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**Corrosion of metals and alloys —  
Stress corrosion testing —**

**Part 6:  
Preparation and use of precracked  
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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# Contents

	Page
Foreword .....	iv
<b>1 Scope</b> .....	<b>1</b>
<b>2 Normative references</b> .....	<b>1</b>
<b>3 Terms and definitions</b> .....	<b>1</b>
<b>4 Principle</b> .....	<b>4</b>
<b>5 Specimens</b> .....	<b>5</b>
5.1 General .....	5
5.2 Specimen design .....	7
5.3 Stress intensity factor considerations .....	17
5.4 Specimen preparation .....	23
5.5 Specimen identification .....	25
<b>6 Initiation and propagation of fatigue cracks</b> .....	<b>25</b>
<b>7 Procedure</b> .....	<b>27</b>
7.1 General .....	27
7.2 Environmental considerations .....	27
7.3 Environmental chamber .....	28
7.4 Environmental control and monitoring .....	29
7.5 Determination of $K_{ISCC}$ by crack arrest .....	29
7.6 Determination of $K_{ISCC}$ by crack initiation .....	32
7.7 Measurement of crack velocity .....	34
<b>8 Test report</b> .....	<b>35</b>
<b>Annex A (informative) Use of notched specimens for stress corrosion tests</b> .....	<b>36</b>
<b>Annex B (informative) Determination of crack growth velocity</b> .....	<b>39</b>
<b>Bibliography</b> .....	<b>40</b>

## 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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

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

This fourth edition cancels and replaces the third edition (ISO 7539-6:2011), which has been technically revised to revise [Figure 14](#).

This corrected version of ISO 7539-6:2018 incorporates the following corrections:

- in [Figure 2](#), the symbol “^” has been corrected to “≥” in two places.

A list of all parts in the ISO 7539 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

# 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

This document specifies 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 document includes alloys.

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.

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.

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 documents are referred to in the text in such a way that some or all of their content constitutes requirements 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*

## 3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

**3.1  
crack length**

*a*

distance 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*

distance 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<sub>n</sub>*

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

**3.5  
specimen half-height**

*H*

50 % of the distance between both sides of the specimen measured parallel to the direction of *load* (3.6) application for compact tension, double cantilever beam and modified wedge-opening-loaded test pieces

**3.6  
load**

*P*

force, 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<sub>LL</sub>*

crack opening displacement produced at the loading line during the application of *load* (3.6) to a constant displacement specimen

**3.8  
deflection away from the loading line**

*V<sub>0</sub>*

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* (3.6) to a constant displacement specimen

**3.9  
modulus of elasticity**

*E*

ratio of stress to strain without deviation in proportionality of the stress and strain (Hooke's law)

**3.10****stress intensity factor** $K_I$ 

function of applied *load* (3.6), *crack length* (3.1) and specimen geometry having dimensions of stress  $\times \sqrt{\text{length}}$  which uniquely define the elastic-stress field intensification at the tip of a crack subjected to opening mode displacements (mode I)

Note 1 to entry: 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 document, 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  $K_{Ic}$**  $K_Q$ 

$K_Q = K_{Ic}$  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* (3.10) 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  $K_{ISCC}$**  $K_{QSCC}$ 

$K_{QSCC} = K_{ISCC}$  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* (3.10) in a cycle, corresponding to the maximum *load* (3.6)

**3.17****0,2 % proof stress** $R_{p0,2}$ 

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

**3.18****applied stress** $\sigma$ 

stress resulting from the application of *load* (3.6) 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* (3.10) for a given *crack length* (3.1) to the *load* (3.6) and specimen dimensions

**3.20**  
**load ratio in fatigue loading**

R

algebraic ratio of minimum to maximum *load* (3.6) in a cycle:

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

**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* (3.1) 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 1 to entry: Where X, Y and Z are defined as follows:

- X is coincident with the direction of grain flow (longitudinal axis);
- Z is coincident with the main working force used during manufacture of the material (short-transverse 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:

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

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

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

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:

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

and preferably should be not less than:

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

where  $K_I$  is the stress intensity to be applied during testing.

The threshold stress intensity value eventually determined should be substituted for  $K_I$  in the first of these expressions as a test for its validity.

**5.1.3** If the specimens are to be used for the determination of  $K_{ISCC}$ , the initial specimen size should be based on an estimate of the  $K_{ISCC}$  of the material (in the first instance, it 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.

**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 remotely-loaded 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.

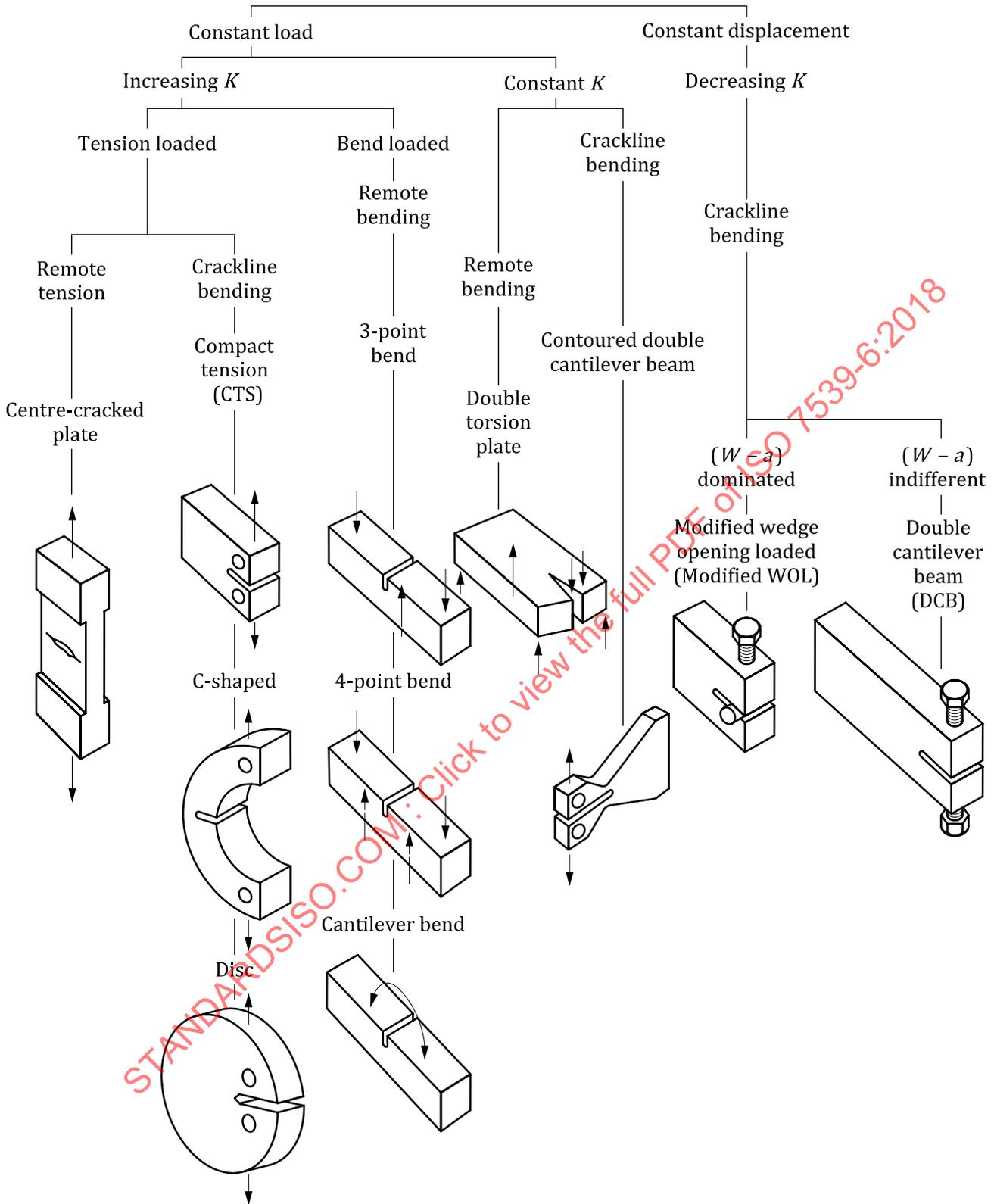
**5.2.4** Constant- $K$  constant load specimens can be subjected to either torsion loading as in the case of the double-torsion single edge cracked plate specimen, or tension loading as in the case of contoured double-cantilever-beam specimens. Although loaded in tension, the design of the latter specimens 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 distant 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;



