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Corrosion of metals and alloys — Stress corrosion testing —

Part 6:

Preparation and use of pre-cracked specimens for tests under constant load or constant displacement

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

Partie 6: Préparation et utilisation des éprouvettes préfissurées pour essais sous charge constante ou sous déplacement constant

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 7539-6 was prepared by Technical Committee ISO/TC 156, *Corrosion of metals and alloys*, in collaboration with the National Physical Laboratory (United Kingdom).

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This second edition cancels and replaces the first edition (ISO 7539-6:1989), Clauses 1, 2, 3, 4 and 7; subclause 5.2.5 d); Figures 1, 2 d), 5 b), 8, 9, and 10; Annexs A and B of which have been technically revised.

ISO 7539 consists of the following parts, under the general title *Corrosion of metals and alloys — Stress corrosion testing*:

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- *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 for tests under constant load or constant displacement*
- *Part 7: 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*

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Corrosion of metals and alloys — Stress corrosion testing —

Part 6:
Preparation and use of pre-cracked specimens for tests under constant load or constant displacement

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. It gives recommendations for the design, preparation and use of 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.

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1.2 Because of the need to confine plasticity 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.

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1.3 Pre-cracked specimens may be loaded with equipment for application of a constant load or can incorporate a device to produce a constant displacement at the loading points. Tests conducted under increasing displacement or increasing load are dealt with in ISO 7539-9.

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. The latter data may be taken into account when monitoring parts containing defects during service.

2 Normative references

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

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

ISO 11782-2, *Corrosion of metals and alloys — Corrosion fatigue testing — Part 2: Crack propagation testing using precracked specimens*

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3 Terms and definitions

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

3.1

crack length

a

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

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

side-to-side dimension of the specimen being tested

3.4

reduced thickness at side grooves

B_n

minimum side-to-side dimension between the notches in side-grooved specimens

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3.5

specimen half-height

H

50 % of the specimen height measured parallel to the direction of load application for compact tension, double cantilever beam and modified wedge opening loaded test pieces

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3.6

load

P

that load which, when applied to the specimen, is considered positive if its direction is such as to cause the crack faces to move apart

3.7

deflection at loading point axis

V_LL

crack opening displacement produced at the loading line during the application of load to a constant displacement specimen

3.8

deflection away from the loading line

V_0

crack opening displacement produced at a location remote from the loading plane, e.g. at knife edges located at the notch mouth, during the application of load to a constant displacement specimen

3.9

modulus of elasticity

E

elastic modulus (i.e. stress/strain) in tension

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3.10

stress intensity factor

K_{I}

function of applied load, crack length and specimen geometry having dimensions of stress × $\sqrt{\text{length}}$ which uniquely define the elastic stress field intensification at the tip of a crack subjected to opening mode displacements (mode I)

NOTE It has been found that stress intensity factors, calculated assuming that specimens respond purely elastically, correlate the behaviour of real cracked bodies provided that the size of the zone of plasticity at the crack tip is small compared to the crack length and the length of the uncracked ligament. In this part of ISO 7539, mode I is assumed and the subscript I is implied everywhere.

3.11

initial stress intensity factor

K_{Ii}

stress intensity applied at the commencement of the stress corrosion test

3.12

plane strain fracture toughness

K_{Ic}

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 resistance to plastic deformation

3.13

provisional value of K_{Ic}, K_{Q}

$K_{\mathrm{Q}} = K_{\mathrm{Ic}}$ when the validity criteria for plane strain predominance are satisfied

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3.14

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 resistance to plastic deformation, i.e. under plane strain predominant conditions

3.15

provisional value of K_{ISCC}, K_{QSCC}

$K_{\mathrm{QSCC}} = K_{\mathrm{ISCC}}$ when the validity criteria for plane strain predominance are satisfied

3.16

maximum stress intensity factor

K_{max} in fatigue

highest algebraic value of the stress intensity factor in a cycle, corresponding to the maximum load

3.17

0,2 % proof stress

$R_{\mathrm{p0,2}}$

stress which must be applied to produce a plastic strain of 0,2 % during a tensile test

3.18

applied stress

σ

stress resulting from the application of load to the specimen

3.19

stress intensity factor coefficient

Y

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

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3.20
load ratio
R in fatigue loading
algebraic ratio of minimum to maximum load in a cycle:

$$R = \frac{P_{\text{min}}}{P_{\text{max}}} = \frac{K_{\text{min}}}{K_{\text{max}}}$$

3.21
crack velocity
instantaneous rate of stress corrosion crack propagation measured by a continuous crack monitoring technique

3.22
average crack velocity
average rate of crack propagation calculated by dividing the change in crack length due to stress corrosion by the test duration

3.23
specimen orientation
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 identified by the letters X, Y and Z

where

Z is coincident with the main working force used during manufacture of the material (short-transverse axis);

X is coincident with the direction of grain flow (longitudinal axis);

Y is normal to the X and Z axes

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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 by fatigue, from a machined notch, to either a constant load or displacement at the loading points 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.

