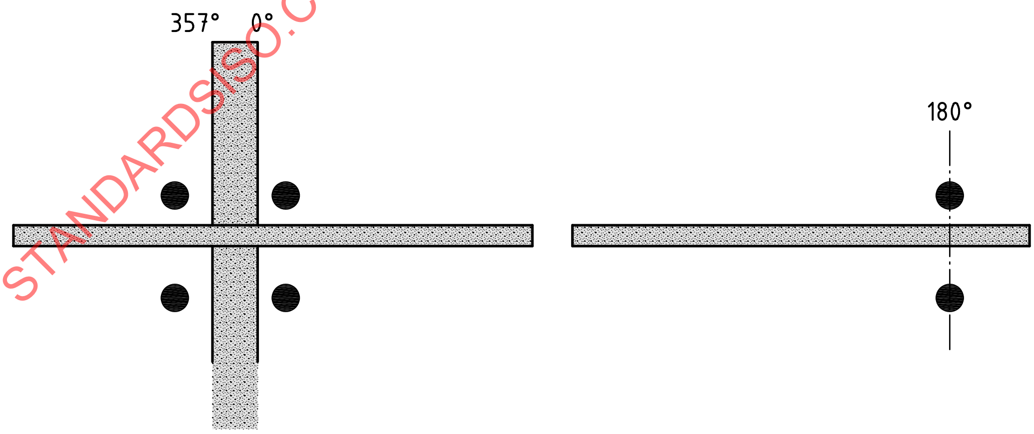
● T gauge

L length of pipe specimen

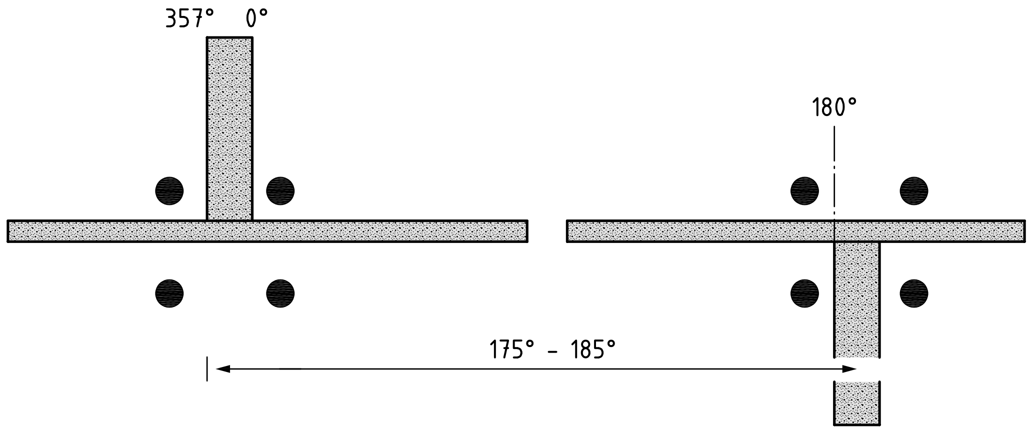
NOTE See 9.2.3.4.

Figure B.5 — Gauge positions for ring specimens that contain both circumferential and longitudinal weld seams and have an angular gap of between 5° and 175° between longitudinal seams

If the angular gap between longitudinal weld seams is 0° to 5° or 175° to 185°, then additional gauging in the target zone (and about 180°) shall be provided as shown in Figure B.6.



a) Modified gauge positions for ring specimens that contain both circumferential and longitudinal weld seams and have an angular off-set of <±5° between longitudinal weld seams



b) Modified gauge positions for ring specimens that contain both circumferential and longitudinal weld seams and have an angular off-set of 175° to 185° between longitudinal weld seams