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

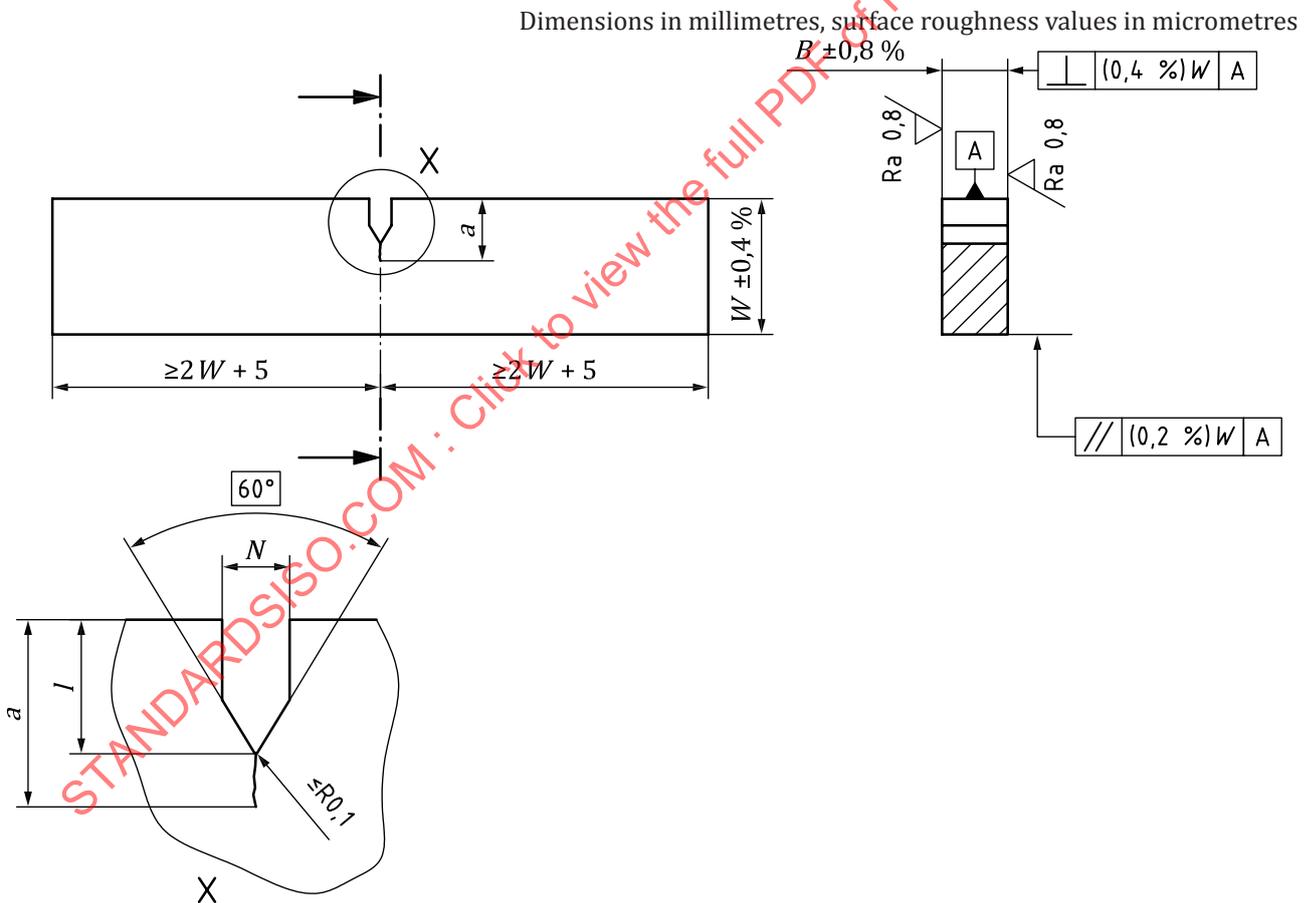
Figure 1 — Precracked specimen geometries for stress corrosion testing

- 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](#).

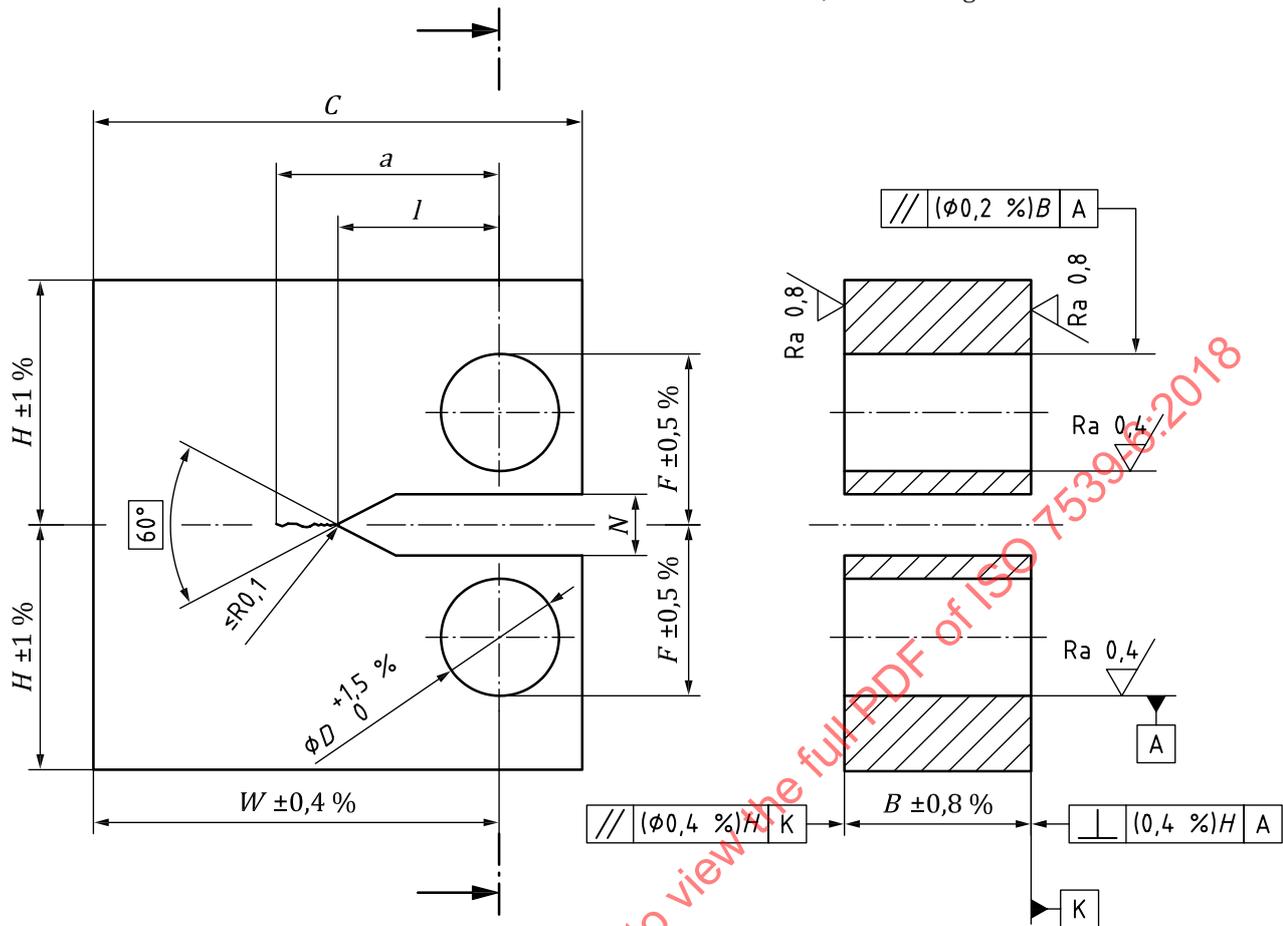


**Key**

$W$	width	
$B$	thickness	$= 0,5W$
$N$	notch width	$= 0,065W$ maximum (if $W > 25$ mm) or 1,5 mm maximum (if $W \leq 25$ mm)
$l$	effective notch length	$= 0,25W$ to $0,45W$
$a$	effective crack length	$= 0,45W$ to $0,55W$

