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Full ring ovalization test for determining the susceptibility to cracking of linepipe steels in sour service – Test method

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 48, an inside back cover and a back cover.

Foreword

Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 30 June 2016. It was prepared by Technical Committee PSE/17, *Materials and equipment for petroleum, petrochemical and natural gas industries*. A list of organizations represented on this committee can be obtained on request to its secretary.

Use of this document

It has been assumed in the preparation of this British Standard that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

Presentational conventions

The provisions of this standard are presented in roman (i.e. upright) type. Its methods are expressed as a set of instructions, a description, or in sentences in which the principal auxiliary verb is "shall".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Where words have alternative spellings, the preferred spelling of the Shorter Oxford English Dictionary is used (e.g. "organization" rather than "organisation").

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

Introduction

Sour service cracking problems in susceptible pipeline steels are caused by the various forms of hydrogen damage due to the presence of wet hydrogen sulfide (H_2S). The main mechanisms are hydrogen pressure induced cracking (HPIC) [also called hydrogen induced cracking (HIC) or stepwise cracking (SWC)], sulfide stress corrosion (SSC) and stress oriented hydrogen induced cracking (SOHIC). An industry proven technique for assessing pipeline steels is to stress a full ring specimen in a sour environment.

The advantage of the full ring test specified in this British Standard is that it is not necessary to pressurize the linepipe full ring specimen to achieve the required stress loading and residual stresses are retained. Equivalent stresses can be produced using mechanical means to deform the pipe by ovalization. Additional advantages are representative sample and single sided exposure.

This test uses well tried experimental procedures to exert a known stress level at two regions on a full ring section of pipe steel. The pipe specimen is then exposed internally to the sour test solution, although some cases require the sour media externally. Ultrasonic monitoring and hydrogen permeation measurements are conducted regularly during the exposure period. Both crack initiation and propagation can therefore be monitored. Finally, a metallographic study of indications is undertaken to classify any defects found by the ultrasonic survey.

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 pipeline steels, 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 forms the basis of this British Standard.

1 Scope

This British Standard gives a method for determining the susceptibility to cracking of steel pipes in sour service.

This British Standard utilizes a tubular specimen comprising a full circumferential ring. The test method applies to any pipe with or without seam (longitudinal or spiral) or girth weld (with or without filler).

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.

This British Standard provides guidance on determination of specimen size to ensure it retains residual stresses from manufacture and welding.

NOTE 2 See Clause 7 for specimen sizes.

The method utilizes ovalization to simulate hoop stress, using mechanical loading on a tubular form. The specimen is subjected to single sided exposure to the sour test environment.

NOTE 3 The test also allows measurement of hydrogen permeation rates which can provide useful information, such as highlighting the effects of galvanic coupling between materials of apparent compatibility.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN 12668 (all parts), *Non-destructive testing – Characterization and verification of ultrasonic examination equipment*

BS EN ISO 2400, *Non-destructive testing – Ultrasonic testing – Specification for calibration block No.1*

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

BS EN ISO 8044, *Corrosion of metals and alloys – Basic terms and definitions*

BS EN ISO 9712, *Non-destructive testing – Qualification and certification of NDT personnel*

BS EN ISO 11666, *Non-destructive testing of welds – Ultrasonic testing – Acceptance levels*

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

BS EN ISO 17640, *Non-destructive testing of welds – Ultrasonic testing – Techniques, testing levels, and assessment*

ASTM D1193, *Standard Specification for Reagent Water*

Other publications

[N1]NACE TM0177, *Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking in H₂S Environments*. NACE International, PO Box 218340, Houston, TX. 77218.

3 Terms and definitions

For the purposes of this British Standard, the terms and definitions given in BS EN ISO 8044 and the following apply.