Key

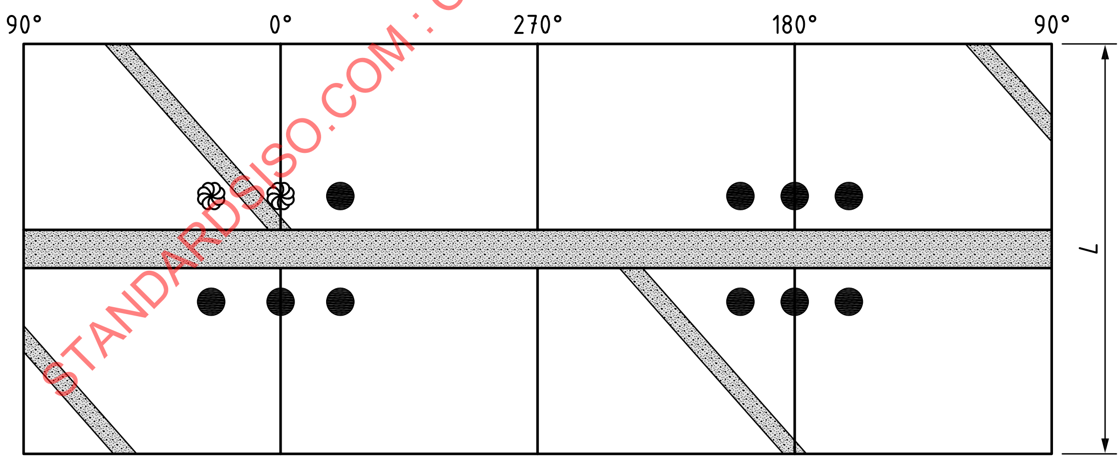
● T gauge

Figure B.6 — Modified gauge positions for ring specimens that contain both circumferential and longitudinal weld seams

B.15 Girth weld specimens combined with longitudinal helical welds

NOTE Occasionally, risers and similar sections come under test and, in such cases, the thickness of ring sections either side of the girth weld seam can vary considerably. In most cases with this form of girth juncture, the ring wall thickness difference is taken upon the internal bore diameter. Hence the internal ring wall is stepped. In some cases, this step is unequal, which gives rise to different widths of gap behind the loading blocks at the larger inside diameter ring.

Packer shims of correct thickness shall be produced for behind each loading block to ensure an even distribution of load throughout the ring assembly.



Key

● T gauge

45° stacked rosette gauge

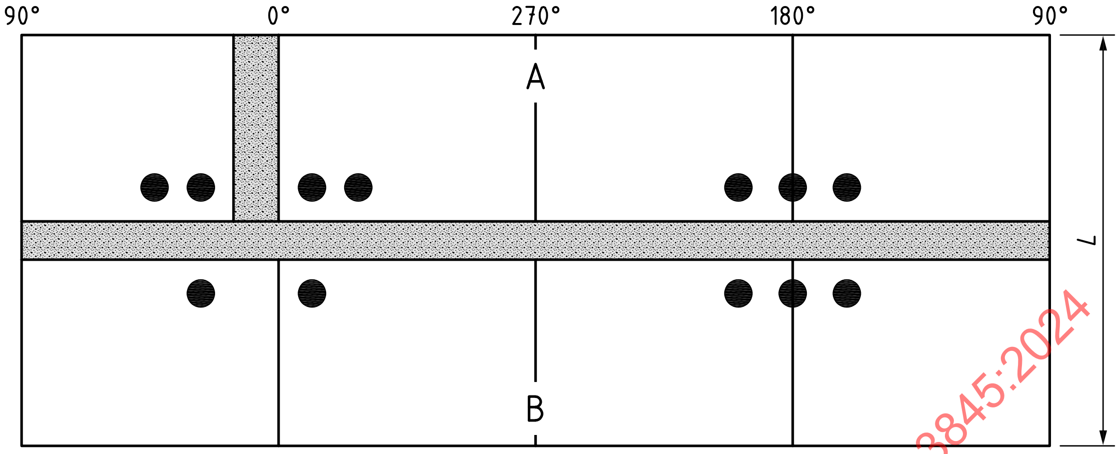
L length of pipe specimen

NOTE See 9.2.3.4.

Figure B.7 — Gauge positions for specimens having helically wound weld seams combined with a girth weld

B.16 Seamless rings combined with longitudinal weld specimens

For seamless rings combined with longitudinal weld specimens, gauges shall be placed as shown in Figure B.8.



Key

● T gauge

L length of pipe specimen

Figure B.8 — Gauge positions for ring specimens that contain both circumferential and longitudinal weld seams

Annex C
(normative)

Analysis of test solution – Iodometric titration procedure

C.1 Principle

A portion of the test solution containing the dissolved hydrogen sulfide and soluble sulfides is added to an excess of 0,1 N / 0,01 N iodine solution, acidified by HCl and the excess iodine is titrated with 0,1 N / 0,01 N sodium thiosulphate.

