BS EN ISO 7539-6:2011

BSI Standards Publication

Corrosion of metals and alloys — Stress corrosion testing

Part 6: Preparation and use of precracked specimens for tests under constant load or constant displacement (ISO 7539-6:2011)

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National foreword

This British Standard is the UK implementation of EN ISO 7539-6:2011. It supersedes BS EN ISO 7539-6:2003 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee ISE/NFE/8, Corrosion of metals and alloys.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Korrosion der Metalle und Legierungen - Prüfung der Spannungsrisskorrosion - Teil 6: Vorbereitung und Anwendung von angerissenen Proben für die Prüfung unter konstanter Kraft oder konstanter Verformung (ISO 7539-6:2011)

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Foreword

This document (EN ISO 7539-6:2011) has been prepared by Technical Committee ISO/TC 156 "Corrosion of metals and alloys" in collaboration with Technical Committee CEN/TC 262 “Metallic and other inorganic coatings” the secretariat of which is held by BSI.

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of an identical text or by endorsement, at the latest by April 2012, and conflicting national standards shall be withdrawn at the latest by April 2012.

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

This document supersedes EN ISO 7539-6:2003.

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Endorsement notice

The text of ISO 7539-6:2011 has been approved by CEN as a EN ISO 7539-6:2011 without any modification.

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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.

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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).

This third edition cancels and replaces the second edition (ISO 7539-6:2003), of which it constitutes a minor revision.

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 precracked specimens for tests under constant load or constant displacement*
- *Part 7: Method fo 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*

The following parts are under preparation:

- *Part 10: Testing of alloys using reverse U-bend test method*
- *Part 11: Guidelines for testing the resistance of metals and alloys to hydrogen embrittlement and hydrogen assisted cracking*

Corrosion of metals and alloys — Stress corrosion testing —

Part 6:
Preparation and use of precracked 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 precracked specimens for investigating susceptibility to stress corrosion. It gives recommendations for the design, preparation and use of precracked 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 confine plasticity at the crack tip, precracked 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 Precracked specimens can 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 precracked specimens is that they allow data to be acquired from which critical defect sizes, above which stress corrosion cracking can 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 can 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 11782-2:1998, *Corrosion of metals and alloys — Corrosion fatigue testing — Part 2: Crack propagation testing using precracked specimens*

3 Terms and definitions

For the purposes of this document, the terms and 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

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

3.6
load

P

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

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 with 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

3.14
threshold stress intensity factor for susceptibility to stress corrosion cracking
K_ISCC
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

3.20
load ratio in fatigue loading

R

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

NOTE

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.

4 Principle

4.1 The use of precracked 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 precracked 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, 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.

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 to 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.

From the point of 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 also be used regarding specimen dimensions, i.e. both a and B shall 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 is 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 precrack, in which case a series of specimens must be used to pinpoint 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 three) is often recommended, taking into account the disadvantages described in 5.1.6.

5.1.6 The disadvantages of constant displacement specimens are as follows:

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;

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;

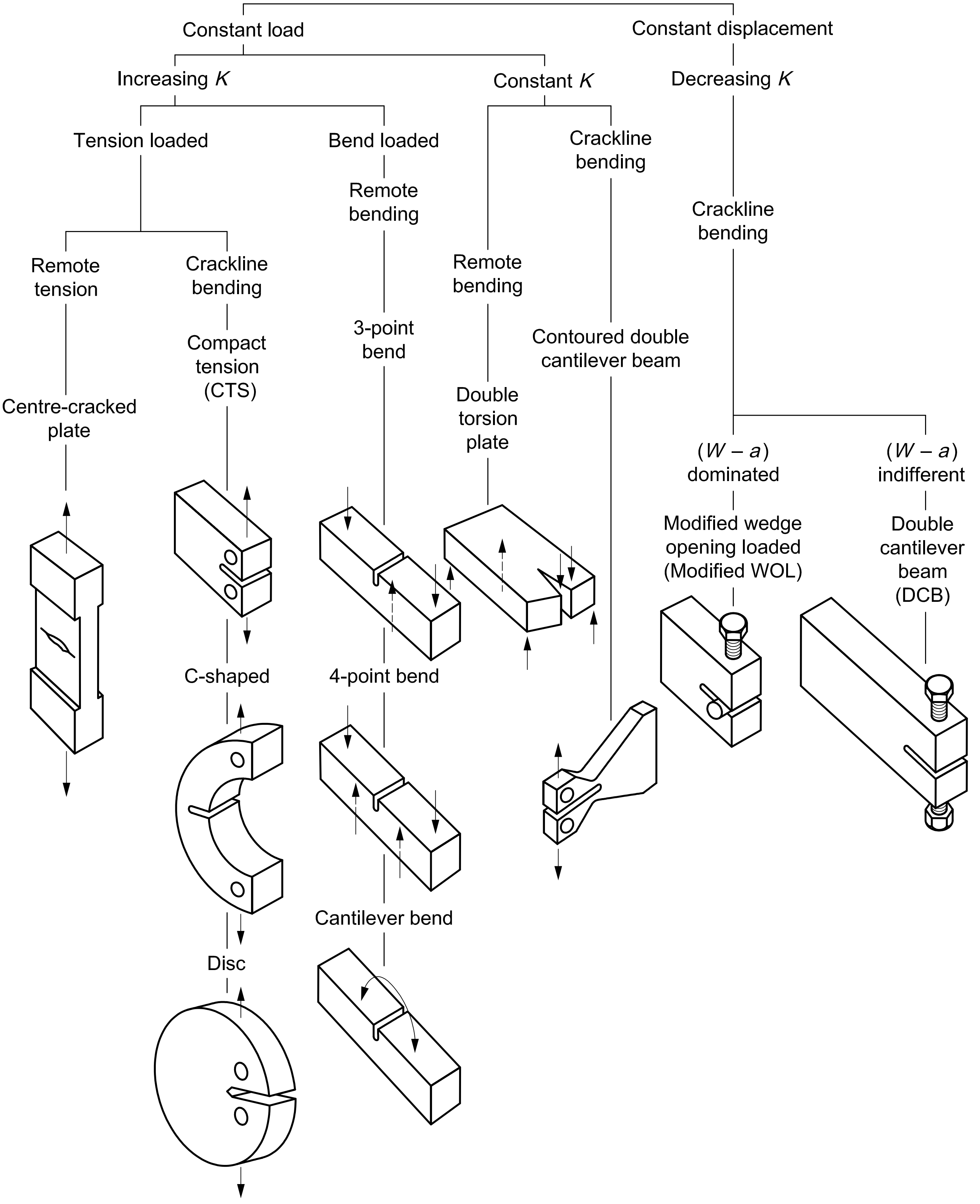
g) it is sometimes impossible to introduce the test environment prior to application of the load, which can retard crack initiation during subsequent testing.

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 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 precracked specimen geometries which are used for stress corrosion testing.



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

Figure 1 — Precracked 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:

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.

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 the following:

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;

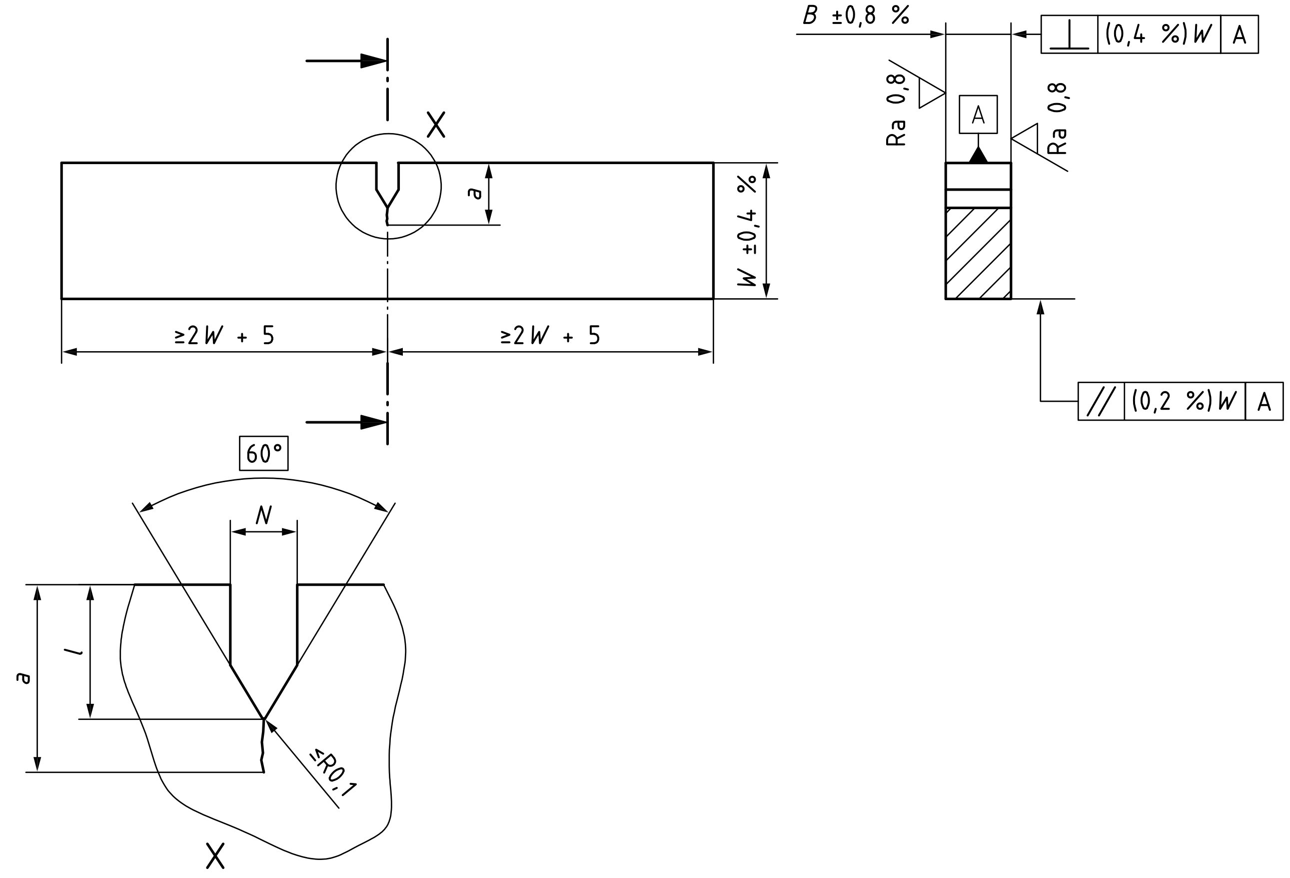
e) C-shaped specimens, which can be machined from thick-walled cylinders in order to study the radial propagation of longitudinally oriented cracks under constant load.

Details of standard specimen designs for each of these types of specimen are given in Figures 2 to 6.