3.1 ancillary components

parts of the apparatus necessary for the test which are not the loading components to impart stress

3.2 anodic

reaction involving an oxidation process and conjoint generation of electrons

3.3 cathodic

reaction involving a reduction process with conjoint consumption of electrons

3.4 free corrosion potential

naturally occurring electrode potential measured against a standard reference adopted by a metal undergoing corrosion in an aqueous environment

3.5 galvanic coupling

electrical contact between two or more materials which exhibit different free corrosion potentials within the same electrolyte, resulting in a combined mixed potential and an increased oxidation rate on the anodic material driven by the more noble material, determined by the relative areas and governed by efficiency of the cathodic reduction

- 3.6 girth weld**
butt weld joining one pipe to another (or bend or flange)
- 3.7 hardness**
resistance of metal to plastic deformation, usually determined by indentation
- 3.8 heat affected zone (HAZ)**
portion of base metal not melted during brazing, cutting or welding, but whose microstructure and properties are altered by the thermal cycle of these processes
- 3.9 hydrogen embrittlement**
action of absorbed atomic hydrogen to cause loss of ductility in a metal
NOTE Hydrogen atoms are attracted to grain boundaries and slip plane movement is reduced.
- 3.10 hydrogen flux**
rate of hydrogen flow per unit area through a material
- 3.11 hydrogen pressure induced cracking (HPIC)**
cracking caused by atoms of hydrogen concentrating at discontinuities and forming molecular hydrogen within the steel
NOTE 1 The resultant gas pressure induces cracking.
NOTE 2 This is also called hydrogen induced cracking (HIC), stepwise cracking and blister cracking (HIBC).
- 3.12 hydrogen permeation**
process of atomic hydrogen diffusion through a metal
- 3.13 longitudinal weld**
straight weld running along the longitudinal axis of a pipe
- 3.14 low alloy steel**
steel with a total alloying element content of less than approximately 5% but more than specified for carbon steel
- 3.15 measured strain**
 E_1, E_2, E_3
surface strain as measured by various techniques in one or more of three known directions at the surface
- 3.16 microstructure**
crystalline structure of a metal as revealed by the microscopic examination of a suitably prepared specimen
- 3.17 stress**
applied force per unit area existing on any object as a result of external mechanical or thermal influences acting in that direction
- 3.18 partial pressure**
total pressure multiplied by its mole fraction equal to each component in a gas mixture
NOTE For an ideal gas, the mole fraction is equal to the volume fraction of the component.
- 3.19 plastic deformation**
permanent deformation caused by straining beyond the elastic limit

- 3.20 Poisson effect**
component subjected to loading in one direction causing extension or compression in that direction, experiencing tangentially a lesser opposing compression or expansion
- 3.21 Poisson's ratio**
 ν
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
- 3.22 principal strain**
 $E_{x,y}$
maximum and minimum strain levels existing at a point on the test surface acting at 90° to each other as calculated from measured strain values
- 3.23 residual stress**
 δ_{res}
stress present in a component free of external forces or thermal gradients
- 3.24 stress oriented hydrogen induced cracking (SOHIC)**
staggered small cracks formed approximately perpendicular to the principal stress (residual or applied) resulting in a "ladder-like" crack array linking (sometimes small) pre-existing HIC cracks
- 3.25 sour environment**
environment where hydrogen sulfide exists in the presence of water
NOTE For steel products a threshold concentration is usually applied.
- 3.26 spiral weld**
weld running spirally (helically) around the circumference of a pipe formed from strip
- 3.27 strain**
 E
dimensionless ratio of the change in length per unit length (e.g. mm/mm) and is normally expressed in parts per million ($E \times 10^6$) of microstrain ($\mu\epsilon$)
- 3.28 specified minimum yield strength (SMYS)**
relates to the minimum yield strength permitted for a given grade of material in product specifications
- 3.29 strain gauge**
device using electrical resistance, which changes in proportion to applied strain
- 3.30 sulfide stress cracking**
brittle failure by cracking under the combined action of tensile stress and corrosion in the presence of water and hydrogen sulfide
- 3.31 tensile strength**
in tensile testing the ratio of maximum load to original cross-sectional area
- 3.32 tensile stress**
net tensile component of all combined stresses

NOTE These stresses include axial or longitudinal, circumferential or hoop and residual.