C.2 Reactions

$$H_2S + I_2 = 2HI + S$$

C.3 Reagents and materials

Analytical grade reagents shall be used.

C.3.1 Standard 0,1 N iodine solution, 0,099 5 N to 0,100 5 N, or Standard 0,01 N iodine solution, 0,099 5 to 0,100 5 N, certified by the manufacturer.

C.3.2 Concentrated HCl, approximately 37 % mass fraction.

C.3.3 Standard 0,1 N sodium thiosulfate solution, 0,099 5 to 0,100 5 N, or Standard 0,01 N sodium thiosulfate solution, 0,099 5 to 0,100 5 N, certified by the manufacturer.

C.3.4 Starch solution, approximately 1 % mass fraction.

C.4 Apparatus

The following shall conform to the requirements of ISO 4787:

C.4.1 10 ml and 25 ml volumetric pipettes.

C.4.2 50 ml and 100 ml volumetric flasks.

C.4.3 250 ml conical (Erlenmeyer) flask.

C.4.4 100 ml beaker.

C.4.5 25 ml burette.

C.4.6 50 ml syringe graduated to 60 ml.

C.5 Sampling

An aliquot of H_2S containing solution is taken from the test cell, see Table C.1.

Table C.1 — Titration parameters for determination of the test solution H_2S concentration

pH_2S kPa	cH_2S mg/l	Test solution sample volume ml	Iodine / $Na_2S_2O_3$ concentration N
40 to 100	920 to 2 300	10	0,1
16 to 40	370 to 920	25	0,1
8,0 to 20	185 to 460	50	0,1
4,0 to 10	92 to 230	100	0,1
1,6 to 4,0	37 to 92	25	0,01
0,8 to 2,0	18 to 46	50	0,01
< 1,0	< 23	100	0,01

C.6 Procedure

Pipette 25 ml of the selected (0,1 N or 0,01 N) standard iodine solution (C.3.1) into a conical flask.

Acidify with a few drops of concentrated HCl (C.3.2). If sampling using a syringe weigh the conical flask containing the acidified iodine solution and record the result.

When sampling using a volumetric pipette, transfer an initial 25 ml to 50 ml of test solution from the test vessel into a clean beaker. Rinse the beaker with the test solution and discard. Transfer a further 50 ml to 100 ml of test solution to the beaker. Fill the pipette from the beaker, rinse with the test solution and discard. Accurately measure the required volume of test solution from the beaker via the pipette, and immediately transfer to the conical flask containing the acidified iodine solution. Record the volume of test solution transferred.

When sampling using a volumetric flask, transfer an initial 25 ml to 50 ml of test solution from the test vessel into the flask. Rinse the flask with the test solution and discard. Measure the required volume sufficient test solution to fill the flask to the required volume and immediately transfer to the conical flask containing the acidified iodine solution. Record the volume of test solution transferred.

When sampling using a syringe, extract an initial 25 ml to 50 ml of test solution from the test vessel. Rinse the syringe with the test solution and discard. Refer to the graduations on the syringe to measure the volume of test solution required and transfer directly to the pre-weighed conical flask containing the acidified iodine solution. Re-weigh the conical flask and record the result. Determine the exact volume of test solution transferred.

Titrate with the selected (0,1 N or 0,01 N) standard sodium thiosulfate solution (C.3.3) until the solution changes colour from dark yellow/tan to pale straw colour.

Add a few drops of the starch solution (C.3.4).

The starch addition should be made near the end point of the titration when most of the iodine has been removed and the colour of the solution starts to fade.

Continue to titrate slowly with the selected (0,1 N or 0,01 N) standard sodium thiosulfate solution until the dark grey/blue colour disappears, and the end point is reached. The end point is a milky yellow suspension of colloidal sulfur. Record the total volume of standard sodium thiosulfate solution used.

C.7 Calculation

Calculate the H_2S concentration, c, in mg/l using Formula (C.1):

$$c = \frac{(A - B)}{v} \text{ x } 17\,040 \quad \text{(C.1)}$$

where

A is the normality of standard iodine solution (equivalents per litre) times the volume used in ml;

B is the normality of standard sodium thiosulfate solution (equivalents per litre) times the volume used in ml;

v is the volume of test solution sample in in ml.

and

17 040 is a constant calculated as follows:

$$\frac{34{,}08 \times 1\,000}{2} \equiv 17\,040$$

where

34,08 is in g/mole H_2S;

1 000 is in mg/g;

2 is in equivalents per mole H_2S.

