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

**Part 9:
Preparation and use of pre-cracked
specimens for tests under rising load
or rising displacement**

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

*Partie 9: Préparation et utilisation des éprouvettes préfissurées pour
essais sous charge croissante ou sous déplacement croissant*



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Contents

Page

Foreword	iv
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 Principle	2
5 Specimens	3
5.1 General	3
5.2 Specimen design	4
5.3 Stress intensity factor considerations	11
5.4 Specimen preparation	15
5.5 Specimen identification	17
6 Initiation and propagation of fatigue cracks	18
7 Procedure	19
7.1 General	19
7.2 Environmental considerations	20
7.3 Environmental chamber	20
7.4 Environmental control and monitoring	21
7.5 Selection of initial K value prior to dynamic loading	22
7.6 Determination of K_{ISCC}	22
7.6.1 General	22
7.6.2 Determination schedule	22
7.6.3 Validation of test results	24
7.7 Determination of crack velocity	25
8 Test report	25
Annex A (informative) Determination of a suitable displacement rate for determining K_{ISCC} from constant displacement rate tests	27
Annex B (informative) Determination of crack growth velocity	29
Annex C (informative) Information on indirect methods for measuring crack length (see also ISO 21153)	30
Bibliography	32

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).

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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.

This document was prepared by Technical Committee ISO/TC 156, *Corrosion of metals and alloys*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 262, *Metallic and other inorganic coatings*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 7539-9:2003), which has been technically revised.

The main change compared to the previous edition is as follows: the formula for K in [Figure 9](#) has been corrected.

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.

Corrosion of metals and alloys — Stress corrosion testing —

Part 9:

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

1 Scope

1.1 This document specifies procedures for designing, preparing and using pre-cracked specimens for investigating the susceptibility of metal to stress corrosion cracking (SCC) by means of tests conducted under rising load or rising displacement. Tests conducted under constant load or constant displacement are dealt with in ISO 7539-6.

The term “metal” as used in this document includes alloys.

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

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

1.4 A particular advantage of pre-cracked specimens is that they allow data to be acquired from which critical defect sizes, above which stress corrosion cracking 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.

1.5 A principal advantage of the test is that it takes account of the potential impact of dynamic straining on the threshold for stress corrosion cracking.

1.6 At sufficiently low loading rates, the threshold stress intensity factor for susceptibility to stress corrosion cracking, K_{ISCC} , determined by this method can be less than or equal to that obtained by constant load or displacement methods and can be determined more rapidly.

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 7539-6, *Corrosion of metals and alloys — Stress corrosion testing — Part 6: Preparation and use of precracked specimens for tests under constant load or constant displacement*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7539-6 as well as the following apply.

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

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

3.1

rate of change of crack opening displacement at loading plane

$\dot{V}_{LL}$

deflection at the loading point axis measured over a fixed period

3.2

stress intensity factor at crack initiation

K_{I-init}

stress intensity applied at the commencement of measurable crack growth

3.3

displacement rate

dq/dt

rate of increase of the deflection either measured at the loading point axis or away from the loading line

4 Principle

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

4.2 The test involves subjecting a specimen in which a crack has been developed from a machined notch by fatigue to an increasing load or displacement 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 Tests may be conducted in tension or in bending. The most important characteristic of the test is the low loading/displacement rate which is applied.

4.4 Because of the dynamic straining which is associated with this method the data obtained may differ from those obtained for pre-cracked specimens with the same combination of environment and material when the specimens are subjected to static loading only.

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

4.6 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.

4.7 The mechanical driving force includes both applied and residual stresses. The possible influence of the latter should 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.

4.8 K_{ISCC} is a function of the environment, which should simulate that in service, and of the conditions of loading.

5 Specimens

5.1 General

5.1.1 A wide range of standard specimen geometries of the type employed in fracture toughness tests may be used, those most commonly employed are described in ISO 7539-6. The particular type of specimen used will be dependent upon the form, the strength and the susceptibility to stress corrosion cracking of the material to be tested and also on the objective of the test.

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

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

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

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

should be used to ensure adequate constraint.

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

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

and preferably should be not less than

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

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

As a test for its validity, the threshold stress intensity value eventually determined shall be substituted for K_{I} in the first of these formulae.

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 that which 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 provisional value of K_{ISCC} obtained, K_{QSCC} , is of relevance only to that specific application. Where it is required to determine stress corrosion crack growth behaviour as a function of stress intensity, the specimen size should be based on an estimate of the highest stress intensity at which crack growth rates are to be measured.

5.1.4 A wide choice of specimen geometries is available to suit the form of the test material, the experimental facilities available and the objectives of the test. Two basic types of specimen can be used:

- a) those intended for being loaded by means of a tensile force;
- b) those intended for being loaded by means of a bending force.

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 and for measurements of crack growth rates. Since the specimens are loaded during exposure to the test environment the risk of unnecessary incubation periods is avoided.

5.1.5 Crack length measurements can be made readily with a number of continuous monitoring methods such as the electrical resistance technique (see [Annex C](#)).

5.1.6 Bend specimens can in principle be tested in relatively simple cantilever beam equipment but specimens subjected to tension loading require a tensile test machine.

5.2 Specimen design

5.2.1 The 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 crack-line 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.

5.2.2 The occurrence of crack-line bending with an associated tendency for crack growth out of plane can be curbed by the use of side grooves.

5.2.3 A number of specimen geometries have specific advantages which have caused them to be frequently used for rising load/displacement stress corrosion testing. These include

- a) compact tension (CTS) specimens which minimize the material requirement;
- b) cantilever, three-point, and four-point bend specimens which are easy to machine and inexpensive to test;
- c) C-shaped specimens which can be machined from thick walled cylinders in order to study the radial propagation of longitudinally oriented cracks.

Details of standard specimen designs for several of these types of specimen are given in [Figures 1](#) to [3](#). Further examples for other geometries including three-point bend can be found in Reference [\[7\]](#).