5.2.7 If required, for example 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.

Dimensions in millimetres,
surface roughness values in micrometres



Width = W

Thickness, B = $0{,}5W$

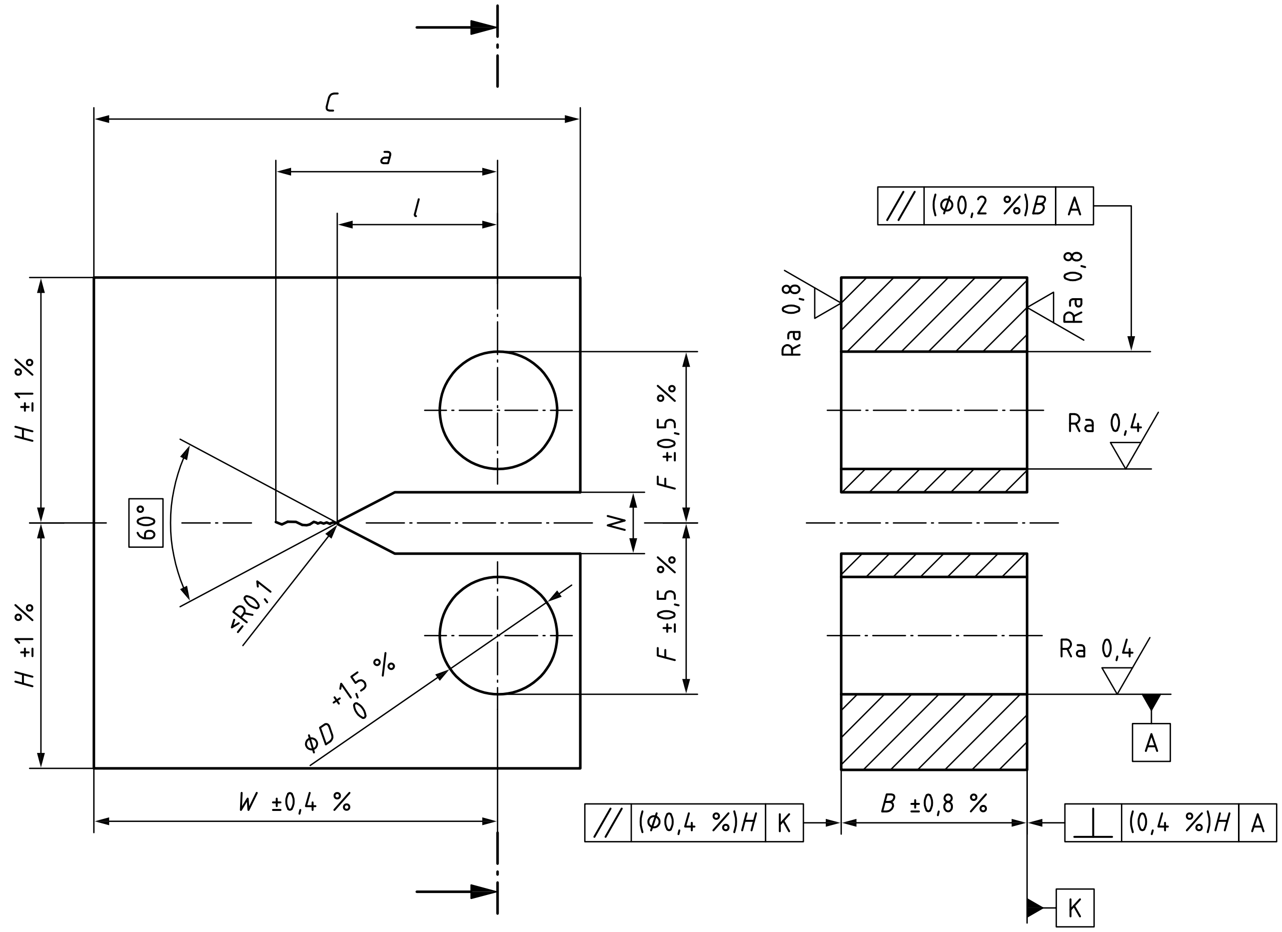
Notch width, N = $0{,}065W$ maximum (if $W > 25$ mm) or 1,5 mm maximum (if $W \leq 25$ mm)

Effective notch length, l = $0{,}25W$ to $0{,}45W$

Effective crack length, a = $0{,}45W$ to $0{,}55W$

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

Dimensions in millimetres,
surface roughness values in micrometres



Net width = W

Total width, C = 1,25W minimum

Thickness, B = 0,5W

Half-height, H = 0,6W

Hole diameter, D = 0,25W

Half-distance between hole outer edges, F = 1,6D

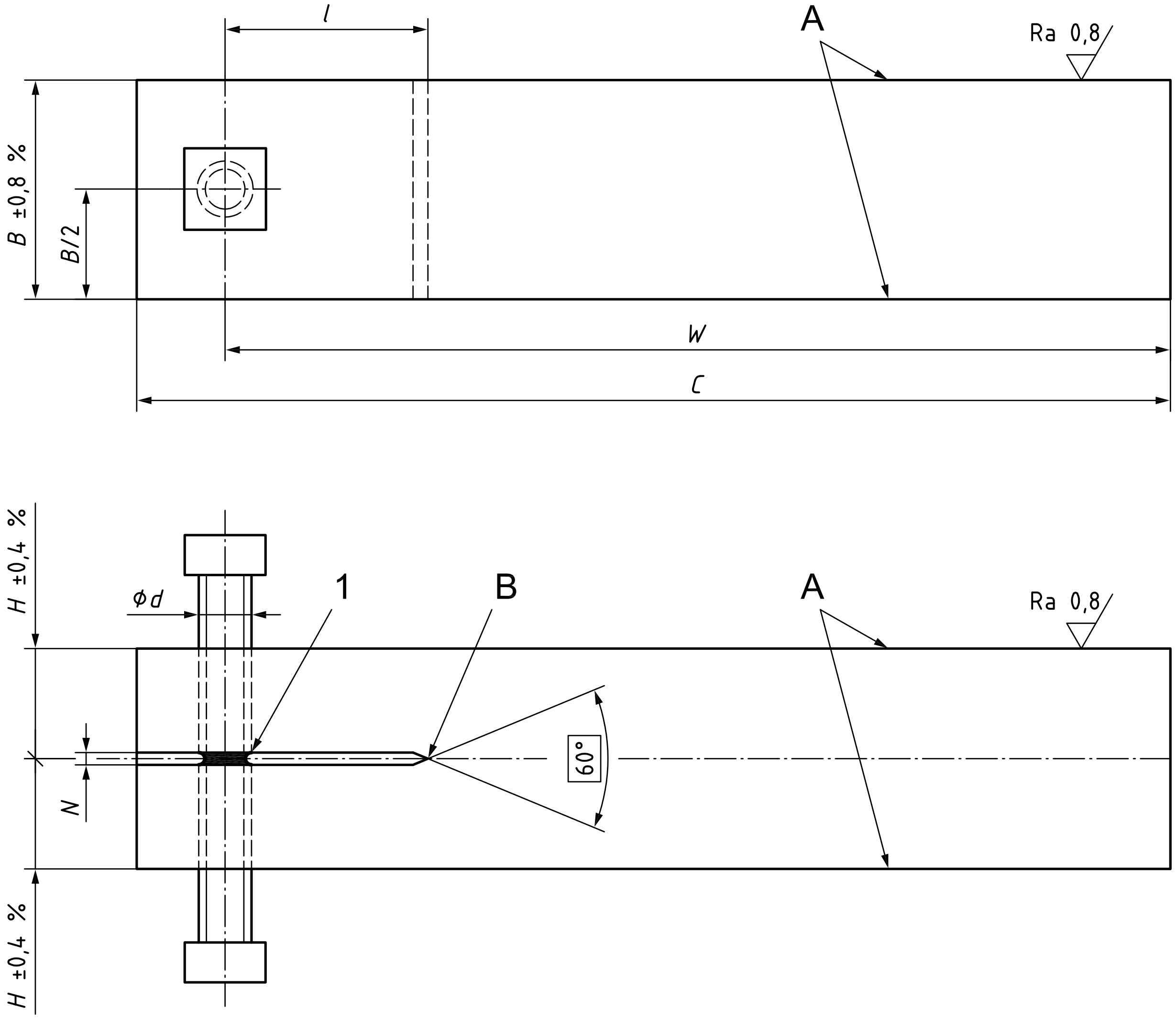
Notch width, N = 0,065W maximum

Effective notch length, l = 0,25W to 0,40W

Effective crack length, a = 0,45W to 0,55W

Figure 3 — Proportional dimensions and tolerances for compact tension test pieces

Dimensions in millimetres,
surface roughness values in micrometres



Key

1 screw tip radius 12,5 to 50

Half-height = H
Thickness, B = $2H$
Net width, W = $10H$ minimum
Total width, C = $W + d$
Screw diameter, d = $0{,}75H$ minimum
Notch width, N = $0{,}14H$ maximum
Effective notch length, l = $2H$

NOTES

1 “A” surfaces should be perpendicular and parallel, as applicable, to within $0{,}002H$ TIR.

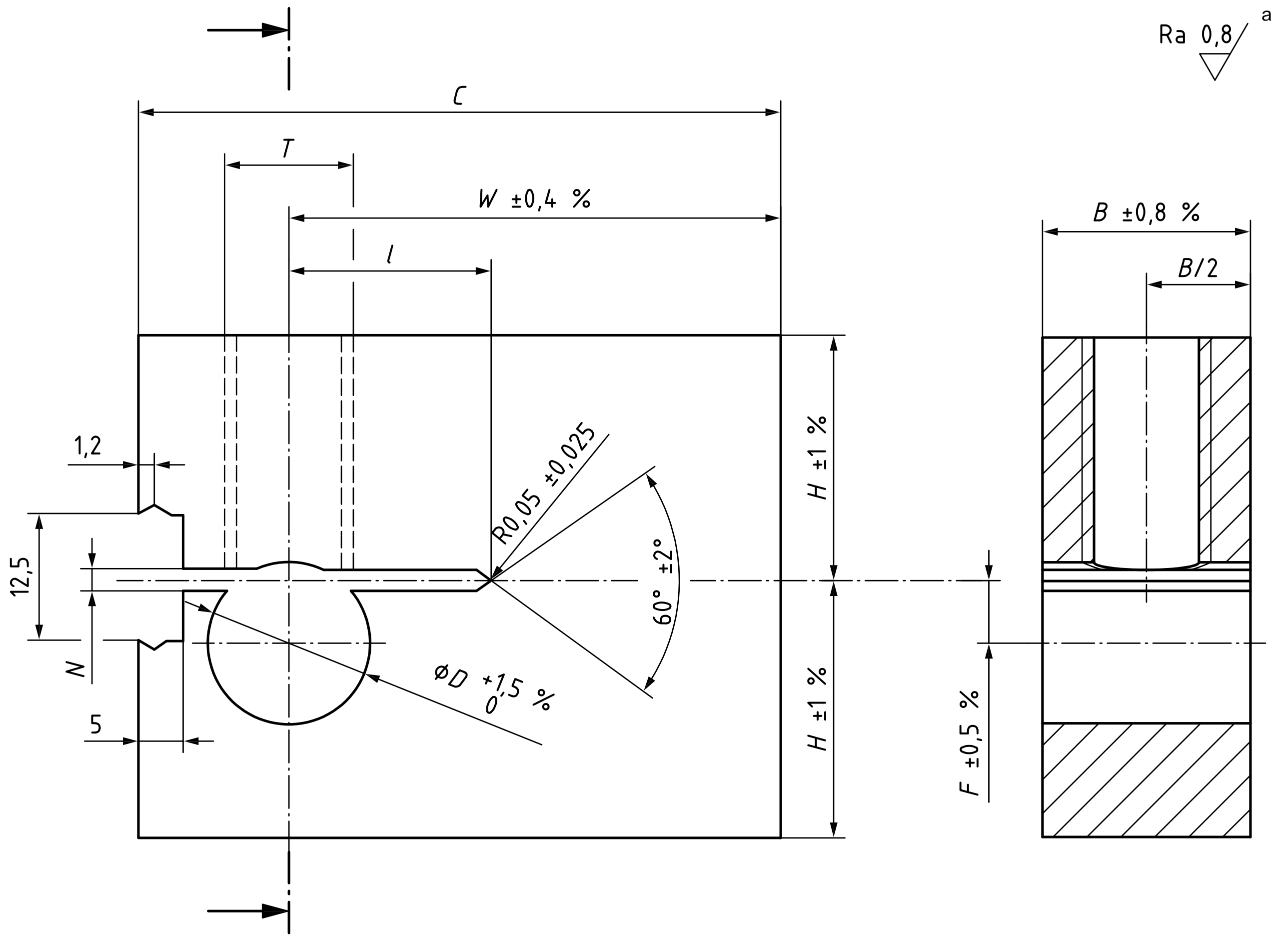
2 At each side point, “B” should be equidistant from the top and bottom surface to within $0{,}001H$.

