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Corrosion of metals and alloys — Stress corrosion testing —

Part 6:
Preparation and use of pre-cracked specimens

Corrosion des métaux et alliages — Essais de corrosion sous contrainte —

Partie 6: Préparation et utilisation des éprouvettes préfissurées

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 7539-6 was prepared by Technical Committee ISO/TC 156, *Corrosion of metals and alloys.*

ISO 7539 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 pre-cracked specimens*
- *Part 7: Slow strain rate testing*
- *Part 8: Preparation and use of welded specimens*

Annex A forms an integral part of this part of ISO 7539.

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Introduction

This part of ISO 7539 is one of a series giving procedures for designing, preparing and using various forms of test specimen to carry out tests to establish a metals resistance to stress corrosion.

Each of the standards in the series needs to be read in association with ISO 7539-1. This helps in the choice of an appropriate test procedure to suit particular circumstances as well as giving guidance towards assessing the significance of the results of the tests.

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Corrosion of metals and alloys — Stress corrosion testing —

Part 6:
Preparation and use of pre-cracked specimens

1 Scope

1.1 This part of ISO 7539 covers procedures for designing, preparing and using pre-cracked specimens for investigating susceptibility to stress corrosion. Recommendations concerning notched specimens are given in annex A.

The term "metal" as used in this part of ISO 7539 includes alloys.

1.2 Because of the need to maintain elastically constrained conditions at the crack tip, pre-cracked specimens are not suitable for the evaluation of thin products such as sheet or wire and are generally used for thicker products including plate, bar and forgings. They can also be used for parts joined by welding.

1.3 Pre-cracked specimens may be stressed quantitatively with equipment for application of a constant load or a monotonically increasing load or can incorporate a device to produce a constant displacement at the loading points.

1.4 A particular advantage of pre-cracked specimens is that they allow data to be acquired from which critical defect sizes, above which stress corrosion cracking may occur, can be estimated for components of known geometry subjected to known stresses. They also enable rates of stress corrosion crack propagation to be determined.

2 Normative reference

The following standard contains provisions which, through reference in this text, constitute provisions of this part of ISO 7539. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this part of ISO 7539 are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

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

3 Definitions

For the purposes of this part of ISO 7539, the following definitions and those given in ISO 7539-1 apply.

3.1 crack length, a : The effective crack length measured from the crack tip to either the mouth of the notch or the loading point axis depending on the specimen geometry.

3.2 specimen width, W : The effective width of the specimen measured from the back face to either the face containing the notch or the loading plane depending on the specimen geometry.

3.3 specimen thickness, B.

Self-explanatory term.

3.4 reduced thickness at side grooves, B_n.

Self-explanatory term.

3.5 specimen half-height, H.

Self-explanatory term.

3.6 applied load, P.

Self-explanatory term.

3.7 deflection at loading point axis, V_y.

Self-explanatory term.

3.8 deflection away from the loading line, V.

Self-explanatory term.

3.9 Modulus of elasticity, E.

Self-explanatory term.

3.10 stress intensity factor coefficient, Y : A factor derived from the stress analysis for a particular specimen geometry which relates the stress intensity factor for a given crack length to the load and specimen dimensions.

3.11 plane strain stress intensity factor, K_I: A function of applied load, crack length and specimen geometry having dimensions of stress × length which uniquely defines the elastic stress field intensification at the tip of a crack subjected to opening mode displacements:

$$K_\mathrm{I} = \text{applied stress} \cdot \sqrt{\text{length}}, \text{ in } \mathrm{N \cdot m^{-3/2}}$$

3.12 initial stress intensity factor, K_Ii.

Self-explanatory term.

3.13 plane strain fracture toughness, K_Ic: The critical value of K_I at which the first significant environmentally independent extension of the crack occurs under the influence of rising stress intensity under conditions of high constraint to plastic deformation.

3.14 a provisional value of K_Ic, K_Q: $K_\mathrm{Q} = K_\mathrm{Ic}$ when the validity criteria for plane strain predominance are satisfied.

