SLOVENSKI STANDARD
SIST EN ISO 7539-6:1999

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Korozija kovin in zlitin - Ugotavljanje pokanja zaradi napetostne korozije - 6. del: Priprava in uporaba preskušancev z umetno razpoko (ISO 7539-6:1989)

Corrosion of metals and alloys - Stress corrosion testing - Part 6: Preparation and use of pre-cracked specimens (ISO 7539-6:1989)

Korrosion der Metalle und Legierungen - Prüfung der Spannungsrißkorrosion - Teil 6: Vorbereitung und Anwendung von angerissenen Proben (ISO 7539-6:1989)

Corrosion des métaux et alliages - Essais de corrosion sous contrainte - Partie 6: Préparation et utilisation des éprouvettes préfissurées (ISO 7539-6:1989)

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CEN

European Committee for Standardization
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Foreword

The text of the International Standard from ISO/TC 156 "Corrosion of metals and alloys" of the International Organization for Standardization (ISO) has been taken over as a European Standard by the Technical Committee CEN/TC 262 "Protection of metallic materials against corrosion".

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by December 1995, and conflicting national standards shall be withdrawn at the latest by December 1995.

According to the CEN/CENELEC Internal Regulations, the following countries are bound to implement this European Standard: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Endorsement notice

The text of the International Standard ISO 7539-6:1989 has been approved by CEN as a European Standard without any modification.

INTERNATIONAL STANDARD

ISO 7539-6

First edition
1989-12-15

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

Reference number
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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:

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

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: $K_Q = K_{Ic}$ 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}: $K_{QSCC} = K_{ISCC}$ 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, $R_{p0,2}$.

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

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

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

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

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

$$2{,}5\left(\frac{K_I}{R_{p0,2}}\right)^2$$

and preferably should be not less than

$$4\left(\frac{K_I}{R_{p0,2}}\right)^2$$

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