3 The bolt centreline should be normal to the specimen centreline to within 1°.

4 The bolt material should be similar to that of the specimen, fine-threaded with a square or Allen-screw head.

Figure 4 — Proportional dimensions and tolerances for double-cantilever-beam test pieces

Dimensions in millimetres,
surface roughness values in micrometres



[a] All over.

Thickness = *B*
Net width, *W* = 2,55*B*
Total width, *C* = 3,20*B*
Half-height, *H* = 1,24*B*
Hole diameter, *D* = 0,718*B* ± 0,003*B*
Effective notch length, *l* = 0,77*B*
Notch width, *N* = 0,06*B*
Thread diameter, *T* = 0,625*B*
Distance from hole centreline to notch centreline, *F* = 0,239*B*

NOTES

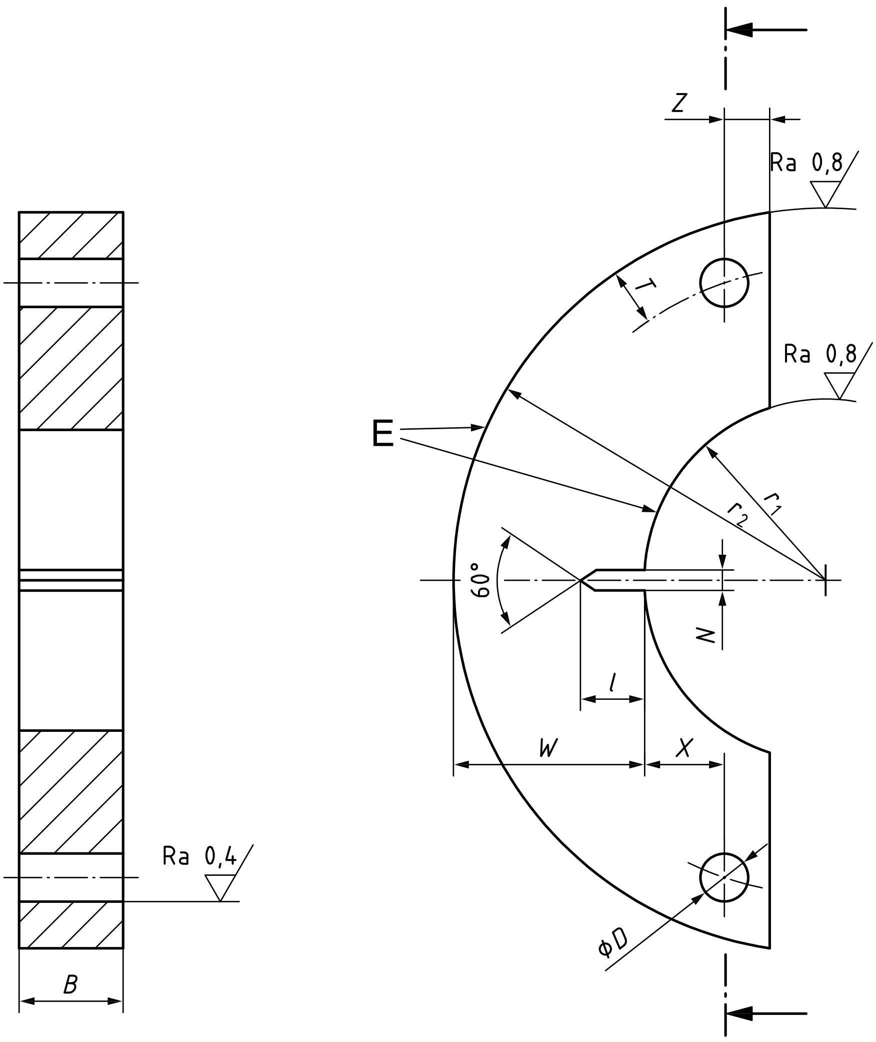
1 The surface should be perpendicular and parallel, as applicable, to within 0,002*H* TIR.

2 The bolt centreline should be normal to the specimen centreline to within 1°.

3 The bolt material should be similar to that of the specimen, fine-threaded with a square or Allen-screw head.

Figure 5 — Proportional dimensions and tolerances for modified wedge-opening-loaded test pieces

Dimensions in millimetres,
surface roughness values in micrometres



Net width = W

Thickness, B = 0,50W ± 0,01W

Distance from the hole axis to a tangent with the inner surface, X = 0,50W ± 0,005W

Notch width, N = 1,5 mm minimum (0,1W maximum)

Notch length, l = 0,3W

Distance from the hole axis to face of specimen, Z = 0,25W ± 0,01W

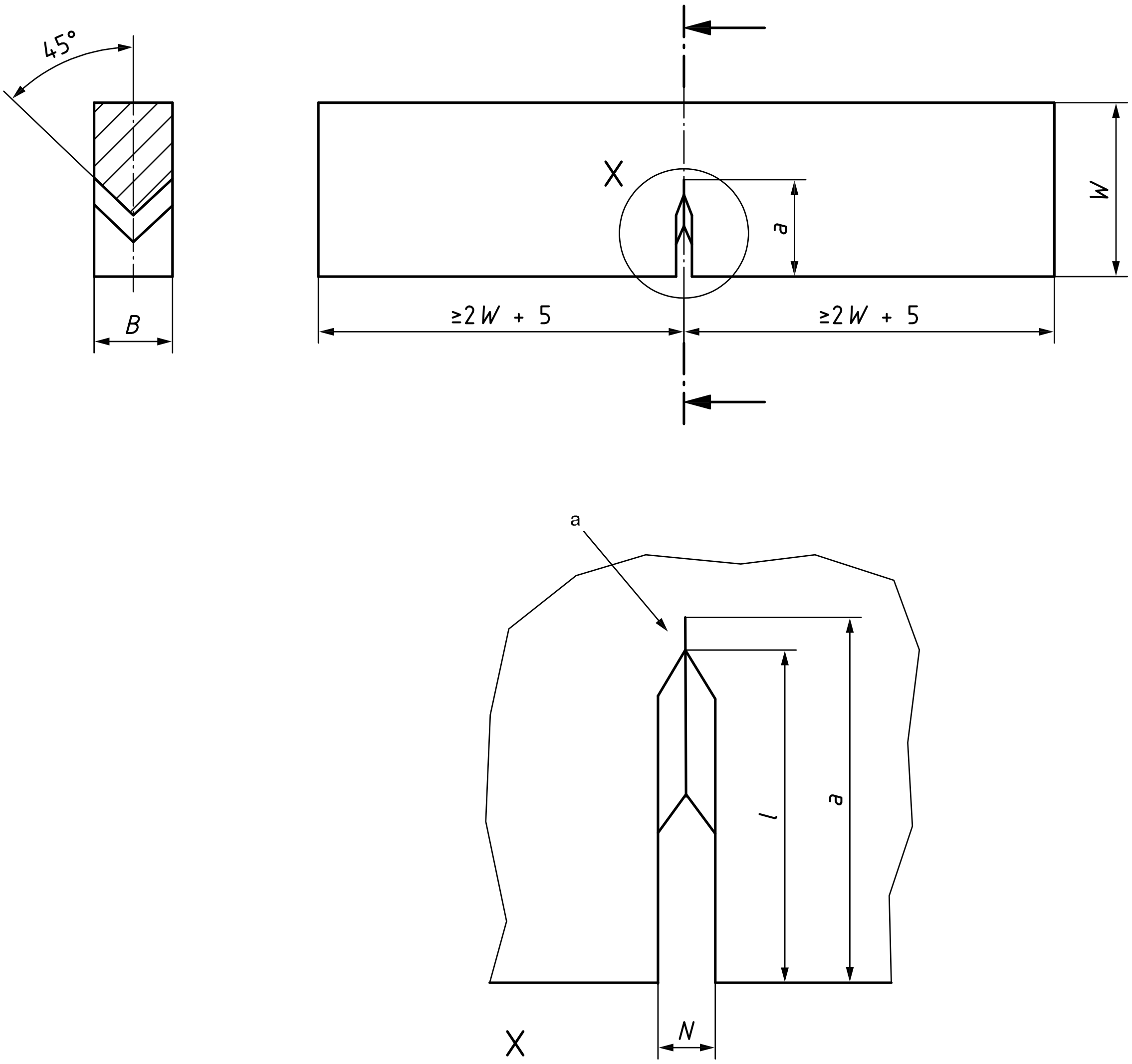
Distance from the hole axis to outer surface, T = 0,25W ± 0,01W

Diameter of holes, D = 0,25W ± 0,005W

NOTE All surfaces should be perpendicular and parallel, as applicable, to within 0,002W TIR and “E” surfaces should be perpendicular to “Y” surfaces to within 0,02W TIR.

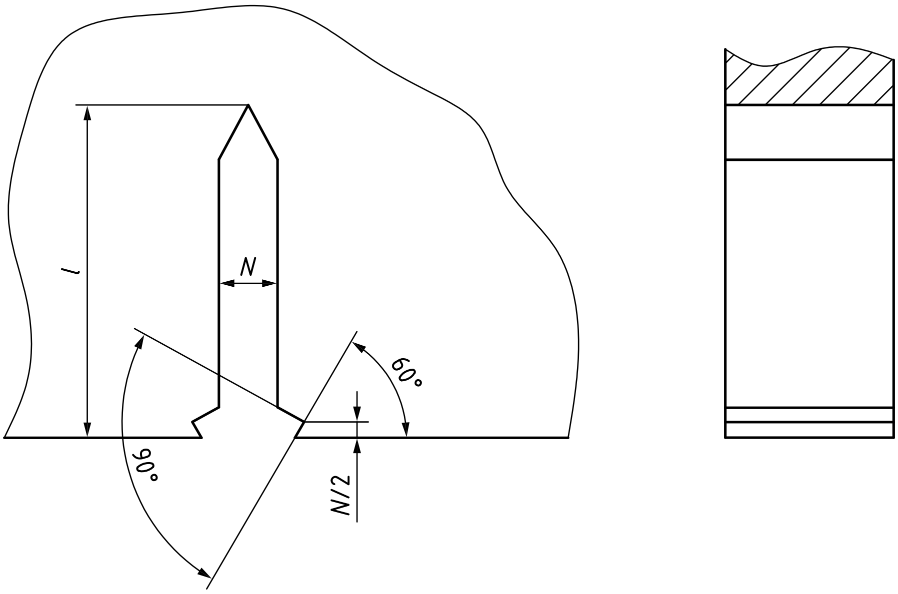
Figure 6 — Proportional dimensions and tolerances for C-shaped test pieces

Dimensions in millimetres

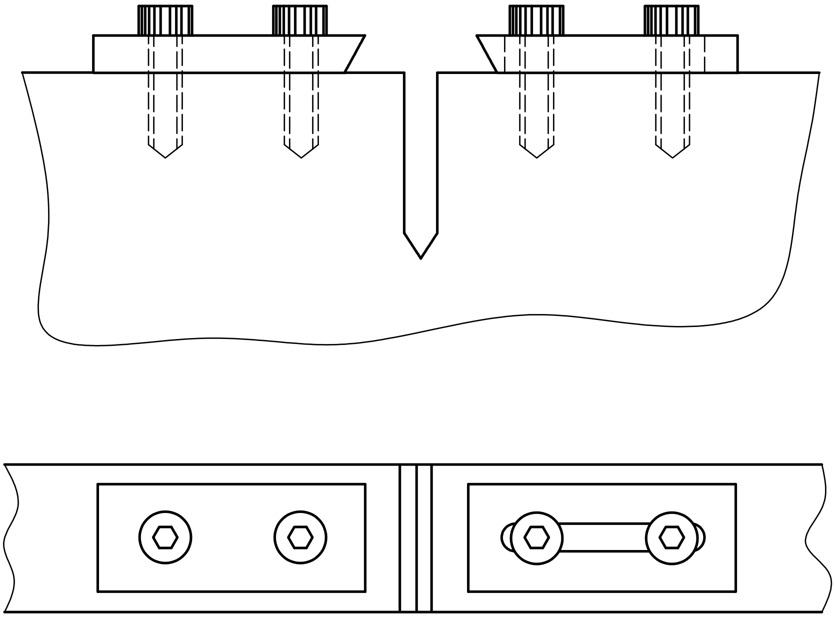


[a] Mill with a 60° cutter; notch root radius 0,3 mm maximum for all test piece sizes.