3.15 threshold stress intensity factor for susceptibility to stress corrosion cracking, K_ISCC: That stress intensity factor above which stress corrosion cracking will initiate and grow for the specified test conditions under conditions of high constraint to plastic deformation, i.e. under plane strain predominant conditions.

3.16 a provisional value of K_ISCC, K_QSCC: $K_\mathrm{QSCC} = K_\mathrm{ISCC}$ when the validity criteria for plane strain predominance are satisfied.

3.17 fatigue stress intensity, K_f: The plane strain stress intensity corresponding to the maximum force of the fatigue cycle.

3.18 fatigue stress intensity range, ΔK_f.

Self-explanatory term.

3.19 0,2 % proof stress, $R_\mathrm{p0,2}$.

Self-explanatory term.

3.20 applied stress, σ.

Self-explanatory term.

3.21 geometrical correction factor, Q.

Self-explanatory term.

3.22 fatigue force ratio, R : The algebraic ratio of minimum to maximum force in the fatigue cycle.

3.23 crack velocity: The instantaneous rate of stress corrosion crack propagation measured by a continuous crack monitoring technique.

3.24 average crack velocity: The average rate of crack propagation calculated by dividing the change in crack length due to stress corrosion by the test duration.

3.25 specimen orientation: The fracture plane of the specimen identified in terms of firstly the direction of stressing and secondly the direction of crack growth expressed with respect to three reference axes. These are identified by the letters X, Y and Z where: Z is coincident with the main working force employed during manufacture of the material (short-transverse axis); X is coincident with the direction of grain flow (longitudinal axis); and Y is normal to the X and Z axes (see figure 6).

4 Principle

4.1 The use of pre-cracked specimens acknowledges the difficulty of ensuring that crack-like defects introduced during either manufacture or subsequent service are totally absent from structures. Furthermore, the presence of such defects can cause a susceptibility to stress corrosion cracking which in some materials (e.g. titanium) may not be evident from tests under constant load on smooth specimens. The principles of linear elastic fracture mechanics can be used to quantify the stress situation existing at the crack tip in a pre-cracked specimen or structure in terms of the plane strain-stress intensity.

4.2 The test involves subjecting a specimen in which a crack has been developed from a machined notch by fatigue to either a constant load or displacement at the loading points or to an increasing load during exposure to a chemically aggressive environment. The objective is to quantify the conditions under which environmentally-assisted crack extension can occur in terms of the threshold stress intensity for stress corrosion cracking, K_ISCC, and the kinetics of crack propagation.

4.3 The empirical data can be used for design or life prediction purposes in order to ensure either that the stresses within large structures are insufficient to promote the initiation of environmentally-assisted cracking at whatever pre-existing defects may be present or that the amount of crack growth which would occur within the design life or inspection periods can be tolerated without the risk of unstable failure.

5 Specimens

5.1 General

5.1.1 A wide range of standard specimen geometries of the type employed in fracture toughness tests may be used. The particular type of specimen used will be dependent upon the form, the strength and the susceptibility to stress corrosion cracking of the material to be tested and also on the objective of the test.

5.1.2 A basic requirement is that the dimensions shall be sufficient to maintain predominantly triaxial (plane strain) conditions in which plastic deformation is limited in the vicinity of the crack tip. Experience with fracture toughness testing has shown that for a valid K_Ic measurement, both the crack length, a, and the thickness, B, should be not less than

$$2{,}5 \left(\frac{K_\mathrm{Ic}}{R_\mathrm{p0,2}} \right)^2$$

and that, where possible, larger specimens where both a and B are at least

$$4\left(\frac{K_{\mathrm{Ic}}}{R_{\mathrm{p0,2}}}\right)^2$$

should be used to ensure adequate constraint.