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

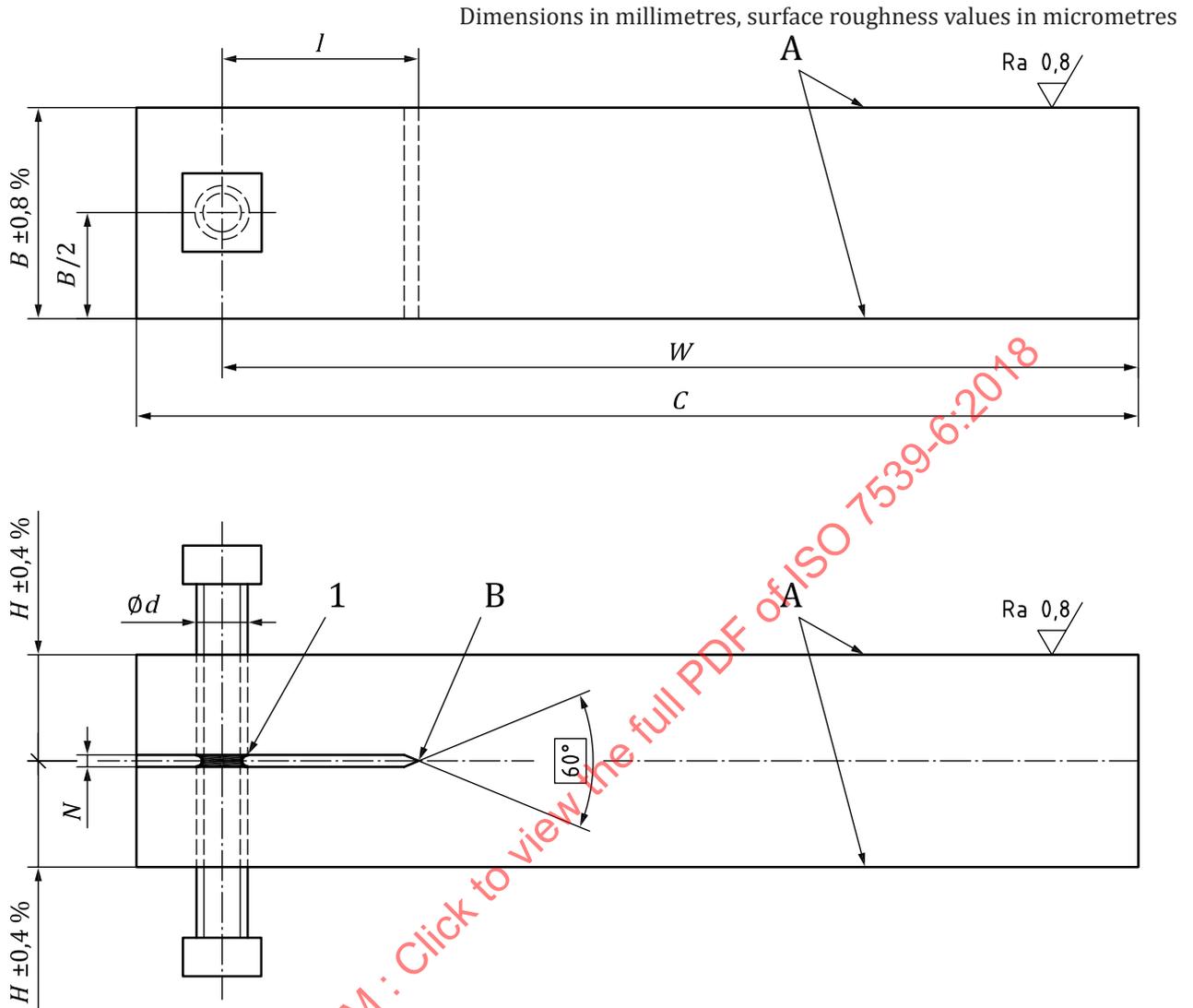
Dimensions in millimetres, surface roughness values in micrometres



**Key**

- $W$  net width
- $C$  total width  
=  $1,25W$  minimum
- $B$  thickness  
=  $0,5W$
- $H$  half-height  
=  $0,6W$
- $D$  hole diameter  
=  $0,25W$
- $F$  half-distance between hole outer edges  
=  $1,6D$
- $N$  notch width  
=  $0,065W$  maximum
- $l$  effective notch length  
=  $0,25W$  to  $0,40W$
- $a$  effective crack length  
=  $0,45W$  to  $0,55W$

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



**Key**

- 1 screw tip radius 12,5 to 50
- $H$  half-height
- $B$  thickness =  $2H$
- $W$  net width =  $10H$  minimum
- $C$  total width =  $W + d$
- $d$  screw diameter =  $0,75H$  minimum
- $N$  notch width =  $0,14H$  maximum
- $l$  effective notch length =  $2H$

NOTE 1 "A" surfaces should be perpendicular and parallel, as applicable, to within  $0,002H$  TIR.

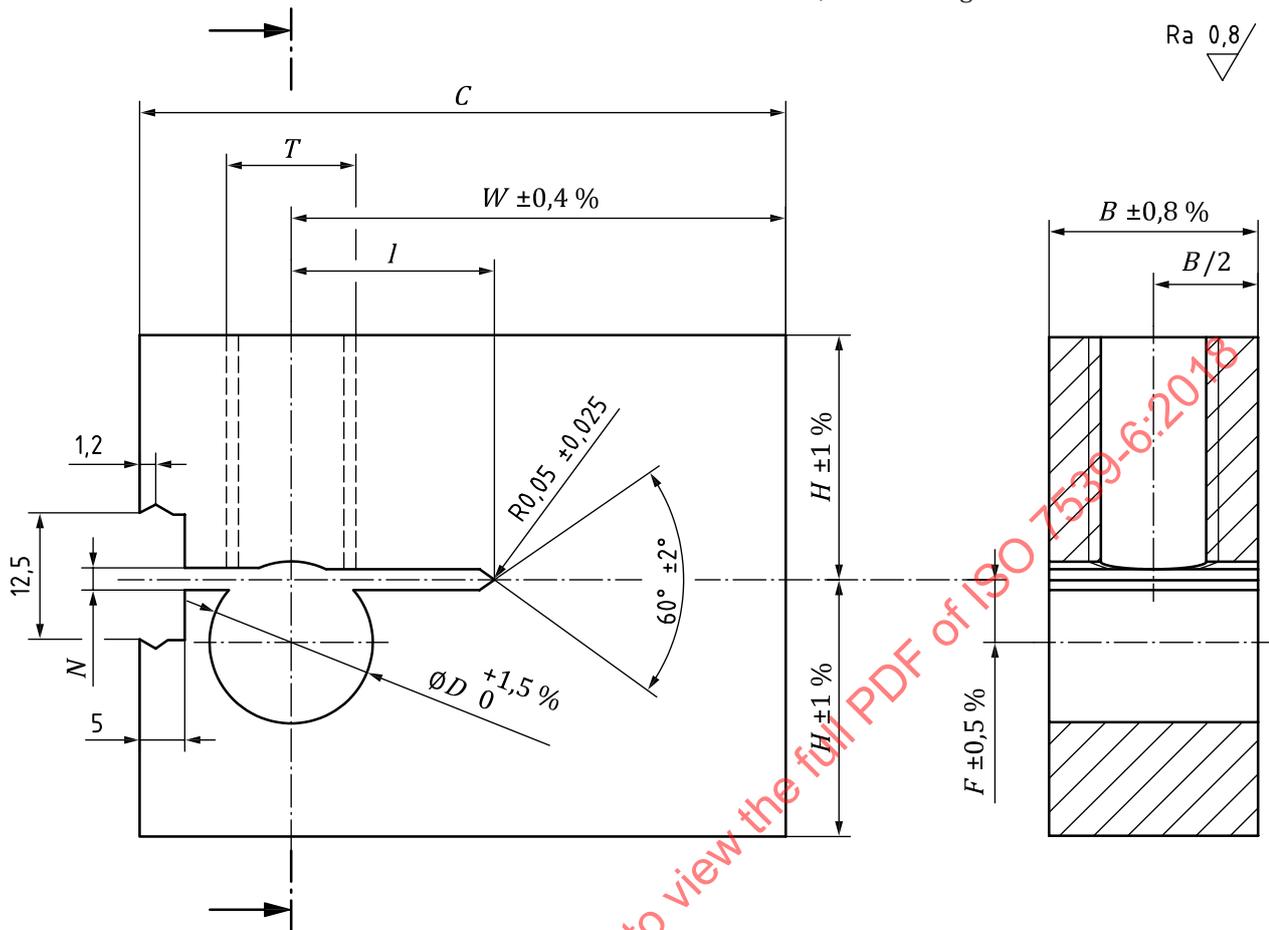
NOTE 2 At each side point, "B" should be equidistant from the top and bottom surface to within  $0,001H$ .

NOTE 3 The bolt centreline should be normal to the specimen centreline to within  $1^\circ$ .

NOTE 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



**Key**

- $B$  thickness
- $W$  net width =  $2,55B$
- $C$  total width =  $3,20B$
- $H$  half-height =  $1,24B$
- $D$  hole diameter =  $0,718B \pm 0,003B$
- $l$  effective notch length =  $0,77B$
- $N$  notch width =  $0,06B$
- $T$  thread diameter =  $0,625B$
- $F$  distance from hole centreline to notch centreline =  $0,239B$
- <sup>a</sup> All over.

