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Corrosion of metals and alloys — Methodology for determining the resistance of metals to stress corrosion cracking using the four-point bend method

Corrosion des métaux et alliages — Méthodologie de détermination de la résistance des métaux à la fissuration par corrosion sous contrainte au moyen de la méthode de flexion quatre points

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Foreword

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The committee responsible for this document is ISO/TC 156, *Corrosion of metals and alloys*.

This International Standard is based on a draft NACE International standard on Four-Point Bend Testing of Materials for Oil and Gas applications. NACE International grants the right to ISO to reproduce material extracted from that document.

Introduction

This International Standard has been prepared as a sub-set of ISO 7539 which consists of the following parts, under the general title *Corrosion of metals and alloys — Stress corrosion testing*:

— *Part 1: General guidance on testing procedures*

— *Part 2: Preparation and use of bent-beam specimens*

— *Part 3: Preparation and use of U-bend specimens*

— *Part 4: Preparation and use of uniaxially loaded tension specimens*

— *Part 5: Preparation and use of C-ring specimens*

— *Part 6: Preparation and use of precracked specimens for tests under constant load or constant displacement*

— *Part 7: Method for slow strain rate testing*

— *Part 8: Preparation and use of specimens to evaluate weldments*

— *Part 9: Preparation and use of pre-cracked specimens for tests under rising load or rising displacement*

— *Part 10: Reverse U-bend method*

— *Part 11: Guidelines for testing the resistance of metals and alloys to hydrogen embrittlement and hydrogen-assisted cracking*

Corrosion of metals and alloys — Methodology for determining the resistance of metals to stress corrosion cracking using the four-point bend method

1 Scope

This International Standard provides guidelines for the use of four-point bend testing to evaluate the resistance of metals including carbon steel, low alloy steels, and corrosion resistant alloys (CRAs) to stress corrosion cracking. The method gives guidance on testing of both parent plate and welds and includes procedures for metals that have no distinct yield point in their stress-strain behaviour as well as metals with a distinct yield point. The emphasis in this International Standard is on the generic methodology of the four-point bend test. Service application will be varied and the relevant industry standard is to be consulted where appropriate.

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.

ISO 8407, *Corrosion of metals and alloys — Removal of corrosion products from corrosion test specimens*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
corrosion resistant alloy
CRA
alloy designed to be resistant to general and localized corrosion in environments that are corrosive to carbon steel

3.2
heat affected zone
HAZ
portion of the base metal that is not melted during brazing, cutting, or welding, but whose microstructure and properties are altered by the heat of these processes

3.3
soft zone cracking
SZC
form of sulphide stress cracking that may occur when a steel contains a local "soft zone" of low yield strength material and is exposed under stress to environments containing H_2S

Note 1 to entry: Under service loads, soft zones may yield and accumulate plastic strain locally increasing the susceptibility to cracking of an otherwise cracking resistant material. Such soft zones are typically associated with welds in carbon steels.

4 Principle

The four-point bend test is a constant displacement test that is performed by supporting a beam specimen on two loading rollers (bearing cylinders) and applying a load through two other loading rollers so that one face of the specimen is in tension (and uniformly stressed between the inner rollers) and the other is in compression. The stress at mid-thickness is zero and there will be significant gradients in stress through the thickness, this being most marked for thin specimens. As a consequence, cracks may initiate, but then arrest or their growth rate decrease. Hence, complete fracture might not always occur during the test exposure period. Important parameters are roller spacing, ratio between outer and inner span, specimen dimensions, width-to-thickness ratio, and roller diameter. Testing of as-welded specimens presents a particular challenge due to significant variations in root profile, surface roughness, extent of micro-cracks, and degree of misalignment.

5 Loading jig design

5.1 A loading jig similar to that shown in Figure 1 shall be used to apply a constant deflection to the specimen. The dimensions are often chosen so that A = H/4.

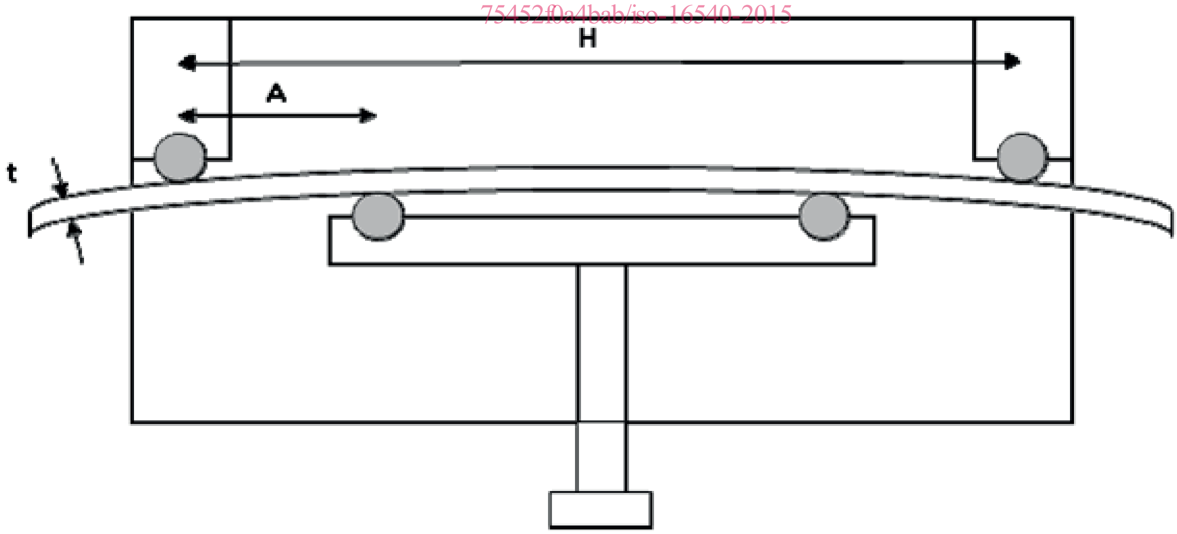
5.2 Specimens of thickness up to 5 mm present few problems for parent material specimens as they can be easily accommodated in test vessels of modest size with typical dimensions for the loading jig of the following:

— spacing between inner rollers: 50 mm-60 mm;

— spacing between outer rollers: 100 mm-130 mm;

— roller diameter: 6 mm-10 mm.

5.3 Thicker specimens, up to full wall thickness, are advisable for testing welded specimens. Here, there is a balance between minimizing the load by increasing the spacing between span supports and accommodating the increased size of the jig with possible constraints associated with the size of the test vessel. This is an individual judgement.



Key

t specimen thickness

A distance between the inner and outer supports

H distance between the outer supports

Figure 1 — Typical four-point bend loading jig design

5.4 The specimen shall be electrically isolated from the loading jig in order to avoid undesirable galvanic and crevice corrosion. This is best achieved by the use of ceramic rollers as these also satisfy the additional requirement that the rollers should not exhibit any yielding or creep during the test.

5.5 Friction between the rollers (bearing cylinders) and the specimen should be minimised to ensure that frictional constraint does not impact on the stress distribution in the specimen. This is best achieved by the use of ceramic rollers that have a low friction contact surface and can be further reduced if they are free to rotate while loading the test specimen. In the absence of free rotation, there will be some effect of friction on the force required to achieve the required strain. However, provided the specimen is strain gauged and the frictional forces are not excessive, this will not impact on the test results. Nevertheless, an increase in friction will increase the stress and strain on the tensile surface locally at the inner loading pins and can enhance the likelihood of cracks forming in the specimen at those locations (see Clause 11). The extent of overstraining for a particular loading jig can be assessed by strain gauging in that region for a typical test condition.

5.6 The material of construction of the loading jig shall be resistant to stress corrosion cracking in the test environment and the jig should be sufficiently rigid. Contamination of the solution with corrosion products from the jig material shall be minimized to avoid impacting on the test results. This can be achieved by the use of corrosion resistant alloys or by application of a coating to the jig. When testing carbon and low alloy steels with higher alloyed jigs, electrical bridging from corrosion products is a possibility and electrical resistance checks shall be made at test termination. Where electrical isolation is not undertaken, then the material of construction of the jigs shall be similar to that of the specimens. For testing of carbon and low alloy steel specimens, adoption of low alloy steel jigs may be preferred to ensure an absence of galvanic interaction. In this case, a suitable inert coating may be applied to the jigs to minimize accumulation of corrosion products.

6 Specimen preparation

6.1 General

6.1.1 Four-point bend specimens shall be flat strips of metal of uniform rectangular cross section and uniform thickness except in the case of testing welded specimens with one face in the as-welded condition for which a non-uniform cross section is inherent, or when testing the inner surface of piping material in its original surface state (for which the surface would be concave) or outer surface of a piping material in its original surface state (for which the surface would be convex).

6.1.2 Identification marks or numbers shall be permanently inscribed on each end of the specimen. This is the region of lowest stress and the identification marks should therefore not initiate cracking.

6.1.3 Specimen preparation techniques which generate hydrogen at the specimen surface, e.g. electric discharge machining, should not be used on materials that are susceptible to hydrogen-induced damage. If the use of such techniques is necessary, a final grinding of the outer surfaces of the specimen shall be carried out to remove material containing retained hydrogen. The grinding shall be carried out as soon as possible to minimize the time available for the hydrogen to diffuse into the specimen from the outer surface. The thickness removed should reflect conservative evaluation of the effective hydrogen diffusivity in the material. For most corrosion resistant alloys, removal of 500 µm from each surface of the specimen is sufficient. Baking out of the hydrogen can also be considered, but only where this does not introduce changes in the material microstructure/microchemistry.

6.2 Parent material specimens

6.2.1 Parent material specimens shall be machined, avoiding sharp edges, from the pipe or plate in the longitudinal direction unless otherwise specified.