From the view of fracture mechanics, a minimum thickness from which an invariant value of K_{ISCC} is obtained cannot be specified at this time. The presence of an aggressive environment during stress corrosion may reduce the extent of plasticity associated with fracture and hence the specimen dimensions needed to limit plastic deformation. However, in order to minimize the risk of inadequate constraint, it is recommended that similar criteria to those employed during fracture toughness testing should be employed regarding specimen dimensions, i.e. both a and B should be not less than

$$2,5\left(\frac{K_{\mathrm{I}}}{R_{\mathrm{p0,2}}}\right)^2$$

and preferably should be not less than

$$4\left(\frac{K_{\mathrm{I}}}{R_{\mathrm{p0,2}}}\right)^2$$

where K_{I} is the stress intensity to be applied during testing.

The threshold stress intensity value eventually determined should be substituted for K_{I} in the first of these expressions as a test for its validity.

5.1.3 If the specimens are to be used for the determination of K_{ISCC}, the initial specimen size should be based on an estimate of the K_{ISCC} of the material (in the first instance, it being better to over-estimate the K_{ISCC} value and therefore use a larger specimen than may eventually be found necessary). Where the service application involves the use of material of insufficient thickness to satisfy the conditions for validity, it is permissible to test specimens of similar thickness, provided that it is clearly stated that the threshold intensity value obtained, K_{QSCC}, is of relevance only to that specific application. Where it is required to determine stress corrosion crack growth behaviour as a function of stress intensity, the specimen size should be based on an estimate of the highest stress intensity at which crack growth rates are to be measured.

5.1.4 Two basic types of specimen can be used

a) those intended for testing under constant displacement, which are invariably self-loaded by means of built-in loading bolts;

b) those intended for testing under constant load, for which an external means of load application is required.

5.1.5 Constant displacement specimens, being self-loaded, have the advantage of economy in use since no external stressing equipment is required. Their compact dimensions also facilitate exposure to operating service environments. They can be used for the determination of K_{ISCC} by the initiation of stress corrosion cracks from the fatigue pre-crack, in which case a series of specimens must be used to pin-point the threshold value, or by the arrest of a propagating crack since under constant displacement testing conditions the stress intensity decreases progressively as crack propagation occurs. In this case a single specimen will suffice in principle, but in practice the use of several specimens (not less than 3) is often recommended, taking into account the disadvantages described in 5.1.6.

5.1.6 The disadvantages of constant displacement specimens are

a) applied loads can only be measured indirectly by displacement changes;

b) oxide formation or corrosion products can either wedge open the crack surfaces, thus changing the applied displacement and load, or can block the crack mouth, thus preventing the ingress of corrodant and can impair the accuracy of crack length measurements by electrical resistance methods;

c) crack branching, blunting or growth out of plane can invalidate crack arrest data;

d) crack arrest must be defined by crack growth below some arbitrary rate which can be difficult to measure accurately;

e) elastic relaxation of the loading system during crack growth can cause increased displacement and higher loads than expected;

f) plastic relaxation due to time-dependent processes within the specimen can cause lower loads than expected;

g) it is sometimes impossible to introduce the test environment prior to application of the load which can retard crack initiation during subsequent testing.

5.1.7 Constant load specimens have the advantage that stress parameters can be quantified with confidence. Since crack growth results in increasing crack opening there is less likelihood that oxide films will either block the crack or wedge it open. Crack length measurements can be made readily with a number of continuous monitoring methods. A wide choice of constant load specimen geometries is available to suit the form of the test material, the experimental facilities available and the objectives of the test. This means that crack growth can be studied under either bend or tension loading conditions. The specimens can be used for either the determination of K_{ISCC} by the initiation of a stress corrosion crack from a pre-existing fatigue crack using a series of specimens or for measurements of crack growth rates. Constant load specimens can be loaded during exposure to the test environment in order to avoid the risk of unnecessary incubation periods.

5.1.8 The principal disadvantage of constant load specimens is the expense and bulk associated with the need for an external loading system. Bend specimens can be tested in relatively simple cantilever beam equipment but specimens subjected to tension loading require constant load creep rupture or similar testing machines. In this case the expense can be minimized by testing chains of specimens connected by loading links which are designed to prevent unloading on the failure of specimens. The size of these loading systems means that it is difficult to test constant load specimens under operating conditions but they can be tested in environments bled off from operating systems.