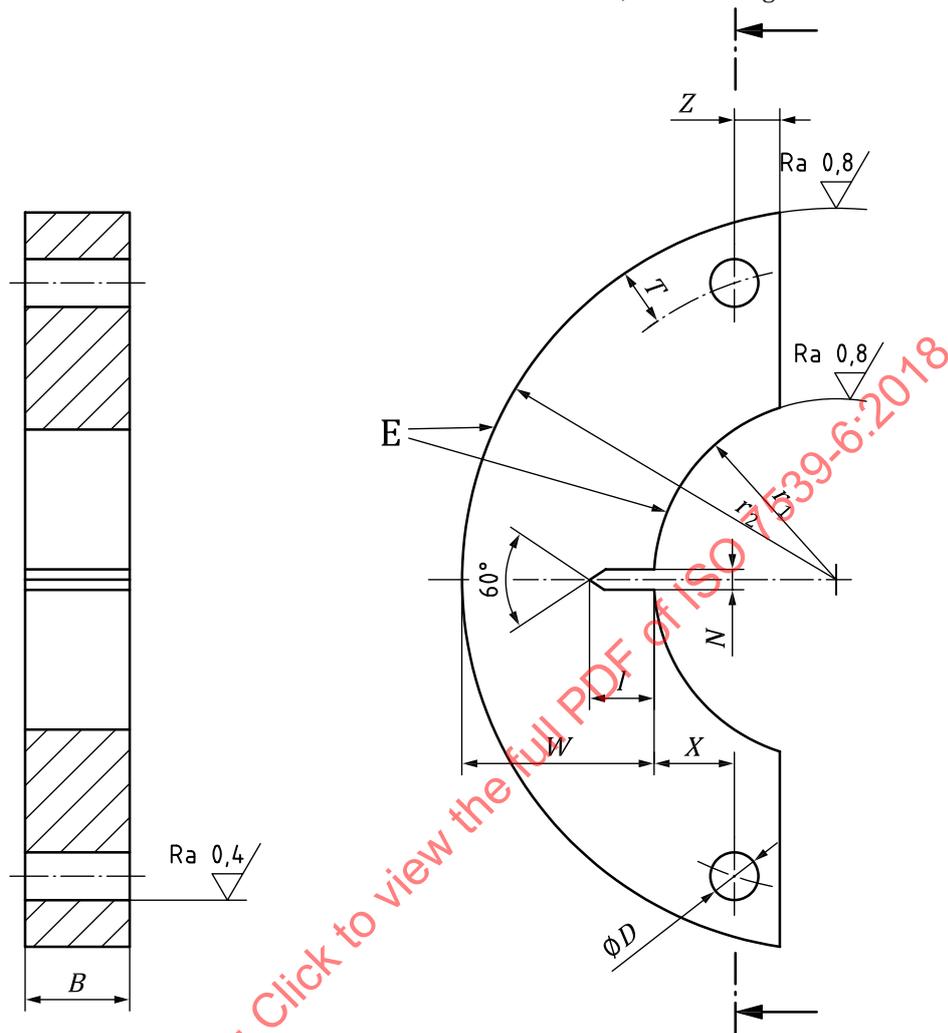
NOTE 1 The surface should be perpendicular and parallel, as applicable, to within  $0,002H$  TIR.

NOTE 2 The bolt centreline should be normal to the specimen centreline to within  $1^\circ$ .

NOTE 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



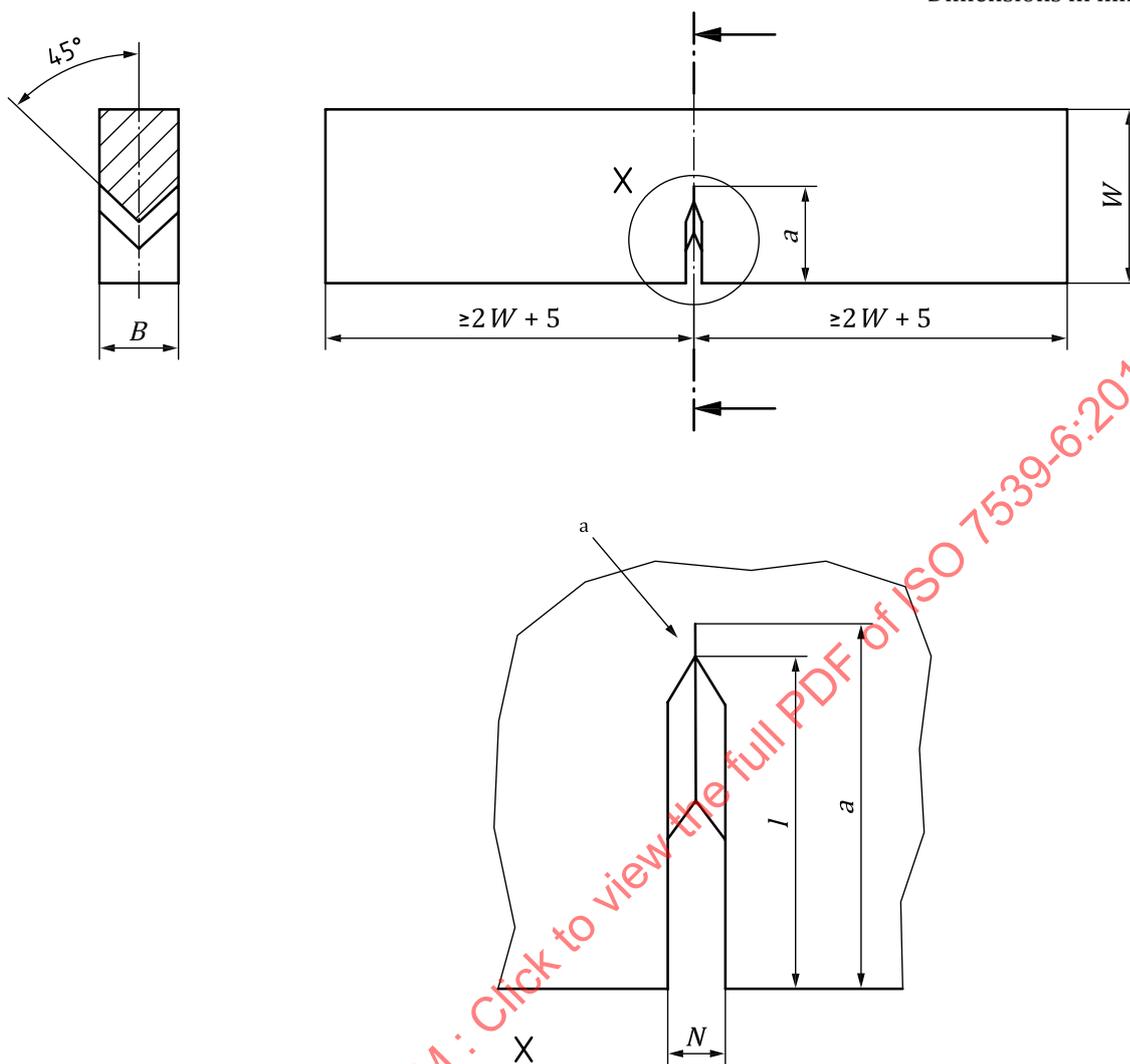
**Key**

$W$	net width	
$B$	thickness	$= 0,50W \pm 0,01W$
$X$	distance from the hole axis to a tangent with the inner surface	$= 0,50W \pm 0,005W$
$N$	notch width	$= 1,5 \text{ mm minimum } (0,1W \text{ maximum})$
$l$	notch length	$= 0,3W$
$Z$	distance from the hole axis to face of specimen	$= 0,25W \pm 0,01W$
$T$	distance from the hole axis to outer surface	$= 0,25W \pm 0,01W$
$D$	diameter of holes	$= 0,25W \pm 0,005W$

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.