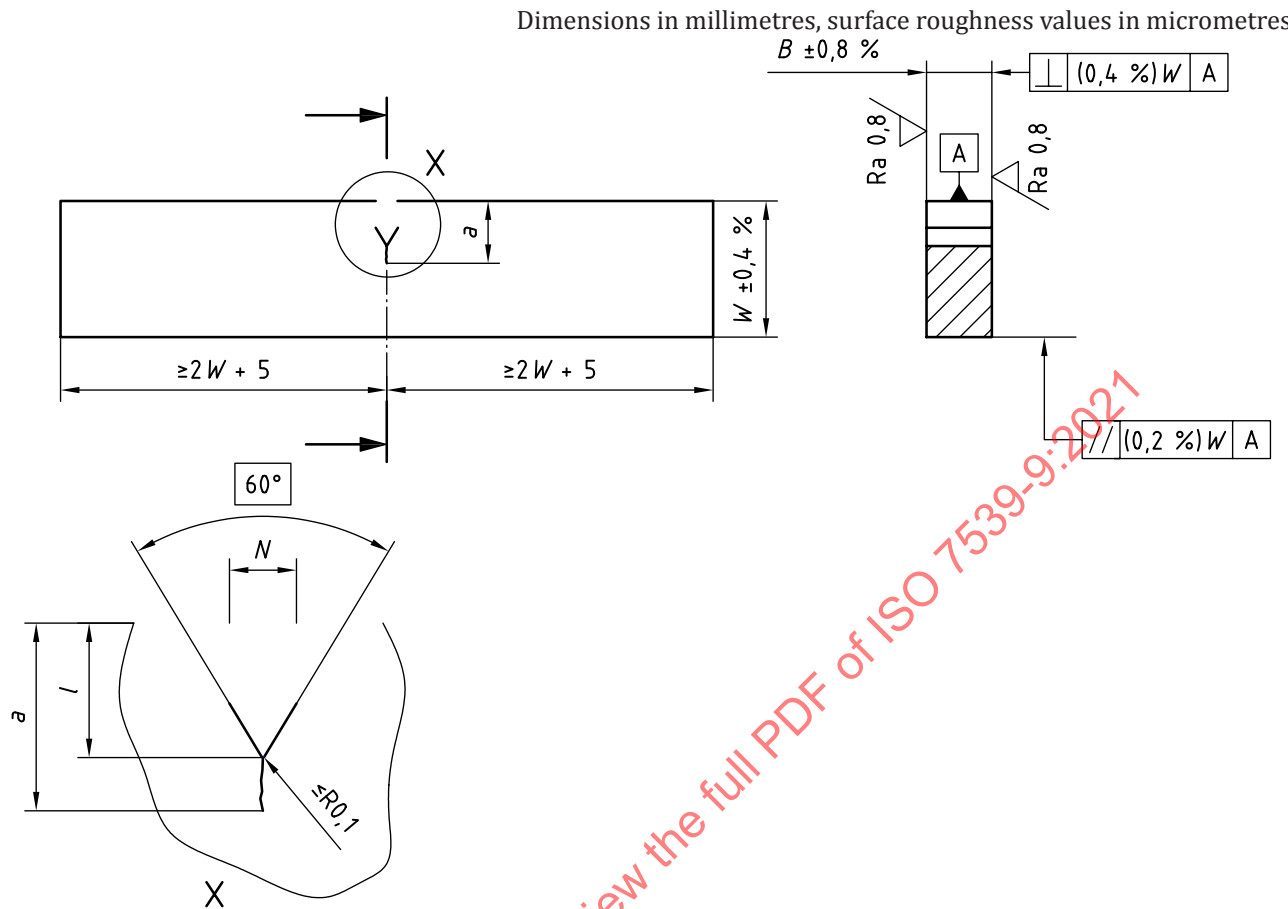
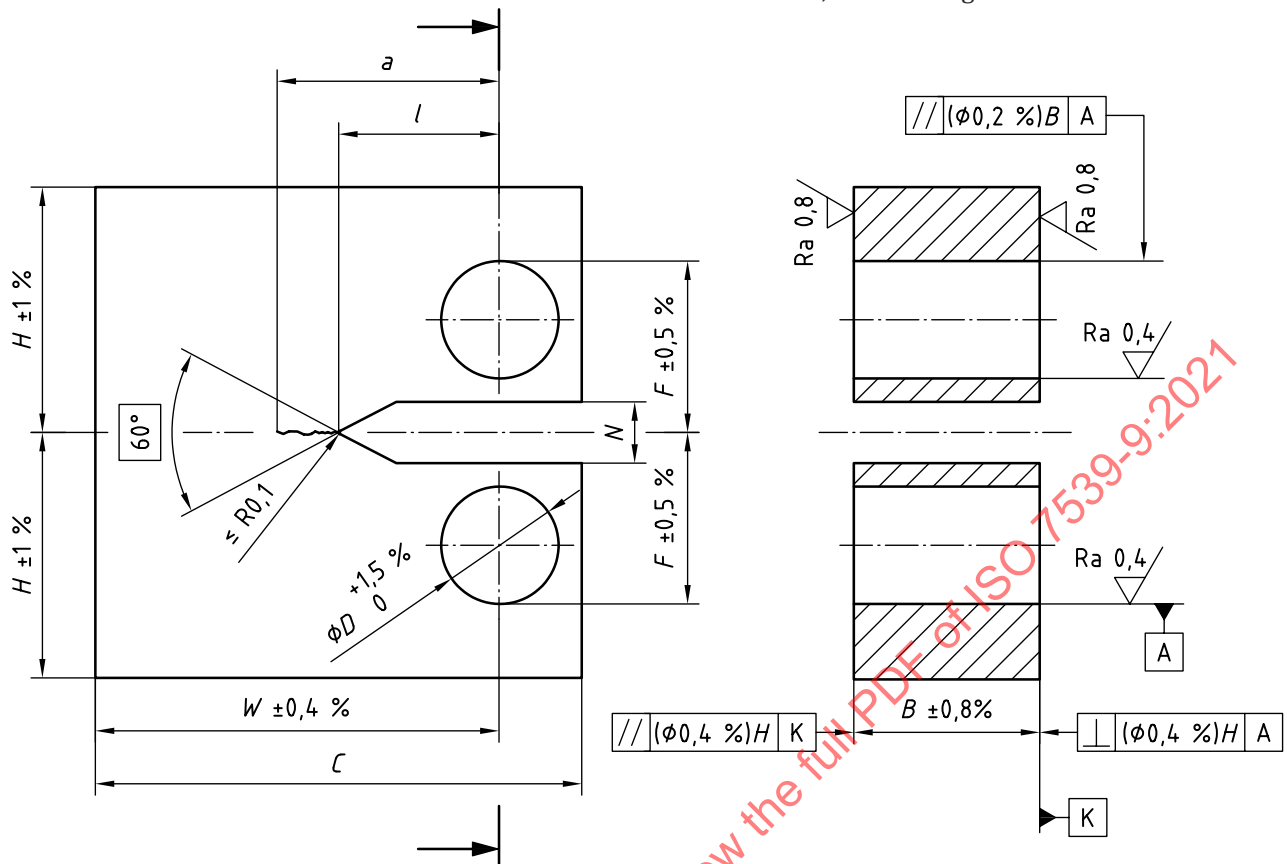


Figure 1 — Proportional dimensions and tolerances for cantilever, three-point and four-point bend test pieces