5.2 Specimen design

Figure 1 shows some of the pre-cracked specimen geometries which are used for stress corrosion testing.

5.2.1 Constant load specimens can be of two distinct types

a) those in which the stress intensity increases with increasing crack length;

b) those in which the stress intensity is effectively independent of crack length.

Type a) is suitable for K_{ISCC} determinations and studies of crack propagation rates as a function of K_I, while type b) is useful for fundamental studies of stress corrosion mechanisms.

5.2.2 Increasing K constant load specimens can be subjected to either tension or bend loading. Depending on the design, tension loaded specimens can experience stresses at the crack tip which are predominantly tensile (as in remote tension types such as the centre-cracked plate) or contain a significant bend component (as in crackline loaded types such as compact tension specimens). The presence of significant bending stress at the crack tip can adversely affect the crack path stability during stress corrosion testing and can facilitate crack branching in certain materials. Bend specimens can be loaded in 3-point, 4-point or cantilever bend fixtures.

5.2.3 Constant K constant load specimens can be subjected to either torsion loading, as in the case of the double torsion single edge cracked plate specimen, or tension loading as in the case of contoured double cantilever beam specimens. Although loaded in tension, the design of the latter specimens produces crackline bending with an associated tendency for crack growth out of plane which can be curbed by the use of side grooves.

5.2.4 Constant displacement specimens are usually self-loaded by means of a loading bolt in one arm which impinges on either an anvil or a second loading bolt in the opposite arm. Two types are available

a) those which are (W-a) dominated, such as the T-type wedge opening loaded (T-WOL) specimen in which the proximity of the back face to the crack tip influences the crack tip stress field;

b) those which are (W-a) indifferent, such as the double cantilever beam (DCB) specimen in which the back face is sufficiently remote from the crack tip to ensure that its position has a negligible effect on the crack tip stress field.

5.2.5 A number of the specimen geometries described above have specific advantages which have caused them to be frequently used for stress corrosion testing. These include

a) cantilever bend specimens which are easy to machine and inexpensive to test under constant load;

b) compact tension (CTS) specimens which minimize the material requirement for constant load testing;

c) self-loaded double cantilever beam (DCB) specimens which are easy to test under constant displacement in service situations;

d) T-type wedge opening loaded (T-WOL) specimens which are also self-loaded and minimize the material requirement for constant displacement testing;

e) C-shaped specimens which can be machined from thick walled cylinders in order to study the radial propagation of longitudinally oriented cracks under constant load.

Details of standard specimen designs for each of these types of specimen are given in figures 2a) to e).

5.2.6 If required, for example if fatigue crack initiation and/or propagation is difficult to control satisfactorily, a chevron notch configuration as shown in figure 3 may be used. If required, its included angle may be increased from 90° to 120°.

5.2.7 Where it is necessary to mesure crack opening displacements, as during the application of deflection to constant displacement specimens, knife edges for the location of displacement gauges can be machined into the mouth of the notch, as shown in figure 4a). Alternatively, separate knife edges can either be screwed or glued onto the specimen at opposite sides of the notch, as shown in figure 4b). Details of a suitable tapered beam displacement gauge are given in figure 4c).

5.3 Stress intensity factor considerations

5.3.1 It can be shown using elastic theory that the stress intensity, K_I, acting at the tip of a crack in specimens or structures of various geometries can be expressed by relationships of the form

$$K_I = Q\sigma\sqrt{a}$$

where

Q is the geometrical constant;

σ is the applied stress;

a is the crack length.

5.3.2 The solutions for K_I for specimens of particular geometry and loading method can be established by means of finite element stress analysis, or by either experimental or theoretical determinations of specimen compliance.