Figure 7 — Chevron notch



a) Integral type

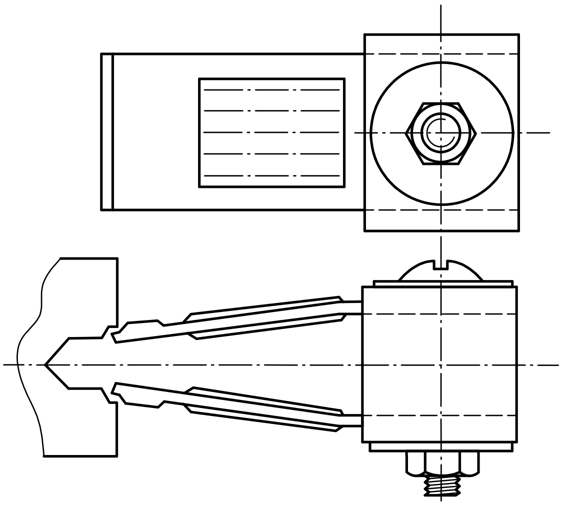


b) Screw-on type

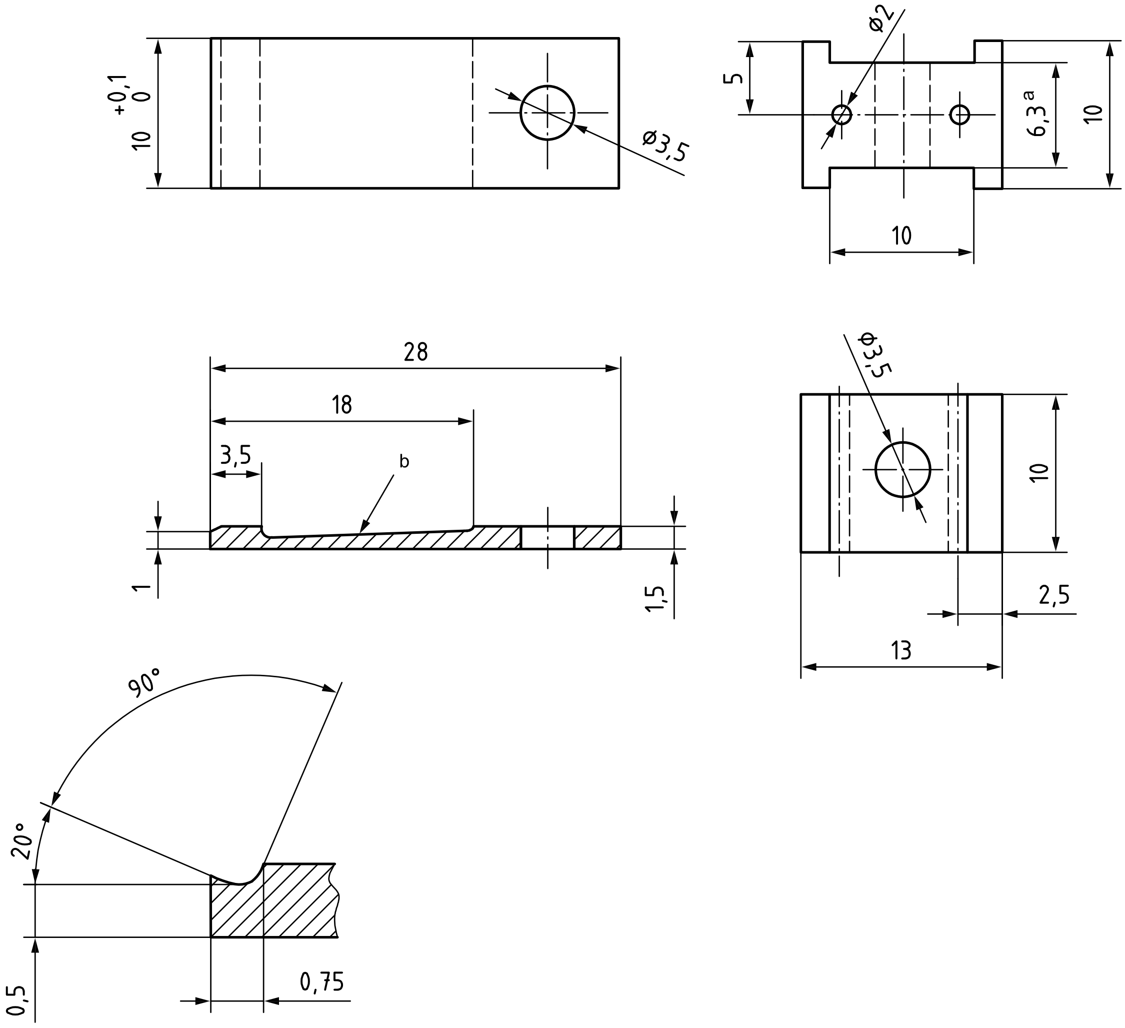
NOTE Provided adequate strength can be assured, the above knife edges may be fixed using adhesive.

Figure 8 — Knife edges for location of displacement gauges

Dimensions in millimetres



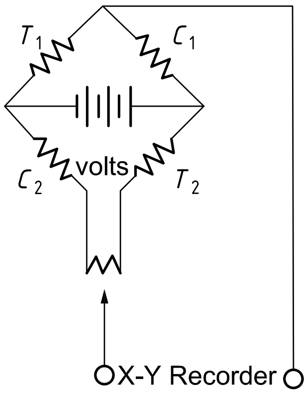
a) **Displacement gauge mounted on a test piece**



b) **Dimensions of beams**

Figure 9 — Details of tapered beam displacement gauge (*continued*)

Dimensions in millimetres



c) Bridge measurement circuit

[a] This dimension should be 3,8 × the minimum initial gauge length.

[b] Beam thickness taper: 0,5 to 0,8.

Strain gauges and materials should be selected to suit the test environment.

Figure 9 — Details of tapered beam displacement gauge

5.3 Stress intensity factor considerations

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

$$K_{\text{I}} = Q \times \sigma \times \sqrt{a}$$

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 a 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 Stress intensity factors 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 a stress intensity function of the form:

$$K_{\text{I}} = \frac{YP}{B\sqrt{W}}$$

for compact tension or C-shaped specimens or

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

for T-type wedge-opening-loaded specimens or

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

for double-cantilever-beam specimens.

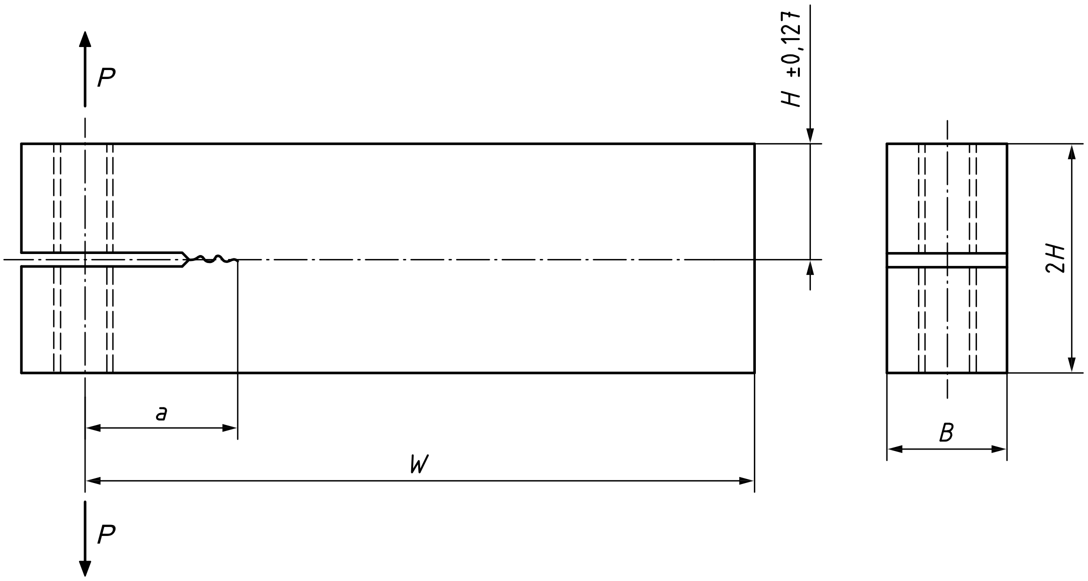
5.3.4 Where it is necessary to use side-grooved specimens in order to curb crack branching tendencies, etc., shallow side grooves (usually 5 % of the specimen thickness on both sides) can be used. Either semi-circular or 60° V-grooves can be used, but it should be noted that, even with semi-circular 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 used, 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

$$\sqrt{B \times B_{\mathrm{n}}}$$

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 10 to 14.

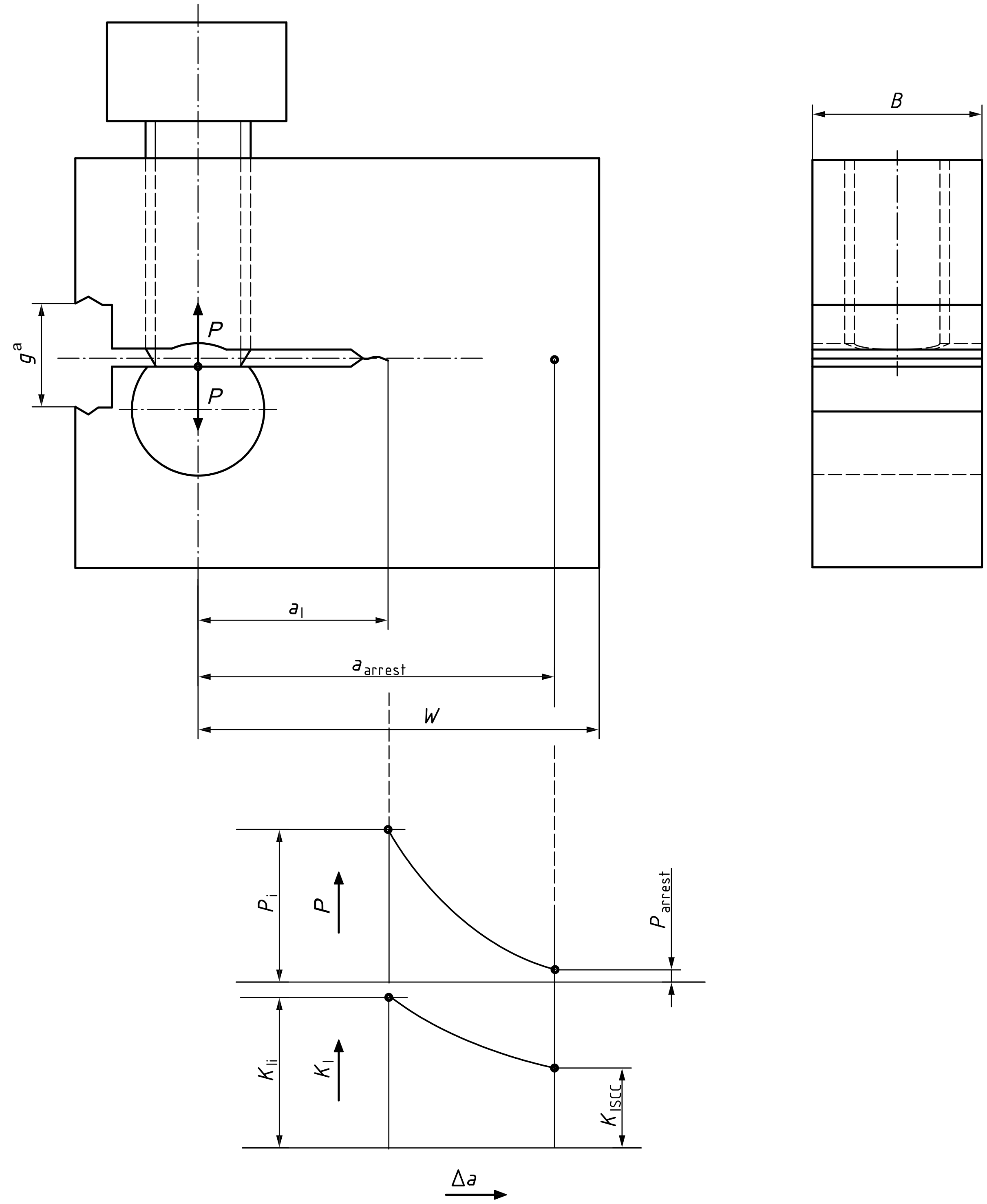
Dimensions in millimetres



$$K_{\mathrm{I}} = \frac{E \times V_{\mathrm{yLL}} H \sqrt{3H(a+0{,}6H)^2 + H^3}}{4\left[(a+0{,}6H)^3 + H^2 a\right]}$$

NOTE This expression was derived from elastic compliance theory and, although its inaccuracy and validity limits are not well-defined, it has been used over the range $2 \le \frac{a}{H} \le 5$. For greater confidence, it is recommended that an empirical compliance be used.

