

Fracture mechanics toughness tests —

Part 4: Method for determination of fracture resistance curves and initiation values for stable crack extension in metallic materials

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Committees responsible for this British Standard

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- British Non-ferrous Metals Federation
- British Railways Board
- Copper Development Association
- Electricity Association
- ERA Technology Ltd.
- GAMBICA (BEAMA Ltd.)
- Institute of Materials
- Ministry of Defence
- National Physical Laboratory
- Society of British Aerospace Companies Limited
- The Welding Institute
- UK Steel Association
- United Kingdom Accreditation Service
- University College London
- Co-opted members

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- BEAMA Ltd.
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Foreword

This Part of BS 7448 has been prepared by Technical Committee ISE/NFE/4.

It gives a method for the determination of fracture resistance curves and initiation values for stable crack extension in metallic materials.

BS 7448 is being published in four Parts.

Part 1 describes a method for determining K_{Ic} , critical crack tip opening displacement (CTOD) and critical J values of fracture toughness for metallic materials under displacement controlled monotonic loading at quasistatic rates.

Part 2 describes a method for determining the fracture toughness of weldments in metallic materials.

A further Part of BS 7448 is in preparation as follows.

Part 3 describes a method for determining dynamic fracture toughness.

It has been assumed in the drafting of this standard that the execution of its provisions is entrusted to appropriately qualified and experienced people.

CAUTION. It is important to note that tests of the type described involve the use of large forces, and may involve the rapid movement of machine parts and fractured test specimens. Therefore it is important to consider the safety of machine operators.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 46, an inside back cover and a back cover.

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1 Scope

This Part of BS 7448 gives a method for determining the resistance to stable crack extension of metallic materials. The method uses fatigue precracked specimens. These are tested in displacement controlled loading at a constant rate of increase in stress intensity factor within the range $0.5 \text{ MPa} \cdot \text{m}^{0.5} \text{s}^{-1}$ to $3.0 \text{ MPa} \cdot \text{m}^{0.5} \text{s}^{-1}$ ¹⁾ during the initial elastic deformation. Resistance to crack extension is characterized in terms of the variation in crack tip opening displacement (CTOD) and/or J with stable crack extension. These characterizations are referred to in this standard as δ and J R-curves, respectively.

The method is only suitable for tests on specimens that exhibit stable crack extension. If unstable fracture or crack arrest occurs in any of the tests in an R-curve determination it is necessary also to assess the test results in accordance with BS 7448-1.

Testing requirements and analysis procedures are given which enable crack extension resistance curves to be calculated from both straight notch and stepped notch compact specimens and single edge notch bend specimens. Individual fracture parameters are also defined for CTOD and J at a point where stable crack extension is close to the onset of initiation.

The definition of fracture toughness values relevant to particular structural integrity assessments is outside the scope of this British Standard.

NOTE Publications of relevance to the subject matter covered by this Part of BS 7448 are listed in the bibliography in Annex A. A system of crack plane identification is given in Annex B.

2 References

2.1 Normative references

This Part of BS 7448 incorporates, by dated or undated reference, provisions from other publications. These normative references are made at the appropriate places in the text and the cited publications are listed on the inside back cover. For dated references, only the edition cited applies; any subsequent amendments to or revisions of the cited publication apply to this Part of BS 7448 only when incorporated in the reference by amendment or revision. For undated references, the latest edition of the cited publication applies, together with any amendments.

2.2 Informative references

This Part of BS 7448 refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on the inside back cover, but reference should be made to the latest editions.

3 Definitions

For the purposes of this Part of BS 7448 the following definitions apply.

3.1

stress intensity factor (K)

the magnitude of the elastic stress field singularity for a homogeneous, linear-elastic body

NOTE It is a function of applied force, crack length and specimen geometry, and is expressed in units of $\text{MPa} \cdot \text{m}^{0.5}$.

