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Methodology for determining the resistance of welded corrosion resistant alloys to stress corrosion using the four-point bend method

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NOVEMBER 2004

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Methodology for determining the resistance of welded corrosion resistant alloys to stress corrosion using the four-point bend method

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FOREWORD

This document describes the methodology for 4-point bend testing of welded corrosion resistant alloys with respect to stress corrosion cracking. It is written in the same format as an ISO standard.

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ISSN 1744-0262

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We gratefully acknowledge the financial support of the UK Department of
Trade and Industry (National Measurement System Policy Unit)

Approved on behalf of the Managing Director, NPL,
by Dr M G Gee, Knowledge Leader, Materials Performance Team
authorised by Director, Engineering and Process Control Division

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1 SCOPE

1.1 This document provides guidelines for four-point bend testing of welded corrosion resistant alloys (CRAs) to evaluate their resistance to stress corrosion and sulphide stress corrosion cracking.

1.2 The emphasis in this document is on specimen preparation and stressing. Details in relation to water chemistry are described in other documents.

2 REFERENCES

The following documents should be consulted when considering application of the test methodology described herein.

ISO 7539-1: 1987, *Corrosion of metals and alloys - Stress corrosion testing - Part 1: General guidance on testing procedures.*

ISO 7539- 2: 1989, *Corrosion of metals and alloys - Stress corrosion testing - Part 2: Preparation and use of bent-bean specimens*

ISO 7539-8: 2000 *Corrosion of metals and alloys - Stress corrosion testing—Part 8: Preparation and use of specimens to evaluate weldments.*

Corrosion Resistant Alloys for Oil and Gas Production: Guidance on General Requirements and Test Methods for H_2S Service, European Federation of Corrosion, Publication Number 17, 2nd edition, 2002, The Institute of Materials, London.

British Society for Strain Measurement, Code of Practice CP1: 1992.

3 PRINCIPLE

The four-point bend test is a constant displacement test that is performed by supporting a beam specimen on two loading rollers and applying a load through two other loading rollers so that one face of the specimen is in tension and the other in compression. The stress at mid-thickness is zero and there will be significant gradients in stress through the thickness, most marked for thin specimens. As a consequence, fracture may not always occur and the existence of any crack represents failure. Important parameters are roller spacing, ratio between outer and inner span, specimen dimensions, width-to-thickness ratio, span-to-thickness ratio, and roller diameter. For welded material, the method has the advantage of enabling testing of the as-welded surface, usually the root, in tension. Two factors are of importance. The weld metal may have quite different mechanical properties from the parent material, thus affecting the distribution of strain. In addition, when one surface is in the as-welded condition and the other machined, there may be variations in thickness along the specimen. This is quite common in welded pipes as there can be a step on either side of the weld caused by lateral misalignment of the pipe sections during welding. Both

these factors may influence the test results and need to be accounted for in testing. As with any constant displacement test, the possibility of relaxation needs to be considered. This may originate from creep of the parent or weld metal or from cracking.

It should be emphasised that the electrochemical activity of the as-welded surface may be different from that of the machined surface and the root profile geometry may have a strong influence on the magnitude of stress concentrations.

4 STRESSING JIG DESIGN

4.1 Specimens of thickness up to 4 mm present few problems as they can be easily accommodated in autoclaves of modest size with typical dimensions for the loading jig of:

Spacing between inner rollers: 50 mm;
Spacing between outer rollers: 100 mm;
Roller diameter: 6mm.

4.2 Thicker specimens, up to near full wall thickness, are advisable for testing with one surface in the as-welded state. Here, there is a balance between minimising the load by increasing the spacing between span supports and accommodating the jig in an autoclave. This is an individual judgement. For specimens of thickness 8 mm, typical dimensions for the loading jig might be:

Spacing between inner rollers: 60 mm
Spacing between outer rollers: 120 mm
Roller diameter: 10mm.