Dimensions in millimetres, surface roughness values in micrometres

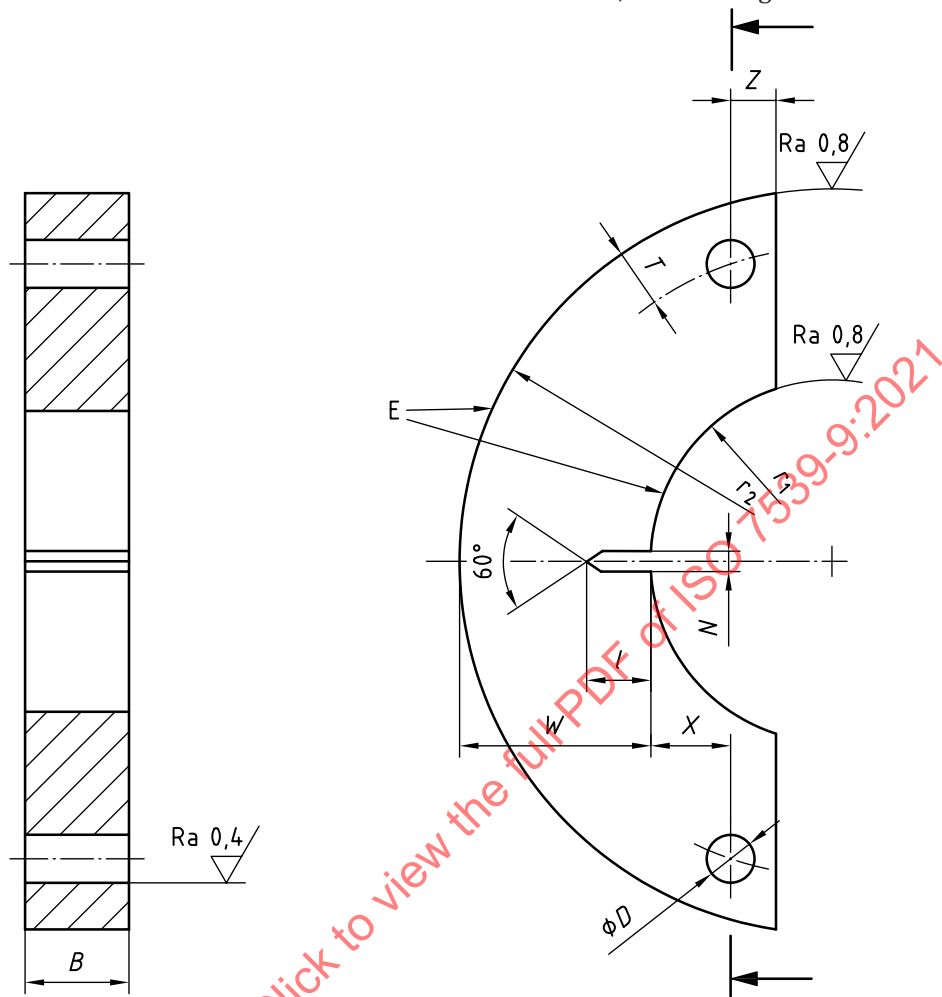


Key

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

Figure 2 — Proportional dimensions and tolerances for compact tension test pieces

Dimensions in millimetres, surface roughness values in micrometres



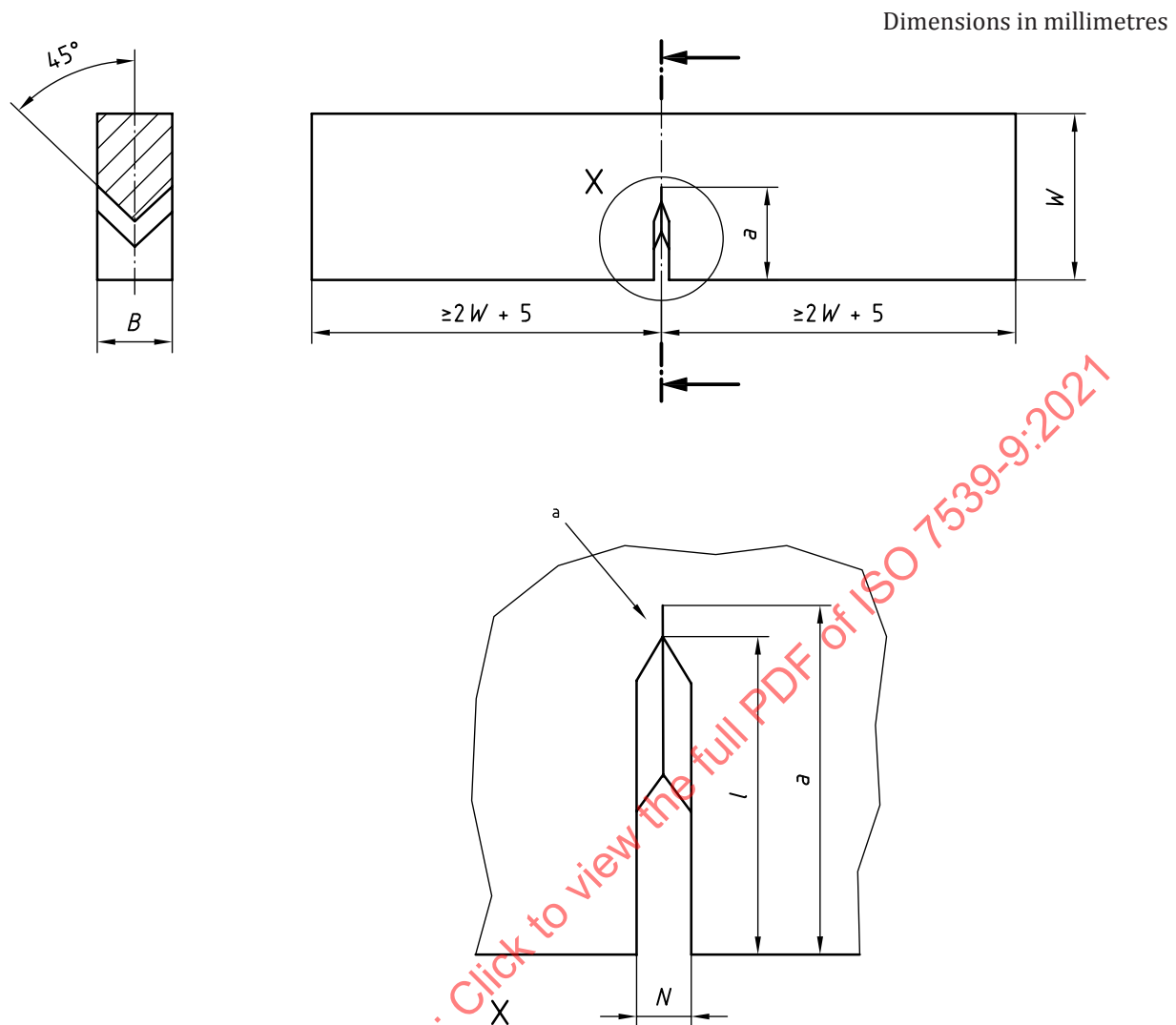
Key

- B thickness, $B = 0,50W \pm 0,01W$
 D diameter of holes, $D = 0,25W \pm 0,005W$
 l effective notch length, $l = 0,3W$
 N notch width, $N = 1,5$ mm minimum ($0,1W$ maximum)
 r_1 internal radius
 r_2 external radius
 T Distance from the hole axis to outer surface, $T = 0,25W \pm 0,01W$
 W net width
 X distance from the hole axis to a tangent with the inner surface, $X = 0,50W \pm 0,005W$
 Z distance from the hole axis to face of specimen, $Z = 0,25W \pm 0,01W$

All surfaces should be perpendicular and parallel, as applicable, to within $0,002W$ total indicator reading (TIR) and "E" surfaces should be perpendicular to "Y" surfaces to within $0,02W$ TIR.

Figure 3 — Proportional dimensions and tolerances for C-shaped test pieces

5.2.4 If required, for example if either fatigue crack initiation or propagation, or both, are difficult to control satisfactorily, a chevron notch configuration as shown in [Figure 4](#) may be used. If required, its included angle may be increased from 90° to 120° .