3.2

crack tip opening displacement (CTOD)

the relative displacement of the surfaces of a crack normal to the original (undeformed) crack plane at the tip of the fatigue precrack, expressed in millimetres

3.3

J -integral

a line or surface integral that encloses the crack front from one crack surface to the other, which characterizes the local stress-strain field at the crack tip, expressed in MJ/m^2 ²⁾

3.4

J

an experimental equivalent of the J -integral as determined by the method given in the present standard

¹⁾ $0.0316 \text{ MPa} \cdot \text{m}^{0.5} = 1 \text{ N} \cdot \text{mm}^{-1.5} = 0.0316 \text{ MN} \cdot \text{m}^{-1.5}$.

²⁾ $1 \text{ MJ/m}^2 = 1 \text{ MN/m}$.

3.5**unstable crack extension**

an abrupt crack extension which occurs with or without prior stable crack extension

3.6**pop-in**

an abrupt discontinuity in the force versus displacement record, featured as a sudden increase in displacement and, generally, a decrease in force

NOTE Subsequently displacement and force generally increase to above their values at pop-in.

3.7**stable crack extension**

crack extension which, in displacement control, stops when the applied displacement is held constant

3.8**stretch zone width (SZW)**

the length of crack extension that occurs during crack tip blunting; that is, prior to the onset of slow stable crack extension, and which occurs in the same plane as the fatigue precrack

4 Symbols and designations

For the purposes of this Part of BS 7448 the following symbols and designations apply.

a	nominal crack length (see Figure 2 to Figure 5) or, for the purposes of fatigue precracking (see 7.4.4 and 7.4.5), an assumed value $\leq a_0$, in millimetres
a_0	measured original crack length (see 9.9.2), in millimetres
B	thickness of test specimen, in millimetres
$B_{\min}$	minimum test specimen net thickness, in millimetres
B_N	test specimen net thickness between sidegroove tips, in millimetres
C	specimen elastic compliance, in millimetres per kilonewton
E	Young's modulus of elasticity at the temperature of interest, in gigapascals
F	applied force, in kilonewtons
F_L	collapse force, calculated using R_m , in kilonewtons
F_f	maximum fatigue precracking force during the final stages of fatigue crack extension (see 7.4.4 and 7.4.5), in kilonewtons
J	experimental equivalent of the J -integral, in megajoules per square metre
J_0	resistance to crack extension expressed in terms of J , not allowing for stable crack extension, in megajoules per square metre
J_{corr}	resistance to crack extension expressed in terms of J , corrected for stable crack extension, in megajoules per square metre
$J_{0.2\text{BL}}$	resistance to crack extension expressed in terms of J , at 0.2 mm crack extension offset to the blunting line, in megajoules per square metre
$J_{0.2}$	resistance to crack extension expressed in terms of J , at 0.2 mm crack extension including blunting, in megajoules per square metre
$J_{\max}$	resistance to crack extension expressed in terms of J , at the limit for J controlled crack extension, in megajoules per square metre
K	stress intensity factor, in $\text{MPa}\cdot\text{m}^{0.5}$
$\dot{K}$	rate of change of K with time, in $\text{MPa}\cdot\text{m}^{0.5}\text{s}^{-1}$
q	displacement of bend specimen or stepped notch compact specimen along the load-line, in millimetres
S	span between outer loading points in a three point bend test, in millimetres
T	test temperature, in degrees celsius
U_p	plastic component of area under plot of force (F) versus specimen displacement along the load-line (see Figure 16), in joules

V	notch opening displacement at or near to notch mouth, in millimetres
V_e	elastic component of V , in millimetres
V_p	plastic component of V , in millimetres
W	width of test specimen, in millimetres
W_t	total width of compact specimen, in millimetres
z	for bend and straight notch compact specimens, distance of the notch opening gauge location above the surface of the specimen [see Figure 6 b)], or, in the case of a stepped notch compact specimen the distance of the notch opening gauge location above the load line, in millimetres
δ	crack tip opening displacement (CTOD)
δ_o	resistance to crack extension expressed in terms of CTOD, not allowing for stable crack extension, in millimetres
δ_{corr}	resistance to crack extension expressed in terms of CTOD corrected for stable crack extension, in millimetres
$\delta_{0.2}$	resistance to crack extension expressed in terms of CTOD at 0.2 mm crack extension including blunting, in millimetres
$\delta_{0.2\text{BL}}$	resistance to crack extension expressed in terms of CTOD at 0.2 mm crack extension offset to the blunting line, in millimetres
δ_{max}	CTOD limit for CTOD controlled crack extension, in millimetres
Δa	stable crack extension, including SZW (see 9.9.3), in millimetres
Δa_{max}	crack extension limit for CTOD/ J controlled crack extension, in millimetres
ν	Poisson's ratio
η_p	J calibration function
R_{mB}	tensile strength at the temperature of fatigue precracking, in megapascals
R_{m}	tensile strength at the temperature of the fracture test ³⁾ , in megapascals
$R_{p0.2\text{B}}$	0.2 % proof strength at the temperature of fatigue precracking, in megapascals
$R_{p0.2}$	0.2 % proof strength at the temperature of the fracture test ³⁾ in megapascals