5.3.3 K_I values can be calculated by means of a dimensionless stress intensity coefficient, Y, related to crack length expressed in terms of a/W, or a/H for (W-a) indifferent specimens, where W is the width and H is the half-height of the specimen, through relationship of the form

$$K_I = \frac{YP}{B\sqrt{W}}$$

for compact tension or C-shaped specimens or

$$K_\mathrm{I} = \frac{YP}{B\sqrt{a}}$$

for T-type wedge opening loaded specimens

or

$$K_\mathrm{I} = \frac{YP}{B\sqrt{H}}$$

for double cantilever beam specimens.

5.3.4 Where it is necessary to use side-grooved specimens in order to curb crack branching tendencies, etc., shallow side grooves (usually 5 % of the specimen thickness on both sides) can be employed. Either semi-circular or 60° V-grooves can be used, but it should be noted that even with semi-circular side grooves of up to 50 % of the specimen thickness it is not always possible to maintain the crack in the desired plane of extension. Where side grooves are employed, the effect of the reduced thickness, B_n, due to the grooves on the stress intensity can be taken into account by replacing B by $\sqrt{B \cdot B_\mathrm{n}}$ in the above expressions. However, the influence of side grooving on the stress intensity factor is far from established and correction factors should be treated with caution, particularly if deep side grooves are used.

5.3.5 Solutions for Y for specimens with geometries which are often used for stress corrosion testing are given in figures 5a) to e).

5.4 Specimen preparation

5.4.1 Specimens of the required orientation (see figure 6) should, where possible, be machined in the fully heat-treated condition. For specimens in material that cannot easily be completely machined in the fully heat-treated condition, the final heat treatment may be given prior to the notching and finishing operations provided that at least 0,5 mm per face is removed from the thickness at this finish machining stage. However, heat treatment may be carried out on fully machined specimens in cases in which heat treatment will not result in detrimental surface conditions, residual stress, quench cracking or distortion.

5.4.2 After machining, the specimens should be fully degreased in order to ensure that no contamination of the crack tip occurs during subsequent fatigue pre-cracking or stress corrosion testing. In cases where it is necessary to attach electrodes to the specimen by soldering or brazing for crack monitoring by means of electrical resistance measurements, the specimens should be degreased following this operation prior to pre-cracking in order to remove traces of remnant flux.

5.5 Specimen identification

Specimen identification marks may be stamped or scribed on either the face of the specimen bearing the notch or on the end faces parallel to the notch.

6 Initiation and propagation of fatigue cracks

6.1 The machine used for fatigue cracking should have a method of loading such that the stress distribution is symmetrical about the notch and the applied force should be known to an accuracy within ± 2,5 %.

6.2 The environmental conditions employed during fatigue pre-cracking, as well as the stressing conditions, can influence the subsequent behaviour of the specimen during stress corrosion testing. In some materials the introduction of the stress corrosion test environment during the pre-cracking operation will promote a change from the normal ductile transgranular mode of fatigue cracking to one which more closely resembles stress corrosion cracking. This may facilitate the subsequent initiation of stress corrosion cracking and lead to the determination of consecutive initiation values of K_ISCC. However, unless facilities are available to commence stress corrosion testing immediately following the pre-cracking operation, corrodant remaining at the crack tip may promote blunting due to corrosive attack. Furthermore, the reproducibility of results may suffer when pre-cracking is conducted in the presence of an aggressive environment because of the greater sensitivity of the corrosion fatigue fracture mode to the cyclic loading conditions. In addition, more elaborate facilities may be needed for environmental control purposes during pre-cracking. For these reasons, it is recommended that, unless agreed otherwise between the parties, fatigue pre-cracking should be conducted in the normal laboratory air environment.

6.3 The specimens should be pre-cracked by fatigue loading with an R value in the range 0 to 0,1 until the crack extends at least 2,5 % W or 1,25 mm beyond the notch at the side surfaces, whichever is greater. The crack may be started at higher K_I values but, during the final 0,5 mm of crack extension, the fatigue pre-cracking should be completed at as low a maximum stress intensity as possible (below the expected K_ISCC, if possible).