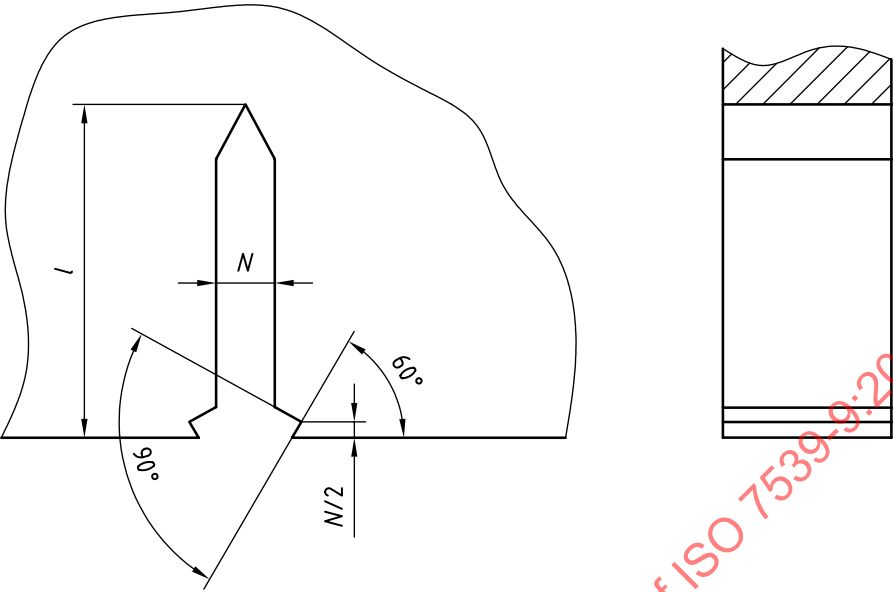


Key

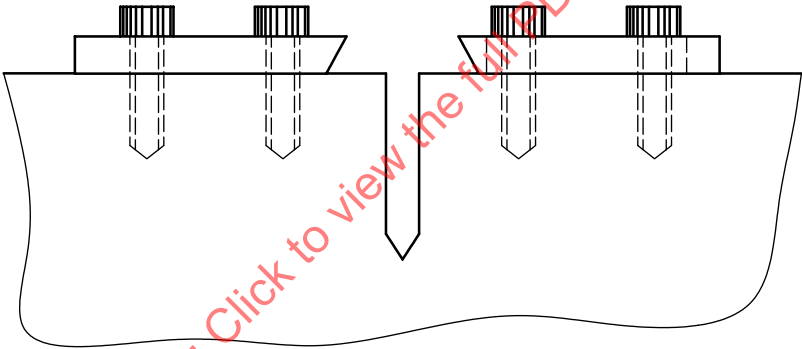
- ^a Mill with a 60° cutter; notch root radius 0,3 mm maximum for all test piece sizes.

Figure 4 — Chevron notch

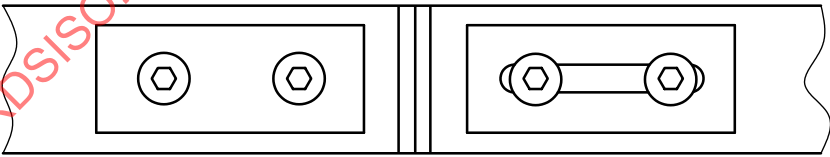
5.2.5 Where it is necessary to measure crack opening displacements knife edges for the location of displacement gauges can be machined into the mouth of the notch, as shown in [Figure 5 a](#)). Alternatively, separate knife edges can either be screwed or glued onto the specimen at opposite sides of the notch, as shown in [Figure 5 b](#)). Details of a suitable tapered beam displacement gauge are given in [Figure 6](#).



a) Integral type

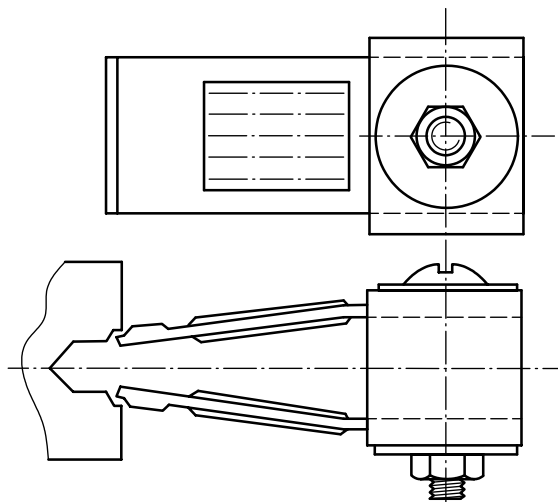


b) Screw-on type

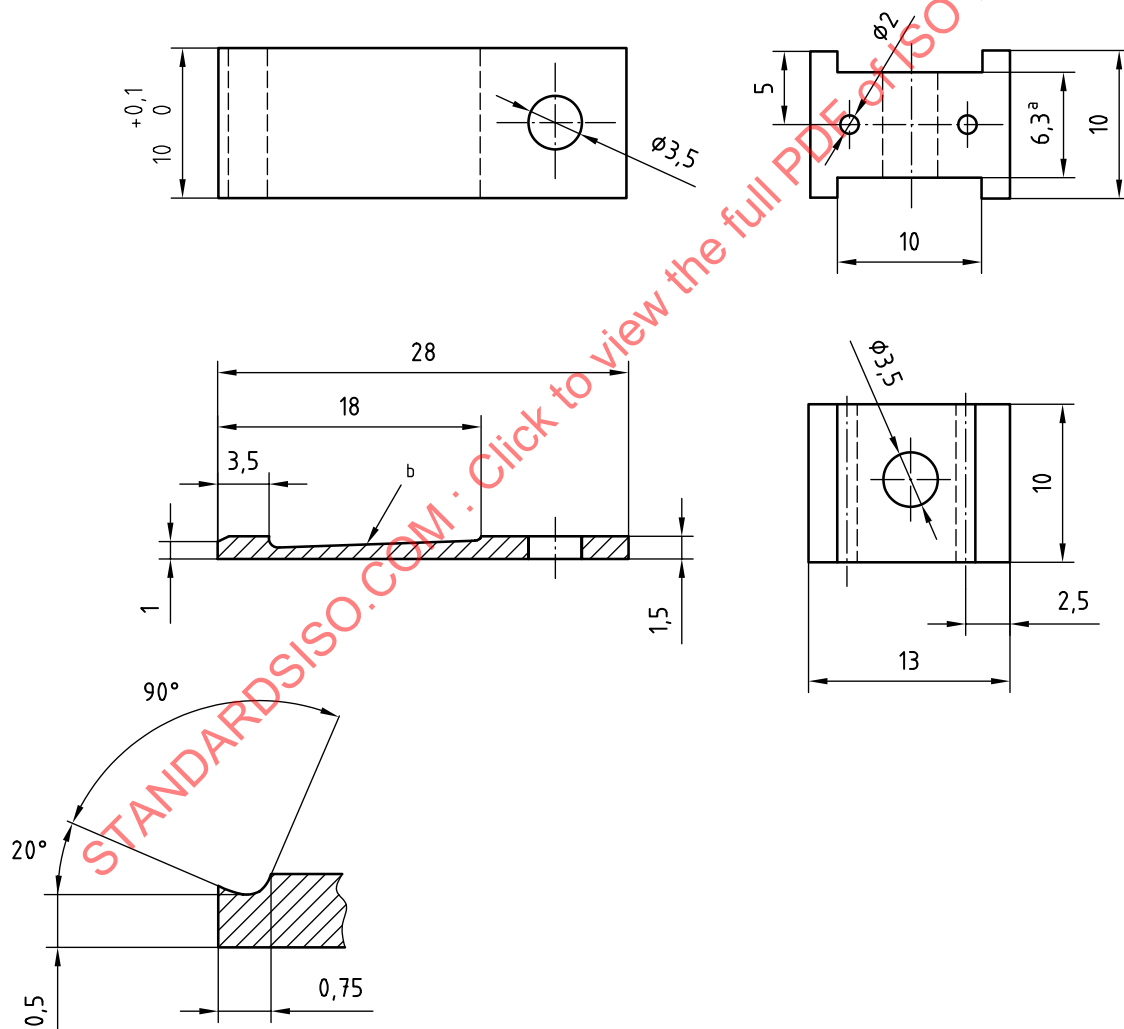


NOTE Provided adequate strength can be ensured, the above knife edges can be fixed using adhesive.