5 Principle

A fatigue crack is extended in a single edge notched bend or compact specimen by applying an alternating force within controlled limits. The specimen is then subjected to an increasing force.

One of two techniques is used to determine crack extension: the multiple specimen method or the single specimen method. The multiple specimen method is regarded as the definitive approach.

In the multiple specimen method a minimum of six nominally identical specimens are monotonically loaded to different displacements.

NOTE If a multiple specimen R-curve is required in terms of both δ and J fracture toughness parameters, it may be necessary to test more than six specimens in order to satisfy the various spacing requirements (see 12.3).

Measurements are made of forces and displacements up to the point of termination of the test. The specimen crack fronts are marked after testing thus enabling measurement of stable crack extension after the specimens have been broken open.

Alternatively, a single specimen method based on, for example, the unloading compliance or potential drop technique is used (see clause 10).

The tests are then analysed to obtain resistance to crack extension curves (R-curves) i.e. a plot of fracture resistance, in terms of δ or J , against stable crack extension Δa . These can then be further analysed to obtain estimates of fracture toughness at the initiation of stable crack extension.

This procedure is summarized in a flow chart in Figure 1.

³⁾ At present no British Standard exists for the measurement of tensile properties below ambient temperature. In these cases the values to be used are subject to agreement between interested parties.

6 Test specimens

6.1 General

6.1.1 Each specimen shall be of one of the following designs (see 6.3):

- a) rectangular cross-section single edge notch three point bend (see Figure 2);
- b) straight notch compact (see Figure 3);
- c) stepped notch compact (see Figure 4).

NOTE Specimens having W/B ratios greater than 2 will have an increased tendency to buckle.

6.1.2 The notch profile shall be such that it is within the envelope shown in Figure 5. In order to expedite fatigue precracking the machined notches in the test specimens are normally produced by milling, sawing or disc grinding.

When a milled notch is used the notch root radius shall be not greater than 0.10 mm. When a sawn, disc ground or spark eroded notch is used, the notch tip shall have a width not greater than 0.15 mm.

Because it is generally impractical to machine 0.15 mm wide notches to depths greater than 2.5 mm, it is allowable to machine a stepped width notch.

The plane of the notch shall be perpendicular to the specimen surfaces to within $\pm 2^\circ$.

When required, knife edges shall either be machined into the specimen or be attached separately as shown in Figure 6 and Figure 7. The dimension $2x$ shall be within the working range of the notch opening displacement gauge. The knife edges shall be square with the specimen surfaces and parallel to within 0.5° . For all types of knife edge, the notch opening displacement gauge shall be free to rotate about the points of contact between the gauge and knife edge.

NOTE For this reason, when inward pointing knife edges or razor blades are used, it may be necessary to use an enlarged notch mouth, as shown in Figure 5 and Figure 7 (see 8.3).

6.2 Sidegrooving

For a multi-specimen test method, sidegrooving (see Figure 8) is optional in the case of specimens with a thickness equal to the structural thickness under consideration and which are of the correct orientation to test the crack plane under consideration. For all other specimens and test methods, the specimens shall be sidegrooved.

NOTE 1 Fatigue precracking after sidegrooving (see 7.4) can result in an uneven fatigue crack front.