6.4 The final length of the fatigue crack should be such that the requirement for plane strain predominance is satisfied, i.e.

$$a > 2{,}5 \left(\frac{K_\mathrm{I}}{R_\mathrm{p0,2}} \right)^2$$

This condition is optimized when the final a/W ratio is in the range 0,45 to 0,55 [except in the case of $(W\text{-}a)$ indifferent specimens].

6.5 In order to avoid the interaction of the stress field associated with the crack with that due to the notch, the crack should lie within the limiting envelope as shown in figure 7.

6.6 In order to ensure the validity of the stress intensity analysis, the fatigue crack should be inspected on each side of the specimen to ensure that no part of it lies in a plane the slope of which exceeds an angle of 10° from the plane of the notch and that the difference in lengths does not exceed 5 % W.

7 Procedure

7.1 General

7.1.1 Before testing, the thickness B and either width W or half-height H [in the case of (W-a) indifferent specimens] shall be measured to within 0,1 % W (or H) on a line not further than 10 % W (or H) from the crack plane. The average length of the fatigue pre-crack on both sides of the specimen shall also be determined and this value is used in assessing the load required to produce the desired initial stress intensity, K_I (see ISO 7539-1).

7.1.2 The environmental testing conditions will depend upon the intent of the test but, ideally, should be the same as those prevailing for the intended use of the alloy or comparable to the anticipated service condition.

7.1.3 Electrochemical polarisation can be applied to specimens exposed to conducting aqueous environments by means of counter electrodes. However, it should be noted that potentiostatic control at the tip of a stress corrosion crack may be subject to large variations as the crack length increases which must be taken into account when considering mechanisms of stress corrosion cracking.

7.1.4 When practical, it is recommended that the specimens be stressed after being brought into contact with the test environment. Otherwise, the stressed specimens should be exposed to the test environment as soon as possible after stressing.

7.1.5 It is recommended that wherever possible the loading points should be excluded from contact with corrosive environments. Where this is not possible, the problems that may be encountered include the following:

a) galvanic effects may influence the results if the loading system or other ancillary equipment (such as electrodes used with electrical resistance crack monitoring methods) are made from a material different from that of the specimen and electrical insulation is then necessary;

b) crevice corrosion may occur within the confines of the restricted spaces between loading systems and specimens and may cause premature failure of loading pins, etc.

These problems can be overcome by the use of local environmental cells of the type shown in figure 8 in which the environment is circulated around the vicinity of the notch, pre-crack and anticipated crack growth region of the specimen. Crevice problems may also arise where the specimen emerges from the test cell and these should be avoided by appropriate design of the cell or by the use of protective coatings at such locations. If total immersion in the corrodant is contemplated, the loading points should be protected against corrosion.

7.2 Determination of K_ISCC by crack arrest

7.2.1 Constant displacement specimens can be used for the determination of K_ISCC by crack arrest. In principle, a single specimen will suffice for this purpose, although it is recommended that additional specimens be tested to reduce the likelihood of an erroneous result.

7.2.2 For the determination of K_ISCC by crack arrest, the pre-cracked specimen should be fixed in a holding device and, if practical, the environment should be applied to the region of the notch root.

7.2.3 The arms of the specimen should then be deflected by turning a bolt to give a pre-determined K_Ii value in excess of the anticipated K_ISCC value. Over-deflection must be avoided. The deflection, V_y, at the loading line can be related to the deflection, V, measured by displacement gauge at knife edges located at the notch mouth by means of the procedure illustrated in figure 9. The sensitivity of the displacement gauge should be not less than 20 mV/mm in order to minimize errors due to over-amplification of a weak signal. The linearity of the gauge should be such that the deviation from true displacement is not more than 0,003 mm for displacements of up to 0,5 mm and not more than 1 % of recorded value for larger displacements.

7.2.3.1 For the (W-a) indifferent DCB specimen the deflection required to give the desired stress intensity, K_Ii, for a given value of a/H can be calculated from the relationship between K_I and V_y given in figure 5a).