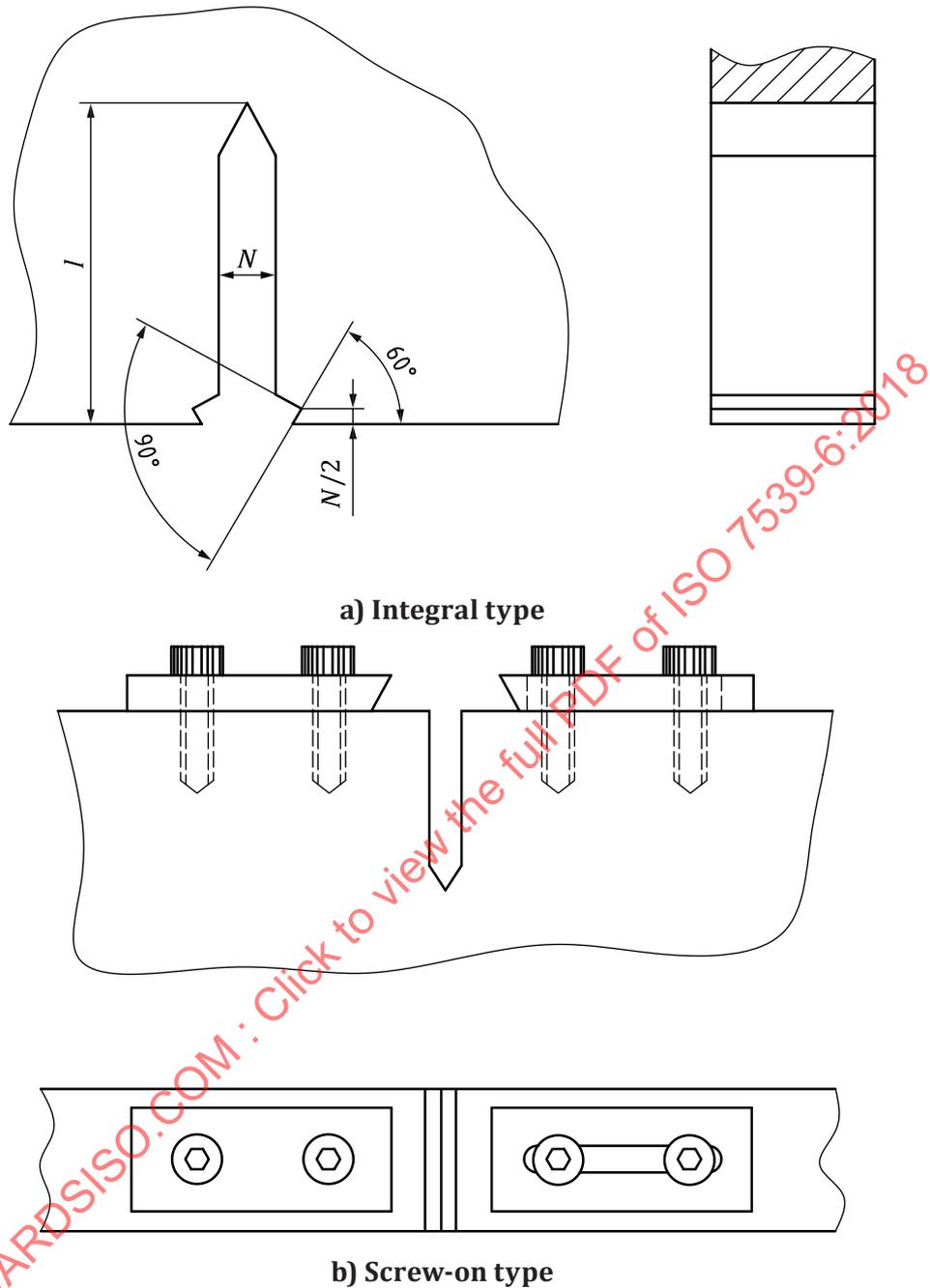
**Figure 6 — Proportional dimensions and tolerances for C-shaped test pieces**

Dimensions in millimetres



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

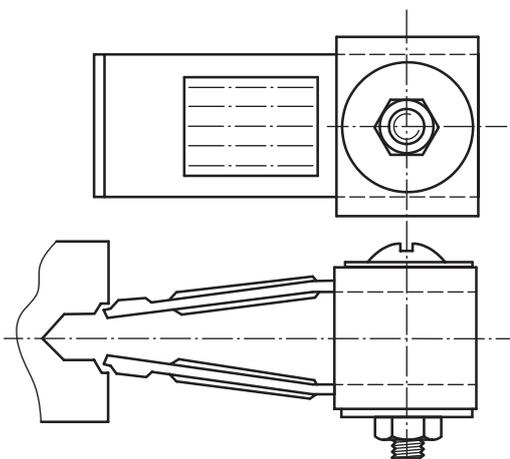
**Figure 7 — Chevron notch**



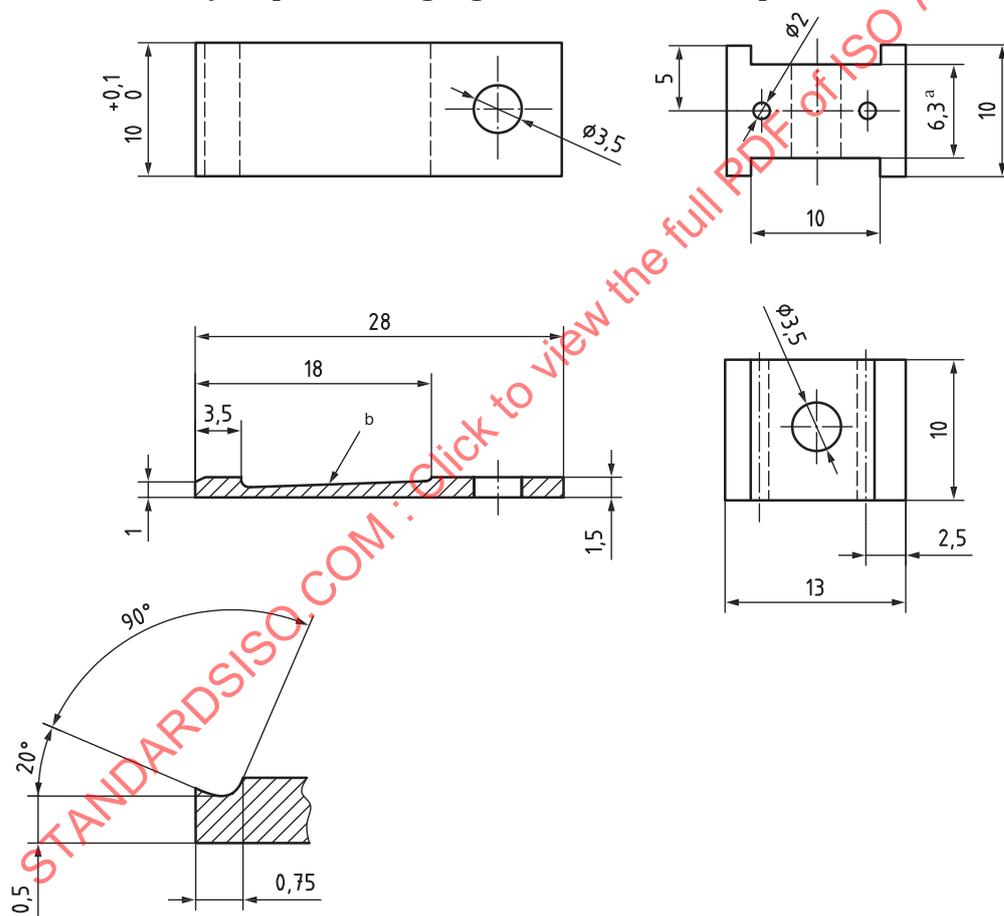
NOTE Provided adequate strength can be ensured, the above knife edges may be fixed using adhesive.

Figure 8 — Knife edges for location of displacement gauges

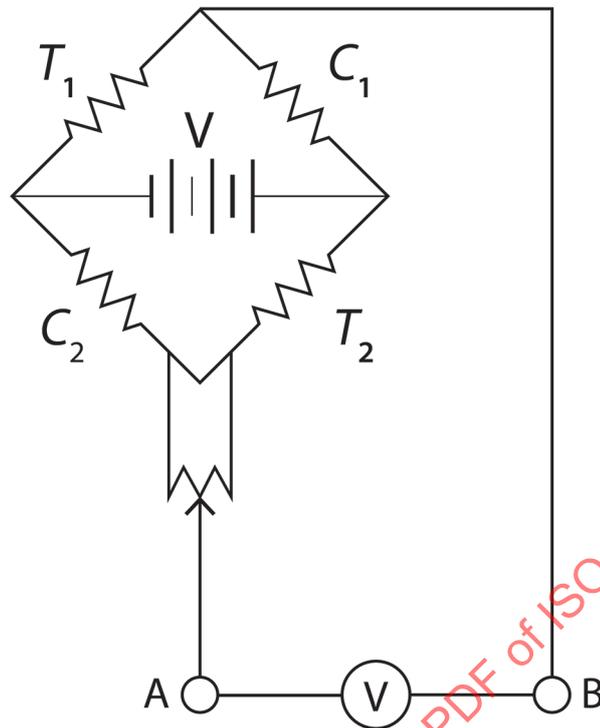
Dimensions in millimetres



a) Displacement gauge mounted on a test piece



b) Dimensions of beams



c) Bridge measurement circuit

**Key**

A, B terminals

V voltage

a This dimension should be  $3,8 \times$  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:

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

where

$Q$  is the geometrical constant;

$\sigma$  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:

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

for compact tension or C-shaped specimens or:

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

for T-type wedge-opening-loaded specimens or:

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

for double-cantilever-beam specimens.