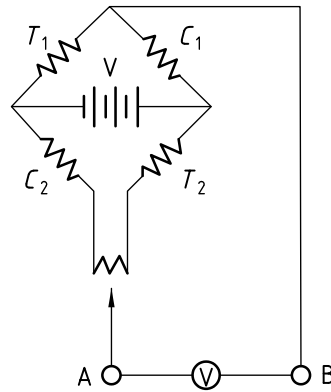
Figure 5 — Knife edges for location of displacement gauges



a) Displacement gauge mounted on a test piece



b) Dimensions of beams



c) Bridge measurement circuit

Key

A, B terminals

V voltage

 T_1, T_2 strain gauges under tension C_1, C_2 strain gauges under compressiona 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 6 — 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, K_I , acting at the tip of a crack in specimens or structures of various geometries can be expressed by formulae of the form

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

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

5.3.3 K_I values can be calculated by means of a dimensionless stress intensity coefficient, Y , related to crack length expressed in terms of a/W through relationship of the form, for compact tension and C-shaped specimens, as shown in:

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

where

P is the width of the specimen;

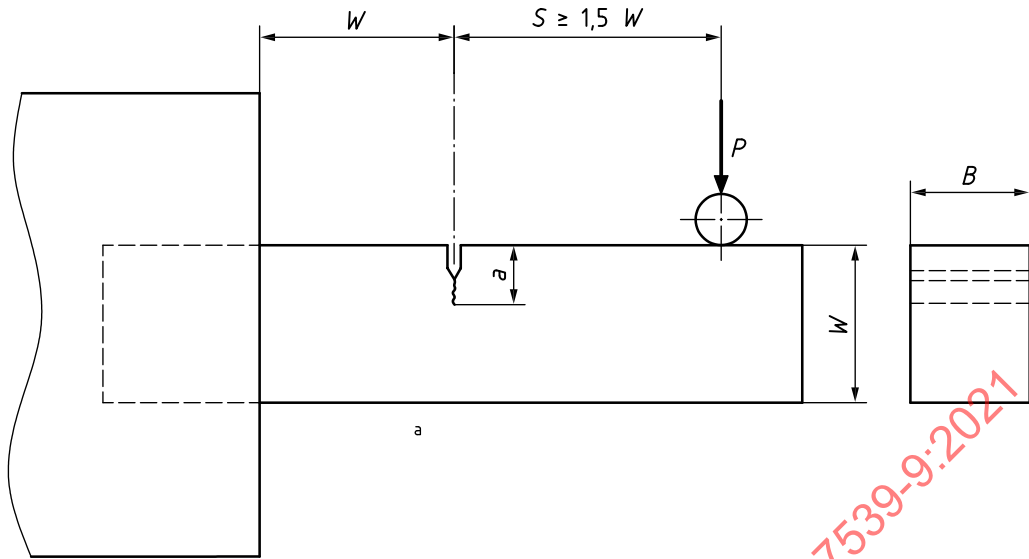
W is the width of the specimen.

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 employed, the effect of the reduced thickness, B_n , due to the grooves on the stress intensity can be taken into account by replacing B in the formula above by:

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

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 7](#) to [9](#). ISO 11782-2, ISO 12135 and Reference [\[7\]](#) provide information for other geometries.



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

where

S

is the distance from centre of notch to loading point

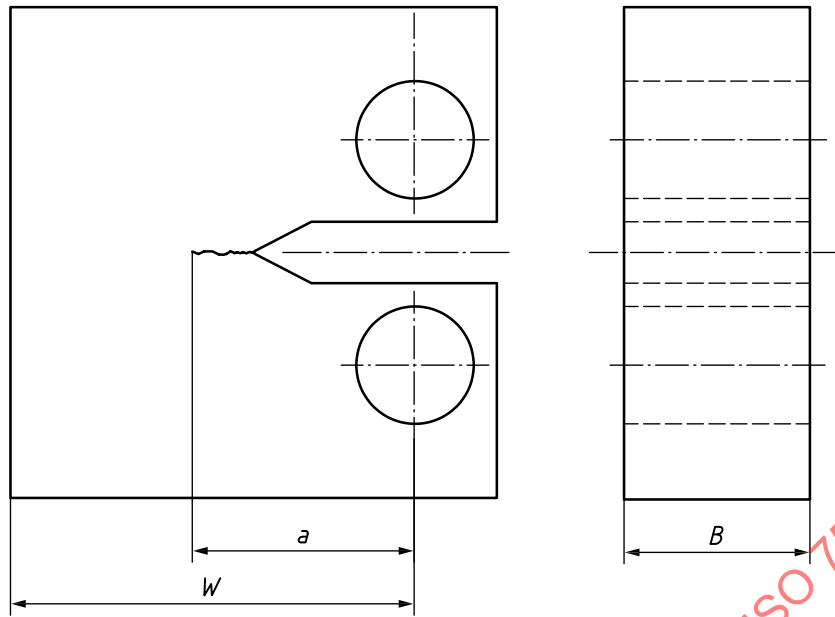
Y

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

This formula 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.

NOTE Formulae for other bend specimens can be found in Reference [7].

Figure 7 — Stress intensity factor solution for cantilever bend specimen

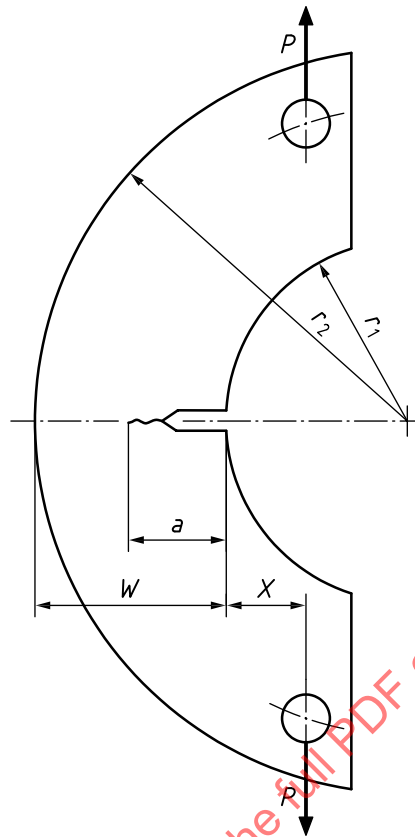


$$K_I = \frac{YP}{B\sqrt{W}}$$

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

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

Figure 8 — Stress intensity factor solution for compact tension specimen



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

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

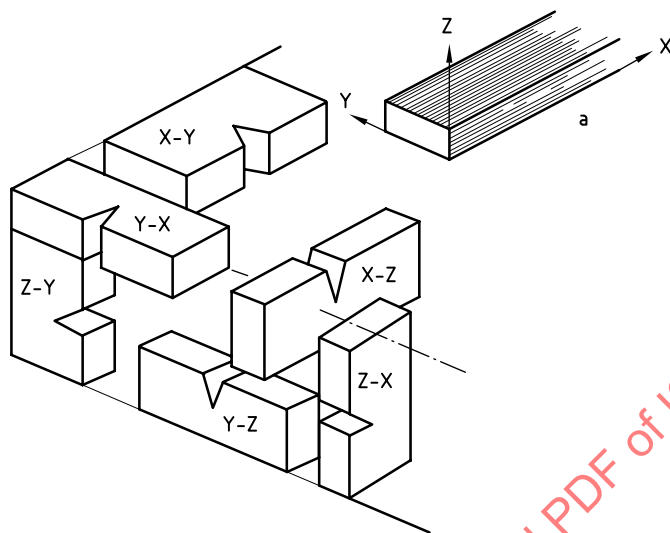
NOTE The accuracy of this formula for $\frac{a}{W}$ for all values of $\frac{r_1}{r_2}$ is considered to be as follows: within 1,0 % over the range $0,45 \leq \frac{a}{W} \leq 0,55$ and $\frac{X}{W}$ of 0 or 0,5; within 1,5 % for $0,2 \leq \frac{a}{W} \leq 1$ and $\frac{X}{W}$ of 0 or 0,5; within 3,0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