7.2.3.2 In the case of the (W-a) dominated T-WOL specimen, a knowledge of the unique compliance calibration is necessary to calculate the deflection required to produce a given stress intensity value for a particular crack length ratio, a/W, using the relationship given in figure 5b). Typical compliance calibration curves for the smooth and side-grooved T-WOL specimens are shown in figure 10. After loading, the displacement gauge should be removed.

7.2.4 Once the environment is applied to the specimen, the crack length is monitored as a function of elapsed time. This can be achieved by either direct optical measurement or indirectly by the use of back face strain measurements, etc. As crack extension occurs, the stress intensity factor decreases. The slope of the relationship between crack length and time defines the crack growth rate which is usually determined by graphical differentiation of the crack length versus time curve. The crack may eventually arrest, thus indicating K_ISCC. Generally, however, the crack extends at an extremely slow rate and K_ISCC is designated as an arbitrarily selected crack growth rate. The most appropriate value of the arrest growth rate depends on the metal/environment system under consideration and must be agreed between the parties. For high strength alloys, velocities of about 10^{-7} mm/s have been suggested but practical experience has indicated that stress corrosion cracks can propagate at growth rates down to below 10^{-9} mm/s. The time for crack arrest can be decreased considerably by the application of K_Ii levels close to K_ISCC if this is known approximately.

7.2.5 When crack arrest is deemed to have occurred, the crack length should be determined and the stress intensity calculated to give a provisional K_ISCC value. This can be confirmed by replacing the displacement gauge and noting the deflection. The specimen can then be unloaded and subsequently reloaded in a tension machine to measure the corresponding load. The specimen should then be broken open and the maximum and minimum final stress corrosion crack length measured to the nearest 0,5 % W and also at the following three positions:

25 % B; 50 % B; and 75 % B.

The average of these last three measurements should be used as the effective crack length in the calculation of K_{ISCC}.

The test is invalid if

a) the difference between any two of these last three measurements exceeds 2,5 % W;

b) the difference between the maximum and minimum crack lengths exceeds 5 % W;

c) any part of the crack surface lies in a plane the slope of which exceeds an angle of 10° from the plane of the notch;

d) the factor $2{,}5 \left(\dfrac{K_{\mathrm{ISCC}}}{R_{\mathrm{p}0{,}2}}\right)^2$ is greater than the thickness of the specimen and/or the crack length.

7.3 Determination of K_{ISCC} by crack initiation

7.3.1 Either constant load or constant displacement specimens can be used for the determination of K_{ISCC} by crack initiation.

7.3.2 A series of specimens is required to allow the value of K_{ISCC} to be determined by crack initiation. Two approaches may be adopted, as described in 7.3.2.1 and 7.3.2.2.

7.3.2.1 In cases where time is at a premium but the availability of specimens and testing apparatus is plentiful, it is most appropriate to simultaneously expose a series of specimens stressed to different K_{Ii} levels encompassing the range within which it is anticipated that K_{ISCC} will lie.

7.3.2.2 In circumstances where time permits, the value of K_{ISCC} can be determined with greater certainty and economy of specimens and testing apparatus by means of the binary search procedure. This requires that an initial specimen be used to determine the fracture toughness of the material, K_{Ic} (or K_{Q} if invalid), using recommended procedures. This value establishes the upper bound to K_{ISCC}. The first stress corrosion test should then be conducted at an initial stress intensity of half K_{Ic} with subsequent tests at other fractions of K_{Ic} in accordance, for example, with the schedule given in ISO 7539-1, depending on whether or not failure (or crack extension) occurred in the preceding tests.

7.3.3 Where constant displacement specimens are employed, the deflection should be applied in accordance with the recommendations made in 7.2.2 and 7.2.3. For constant load specimens, the load required to produce the desired stress intensity can be calculated by means of relationships such as those given in figures 5c) and d). The testing machine used to apply the load should permit the applied force to be measured with an accuracy of ± 1 % and loading fixtures should be made as smoothly as possible following exposure to the test environment.