C.8 Precision

No precision data is currently available.

C.9 Test report

The H_2S concentration, c, in mg/l calculated using Formula (C.1) shall be included in the test report, see Clause 10.

Annex D
(informative)

Summary of the full ring test procedure

The test method is summarized in a series of steps as listed in Table D.1, together with Figure D.1 to Figure D.8.

Table D.1 — Summary of the full ring test procedure

Step	Description	Clause	Figure number
1	Carry out pre-test ultrasonic and Magnetic particle testing/penetrant testing	8.2, 8.3	
2	Machine sample to specified length and to provide clean flat surfaces	9.2.1	D.1
3	Prepare surface	9.2.2	D.1
4	Apply strain gauges to inside surface	9.2.3.3	D.2
5	Apply internal or external load	9.2.3.6	D.3a or D.3b
6	Convert specimen ring into test cell	9.3	D.4
7	Place test specimen in the test cell in a safety enclosure or restricted area	9.3	
8	Affix hydrogen permeation cells (optional)	9.6.3	
9	Purge specimen ring and sparge solution with inert gas	9.5	
10	Fill specimen ring with deaerated solution	9.5	
11	Charge with test gas, monitor pH and H_2S level	9.5	
12	Monitor test solution	9.6.1	
13	Carry out ultrasonic testing at a frequency of (7 ± 2) days (only for internally loaded rings)	9.6.3	D.5
14	After 30 days, drain specimen ring and unload	9.7	D.6
15	Carry out final ultrasonic testing	9.9.2.1	D.7
16	Carry out final magnetic particle testing/penetrant testing	9.9.2.2	
17	Carry out metallographic examination.	9.9.3	
18	Produce hydrogen permeation data (optional)	9.6.2	D.8