Figure 10 — Stress intensity factor solution for double-cantilever-beam specimen [(W-a) indifferent]



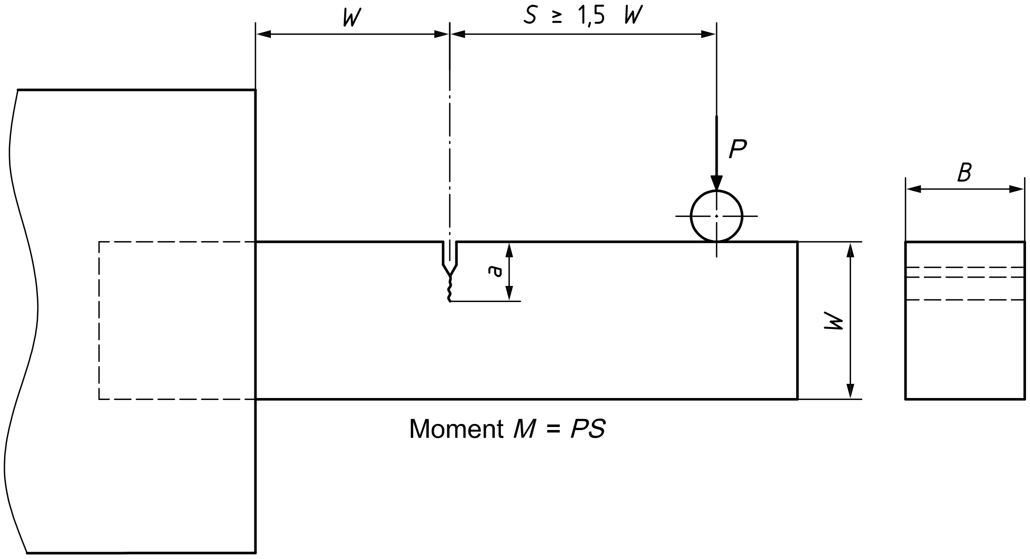
[a] V, the crack-opening displacement (COD) for a rigid bolt, is a constant $(g - g_i)$.

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

where $Y = 30{,}96\left[\frac{a}{W}\right] - 195{,}8\left[\frac{a}{W}\right]^2 + 730{,}6\left[\frac{a}{W}\right]^3 - 1\,186{,}3\left[\frac{a}{W}\right]^4 + 754{,}6\left[\frac{a}{W}\right]^5$

NOTE This expression was derived from elastic compliance theory and, although its inaccuracy and validity limits are not well-defined, it has been used over the range $0{,}3 \le \frac{a}{W} \le 0{,}8$. For greater confidence, it is recommended that an empirical compliance be used.

Figure 11 — Stress intensity factor solution for modified wedge-opening-loaded specimen

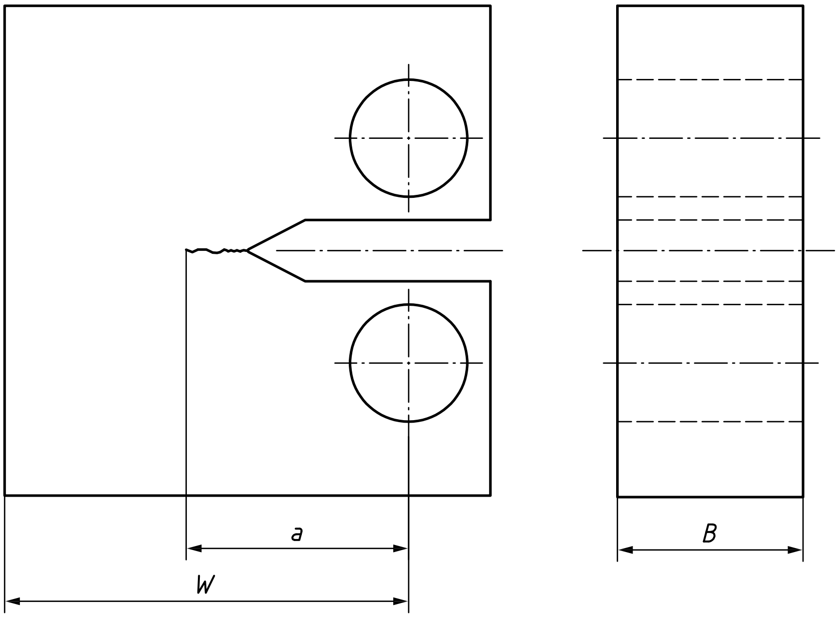


$$K_{\mathrm{I}} = \frac{YP}{B\sqrt{W}}$$

where $Y = 6{,}21\sqrt{\frac{1}{\left(1-\frac{a}{W}\right)^3} - \left(1-\frac{a}{W}\right)^3}$ in the case where $S = 1{,}5W$

NOTE This expression was originally derived from the combined techniques of stress analysis and compliance and, although its inaccuracy and validity limits are not well-defined, it has been used over the range $0{,}2 \le \frac{a}{W} \le 0{,}6$. For greater confidence, it is recommended that an empirical compliance be used.

Figure 12 — Stress intensity factor solution for cantilever bend specimens

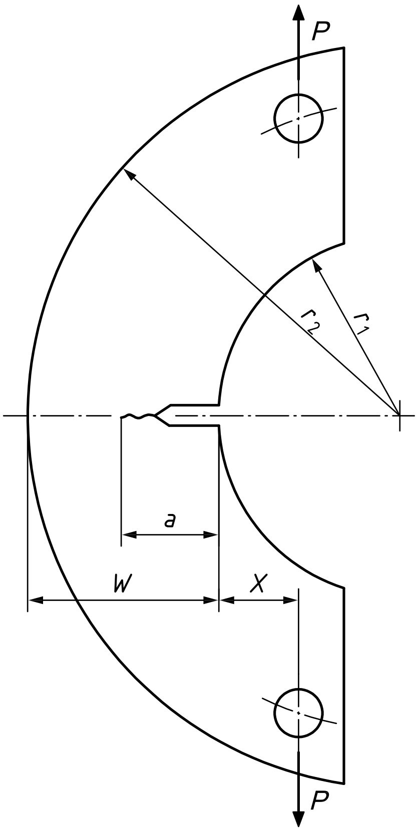


$$K_I = \frac{YP}{B\sqrt{W}}$$

where $Y = \dfrac{2+\dfrac{a}{W}}{\sqrt{\left(1-\dfrac{a}{W}\right)^3}}\left[0{,}886+4{,}64\left(\dfrac{a}{W}\right)-13{,}32\left(\dfrac{a}{W}\right)^2+14{,}72\left(\dfrac{a}{W}\right)^3-5{,}6\left(\dfrac{a}{W}\right)^4\right]$

NOTE The inaccuracy of this expression is considered to be no greater than ±0,5 % over the range $0{,}2 \le \dfrac{a}{W} \le 1{,}0$.

Figure 13 — Stress intensity factor solution for compact tension specimens



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

where

$$Y = \left(18{,}23\sqrt{\frac{a}{W}} - 106{,}2\sqrt{\frac{a^3}{W}} + 397{,}7\sqrt{\frac{a^5}{W}} - 582{,}0\sqrt{\frac{a^7}{W}} - 369{,}1\sqrt{\frac{a^9}{W}}\right) \times \left(1 + 1{,}54\frac{X}{W} + 0{,}5\frac{a}{W}\right) \times \left[1 + 0{,}22\left(1 - \sqrt{\frac{a}{W}}\right)\left(1 - \frac{r_1}{r_2}\right)\right]$$

NOTE The inaccuracy of this expression is considered to be no greater than 1 % over the range $0{,}45 \le \frac{a}{W} \le 0{,}55$. However, it can be used over the wider range $0{,}3 \le \frac{a}{W} \le 0{,}7$ when $0 \le \frac{X}{W} \le 0{,}7$ and $0 \le \frac{r_1}{r_2} \le 1$, in which case the accuracy is believed to be no greater than 2 %.

Figure 14 — Stress intensity factor solution for C-shaped specimens

5.4 Specimen preparation

5.4.1 Residual stresses can have an influence on stress corrosion cracking. The effect can be significant when test specimens are removed from material in which complete stress relief is impractical, such as weldments, as-quenched materials and complex forged or extruded shapes. Residual stresses superimposed on the applied stress can cause the localized crack-tip stress intensity factor to be different from that computed solely from externally applied loads. The presence of significant residual stress often manifests itself in the form of irregular crack growth, namely excessive crack front curvature or out-of-plane crack growth, and generally indicates that residual stresses are affecting behaviour. Measurement of residual stress is desirable.

5.4.2 Specimens of the required orientation (see Figure 15) 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 take place 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.

5.4.3 After machining, the specimens shall be fully degreased in order to ensure that no contamination of the crack tip occurs during subsequent fatigue precracking 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 shall be degreased following this operation prior to precracking 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

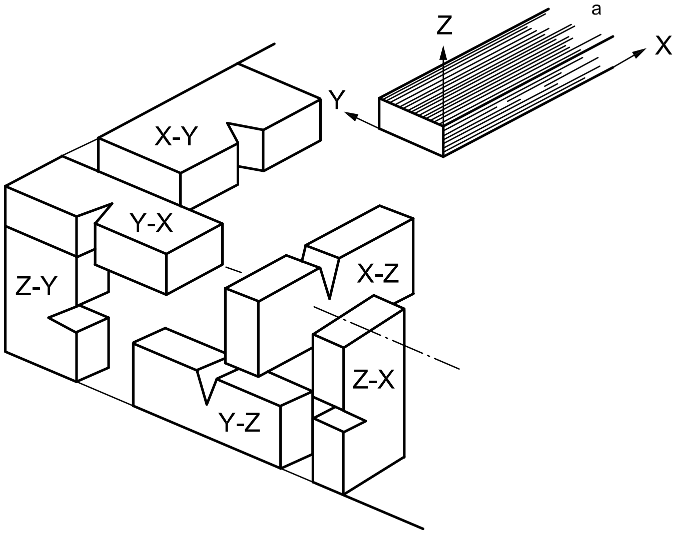
6.1 The machine used for fatigue cracking shall have a means of loading such that the stress distribution is symmetrical about the notch and the applied load shall be known to an accuracy of ±2,5 %.