7.3.4 The test period commences as soon as the required load or displacement is applied. An arbitrary test duration should be chosen for the determination of a preliminary K_{ISCC} value above which stress corrosion cracking will initiate. This duration will depend upon the material and environment in question and should be agreed between parties concerned but for preliminary testing, times of 10 h for titanium alloys, 100 h for ultra-high strength low alloy steels and 1 000 h for lower strength steels, high alloy steels of the maraging type and aluminium alloys may be appropriate minima.

7.3.5 During testing, crack length may be monitored optically at intervals or continuously by means of electrical resistance, back face strain, displacement gauge for alternative techniques, depending on the experimental circumstances. These measurements may facilitate the detection of crack initiation and enable crack growth rates to be determined as a function of stress intensity.

7.3.6 On completion of the test period, the specimen should be inspected for signs of failure. If intact, it should be broken open and the minimum and maximum fatigue pre-crack length should be measured if possible to the nearest 0,5 W and also at the following three positions:

25 % B; 50 % B; and 75 % B.

The average of these last three measurements should be used as the effective crack length in the calculation of K_{QSCC}.

The test is valid, i.e. $K_{\mathrm{QSCC}} = K_{\mathrm{ISCC}}$, unless

a) the difference between any two of these last three measurements exceeds 2,5 % W;

b) the difference between the maximum and minimum crack lengths exceeds 5 % W;

c) any part of the fatigue crack surface lies in a plane the slope of which exceeds an angle of 10° from the plane of the notch;

d) the fatigue crack is not in one plane, i.e. effects of multi-nucleation are present;

e) the factor $2{,}5 \left(\dfrac{K_{\mathrm{QSCC}}}{R_{\mathrm{p}0{,}2}}\right)^2$ is greater than the thickness of the specimen and/or the crack length;

f) there is uncertainty over the fatigue crack length.

Any evidence of stress corrosion crack extension is indicative that the K_{Ii} value was in excess of K_{ISCC}. On completion of the series of tests, the K_{ISCC} value is the highest K_{Ii} value for which no stress corrosion crack extension occurred.

7.3.7 If time permits, the reliability of the preliminary value of K_{ISCC} can be checked by a further stress corrosion test at a stress intensity equal to that value but for which the test endurance is increased by one order of magnitude. Further testing will only be necessary if this test shows evidence of crack extension. Otherwise, some indication of the time-dependence of K_{ISCC} can be gleaned by plotting the times to failure of those specimens in which failure occurred within the exposure time as a function of K_{Ii} to establish whether the curve appears to be asymptotic to the K_{ISCC} value, as illustrated in figure 11.

8 Test report

In reporting the results of tests the information specified in 8.1 to 8.6 shall be given.

8.1 Full description of the test material, including composition, structural condition and mechanical properties, type of product and section thickness from which the specimens were taken.

8.2 Test environment, including chemical constitution, electrochemical conditions, temperature, pressure and method of application (e.g. total immersion, spray, etc.).

8.3 For each specimen

a) specimen type and loading method;

b) thickness, B, in millimetres (and B_n if side-grooved);

c) width W, in millimetres;

d) half height, H, in millimetres [(W-a) indifferent specimens only];

e) fatigue cracking

1) the fatigue stress intensity factor, K_f, during the propagation of the final portion of the crack;

2) the fatigue force ratio, R;

3) the temperature and environment during pre-cracking;

f) the length of the fatigue pre-crack, a;

g) the initial stress intensity, K_Ii;

h) the initial times of exposure to the environment and of loading and the total time of exposure;

i) whether crack extension occurred (or cracked arrest in the case of constant displacement specimens);

j) whether failure occurred and, if so, time to failure;

k) crack plane and propagation direction, identified as shown in figure 6.

8.4 K_Ic (or K_Q if the validity criteria are not obeyed) if determined.

8.5 K_ISCC (or K_QSCC if the validity criteria are not obeyed), stating whether obtained by crack initiation or crack arrest and criteria used.

8.6 Crack growth data (average values or as a function of stress intensity) where available.