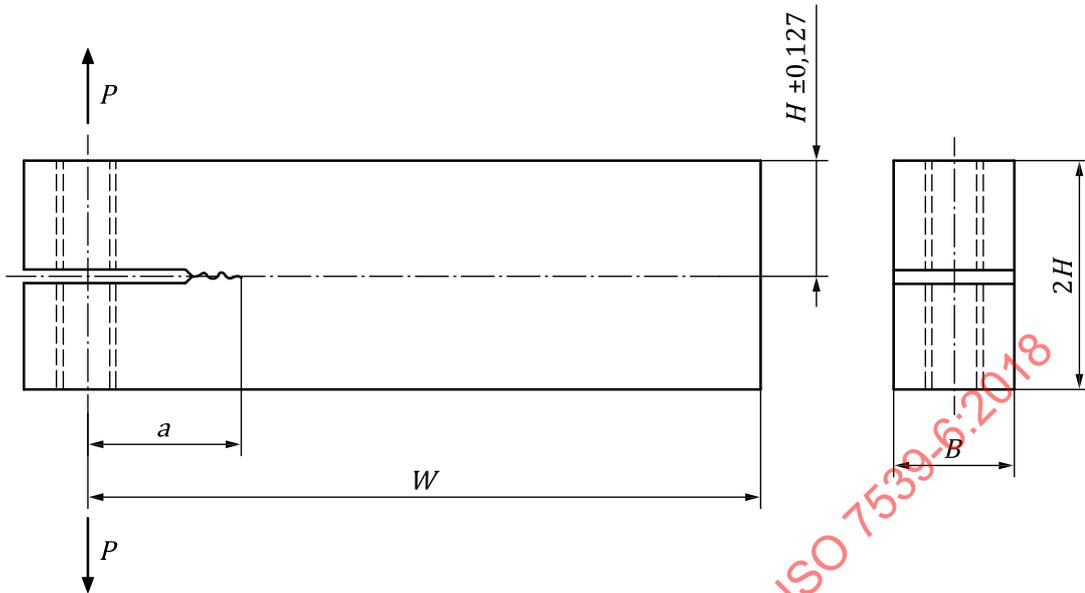
5.3.4 Where it is necessary to use side-grooved specimens in order to curb crack branching tendencies, etc., shallow side grooves (usually 5 % of the specimen thickness on both sides) can be used. Either semi-circular or 60° V-grooves can be used, but it should be noted that, even with semi-circular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

$$\sqrt{B \times B_n}$$

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](#).

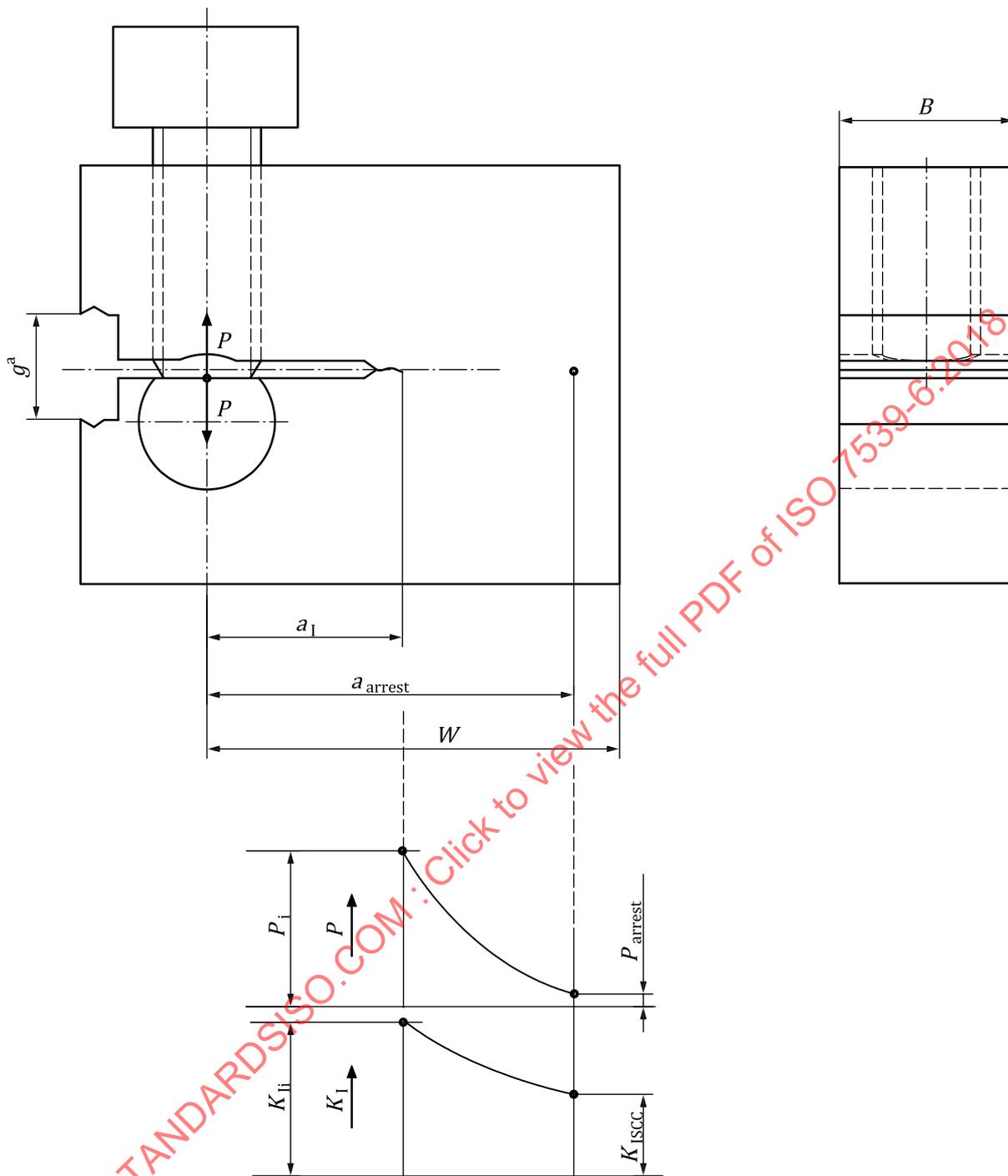
Dimensions in millimetres



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

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  $2 \leq \frac{a}{H} \leq 5$ . 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]**



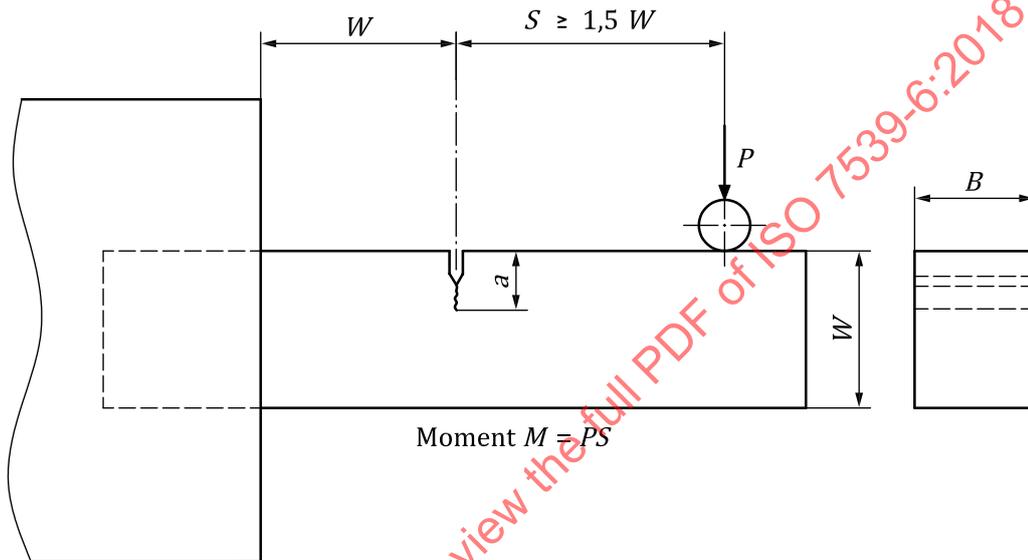
- a  $V$ , the crack-opening displacement (COD) for a rigid bolt, is a constant  $(g - g_i)$ .

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

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  $0,3 \leq \frac{a}{W} \leq 0,8$ . For greater confidence, it is recommended that an empirical compliance be used.

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

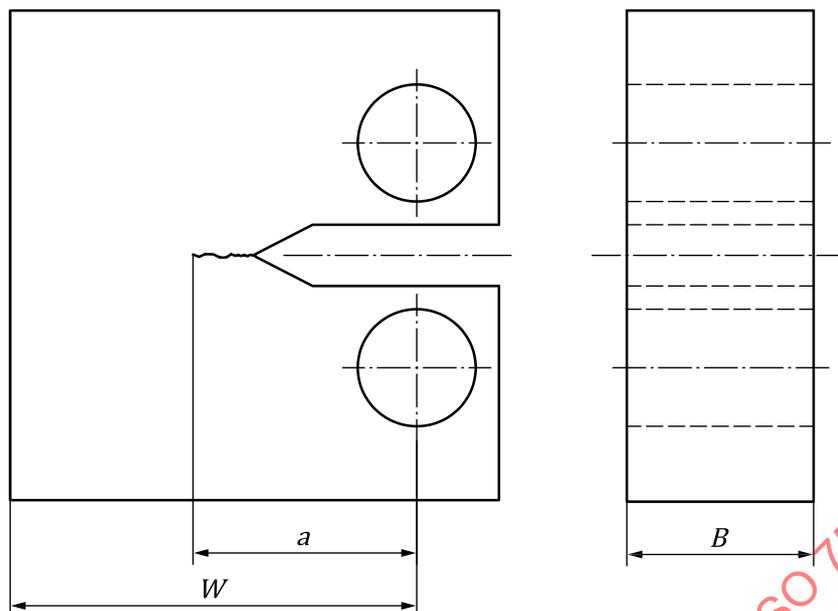


$$K_1 = \frac{YP}{B\sqrt{W}}$$

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  $S = 1,5 W$

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  $0,2 \leq \frac{a}{W} \leq 0,6$ . For greater confidence, it is recommended that an empirical compliance be used.