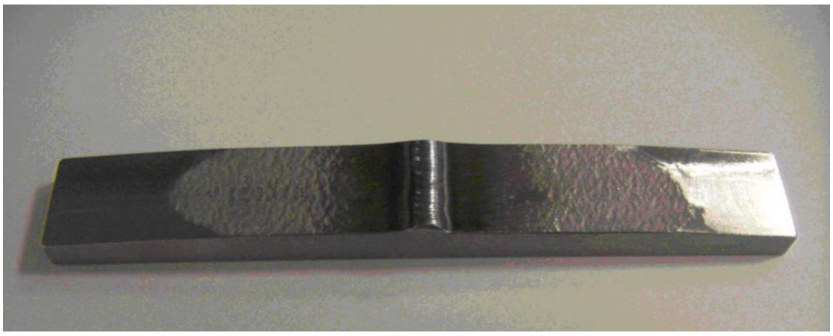
6.2.2 A typical four-point bend parent material specimen is shown in Figure 2 a).

6.2.3 The specimen width shall be 1,5 to 5 times the thickness of the specimen. Any deviation from this requirement, e.g. for very thick C-steel sections, requires demonstration that out-of-plane bending is not significant.

6.2.4 The specimen can be tested with the tensile test surface in its original surface state with no subsequent surface preparation. This recognizes that grinding always induces some change in the near-surface material properties and this may be undesirable. Otherwise, the surface of the specimen shall be prepared to a consistent repeatable finish as agreed with the end-user, but usually with an Ra value, ≤0,25 μm, for any non-welded specimen. The test specimen shall be machined carefully at an appropriate rate to avoid overheating and unnecessary cold working of the surface. If a lubricant is used, this could affect the surface chemistry of the specimen. The test specimen shall be degreased with a suitable degreasing solution and rinsed with an appropriate solvent such as acetone. The effectiveness of all cleaning procedures adopted in this International Standard shall be demonstrated, for example, using an atomizer test.[9]

6.2.5 Deburring of the edges of the specimen can be undertaken by light manual grinding.

a) parent material specimen



b) as-welded specimen

Figure 2 — Typical four-point bend specimens

6.3 Welded specimens

6.3.1 Unless specified otherwise, welded specimens shall be taken transverse to the weld where feasible with the weld bead at the centre of the specimen.

6.3.2 A typical four-point bend welded specimen is shown in Figure 2 b).

6.3.3 When testing with one surface in the as-welded state (in this context this means without further surface treatment by grinding), machining from one side only can often result in variation in thickness on either side of the weld, because of misalignment of the sections during welding, and the extent of this shall be recorded. This variation in thickness will cause non-uniform straining of the specimen, but the impact should be less for thicker specimens. For this case, testing of near full-thickness specimens is preferred.

6.3.4 When testing specimens with one surface in the as-welded state, the locations in contact with the outer rollers should be machined flat to prevent high stress localization on the ceramic supports due to specimen curvature. Otherwise, cracking of the roller can occur.

6.3.5 For both fully machined and as-welded specimens, the specimen width shall be 1,5 to 5 times the thickness of the parent region of the specimen. Any deviation from this requirement, e.g. for very thick C-steel sections, requires demonstration that out-of-plane bending is not significant.

6.3.6 The variation in thickness of the specimen due to tapering, misalignment, and curvature (if the weld is machined from a pipe) shall be recorded.

6.3.7 When testing welds under fully machined conditions, the surface under tension should be as close as possible to the original surface as there might be hardness and microstructural variations through-thickness. In particular, the root pass (or final pass if testing relates to the weld cap surface) shall be retained. Thus, it is useful to conduct a detailed hardness and microstructure characterization prior to testing in order to assess the extent of variation, give guidance on specimen preparation, and identify any possible influence on test results. There can also be variations in residual stress through the thickness. Accordingly, the location of the specimen surface in tension with respect to the original surface shall be noted and specimens cut in a consistent way. The surface shall be prepared in accordance with 6.2.4 to a consistent repeatable finish as agreed with end-user, but usually with an Ra value, ≤0,25 µm. The test specimen shall be fabricated carefully at an appropriate machining rate to avoid overheating and unnecessary cold working of the surface. If a lubricant is used, this could affect the surface chemistry of the specimen. The lubricant shall be cleaned from the surface of the specimen using a suitable solvent and rinsed with acetone as per 6.2.4.

6.3.8 Deburring of the edges of the specimen can be undertaken by light manual grinding.

6.4 Clad product specimens

6.4.1 When testing corrosion resistant alloy specimens from clad pipe or pressure vessel wall, the carbon steel backing shall be completely removed by machining. This inevitably means that thin specimens need to be used.

NOTE The efficacy of removal of the carbon steel backing can be checked by using the copper sulfate test, for example.[8]

6.4.2 For welded specimens, the weld root reinforcement (protrusion) shall be removed unless otherwise specified by the end-user. Removal of the reinforcement should be conducted in such a way as to minimize damage to the adjacent HAZ/parent regions since the surface condition of these regions, in particular the heat tint, can influence the result.

7 Strain gauging

7.1 Strain gauging is required when the loading of the specimen is such that it could induce plastic deformation. Guidance on strain gauging is given in Annex B.

7.2 For testing of parent material specimens at stresses where plastic deformation is induced, the strain gauge shall be attached to the calibration specimen at the centre of the face in tension.