Figure 9 — Stress intensity factor solution for C-shaped specimen

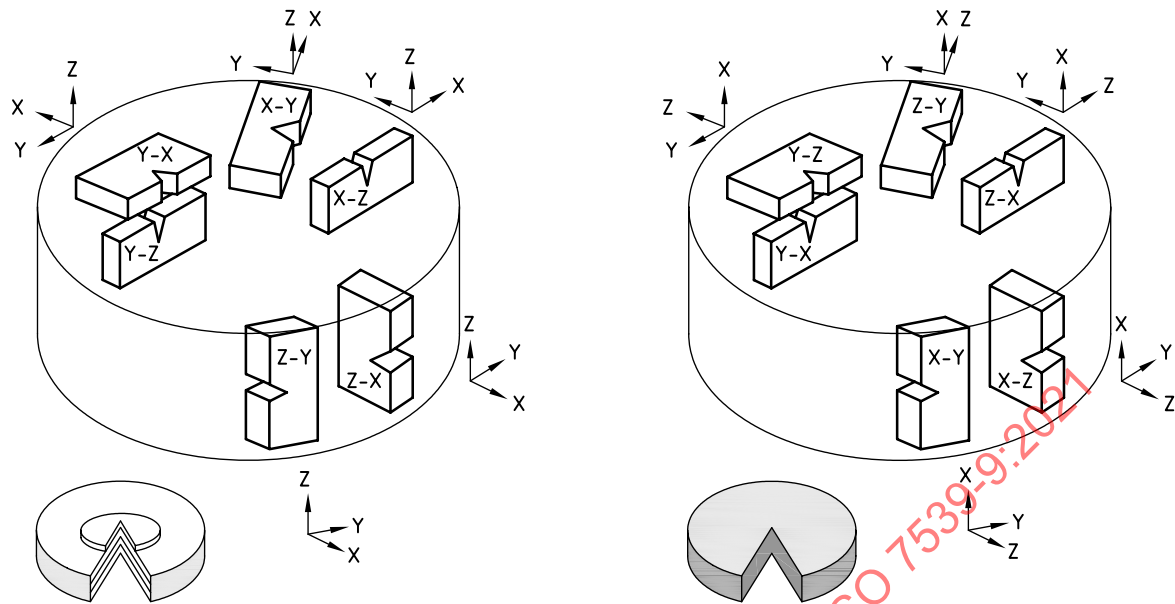
5.4 Specimen preparation

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. Measurement of residual stress is desirable.

5.4.2 Specimens of the required orientation (see [Figure 10](#)) shall, where possible, be machined in the fully heat-treated condition. For specimens in material that cannot easily be completely machined in the fully heat-treated condition, the final heat treatment may be given prior to the notching and finishing operations provided that at least 0,5 mm per face is removed from the thickness at this finish machining stage. However, heat treatment may be carried out on fully machined specimens in cases in which heat treatment will not result in detrimental surface conditions, residual stress, quench cracking or distortion.

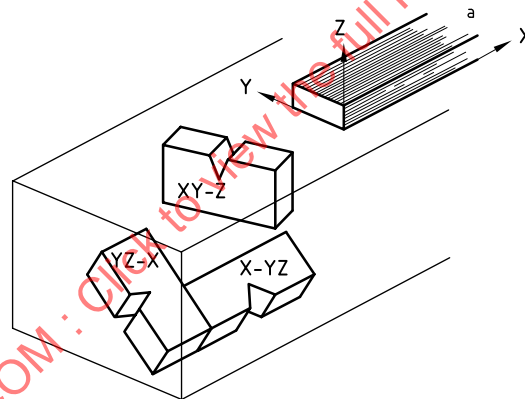


a) Basic fracture plane identification: Rectangular section



b) Basic fracture plane identification:
Cylindrical section with radial grain flow
— Axial working direction

c) Basic fracture plane identification:
Cylindrical section with axial grain flow
— Radial working direction



d) Non-basic fracture plane identification

Key

^a Grain flow.

Figure 10 — 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 pre-cracking or stress corrosion testing. In cases where it is necessary to attach electrodes to the specimen by soldering or brazing for crack monitoring by means of electrical resistance measurements, the specimens shall be fully degreased following this operation prior to pre-cracking in order to remove traces of remnant flux.

5.5 Specimen identification

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

6 Initiation and propagation of fatigue cracks

6.1 The machine used for fatigue cracking shall have a method of loading such that the stress distribution is symmetrical about the notch and the inaccuracy in measurement of applied load is not greater than $\pm 2,5\%$.

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

6.3 The specimens shall be pre-cracked by fatigue loading with an R value in the range 0 to 0,1 until the crack extends at least 2,5 % of W or 1,3 mm beyond the notch at the side surfaces, whichever is greater. The crack may be started at higher K_I values but, during the final 0,5 mm of crack extension, the fatigue pre-cracking shall be completed at as low a maximum stress intensity as possible (below 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.

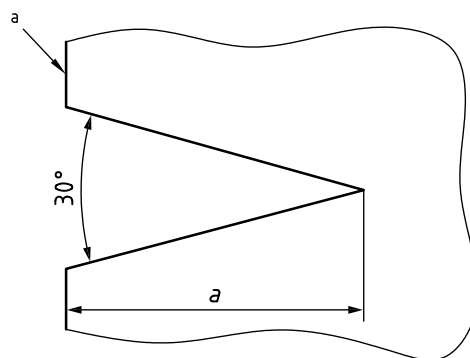
6.4 The final length of the fatigue crack should be such that the requirement for plane strain predominance is satisfied, i.e.

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

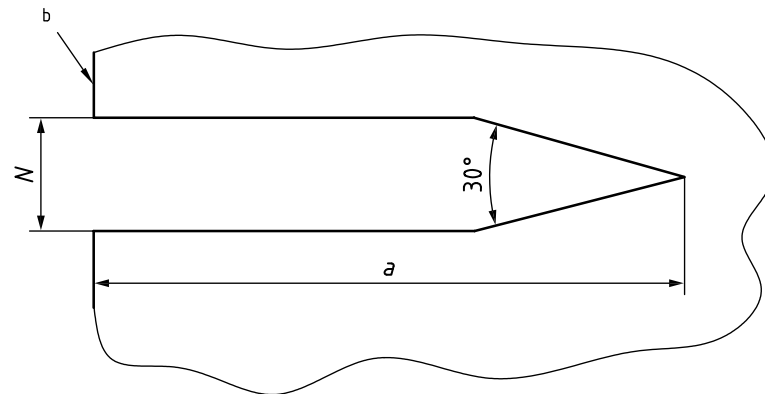
This condition is optimized when the final a/W ratio is in the range 0,45 to 0,55.

NOTE Crack size can be important in relation to SCC.