**Figure 12 — Stress intensity factor solution for cantilever bend specimens**

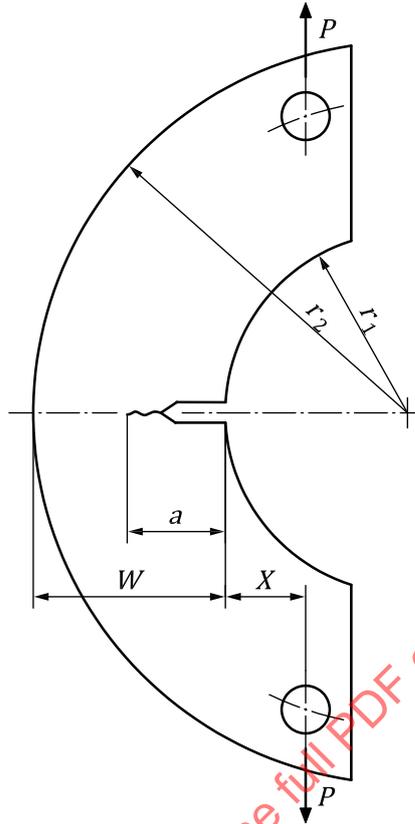


$$K_I = \frac{YP}{B\sqrt{W}}$$

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

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

Figure 13 — Stress intensity factor solution for compact tension specimens



$$K = \frac{P}{B\sqrt{W}} \left( 3 \frac{X}{W} + 1,9 + 1,1 \frac{a}{W} \right) \left[ 1 + 0,25 \left( 1 - \frac{a}{W} \right)^2 \left( 1 - \frac{r_1}{r_2} \right) \right] f \left( \frac{a}{W} \right)$$

$$\text{where } f \left( \frac{a}{W} \right) = \frac{\sqrt{\left( \frac{a}{W} \right)}}{\left( 1 - \frac{a}{W} \right)^{\frac{3}{2}}} \left[ 3,74 - 6,30 \frac{a}{W} + 6,32 \left( \frac{a}{W} \right)^2 - 2,43 \left( \frac{a}{W} \right)^3 \right]$$

NOTE The accuracy of this expression for  $\frac{a}{W}$  for all values of  $\frac{r_1}{r_2}$  is considered to be as follows: within 1,0 % over the range  $0,45 \leq \frac{a}{W} \leq 0,55$  and  $\frac{X}{W}$  of 0 or 0,5; within 1,5 % for  $0,2 \leq \frac{a}{W} \leq 1$  and  $\frac{X}{W}$  of 0 or 0,5; within 3,0 % for  $0,2 \leq \frac{a}{W} \leq 1$  and  $0 \leq \frac{X}{W} \leq 1$ .

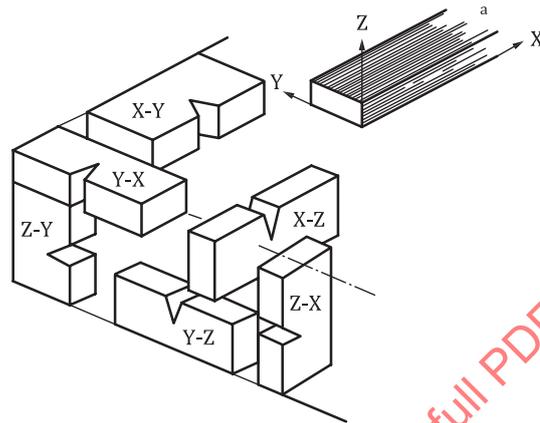
Figure 14 — Stress intensity factor solution for C-shaped specimens

## 5.4 Specimen preparation

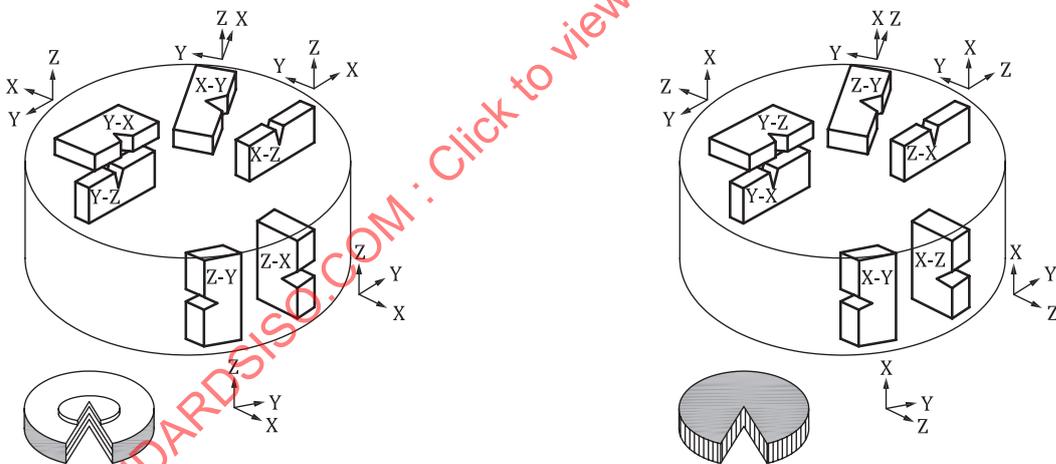
**5.4.1** Residual stresses can have an influence on stress corrosion cracking. The effect can be significant when test specimens are removed from material in which complete stress relief is impractical, such as weldments, as-quenched materials and complex forged or extruded shapes. Residual stresses 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.

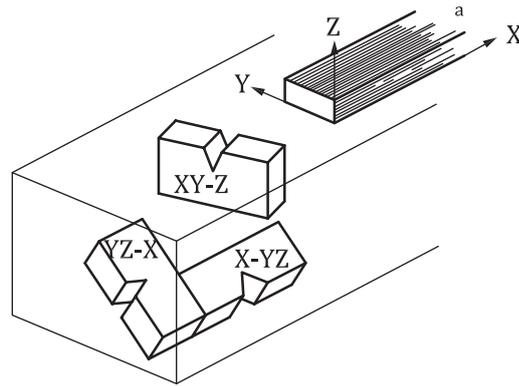


a) Basic fracture plane identification: rectangular section



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

**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  $\pm 2,5\%$ .

**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  $K_{I\text{SCC}}$ . 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  $K_{I\text{SCC}}$  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  $K_{ISCC}$ ).

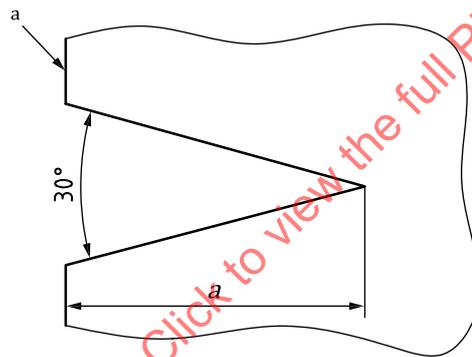
NOTE Load shedding procedures, as described in ISO 11782-2, can be helpful when the  $K_{ISCC}$  values are expected to be low.

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

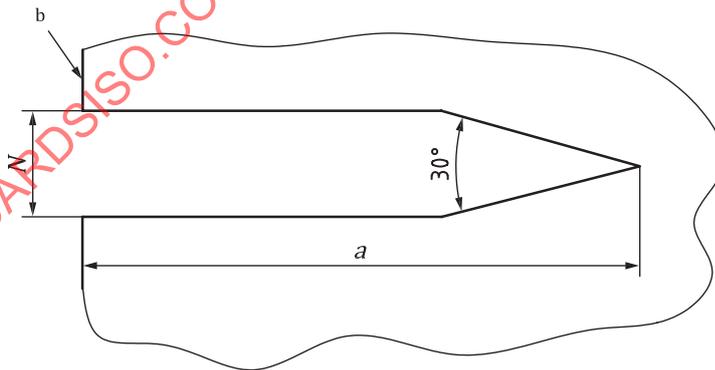
$$a \geq 2,5 \left( \frac{K_I}{R_{p0,2}} \right)^2$$

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].

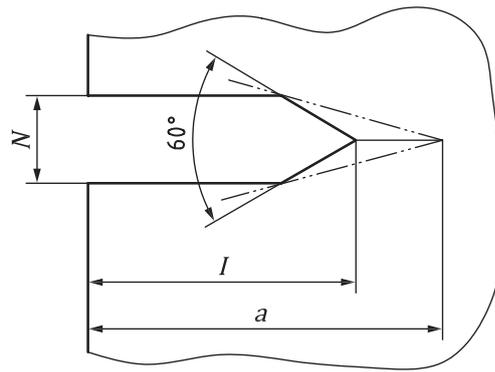
6.5 In order to avoid the interaction of the stress field associated with the crack with that due to the notch, the crack shall lie within the limiting envelope as shown in Figure 16 in which examples for bend and tensile pieces are shown. For the example valid for bend or tensile test pieces, if the 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).