NOTE 2 Sidegrooving is required to promote uniform crack extension along the crack front and can result in lower, hence more conservative, R-curves than if plane sided specimens of the same nominal dimensions are used.

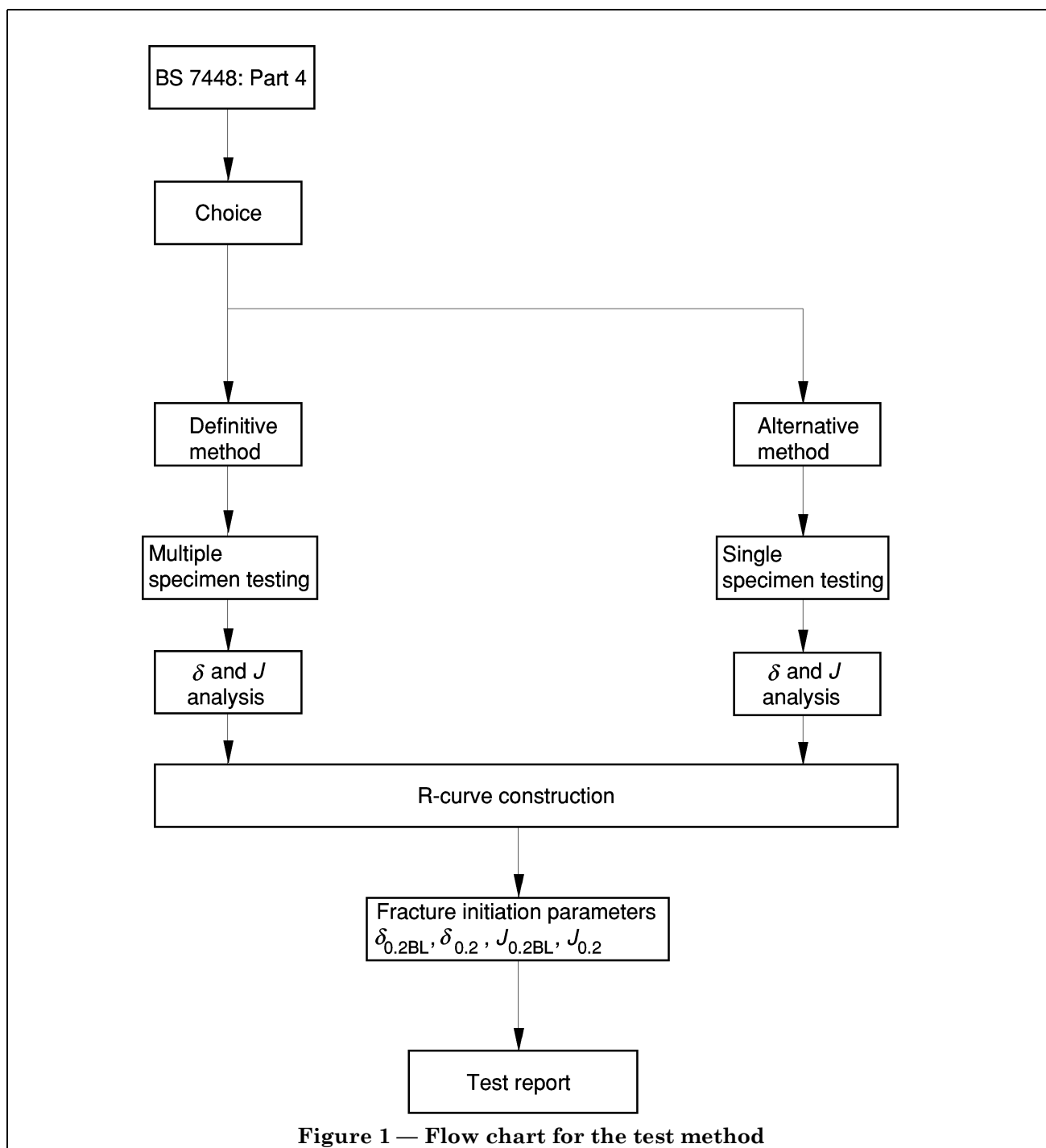
If a specimen is sidegrooved, both sides of the specimen shall have sidegrooves which are equal in depth and which have an included angle, α , of 30° to 90° with a root radius of $0.4 \text{ mm} \pm 0.2 \text{ mm}$. The total depth of sidegrooving, $B - B_N$, shall be equal to $0.20B$ ($0.10B$ each side) where B_N is the net section thickness.