5 SPECIMEN PREPARATION

5.1 When testing welds under fully machined conditions, the surface under tension should be as close as possible to the root surface as there may be hardness and microstructural variations through-thickness. For example, high hardness has been detected at the base of the root filler in a SMSS girth welded pipe. This would not be normally exposed to the environment but if the specimen is machined this could be unwittingly exposed and gave a misleading result. Thus, it is useful to conduct a detailed hardness and microstructure characterisation 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 may also be variations in residual stress through the thickness. Accordingly, the location of the specimen surface in tension with respect to the actual pipe surface should be noted and specimens removed in a consistent way. The surface should be prepared to a consistent repeatable finish as agreed with interested parties but usually with a Ra value $\leq$ 0.25 μm. The test specimen shall be fabricated 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 lubricant should be cleaned from the surface of the specimen using a suitable solvent and the specimen dried in cold air.

5.3 When testing with one surface in the as-welded state, machining from one side only may often result in a variation in thickness on either side of the weld and the extent of this should 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 reason, testing of near full-thickness specimens is preferred.

5.4 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 localisation on the ceramic supports due to specimen curvature. Otherwise, cracking of the ceramic roller may occur.

5.5 For both types of specimen, the specimen width should be 2.5 to 5 times the thickness.

5.6 Whether using as-welded or fully machined specimens, an appropriate cleaning process should be undertaken prior to exposure.

5.7 The variation in thickness of the specimen due to tapering, steps and curvature (if the weld is machined from a pipe) should be recorded. Annex A indicates the locations where the thickness should be measured.

6 STRAIN GAUGING

6.1 Strain gauges should be attached to the parent plate symmetrically on either side of the weld metal as close as possible but sufficiently far from the weld toes that the measured strain is not directly affected by any local stress/strain concentration or non-uniformity of the surface. The position of the strain gauges relative to the weld toe should be recorded. It is common to use crossed or T gauges to determine both longitudinal (ε_l) and transverse strains (ε_t) as the total principal strain (ε_p), the value to be achieved in testing, has contributions from both:

$$\varepsilon_P = [1/(1-\nu^2)\,].\,[\varepsilon_l + \nu\,\varepsilon_t]$$

where ν is Poisson's ratio.

6.2 The strain levels are not usually sensitive to variation in the Poisson's ratio in the range of relevance. In testing of super martensitic stainless steels, the contribution of the transverse component to the total strain was found to be effectively constant throughout the test and only about 7%. For most metals a Poisson's ratio can be assumed from reference data without the need for measurement. The value used should be recorded.

6.3 In strain gauging of as-welded material, it is inevitable that the surface at those locations will depart from its original state because of the attachment and subsequent removal of the gauges. Care should be taken to constrain the area affected.

7 STRESSING

7.1 SETTING THE TOTAL STRAIN VALUE.

The objective is to achieve a specific value of the strain (typically 0.2% or 0.5% plastic strain) adjacent to the weld. To achieve that, the total strain (elastic and plastic) to give that degree of plastic deformation needs to be identified using flexural data obtained in a separate test on the parent material (see example of Figure 1). Deflection is stopped when the first strain gauge registers the required total stain value. Any specimen strained beyond the intended level should be discarded.