3.33 ultrasonic inspection

inspection of material by ultrasound for the presence of flaws

3.34 welding

joining of two metallic materials, usually by fusion techniques

3.35 yield strength

stress at which a material exhibits a specified deviation from the proportionality of stress to strain

NOTE The deviation is expressed in terms of strain either by the offset method (usually at a strain of 0.2%) or the total-extension-under-load method (usually at a strain of 0.5%) (see ASTM A370).

3.36 Young's modulus of elasticity

relationship between stress and strain within the limits of elastic behaviour expressed as

$$E = \frac{\delta}{\varepsilon} \text{ where:}$$

δ is stress;

ε is strain.

4 Principle

A full ring section of material of a tubular form shall be mechanically loaded to a predetermined strain by ovalization and exposed to an agreed sour environment. Testing shall be undertaken within an enclosure or in a restricted area.

The specimen shall be monitored throughout the test exposure to determine the extent of development of environmentally assisted cracking, and then subjected to post-test destructive examination.

5 Reagents

5.1 A solution made using water type IV in accordance with ASTM D1193, or purer shall be used.

5.2 Inert gas shall be used for removal of oxygen. Inert gas shall mean high purity (99.5% or higher) nitrogen, argon, or other suitable nonreactive gas.

5.3 Reagents with high purity of 99.5% or higher shall be used.

5.4 Test solutions and gases

The composition and preparation of solutions shall be carried out in accordance with Annex D.

NOTE Three test solutions may be used with this method:

- NACE TM0177 [N1] Solution A; The initial pH is between 2.7 and 2.9 rising to approximately 4 by the end of the 30 day test period;*
- NACE TM0177 [N1] Solution A buffered to maintain pH 3.2 by addition of acetic acid/sodium acetate;*
- field specific test solution.*

6 Apparatus

6.1 Containment materials

6.1.1 Lid and base

Lid and base shall be made of either:

- a) polymethylmethacrylate (also known as acrylic) of appropriate thickness to avoid deformation with surfaces pre-treated with 50% acetic acid solution, or;
- b) other material that has been proven not to affect the test solution or be degraded by the test environment.

The materials and thickness used shall be demonstrated to restrict permeation of H_2S to the atmosphere and O_2 contamination of the test environment.

NOTE This should be assessed using a lid and base of the same surface area to volume ratio as used in the test.

6.1.2 Seal rings

Seal rings shall be made of natural rubber or other material that has been proven not to affect the test solution, be degraded by the test environment, or allow permeation of H_2S to the atmosphere or O_2 contamination of the test environment.

6.2 Internal loading components

6.2.1 Turnbuckle for internal loading

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

NOTE 1 Ballistic threading is recommended.

NOTE 2 Austenitic stainless steel has been found to be reusable and has not led to detrimental galvanic effects.

6.2.2 Load blocks

Load blocks shall consist of a galvanically compatible material to that of the internal surface of the specimen. The load distribution blocks shall be sufficiently rigid to ensure that the load is evenly distributed without the blocks bending.

6.3 External loading components

External loading blocks shall be sufficiently rigid to ensure that the load is evenly distributed without the blocks bending.

6.4 Ancillary components

Ancillary components in contact with or exposed to the test environment, such as thermowells, shall be compatible with the test solution and not degrade or affect the solution.

NOTE This may be assessed by visually examining the component or more simply by selecting corrosion resistant alloys suitable for H_2S exposure (see BS EN ISO 15156-3).

7 Samples

The sample(s) shall be typical of the as delivered product and any weld shall be made using an appropriate welding procedure per client requirements.