6.2 The environmental conditions apparent during fatigue precracking, 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 precracking operation will promote a change from the normal ductile transgranular mode of fatigue cracking to one that more closely resembles stress corrosion cracking. This may facilitate the subsequent initiation of stress corrosion cracking and lead to the determination of conservative initiation values of K_{ISCC}. However, unless facilities are available to commence stress corrosion testing immediately following the precracking operation, corrodent remaining at the crack tip may promote blunting due to corrosive attack.

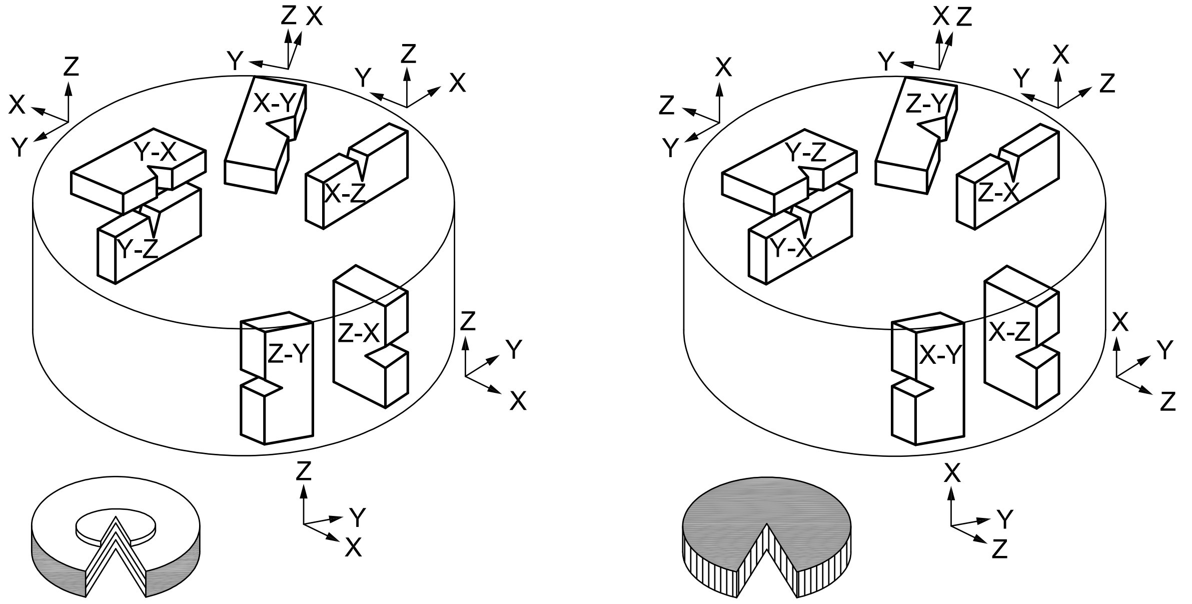
Furthermore, the reproducibility of results may suffer when precracking is conducted in the presence of an aggressive environment because of the greater sensitivity of the corrosion fatigue fracture mode to the cyclic loading conditions. In addition, more elaborate facilities may be needed for environmental control purposes during precracking. For these reasons, it is recommended that, unless agreed otherwise between the parties, fatigue precracking shall be conducted in the normal laboratory-air environment.

6.3 The specimens shall be precracked 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 K_{I} values higher than the expected K_{ISCC} but, during the final 0,5 mm of crack extension, the fatigue precracking shall be completed at as low a maximum stress intensity as possible (less than 60 % of the expected K_{ISCC}).

NOTE Load shedding procedures, as described in ISO 11782-2, might be helpful when the K_{ISCC} values are expected to be low.

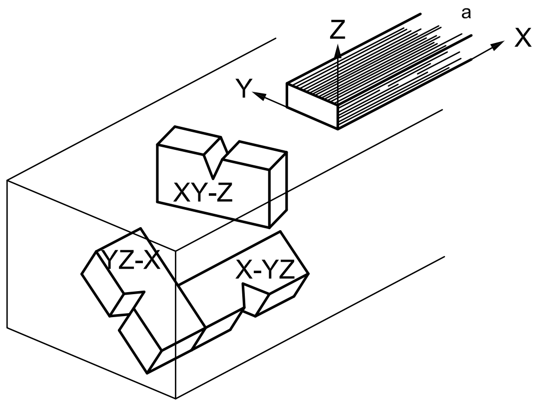


a) Basic fracture plane identification: rectangular section



1) Radial grain flow — Axial working direction 2) Axial grain flow — Radial working direction

b) Basic fracture plane identification: cylindrical sections



c) Non-basic fracture plane identification

[a] Grain flow.

Figure 15 — Fracture plane identification

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

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

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-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 shall lie within the limiting envelope as shown in Figure 16 in which examples for bend and tensile pieces are shown. For the example valid for bend or tensile test pieces, if the apex of the envelope is located at the tip of the fatigue crack, the whole of the machined notch shall lie within the envelope as is shown in Figure 16 c).

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

6.7 Additional guidance on fatigue precracking procedures is available in ISO 11782-2.

7 Procedure

7.1 General

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 precrack 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).

7.2 Environmental considerations

7.2.1 Because of the specificity of metal-environment interactions, it is essential that stress corrosion crack propagation tests be conducted under environmental conditions which are closely controlled (see 7.2.3 and 7.2.4).

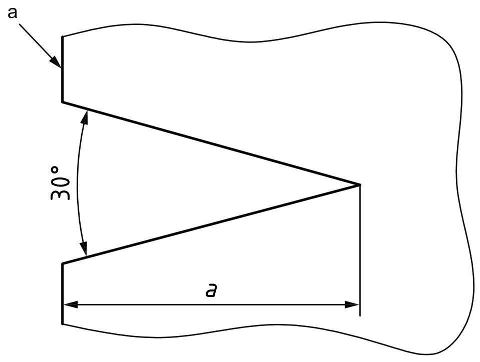
7.2.2 The environmental testing conditions depend upon the intent of the test but, ideally, shall be the same as those prevailing for the intended use of the alloy or comparable to the anticipated service condition.

7.2.3 Environmental factors of importance are electrode potential, temperature, solution composition, pH, concentration of dissolved gases, flowrate and pressure. ISO 7539-1 provides useful background information. In relation to gaseous environments, a critical factor is the purity of the gas.

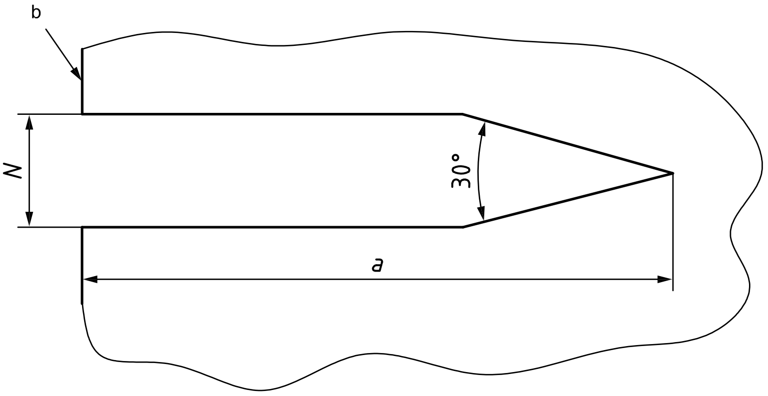
7.2.4 Tests may be conducted under open circuit conditions in which the electrode potential of the metal is dependent on the specific environmental conditions of the test, of which the degree of aeration is an important factor. Alternatively, the electrode potential may be displaced from the open circuit value by potentiostatic or galvanostatic methods.

7.2.5 Auxiliary electrodes to apply external current shall be designed to produce uniform current distribution on the specimen, i.e. the electrode potential shall be constant.

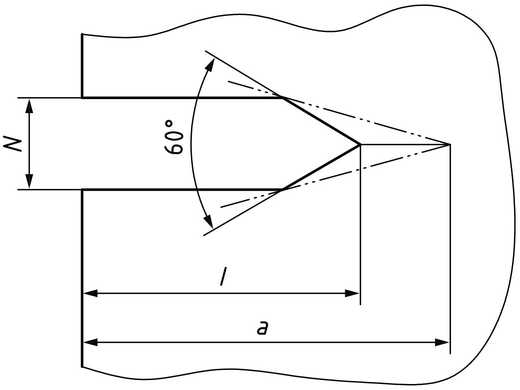
7.2.6 When practical, it is recommended that the specimens be stressed after being brought into contact with the test environment, otherwise, the stressed specimens shall be exposed to the test environment as soon as possible after stressing.



a) Bend test piece



b) Tensile test piece



c) Bend or tensile test piece

[a] Edge of test piece.

[b] Loading line of test piece.

Figure 16 — Envelope limiting size and form of notch and fatigue crack

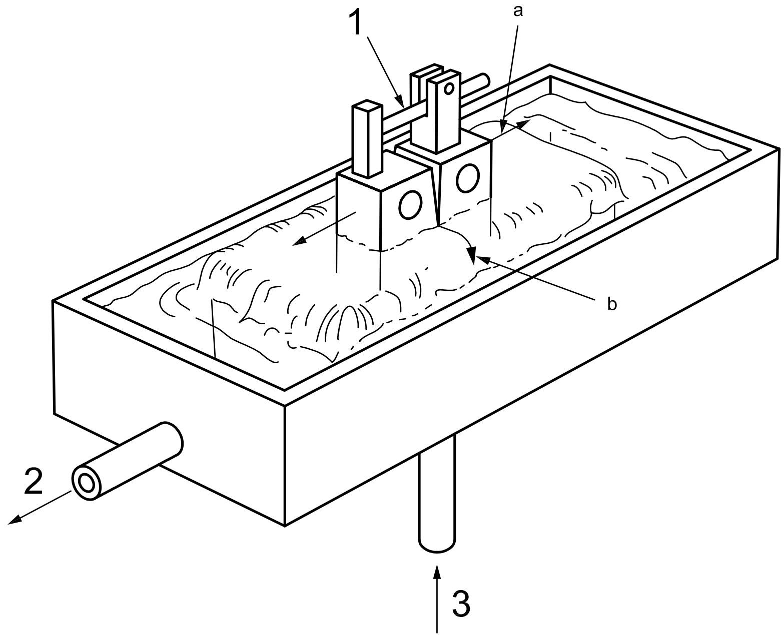
7.3 Environmental chamber

7.3.1 The environmental chamber shall completely enclose the test section of the specimen. Wherever possible, the gripped portions shall be excluded from contact with the solution environment in order to prevent galvanic effects and crevice corrosion. These problems can be overcome by the use of a local environmental cell of the type shown in Figure 17 in which the environment is circulated around the vicinity of the notch, precrack and anticipated crack growth region of the specimen. Crevice problems may also arise where the specimen emerges from the test cell and these shall be avoided by appropriate design of the cell or by the use of protective coatings at such locations. If total immersion in the corrodent is contemplated, the loading points shall be protected against corrosion. If this is not possible, appropriate measures shall be taken through, for example, the use of similar metals, electrical insulation or coatings.

7.3.2 An adequate volume of solution to metal area ratio is required (dependent on reaction rates and exposure time) and a circulation system is usually necessary. For conditions of applied potential or applied current, a separate compartment for the counter electrode may be necessary in order to limit any effects caused by reaction products from this electrode. 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.

7.3.3 Non-metallic materials are recommended for the environmental chamber and circulation system where this is practicable. These materials shall be inert. Note that glass and certain plastics are not inert at elevated temperatures. Where metallic chambers are necessary, these shall be electrically insulated from the specimen in order to prevent galvanic interaction.

7.3.4 For tests in a gaseous environment, an all-metal chamber is preferred.



Key

1 displacement transducer
2 solution outlet
3 solution inlet

[a] Load.

[b] Solution flow.