4.4 Stress corrosion cracking is influenced by both mechanical and electrochemical driving forces. The latter can vary with crack depth, opening or shape because of variations in crack-tip chemistry and electrode potential and may not be uniquely described by the fracture mechanics stress intensity factor.

4.5 The mechanical driving force includes both applied and residual stresses. The possible influence of the latter shall be considered in both laboratory testing and the application to more complex geometries. Gradients in residual stress in a specimen may result in non-uniform crack growth along the crack front.

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5 Specimens

5.1 General

5.1.1 A wide range of standard specimen geometries of the type used in fracture toughness tests may be applied. 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 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, shall not be 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

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

shall be used to ensure adequate constraint.

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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 used during fracture toughness testing should also be used regarding specimen dimensions, i.e. both a and B shall be not less than

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

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 determining stress corrosion crack growth behaviour as a function of stress intensity is required, the specimen size shall 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 corrodent and impairing 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;

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

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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 readily made via 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

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

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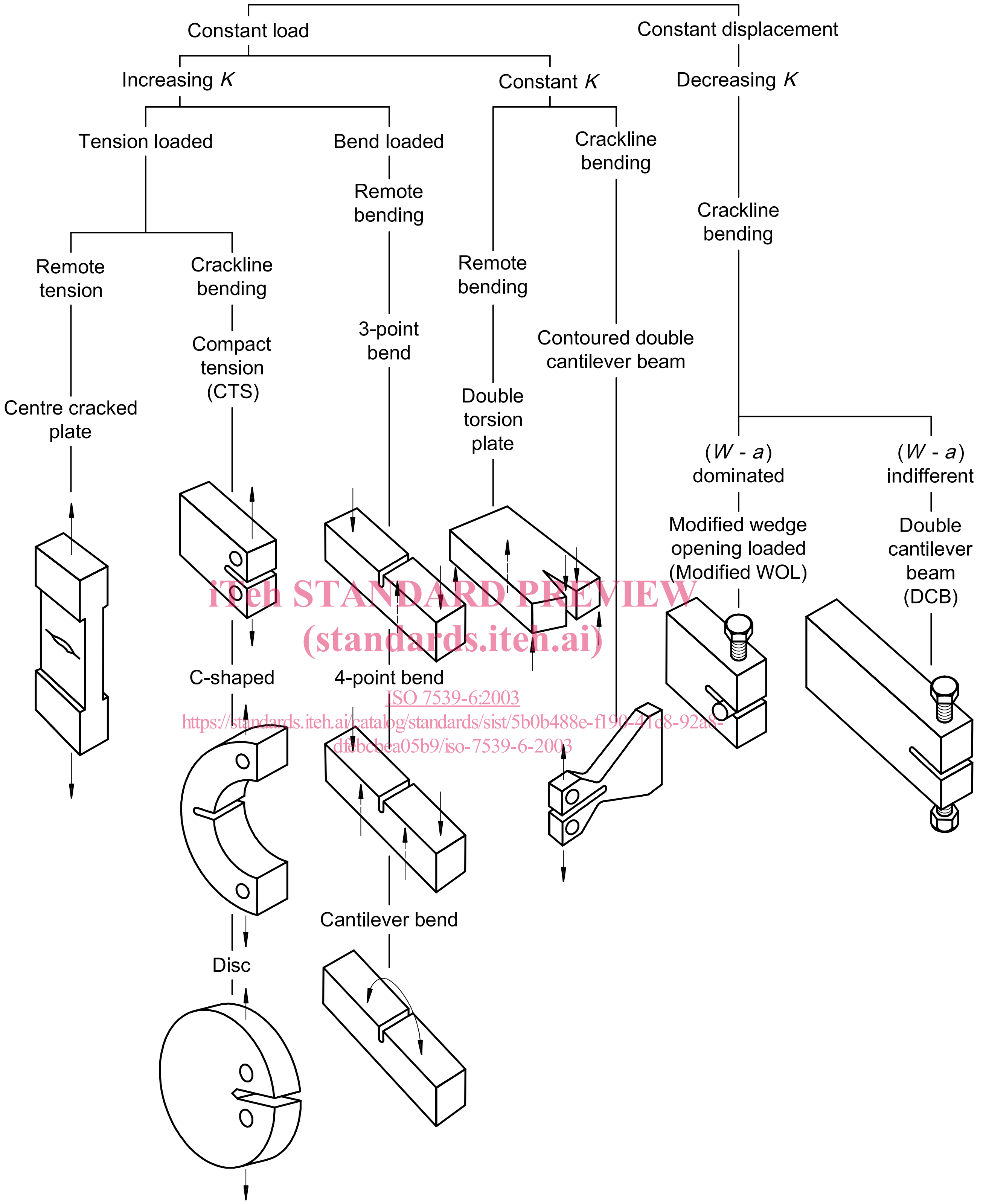

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NOTE Stress intensity factor coefficients for the specimens shown above are available in the published literature.