NOTE 1 Additional material is required to provide the tensile specimens for data to support test configuration.

Test samples that contain a full girth weld shall have the weld positioned at the mid-length of the test piece. To retain the residual stress produced during manufacture and welding, the length of the test pipe shall be equal to, or greater than, the diameter.

If the test piece is to contain 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 2 9.2.2 provides guidance on the alignment of seam welds, repair welds, etc. to optimize the data generated per test specimen.

The ends of the test piece shall be machined to provide clean, flat surfaces so that these can be later sealed to form a gas tight fit.

8 Surface preparation

8.1 Surface preparation for carbon steel

Unless otherwise directed by the client, the internal surface preparation by grit blasting to Sa 2½ using Garnet (20-40 mesh) shall be undertaken using new grit. The grit shall not be recycled.

NOTE Other surface finishes including as-received may be used by agreement with the client.

To avoid flash rusting of the cleaned surface, after completion of grit blasting or other surface preparation, the ring specimen shall be loaded and sealed as soon as possible or stored in a dry atmosphere.

8.2 Surface preparation for corrosion-resistant alloys

Unless otherwise directed by the client, the internal surface shall be degreased but otherwise not abraded.

9 Procedure for test specimens with internal loading

9.1 Ultrasonic inspection

Prior to the section being prepared for test, the external surface shall be 100% inspected using the ultrasonic test procedure detailed in Annex A. The section shall be inspected using a compression probe and shear probes of angles 45°, 60° and 70°. All indications shall be recorded. This technique is very sensitive and the evidence of pre-test indications shall not be taken as indicative of problems.

NOTE The purpose of this inspection is to provide a “fingerprint” which will enable a quantitative comparison to be made with later inspections and to avoid failing a specimen by considering pre-existing indications to have been produced during the test.

The couplant used for the ultrasonic inspection shall be silicone-free because silicone compounds/greases are very detrimental to strain gauge adhesion and can cause errors in load monitoring (see A.3.2.7).

9.2 Sample loading

9.2.1 Strain gauge locations

The ring sample shall be loaded by mechanical jacking as illustrated in Figure 1 and Figure 2. To monitor the load and determine the stress during application of the load, strain gauges shall be attached to the internal surface, (see Annex B). The position of these gauges shall be determined according to 9.2.2 and 9.2.3.