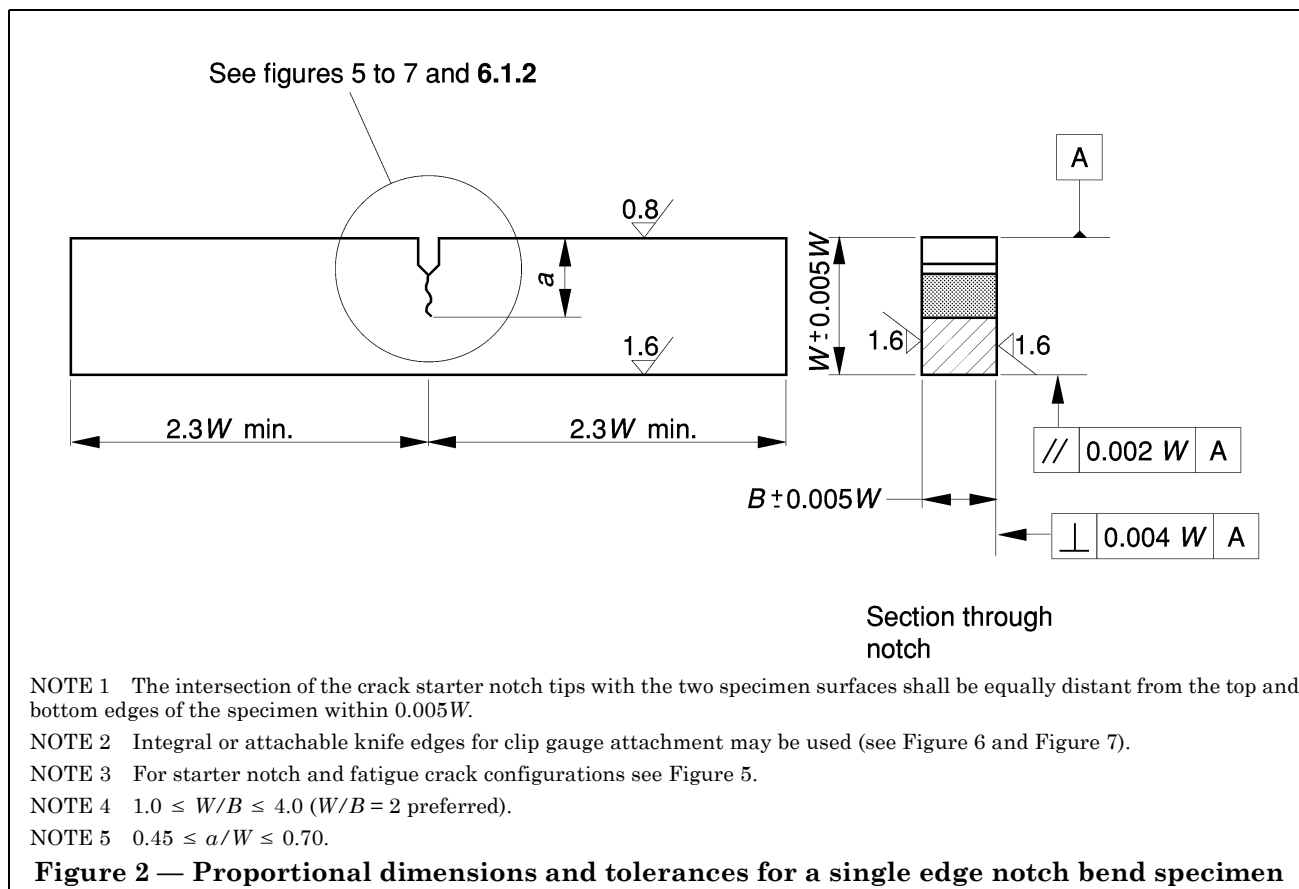
NOTE It is recommended that sidegrooves with an included angle of 90° are used for austenitic specimens. This is because of the large compressive strains that occur at the back face of such specimens which can result in partial or complete closure of the sidegrooves at the back face.