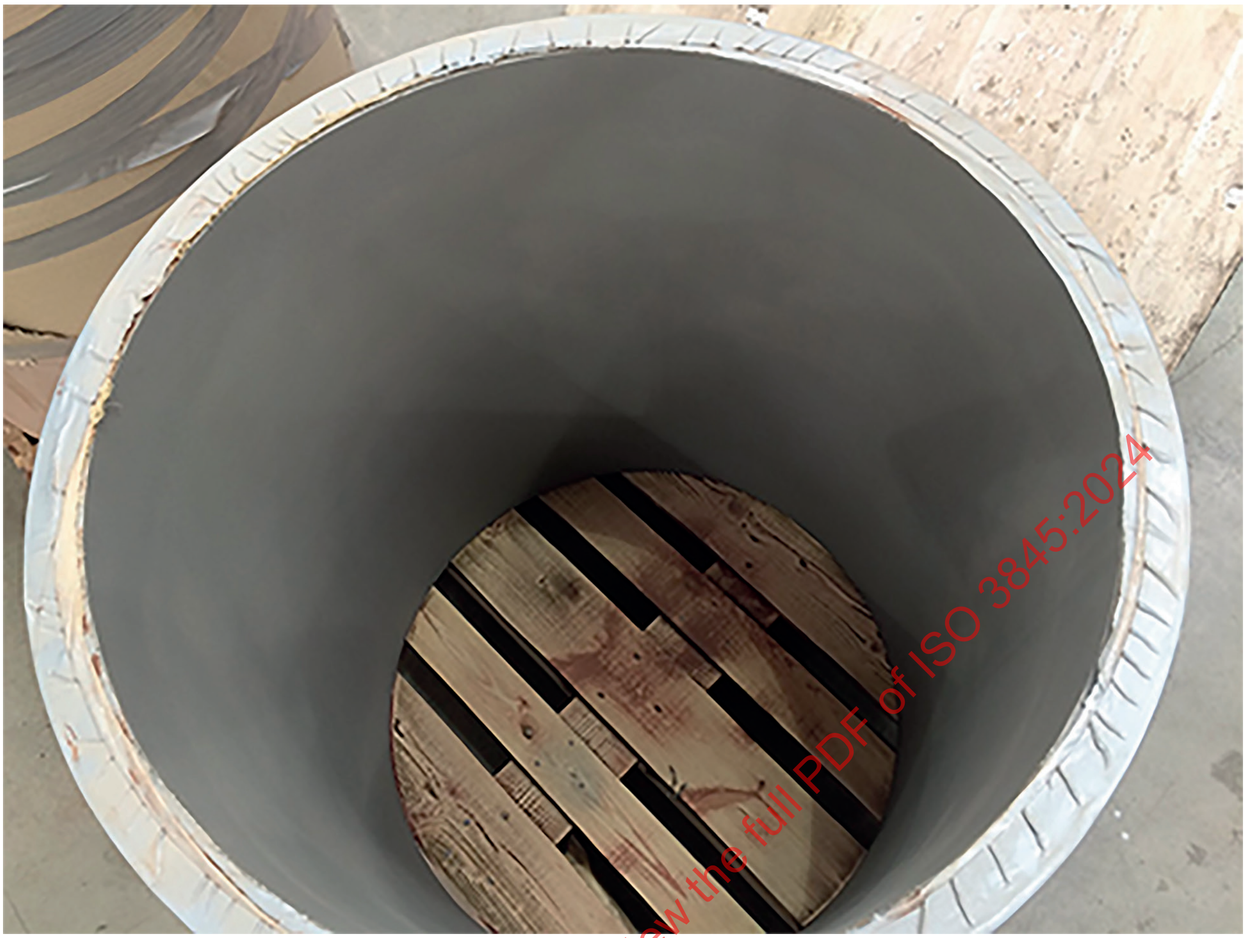
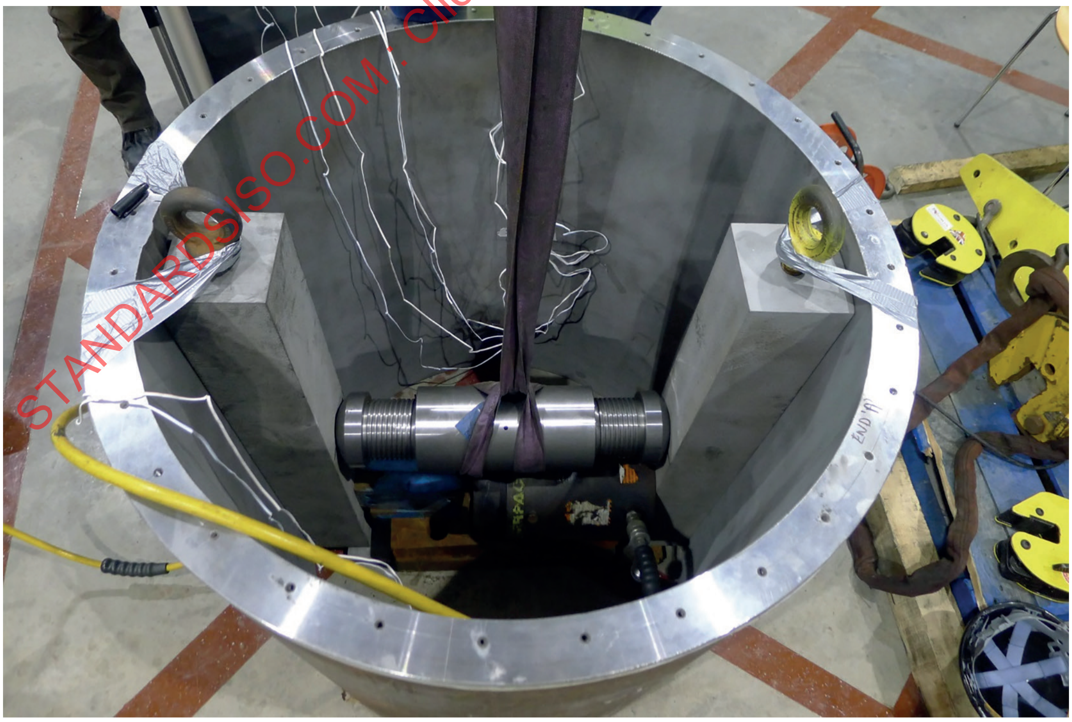


Figure D.1 — Ring machined and grit blasted

Figure D.2 — Ring strain gauged



a) Application of internal load