Figure 1 Full ring test using internal loading techniques

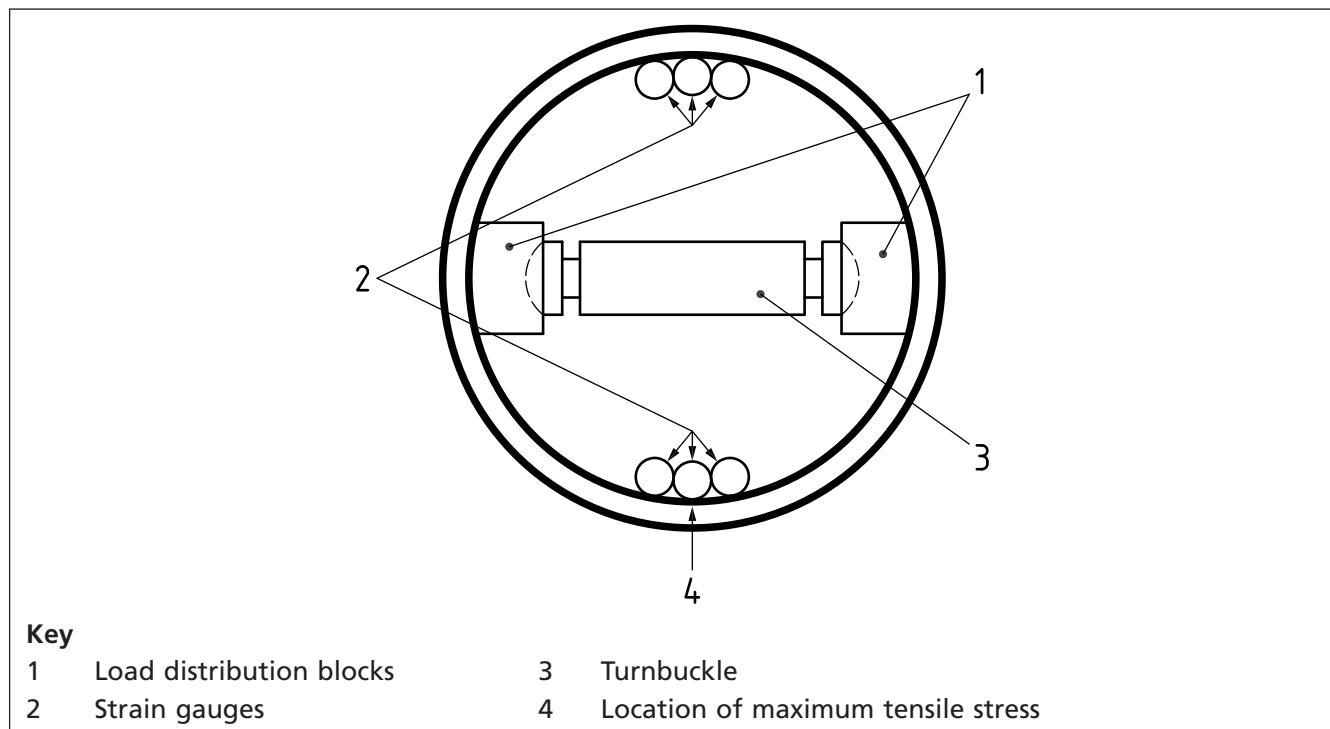
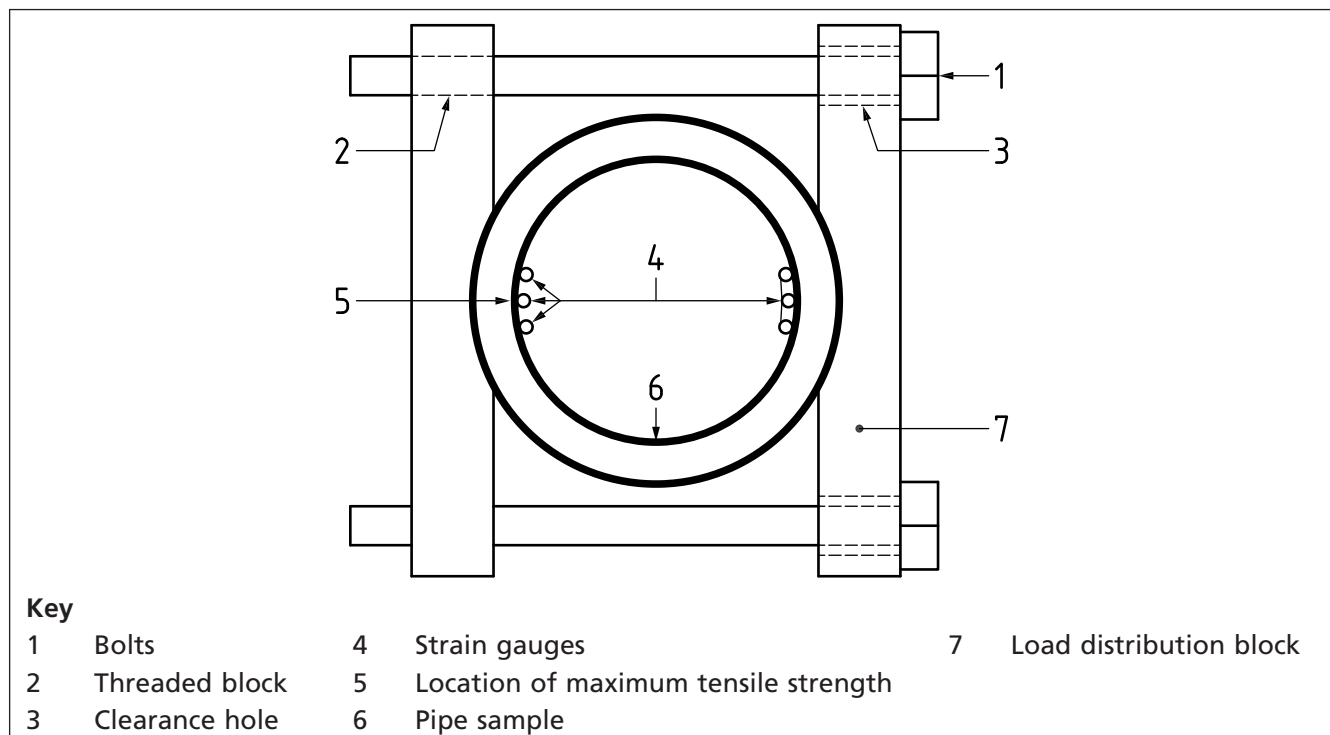