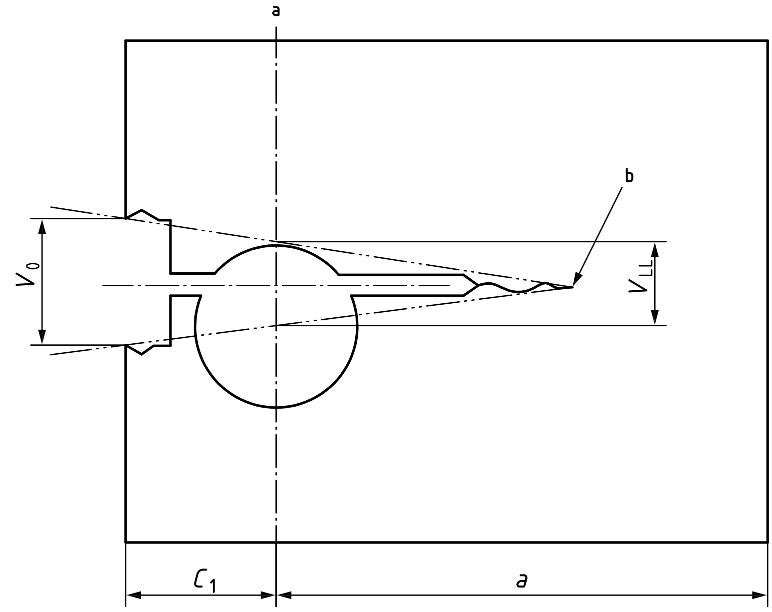
Figure 17 — Position of a typical environmental cell on a fracture-mechanics specimen

7.4 Environmental control and monitoring

7.4.1 The environment shall be monitored and controlled during the test as required. In unbuffered systems, the pH can be maintained constant using an automatic pH control system; otherwise the effect of any variations in pH on crack growth shall be assessed.

7.4.2 In systems open to the atmosphere, aeration can be maintained by bubbling air through the solution. In closed systems, monitoring is required. The flowrates used in testing should simulate the range of conditions in service because flow can affect the electrode potential, e.g. by influencing the flux of oxygen, and mass transfer between the crack enclave and the bulk solution. The orientation of flow with respect to the crack can be important in the latter case. Sealing of the crack sides to limit artificial through-thickness transport should be considered but may introduce local crevice problems.

7.4.3 It is strongly recommended that the electrode potential be measured with a reference electrode appropriate for the application. Care shall be taken to limit IR drop in the measurement of potential. The temperature of the solution should be controlled to ±2 °C.



$$V_{LL} = \frac{V_0}{\left(1 + \frac{3C_1}{2a}\right)}$$

[a] Load.

[b] Crack tip.

Figure 18 — Measurement location and relation between V_0 and V_{LL} values

7.5 Determination of K_{ISCC} by crack arrest

7.5.1 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.

7.5.2 For the determination of K_{ISCC} by crack arrest, the precracked specimen shall be fixed in a holding device and, if practical, the environmental conditions shall be applied to the region of the notch root.

7.5.3 The arms of the specimen shall then be deflected by turning a bolt to give a predetermined K_{Ii} value in excess of the anticipated K_{ISCC} value. Over-deflection shall be avoided. The deflection, V_{LL}, at the loading line can be related to the deflection, V_0, measured by the displacement gauge at knife edges located at the notch mouth, by means of the procedure illustrated in Figure 18. The sensitivity of the displacement gauge shall 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 shall 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 the recorded value for larger displacements.

Loading can be applied to the specimen after carrying out a load/displacement calibration conducted up to a loading level which does not exceed that aimed at for the stress corrosion cracking test.

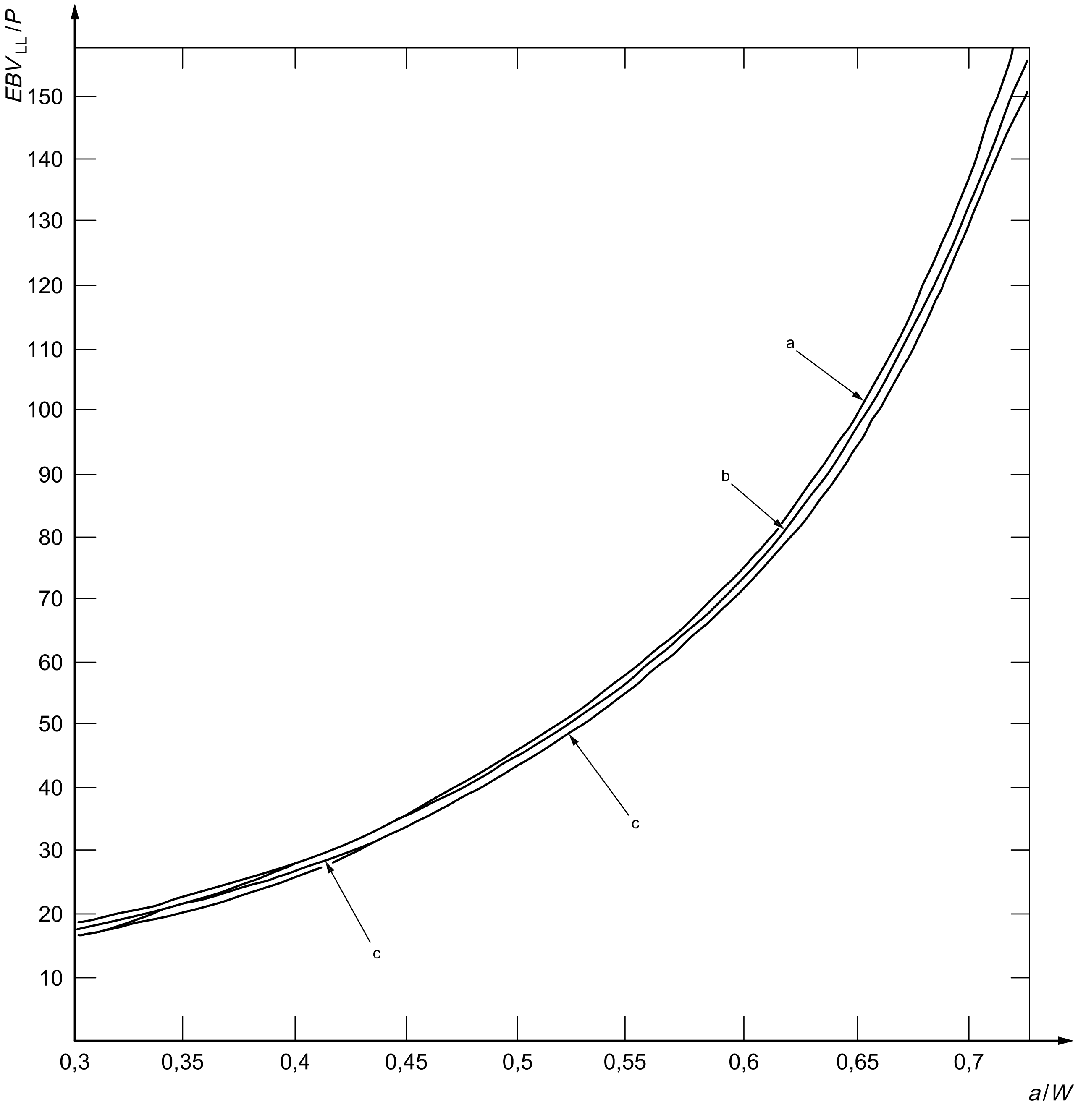
For the (W-a) indifferent DCB specimen, the deflection required to give the desired stress intensity, K_{Ii}, for a given value of a/H can be calculated from the relationship between K_{I} and V_{LL} given in Figure 10.

In the case of the (W-a) dominated modified WOL specimen, a knowledge of the unique compliance calibration is necessary in order 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 11. Typical compliance calibration curves for the smooth and side-grooved modified WOL specimens are shown in Figure 19. After loading, the displacement gauge shall be removed.

7.5.4 Once the environmental conditions are 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 at an arbitrarily selected crack growth rate. The most appropriate value of the arrest growth rate depends on the metal/environment system under consideration and shall 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 an approximation of this is known.

7.5.5 When crack arrest is deemed to have occurred, the final load and final crack length shall be determined, from which the stress intensity at crack arrest can be calculated, to give a provisional value of K_{ISCC} (K_{QSCC}). The final load can be determined 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 shall then be broken open and the final maximum and minimum lengths of the stress corrosion crack measured on the fracture surface to the nearest 0,5 % W. The final length of the stress corrosion crack shall also be measured with the same degree of precision at the following three positions from one edge: 0,25B, 0,50B and 0,75B.

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



[a] Smooth, theoretical.

[b] 5 % face, notched, experimental.

[c] Smooth, experimental.

Figure 19 — Comparison of wedge-opening-loaded specimen compliance at central loadline

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 $2{,}5\left(\frac{K_{\mathrm{ISCC}}}{R_{\mathrm{p0,2}}}\right)^2$ is greater than the thickness of the specimen and/or the crack length.

Otherwise, $K_{\mathrm{QSCC}} = K_{\mathrm{ISCC}}$.

7.6 Determination of K_{ISCC} by crack initiation

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

7.6.2 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 a) and b).

a) 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.

b) 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 shall 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.

7.6.3 Where constant displacement specimens are used, the deflection shall be applied in accordance with the recommendations made in 7.5.2 and 7.5.3. 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 12 and 13. The testing machine used to apply the load shall permit the applied load to be measured to an accuracy of ±1 % and loading fixtures shall allow the load to be applied smoothly following exposure to the test environment.

7.6.4 The test period commences as soon as the required load or displacement is applied. An arbitrary test duration shall 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 shall be agreed upon between the parties concerned. However, 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.

7.6.5 During testing, crack length may be monitored optically at intervals, or continuously by means of electrical resistance, back-face strain, displacement gauge or 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.

7.6.6 On completion of the test period, the specimen shall be inspected for signs of failure. If intact, it shall be broken open and the minimum and maximum fatigue precrack lengths measured, if possible to the nearest 0,5 % W. The length of the fatigue precrack shall also be measured at both edges and at the following three positions from one edge: 0,25B, 0,50B and 0,75B.

The average of these last five measurements shall be used as the effective initial crack length, a_0, in the calculation of K_{QSCC}.

The test is invalid if:

a) the difference between any two of the 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 $2{,}5\left(\frac{K_{\mathrm{QSCC}}}{R_{\mathrm{p0,2}}}\right)^2$ is greater than the thickness of the specimen and/or the crack length;

f) there is uncertainty over the fatigue crack length.

Otherwise, $K_{\mathrm{QSCC}} = K_{\mathrm{ISCC}}$.

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.

NOTE A three-point average, not including the edges of the crack, was specified in the calculation of K_{QSCC} by crack arrest (see 7.5.5). This is because the stress intensity factor is dominated by the deepest parts of the crack which, for stress corrosion cracks grown under constant displacement, are usually located in the central regions of the specimen.

7.6.7 Stress corrosion cracking is a time-dependent process. For this reason, K_{ISCC} is not an absolute material property but depends on the test duration (as well as on the environment and test method used). 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. In general, 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 20.