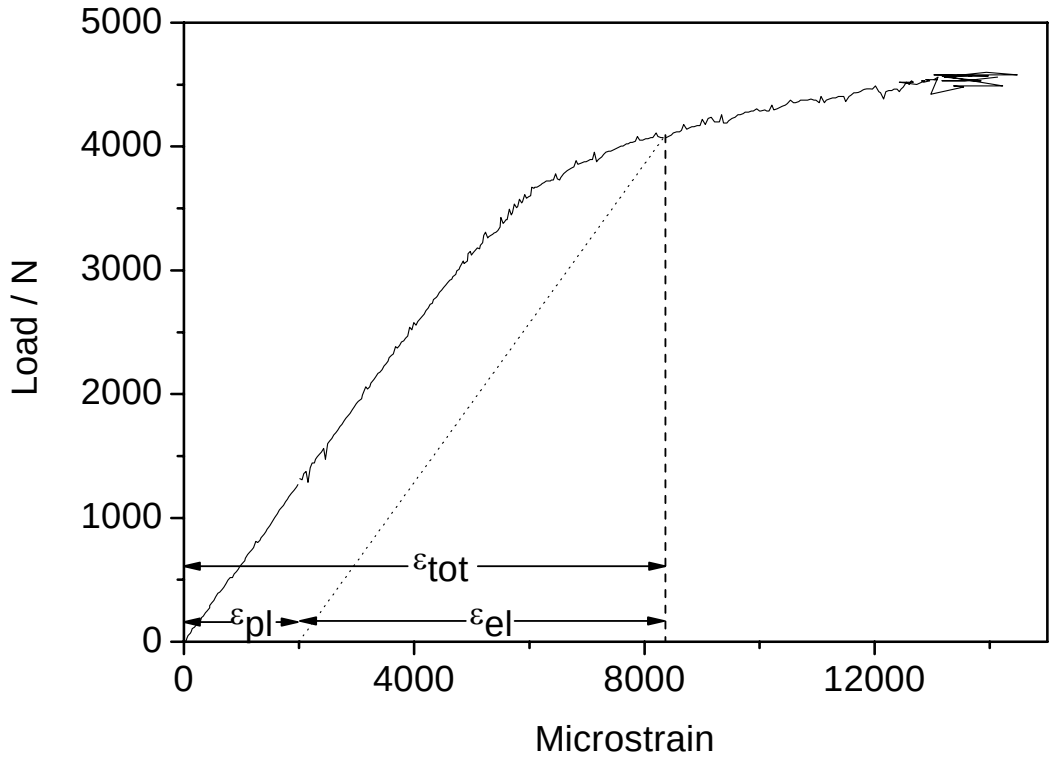


Figure 1 Illustration showing determination of total strain (ε_{tot}) to be applied to achieve 0.2% plastic strain (ε_{pl}) in four point bend testing. The elastic strain is ε_{el}.

Because every weld specimen can be somewhat different, it is not possible to assign a specific deflection based on some calibration specimen. Each weld has to be individually strain gauged. In identifying the total plastic strain as shown in Figure 1, it is necessary to generate the stress-strain behaviour using actual bend specimens of the parent material. Tensile stress-strain data are not really appropriate and can give significant errors for some systems. The relationship between stress and strain in a four-point bend test is different to that in a tensile test because the stress and strain distribution through the thickness of a bend specimen varies from tensile on one face through zero at the neutral axis to compressive on the opposite face. An added complication is the possible difference between compressive mechanical properties

and tensile properties that may also affect the flexural response of a beam. The stress-strain curve in a bend test is therefore a different shape to that produced in tension and the same analysis will give a different equivalent total strain.

7.2 TESTING AT ELEVATED TEMPERATURES

7.2.1 4-point bend specimens are usually stressed at ambient temperature and then heated to the test temperature. This raises a number of issues. The mechanical properties of the weld metal and parent plate will change with temperature, the proof stress usually decreasing. This decrease is most marked for duplex stainless steel (DSS), compared with SMSSs. Creep may also be a significant factor for duplex stainless steels.

7.2.2 For SMSS, with SDSS weld metal, the indication from testing is that relaxation due to creep of the weld metal or increased ductility of the SMSS is relatively modest, of order of a few % up to 130 °C. At higher temperatures, more data are needed. Although the SDSS weld metal might have been expected to creep at 130 °C and cause relaxation, this is constrained by the underlying SDSS weld metal, which is at a lower stress level and just elastically loaded (because of the stress gradient through the specimen), and the unyielded parent material itself.