Figure 2 Modified full ring test using external loading technique



9.2.2 Position of maximum load

Prior to application of strain gauges and actually loading the sample, the two positions of maximum applied stress shall be selected. The following two criteria shall be used:

- a) the area adjacent to the seam weld (if present) shall be at maximum stress; or
- b) any ultrasonic indications found in the girth weld or weld repair shall be at the position of maximum stress.

NOTE 1 It is therefore useful to consider these points prior to producing the test piece 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.

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 positioned at the location of maximum stress. This is warranted if the two sections are in some way different. If the sections are identical, a standard approximately 30° spacing should be made.

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

9.2.3 Strain gauging

The procedure for strain gauging shall be carried out in accordance with Annex B.

NOTE 1 The procedure covers eight categories of ring sample, from seamless pipe, spirally welded pipe to a girth welded sample of unequal wall thickness. In summary, strain gauges are attached at the positions of maximum stress, with other strain gauges positioned to monitor the stress distribution. It is essential that the requirements in Annex B are followed in order that inaccurate loading does not occur. In addition to single element gauges, several "T" gauges or biaxial gauges are used in order that compensation for the Poisson effect can be made.

NOTE 2 Annex B also contains an example format for reporting the strain gauging and loading data.

9.2.4 Loading levels

The loading to be adopted in testing shall be agreed with the user in advance.

NOTE Loading for the test specimen has typically reflected the stress induced under the design conditions, which is predicated upon the SMYS of the line pipe steel. During the latter part of the 20th Century, 72% SMYS was a common loading requirement, although with changes in pipeline design basis, 80% SMYS has become an increasingly common requirement in the 21st Century.

9.2.5 Loading technique

The loading shall be undertaken using a turnbuckle or external bolting arrangement and two load distribution blocks as shown in Figure 1 and Figure 2 respectively.

The face of the distribution block which fits against the ring section shall be profiled preferably to fit the ring section.

NOTE 1 A range of blocks is required if a number of different diameter pipes are to be tested.

Loading shall commence once the two loading blocks and turnbuckle/bolting are in position and the strain gauges are zeroed.

NOTE 2 For thin walled ring sections, the load can be applied manually by turning the centre section of the turnbuckle. For thicker sections, a hydraulic jack positioned under but as near to the turnbuckle as possible should be used. In the latter case, as the load is applied, the turnbuckle is tightened and locked when the required stress level is reached. The hydraulic jack is then released. It should be noted that when using a hydraulic jack, the stress level will drop slightly when the jack is released, a higher stress level might have to be attained before release so that the final relaxed stress level is as required. Care should be taken to avoid excessive load increases and small increments should be applied, e.g. 5%.