7.7 Measurement of crack velocity

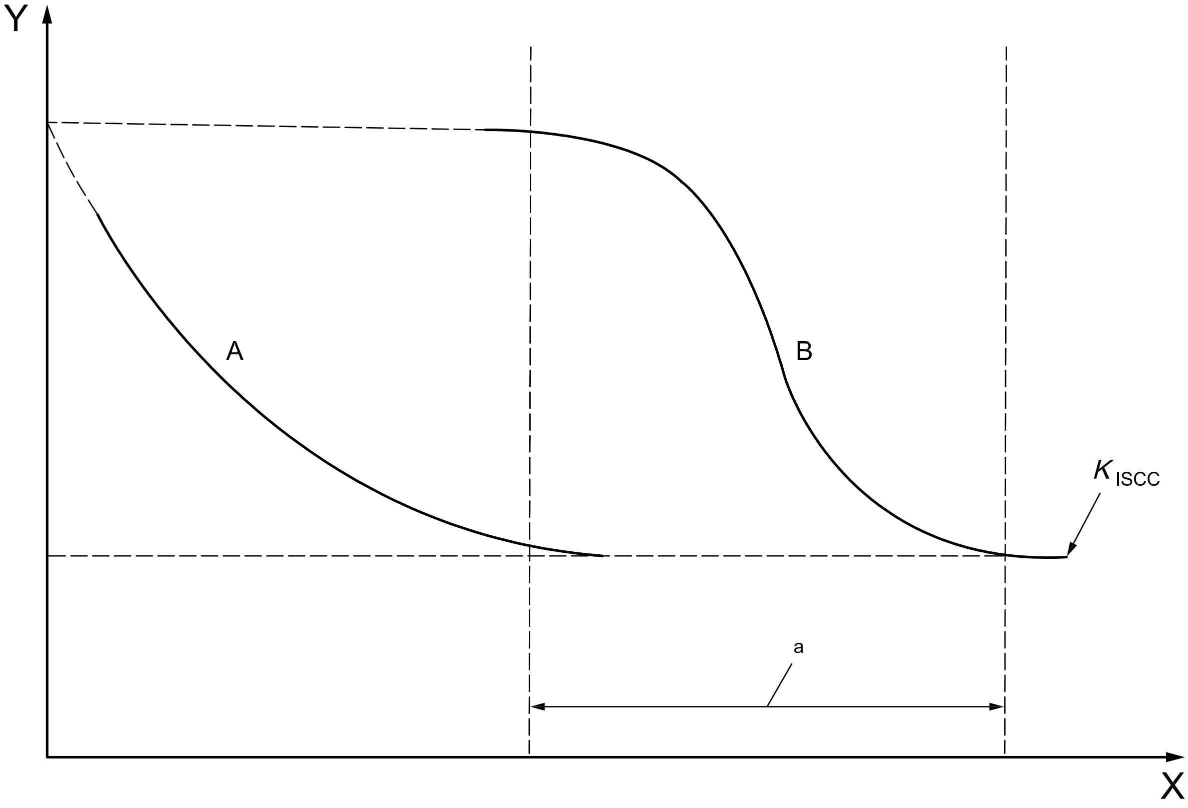
7.7.1 Tests performed in 7.5 or 7.6 to determine K_{ISCC} can also be used for determining the velocity of the environmental crack growth either as average data or as a function of the stress intensity factor K following the procedure given in Annex B. To determine these data, the specimens shall be broken and the fracture surfaces examined by microscopy.

7.7.2 The final crack front shall be measured, if possible, to the nearest 0,5 % W at both edges and at the following three positions: $0{,}25B$, $0{,}50B$ and $0{,}75B$.

The average of these five measurements shall be used as the effective final crack length, a_{f}.

NOTE A five-point average is specified in connection with crack velocity measurement, because on-line crack length measurement methods based on electrical resistance are strongly influenced by the presence of unsevered ligaments at the edges of the specimen.

7.7.3 The average crack velocity, $\Delta a/\Delta t$, is obtained by dividing the difference between the final and initial crack lengths, $a_{\mathrm{f}} - a_0$, by the time elapsed between crack initiation and test termination.



Key

X logarithm of time to failure

Y initial stress intensity, K_{Ii}

[a] Arbitrary times for end of tests.

Figure 20 — Schematic representation of stress corrosion data produced by test method based on time to failure

8 Test report

The test report shall contain the following information:

a) 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;

b) where monitored, initial solution composition, pH, degree of aeration (or concentration of other relevant gases), flow conditions, temperature and electrode potential; specification of flow rate shall be in terms of approximate linear rate past specimen if determined by the recirculation rate;

c) for each specimen:

    1) specimen type and loading method;

    2) thickness, B, in millimetres (and B_{n} if side-grooved);

    3) width, W, in millimetres;

    4) half-height, H, in millimetres [$(W\text{-}a)$ indifferent specimens only];

5) fatigue cracking:
    i) the value of K_{max} during the propagation of the final portion of the crack;
    ii) the fatigue load ratio, R;
    iii) the temperature and environment during precracking;
6) length of the fatigue precrack, a;
7) initial stress intensity, K_{Ii};
8) initial times of exposure to the environment and of loading and the total time of exposure;
9) whether crack extension occurred (or crack arrest in the case of constant displacement specimens);
10) whether failure occurred and, if so, time to failure;
11) crack plane and propagation direction, identified as shown in Figure 15;

d) K_{Ic} (or K_{Q} if the validity criteria are not obeyed), if determined;

e) K_{ISCC} (or K_{QSCC} if the validity criteria are not obeyed), stating whether obtained by crack initiation or crack arrest and criteria used (test duration or arrest growth rate, respectively);

f) crack velocity data (average values or as a function of stress intensity), where available.

Annex A
(normative)

Use of notched specimens for stress corrosion tests

A.1 Scope

A.1.1 Fracture-mechanics specimens can be tested in the blunt notched condition without a fatigue precrack under circumstances where it is desired to evaluate the conditions under which environmentally-assisted cracking can initiate at blunt notches in structures and components.

A.1.2 Basic geometries and methods of loading similar to those outlined in 1.2 and 1.3 can be used with blunt notched specimens.

A.2 Symbols

In addition to those definitions given for precracked specimens (Clause 3), the following symbols apply.

l	Distance from notch root to notch mouth or loading point axis, depending on the specimen geometry
σ_{n}	Nominal stress
σ_{me}	Maximum notch stress based on elasticity
σ_{mk}	Maximum notch stress based on fracture-mechanics methods
$\varepsilon_{\mathrm{Th}}$	Threshold value of notch surface strain above which environmentally assisted cracking will initiate and grow for the specified test conditions
σ_{Th}	Threshold value of notch stress above which environmentally assisted cracking will initiate and grow for the specified test conditions
r	Notch root radius
K_{t}	Theoretical elastic-stress concentration factor
K_{I}'	Apparent crack tip stress intensity factor calculated on the basis of the notch depth and applied load
M	Bending moment
μ	Poisson's ratio

A.3 Principle

A.3.1 The test involves subjecting a specimen containing a machined notch, to either a constant load or displacement at the loading points or to a monotonically 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 surface strain, $\varepsilon_{\mathrm{Th}}$, estimated from the maximum elastically calculated notch stress, σ_{me}.

A.3.2 The empirical data can be used for design purposes in order to ensure that the stress within structures is insufficient to promote environmentally assisted cracking, provided that the validity of the correlation between the maximum strain, based on the elastically calculated maximum stress in the blunt notched specimen, and the maximum strain in the structure or component in question, has been examined.

A.4 Specimens

A.4.1 General

Blunt notched specimens of otherwise similar design to those outlined in Clause 5 for precracked specimens may be utilized apart from the absence of a fatigue precrack.

A.4.2 Specimen design

As in the case of precracked specimens, the dimensions should be sufficient to maintain predominantly plane strain conditions at the notch base since, under conditions when the plastic zone at the notch base is constrained, the total notch strain (elastic plus plastic) will be, to a reasonable approximation, a unique function of the elastically calculated maximum notch stress for a particular material. This should be so provided that both the plastic zone size and the root radius of the notch are small compared to the notch depth. It is therefore recommended that:

a) both the notch depth, l, and thickness, B, be not less than $2{,}5\left(\frac{K_\text{I}'}{R_\text{p0,2}}\right)^2$

where K_I' is the apparent stress intensity calculated on the basis of the applied load and the notch depth;

b) the notch root radius, r, is such that the ratio $\overline{r} = \frac{r}{(W-l)}$ does not exceed a value of 0,2.

A.4.3 Stress considerations

A.4.3.1 The maximum notch stress can be calculated elastically from the product of the nominal stress, σ_n, and the elastic-stress concentration factor, K_t.

A.4.3.2 The elastic-stress concentration factor, K_t, can be determined by elastic finite element analysis, from published tables, or can be estimated from the relationship

$$K_\text{t} = \frac{\sigma_\text{mk}}{\sigma_\text{n}}$$

where

$$\sigma_\text{mk} = \frac{2K_\text{I}'}{\sqrt{\pi r}}$$

It should be noted that the accuracy of the latter method decreases with increasing root radius.

A.4.3.3 The nominal stress, σ_{n}, depends upon the specimen geometry. For bend specimens:

$$\sigma_{\text{n}} = \frac{6M}{(W-l)B}$$

where M is the bending moment.

For compact tension specimens

$$\sigma_{\text{n}} = \left[\frac{P}{(W-l)B}\right]\left[\frac{3(W+l)}{W-l}+1\right]$$

A.4.4 Specimen preparation

A.4.4.1 Notching of specimens shall be conducted after the completion of any heat treatment, using machining conditions which simulate those used during the manufacture of the component of interest.

A.4.4.2 In view of the greater loads associated with crack initiation in notched specimens compared with those for precracked specimens, it may be necessary to use a somewhat greater notch depth such that the value of the ratio $\frac{l}{W}$ is of the order 0,6.

A.4.4.3 Degrease specimens thoroughly before testing.

A.5 Procedure

A.5.1 The threshold surface stress, σ_{Th}, above which the material is susceptible to environmentally assisted cracking, can be determined using either constant displacement or constant load specimens by methods analogous to those outlined in 7.6 for the determination of K_{ISCC} by crack initiation.

A.5.2 The corresponding value of the threshold surface strain, ε_{Th}, above which the material is susceptible to environmentally assisted cracking, can be estimated from the following approximation:

$$\varepsilon_{\text{Th}} = \frac{\left(1-\mu^{2}\right)\sigma_{\text{Th}}}{E}$$

A.6 Test report

In addition to the relevant data listed in Clause 8, the following information shall be recorded for each specimen:

a) notch radius, r;

b) notch depth, l;

c) method of machining of the notch and machining parameters used (since these may influence the surface condition of the notch and hence the conditions required for the initiation of environmentally assisted cracking).

Annex B
(normative)

Determination of crack growth velocity

The crack growth velocity, da/dt, is calculated from the crack length versus elapsed time data (a versus t). If the data are noisy or there are unrealistic outliers, it may be advisable to fit the a vs t curve with a polynomial prior to calculation of crack growth rates, otherwise apparent oscillations in crack growth may arise. Care shall be taken to ensure that real variations in a vs t are not obscured by the fitting procedure.

One recommended method is the Incremental Polynomial Method as described in ISO 11782-2:1998 for the evaluation of fatigue crack growth rates (da/dN). This method involves fitting a second-order polynomial (parabola) to sets of ($2n + 1$) successive data points, where n is usually 1, 2, 3 or 4.

The form of the equation for the local fit is as follows:

$$\hat{a} = b_0 + b_1 \frac{T_\mathrm{i} - C_1}{C_2} + b_2 \left(\frac{T_\mathrm{i} - C_1}{C_2} \right)^2$$

where

$$-1 \leq \frac{T_\mathrm{i} - C_1}{C_2} \leq +1 ;$$

T_i is the time elapsed;

b_0, b_1, and b_2 are the regression parameters that are determined by the least-squares method over the range $a_{\mathrm{i}-n} \leq a \leq a_{\mathrm{i}+n}$.

The value $\hat{a}_\mathrm{i}$ is the fitted value of crack length at T_i.

The parameters $C_1 = 0{,}5 \times (T_{\mathrm{i}-n} + T_{\mathrm{i}+n})$ and $C_2 = 0{,}5 \times (T_{\mathrm{i}+n} - T_{\mathrm{i}-n})$ are used to scale the input data. The crack growth velocity at T_i is obtained from the derivative of the above parabola, which is given by:

$$\left(\mathrm{d}a/\mathrm{d}t \right)_{\hat{a}_\mathrm{i}} = \frac{b_1}{C_2} + 2\, b_2 \frac{T_\mathrm{i} - C_1}{{C_2}^2}$$

The value of K_I associated with the da/dt value is computed using the fitted crack length, $\hat{a}_\mathrm{i}$, corresponding to T_i.

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