7.2.3 Greater relaxation might be expected for a DSS parent material with SDSS weld metal but because of the elastic constraint it is difficult to predict and measurement is required. This would apply to other alloys that exhibit significant temperature variation in mechanical properties over the temperature range of practical interest.

7..2.4 Where creep at temperature is significant, a constant load rather than constant displacement method would be more conservative.

8 PROCEDURE FOR 4-POINT BEND TESTING

8.1 Determine the stress-strain behaviour for the parent material by testing in bend and undertaking at least one repeat test. If elevated temperature exposure is envisaged, it is advisable to test at the exposure temperature also to assess the likelihood of significant material property change that may affect the change in magnitude of the strain of specimens stressed at ambient temperature.

8.2 For the required level of plastic strain (as agreed with the customer), evaluate the total strain as shown by Figure 1.

8.3 For as-welded specimens, testing of five specimens for any one condition may be required to account for specimen-to-specimen variability of the weld profile.

8.4 In selecting as-welded specimens, examine the root profile recognising that shallow, gradual profiles, with no steps, will be less likely to induce failure. Take a photographic record of the profile – this is best done with the batch of specimens to be tested. Documenting the height of the root protusion relative to the width of the root

can be a useful reference index. Note also any variation in thickness on either side of the weld metal.

8.5 Clean the specimens ultrasonically in distilled water, rinse with alcohol, and then with a non-chlorinated solvent.

8.6 Attach the strain gauges and deflect the specimen until the required total strain is first achieved on one of the gauges.

8.7 Remove the gauges from the surface and clean using acetone or similar.

8.8 Immerse the specimens in the test environment, bring to test temperature and expose for the required period.

8.9 Subsequently remove the specimens and examine for cracks. Where no surface cracks are visible at ×10 magnification, undertake longitudinal sectioning at three locations and conduct metallographic examination at up to 100× magnification.

9 TEST REPORT

The test report should include the following information:

a) full description of the test material, including composition and structural condition, type of product, welding parameters;
b) location from which specimen is removed; orientation of specimen, dimensions (including non-uniformity of thickness in as-welded specimens), commentary on root profile, and surface preparation;
c) 4 point bend test set up data (see sample data-sheet in Appendix 1)
d) strain gauging procedure;
e) stressing procedure;
f) environment composition, test temperature and exposure time;
g) method used for detecting cracks;
h) presence and location of any cracks on specimens.

ANNEX A

(Informative)

4 point-bend test set-up data

Specimen Identity:

Other data used

Poisson's ratio: Test span: mm outer mm inner

Thickness under strain gauge (mm):

Thickness values over specimen

Side 1

1	2	3	4	5

Side 2

6	7	8	9	10

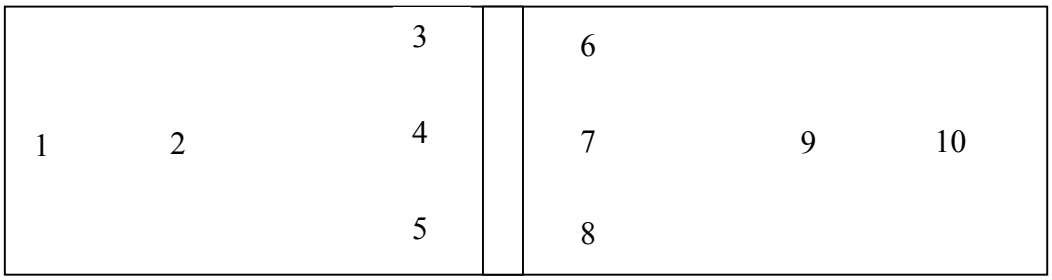
Temperature / °C:

Strain gauge type: Distance from weld root (mm):

Adhesive type:

Adhesive cure:

PTO for notes

Signed Date

Thickness measurement points on 4 point bend specimen, as welded (machined one side)