Once the load has been applied, data collected from all the strain gauges shall be recorded and converted into a stress value, usually expressed as % SMYS. The ring sample shall be left for a minimum of 30 min and monitored to ensure no relaxation or settling takes place. If this does occur, then the load shall be corrected. When the final level is 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.

9.3 Cell containment

The loaded ring sample 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:

- the materials used for the lids and seals shall not contaminate the test solution and extensive use of vulcanized rubber should be avoided (see 6.1.1);
- 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;
- the material shall be strong enough to withstand the small gas pressure above the liquid environment.

NOTE 1 The lid and base can be attached by drilling and tapping the ring sample and bolting the lids to the pipe.

NOTE 2 The lid can be easily drilled to provide sampling and access points, etc. In addition, the lid, being transparent, allows visual checking of solution levels, etc.

In addition the materials and seals shall ensure the test environment remains isolated from all personnel.

NOTE 3 H_2S is an extremely toxic gas and should be handled with care, see Annex G..

After the test section 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.

The test cell shall then be purged in accordance with 5.2 to protect the clean inner surface and to remove oxygen to a concentration of less than or equal to 50ppb (carbon and low alloy steels) or 10 ppb for corrosion resistant alloys prior to filling with the test solution.

9.4 Hydrogen permeation monitoring

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 shall be sufficient. For girth welded full rings of differing materials, two cells shall be required. All cells shall be fitted in areas of low applied stress as the presence of such cells inhibits ultrasonic inspection of these areas, required during test.

NOTE It is desirable, although not mandatory, that hydrogen permeation measurements should be made as the data are extremely valuable in test evaluation. There are several advantages of measuring the hydrogen flux:

- a comparison can be made with field data (if available) to confirm correct severity of test;
- a comparison can be made with existing data; and
- the effect of galvanic coupling on hydrogen permeation can be assessed for the two parent materials in a girth weld.

9.5 Test duration and solution monitoring

The full ring test duration shall be 30 days.

NOTE 1 If the test environment has been reduced in severity from options a) or b) in accordance with 5.4, extended test duration may be considered.

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

The H₂S concentration in solution shall be checked regularly and, for options a) and b), in accordance with 5.4 maintained at 2 300ppm or greater. The H₂S analysis is very important and should be carried out in accordance with Annex E. The analysis shall be undertaken daily until the recommended H₂S concentration is reached and every five days thereafter until completion of the test. All data shall be recorded. The pH shall be measured at the same time as the H₂S sampled.

The full ring test cell shall be controlled at a temperature of (24 ± 3)°C [(75 ± 4)°F] unless otherwise stipulated by the client. For lined and corrosion resistant alloys temperature shall be stipulated by the client.

9.6 Test commencement

The test environment shall be introduced after ultrasonic inspection, loading, sealing and purging with deaeration gas to meet the oxygen concentration requirements in accordance with 9.3.

Before filling with this solution, the test cell shall be checked for leaks. If the test cell is gas tight the prepared solution shall be transferred from the mixing tank to the test cell under a blanket of deaeration gas.

The test gas shall then be introduced into the cell. Continuous bubbling is required throughout the test duration using an open ended gas inlet.

Tube with a diameter of not less than 5 mm shall be used.

Fritted end tubes shall not be used as they are liable to blockage by corrosion product during testing.

The H₂S concentration in solution shall be measured in accordance with the procedure given in Annex E. When the H₂S concentration reaches or exceeds the target value in accordance with 9.5, the test shall be deemed to have commenced.

NOTE 1 This concentration should be reached within 24 h.

NOTE 2 H₂S is an extremely toxic gas and should be handled with care, see Annex G.

9.7 On-line monitoring

The following inspections shall be undertaken during the test exposure:

- ultrasonic inspection, reporting results every (7 ± 2) days, (see Annex A);

NOTE This inspection generally cannot be undertaken on small diameter pipes which have been externally clamped.

- analysis of H₂S concentration in solution and pH measurement every five days after the target has been attained;