Figure 1 — Pre-cracked specimen geometries for stress corrosion testing

5.2.2 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.

5.2.3 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.

5.2.4 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.

5.2.5 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:

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a) those which are (W-a) dominated such as the modified wedge opening loaded (modified 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.

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5.2.6 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) modified wedge opening loaded (modified 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 2 to 6.

5.2.7 If required, e.g. if fatigue crack initiation and/or propagation is difficult to control satisfactorily, a chevron notch configuration as shown in Figure 7 may be used. If required, its included angle may be increased from 90° to 120°.

5.2.8 Where it is necessary to measure 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 8 a). Alternatively, separate knife edges can either be screwed or glued onto the specimen at opposite sides of the notch, as shown in Figure 8 b). Details of a suitable tapered beam displacement gauge are given in Figure 9.

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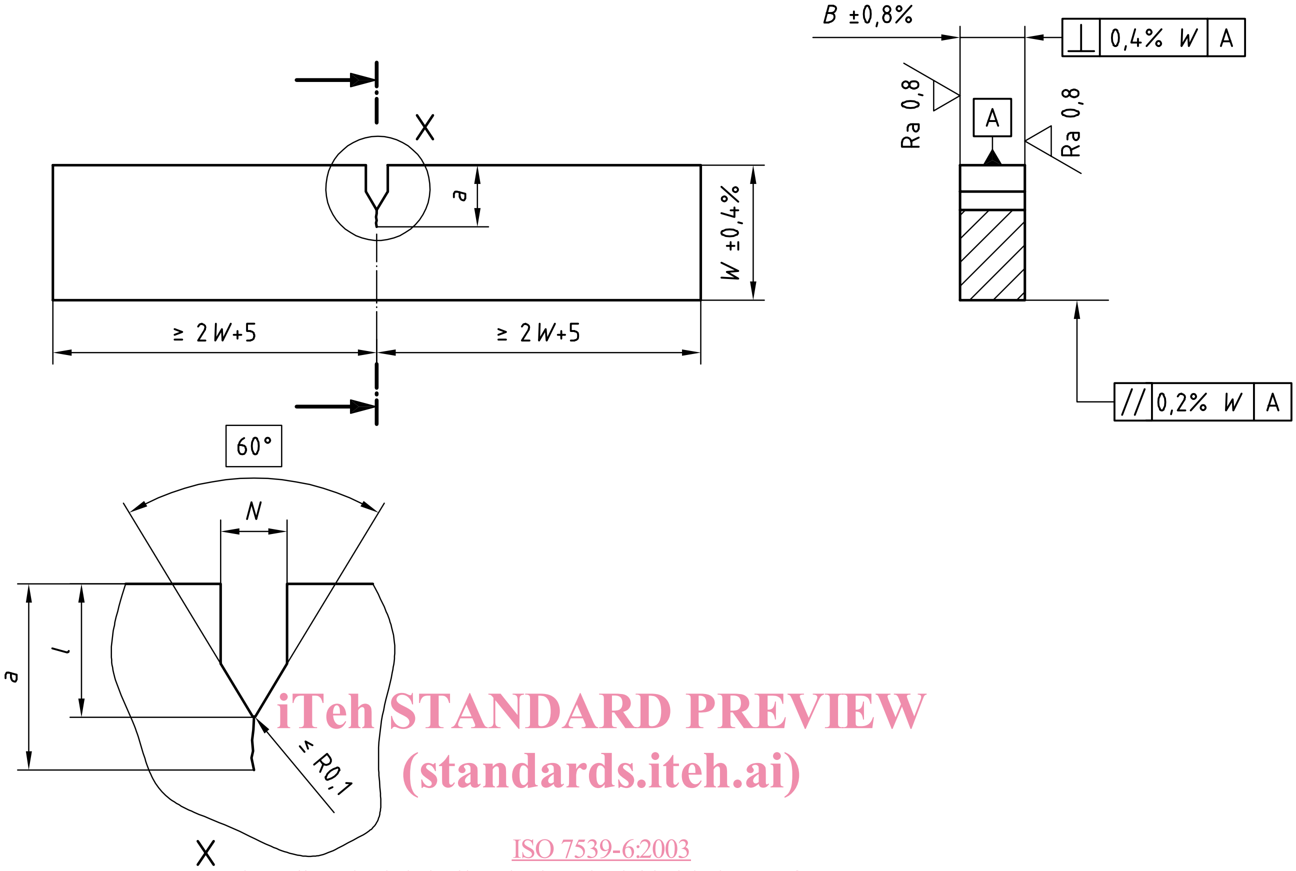
Dimensions in millimetres,
surface roughness values in micrometres



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Width = W
Thickness, B = 0,5 W
Notch width, N = 0,065 W maximum (if $W > 25$ mm) or 1,5 mm maximum (if $W \leqslant 25$ mm)
Effective notch length, l = 0,25 W to 0,45 W
Effective crack length, a = 0,45 W to 0,55 W

Figure 2 — Proportional dimensions and tolerances for cantilever bend test pieces