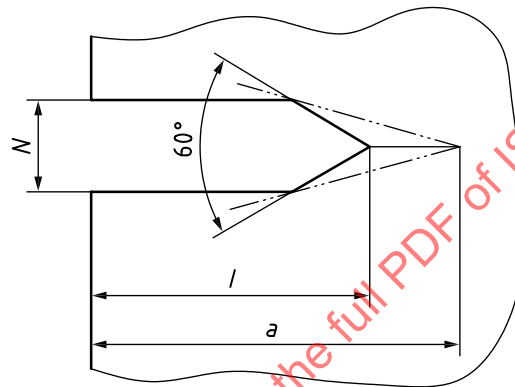
6.5 In order to avoid the interaction of the stress field associated with the crack with that due to the notch, the crack should lie within the limiting envelope as shown in [Figure 11](#).



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 11 — 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 should be inspected on each side of the specimen to ensure that no part of it lies in a plane the slope of which exceeds an angle of 10° from the plane of the notch and that the difference in lengths does not exceed $W = 5\%$.

6.7 Additional guidance on fatigue pre-cracking procedures is available in ISO 11782-2, while ISO 15653 provides guidance for welds.

7 Procedure

7.1 General

Before testing, the thickness B and width W shall be measured to $\pm 0,1\%$ on a line not further than 10% of W from the crack plane. The average length of the fatigue pre-crack on both sides of the specimen shall also be determined and this value is used in assessing the pre-load required to produce the desired initial stress intensity, K_I (see 7.5).

7.2 Environmental considerations

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

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

7.2.3 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 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.

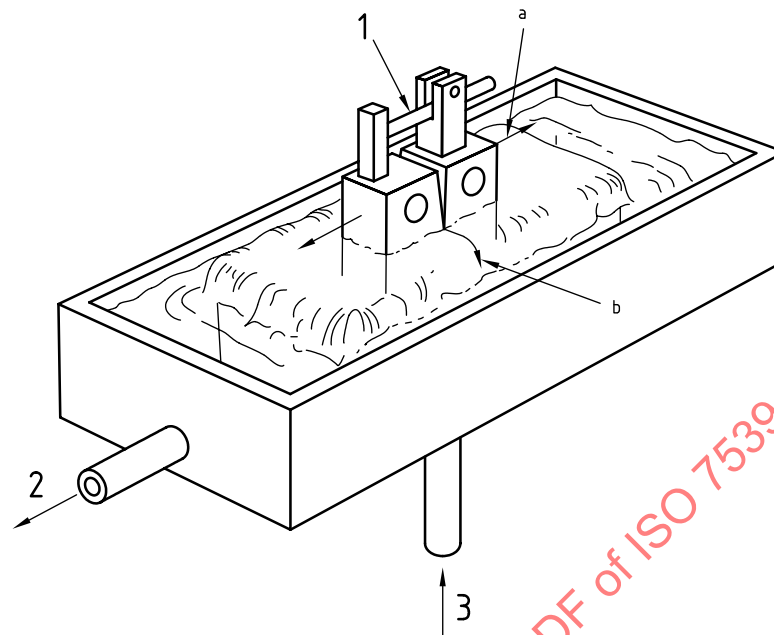
7.2.5 Auxiliary electrodes to apply external current should be designed to produce uniform current distribution on the specimen, i.e. the electrode potential should be constant.

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 should 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 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 12](#) in which the environment is circulated around the vicinity of the notch, pre-crack and anticipated crack growth region of the specimen. Crevice problems may also arise where the specimen emerges from the test cell and these should be avoided by appropriate design of the cell or by the use of protective coatings at such locations. If total immersion in the corrodent is contemplated,

the loading points should 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 12 — Position of a typical environmental cell on a fracture mechanics specimen

7.3.2 An adequate volume-of-solution: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 to limit any effects caused by reaction products from this electrode. It should be noted that the electrode potential developed 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 to prevent galvanic interaction.

7.3.4 For tests in 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, for example, 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 ohmic potential drop in the measurement of potential. The temperature of the solution shall be controlled to ± 2 °C.

7.5 Selection of initial K value prior to dynamic loading

7.5.1 In cases where data from fracture toughness data in air for the material under investigation are not available, a preliminary test should be performed in laboratory air (see ISO 12135). This requires that at least one 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} .

7.5.2 The establishment of cracking conditions in a given metal/environment combination may be time-dependent, if they do not exist at the outset of the test. In such circumstances stress corrosion cracking may only be observed if the displacement rate is sufficiently slow to ensure that failure due to pure mechanical rupture does not occur before the necessary time has elapsed whereby the necessary environmental conditions for cracking have been established. These difficulties can sometimes be minimised by exposure of the specimens to the test environment for some time prior to the initiation of dynamic strain. It is recommended to keep the specimens under pre-load for a time period of at least 24 h in the test environment before starting the test. A typical pre-load for the first test in environment is a value that corresponds to an initial K value of 5 % of K_{Ic} (or K_Q).

7.5.3 Selection of initial K value is important because it determines the length of the test.

7.5.4 The initial value of K may correspond to the final maximum stress intensity factor, K_{max} , following fatigue pre-cracking. Where K_{ISCC} is considered likely to be high, the load may be stepped to an arbitrary higher value prior to dynamic loading. If cracking subsequently ensues without much subsequent increase in K value, a lower initial K should be chosen. Since dynamic loading usually represents an accelerated test procedure compared to static loading a low initial K can be adopted. However, the choice of initial K value may be refined based on the first estimate of K_{I-init} .

7.6 Determination of K_{ISCC}

7.6.1 General

The tests are performed at crosshead displacement rates that are selected prior to each test and shall be kept constant throughout this test. However, the load-line displacement rate is the parameter of most relevance. This will be smaller than the crosshead displacement rate due to additional displacement in the load train in the latter. Clip gauges shall be used to determine the load-line displacement. The load-line displacement rate is relatively constant up until crack initiation, beyond which the rate increases. The value of relevance is the constant rate prior to crack initiation.

7.6.2 Determination schedule

7.6.2.1 In most systems, the stress intensity factor at crack initiation, K_{I-init} is likely to be a function of the applied displacement rate. Therefore tests shall be conducted over an appropriate range of displacement rates for the system under consideration in order to ensure that a conservative value of K_{ISCC} is obtained. The procedure to be adopted involves subjecting a number of specimens to different displacement rates following the schedule outlined in 7.6.2.2 to 7.6.2.9.

7.6.2.2 An arbitrary but low displacement rate shall be chosen for the determination of a preliminary K_{I-init} value above which stress corrosion cracking is likely to initiate. This rate will depend upon the material, specimen size and environment in question and shall be agreed between parties concerned but for preliminary testing, rates of 1×10^{-8} m/s (36 μ m/h) for titanium alloys and 1×10^{-9} m/s (3,6 μ m/h) for higher strength steels and aluminium alloys may be appropriate. Some recommendations for determining an appropriate initial displacement rate are given in [Annex A](#).

The test is started from the pre-load chosen in [7.5.2](#) without unloading the specimen.

7.6.2.3 During testing, crack length may be monitored continuously by means of electrical resistance, back-face strain or alternative techniques, depending on the experimental circumstances (see [Annex C](#)). These measurements should enable the detection of crack initiation. They also enable crack growth rates to be determined as a function of stress intensity factors.

7.6.2.4 The load-displacement behaviour of the specimen and the time elapsed since the start of the test are measured and recorded. The test machine shall be stopped after either the indirect crack length measuring method or a drop in load record indicate that crack initiation and subsequent crack growth have occurred.