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**

**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  $10^\circ$  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 that 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

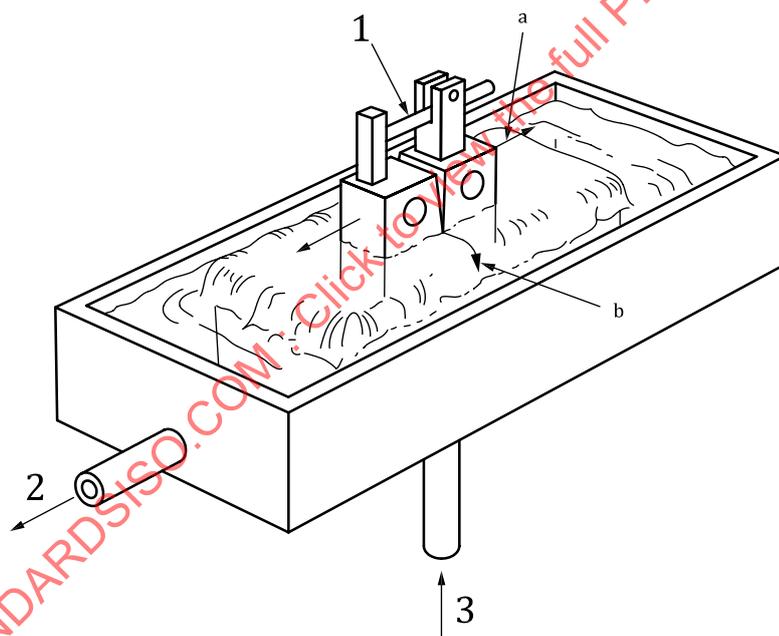
is an important factor. Alternatively, the electrode potential may be displaced from the open circuit value by potentiostatic or galvanostatic methods.

**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.

### 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.



#### 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**

**7.3.2** 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 should 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.

## 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  $\pm 2$  °C.

## 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.

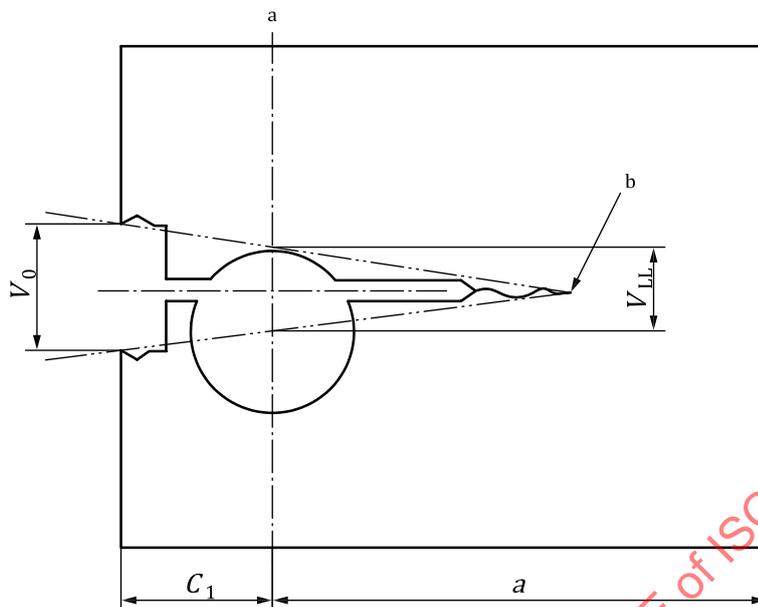
**7.5.3** The arms of the specimen shall then be deflected by turning a bolt to give a predetermined  $K_{II}$  value in excess of the anticipated  $K_{ISCC}$  value. Over-deflection shall be avoided. The deflection,  $V_{LL}$ , at the loading line can be related to the deflection,  $V_0$ , measured 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

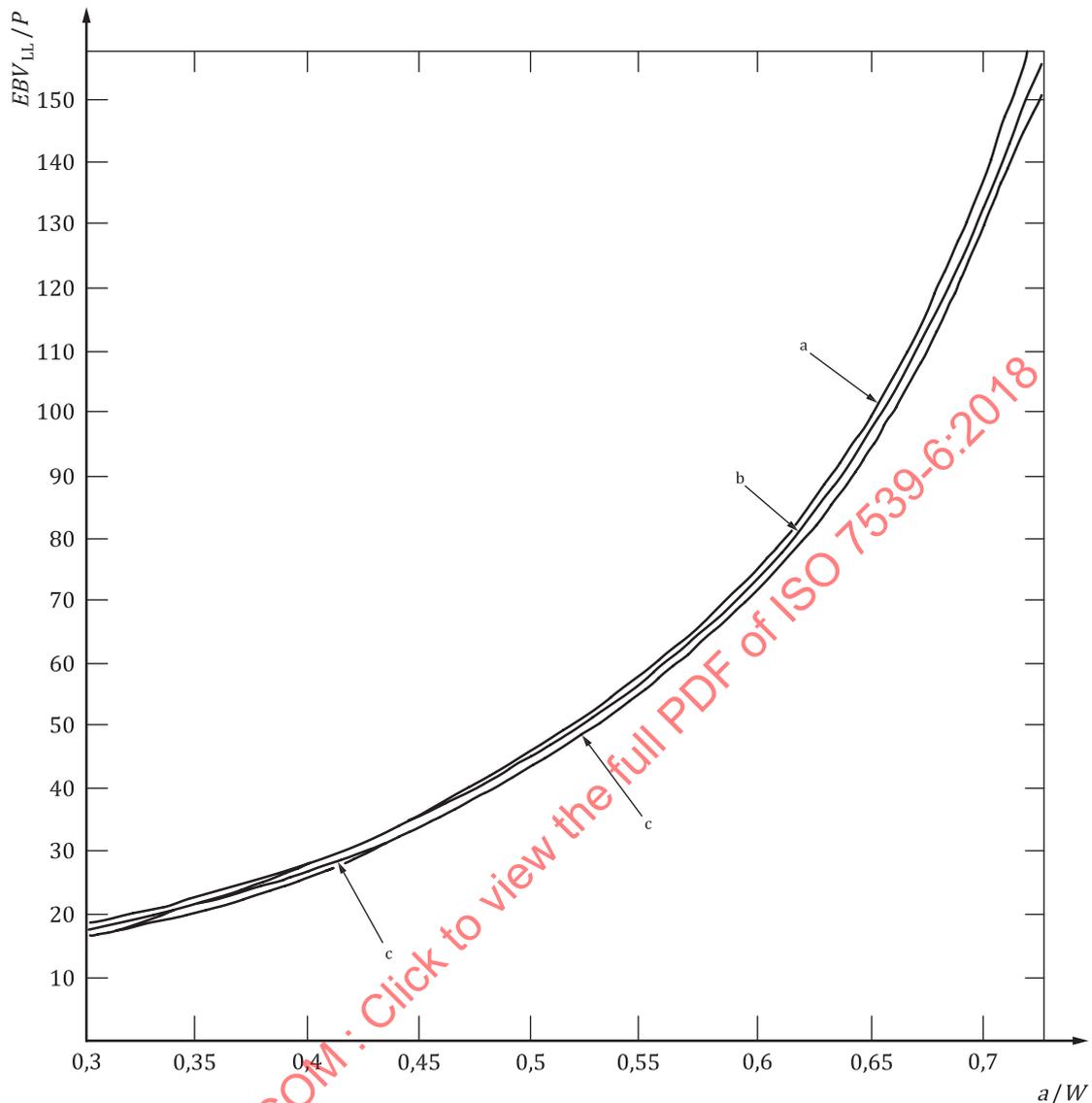
compliance calibration curves for the smooth and side-grooved modified WOL specimens are shown in [Figure 19](#). After loading, the displacement gauge shall be removed.



$$V_{LL} = \frac{V_0}{\left(1 + \frac{3c_1}{2a}\right)}$$

- a Load.
- b Crack tip.

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



- a Smooth, theoretical.
- b 5 % face, notched, experimental.
- c Smooth, experimental.

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

**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: 0,25 $B$ , 0,50 $B$  and 0,75 $B$ .

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

The test is invalid if:

- a) the difference between any two of these last three measurements exceeds 2,5 %  $W$ ;
- b) the difference between the maximum and minimum crack lengths exceeds 5 %  $W$ ;
- c) any part of the crack surface lies in a plane, the slope of which exceeds an angle of 10° from the plane of the notch;
- d) the factor:

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

is greater than the thickness of the specimen and/or the crack length.

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

## 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  $\pm 1$  % and loading fixtures shall allow the load to be applied smoothly following exposure to the test environment.