7.6.2.5 On completion of the test, the specimen is taken out of the test environment and the crack front shall be marked by either heat tinting or fatigue cracking in air. The fatigue cracking shall be performed at an R ratio greater than 0,6 to avoid damage to the fracture surfaces from crack closure effects. The maximum fatigue load shall not exceed three quarters of the final load measured during the test. In certain environments it may turn out that the crack front at test termination is already sufficiently marked by visible remains of the environment so that no additional marking is required.

7.6.2.6 The specimen shall be broken open and the length of the fatigue pre-crack shall be measured at both edges and at the following three positions: $B_1 = 0,25$; $B_2 = 0,50$; $B_3 = 0,75$.

The average of these five measurements should be used as the effective initial crack length a_0 in the calculation of K_{I-init} . Greater accuracy can be obtained by measuring the crack length at nine positions along the crack front as specified in ISO 12135.

7.6.2.7 A new specimen is tested under identical environmental conditions at a lower displacement rate. The initial K value may be modified.

Guidance on selection of the new displacement rate can be made if the fracture surface is examined by microscopy for evidence of stress corrosion crack extension in comparison with the fracture surface of a specimen which was tested in air. The percentage of environmental cracking on the fracture surface in the region of stable crack extension adjacent to the initial crack front can be used as an estimate of a suitable displacement rate for the subsequent test according to [Table 1](#).

Table 1 — Recommended factors by which the strain rate shall be reduced depending upon the proportion of stress corrosion cracking on the fracture surface

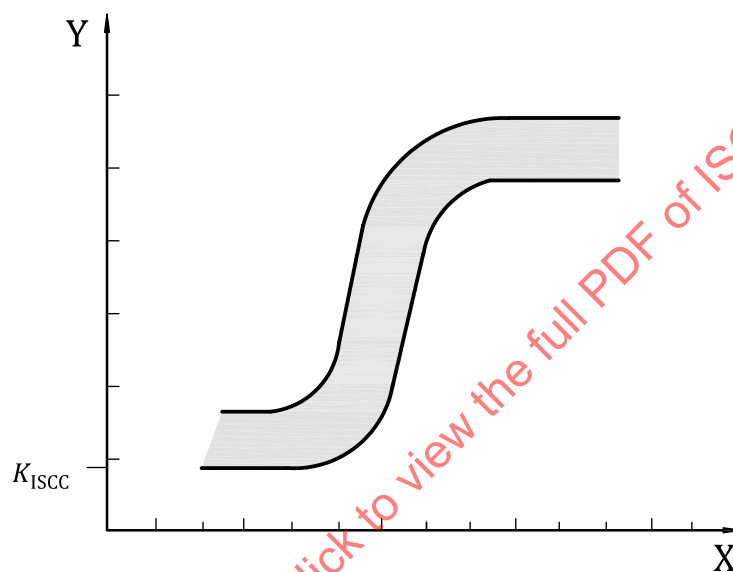
Percentage of SCC on fracture surface, %	Reduce displacement rate by factor of
<10	50
10 to 30	20
30 to 50	10
50 to 80	5
>80	2

If the whole region of stable crack extension is covered by environmental cracking, then a further reduction of displacement rate may not be necessary, although advisable for confirmation. Otherwise,

a displacement rate shall be selected which is by a factor of 10 lower than the rate chosen for the preceeding test.

7.6.2.8 If the values of K_{I-init} determined from two subsequent tests do not differ by more than 5 %, or the desired accuracy of the K_{ISCC} value, then the lower of these two values can be considered as the preliminary value of K_{QSCC} .

7.6.2.9 If time permits, the reliability of the preliminary value of K_{QSCC} can be checked by a further stress corrosion test at a displacement rate which is by a factor of 5 to 10 lower than the one used in [7.6.2.8](#). Further testing will only be necessary if this test shows evidence of a further decrease of the measured value of K_{I-init} . Otherwise, some indication of the displacement rate dependence of K_{I-init} can be gleaned by plotting the measured values of K_{I-init} as a function of the applied displacement rate to establish whether the curve appears to be asymptotic to the K_{QSCC} value, as illustrated in [Figure 13](#).



Key

X $\dot{V}_{LL}$ (mm/h)
Y K_{I-init} (MPa√m)

Figure 13 — Initiation value of stress intensity factor as a function of the applied displacement rate

7.6.3 Validation of test results

The result of the test series is valid, i.e. $K_{QSCC} = K_{ISCC}$, unless:

- the difference between any two of these last three measurements exceeds 2,5 % of W ;
- the difference between the maximum and minimum crack lengths exceeds 5 % of W ;
- 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;
- the fatigue crack is not in one plane, i.e. effects of multi-nucleation are present;
- the factor

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

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

- f) there is uncertainty over the fatigue crack length;
- g) there is significant non-uniformity of the crack front.

7.7 Determination of crack velocity

7.7.1 Tests performed in 7.6 which yielded values of K_{I-init} being in agreement of K_{ISCC} (or K_{QSCC}) can 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 to the procedure given in Annex B. To determine these data the specimens should be broken and the fracture surfaces should be examined by microscopic means.

7.7.2 The final crack front should be measured if possible to the nearest $\pm 0,5$ % of W at both edges and at the following three positions: B1 = 0,25; B2 = 0,50; B3 = 0,75.

The average of these five measurements should be used as the effective final crack length, a_f .

Greater accuracy can be obtained by measuring the crack length at nine positions along the crack front as specified in ISO 12135.

7.7.3 The average crack velocity $\Delta a/\Delta t$ is obtained by dividing the difference between the final and the initial crack length, $a_f - a_0$, by the time elapsed between crack initiation and termination of the test.

8 Test report

The test report shall contain at least the following information.

- a) Full description of the test material from which the specimens were taken, including composition, structural condition and mechanical properties, type of product and section thickness. K_{Ic} (or K_Q if the validity criteria are not obeyed) if determined.
- b) Description of the test machine and equipment used to measure crack length and the precision with which crack length measurements were made.
- c) Description of the environmental chamber and all equipment used for environmental monitoring control.
- d) The initial solution composition, pH, degree of aeration (or concentration of other relevant gases), flow conditions, temperature and electrode potential reported, where monitored. Specification of flow rate should be in terms of approximate linear rate past specimen if determined by the recirculation rate. The reference electrode used should be indicated; the potential should be reported and referred to an appropriate standard electrode (example standard hydrogen electrode or saturated calomel electrode at 25 °C). Variations in these parameters during testing should be recorded.
- e) The starting procedure for the test.
- f) Transients in the environment or in the loading (including test interruptions) during testing, noting the nature and duration and, where applicable, the associated crack lengths.
- g) 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) fatigue cracking
 - i) the fatigue stress intensity factor, K_f , during the propagation of the final portion of the crack,
 - ii) the fatigue load ratio, R , and
 - iii) the temperature and environment during precracking;
- 5) the length of the fatigue pre-crack, a ;
- 6) the initial stress intensity factor, K_{II} ;
- 7) the initial time of exposure to the environment and the total time of testing;
- 8) whether stable crack extension occurred;
- 9) crack plane and propagation direction, identified as shown in [Figure 10](#).
- h) Range of displacement rates used including crosshead rate and load-line displacement rate.
- i) K_{ISCC} (or K_{QSCC} if the validity criteria are not obeyed), stating at which displacement rate determined and criteria used.
- j) Crack growth data (average values or as a function of stress intensity) where available.
- k) Any deviations from the procedure.
- l) Any unusual features observed.
- m) The International standard used, and its year of publication.
- n) Date of test.