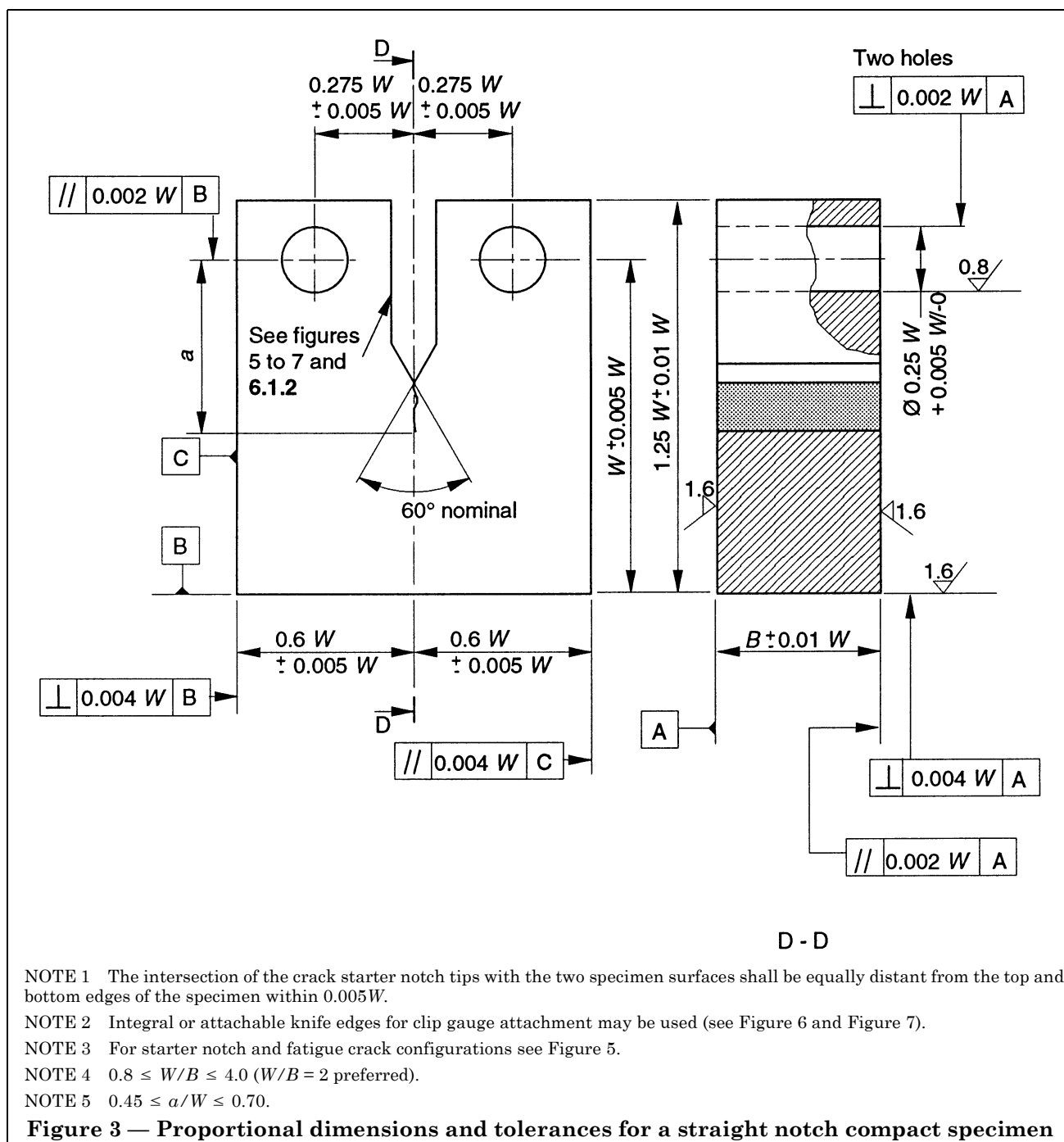
6.3 Choice of specimen design

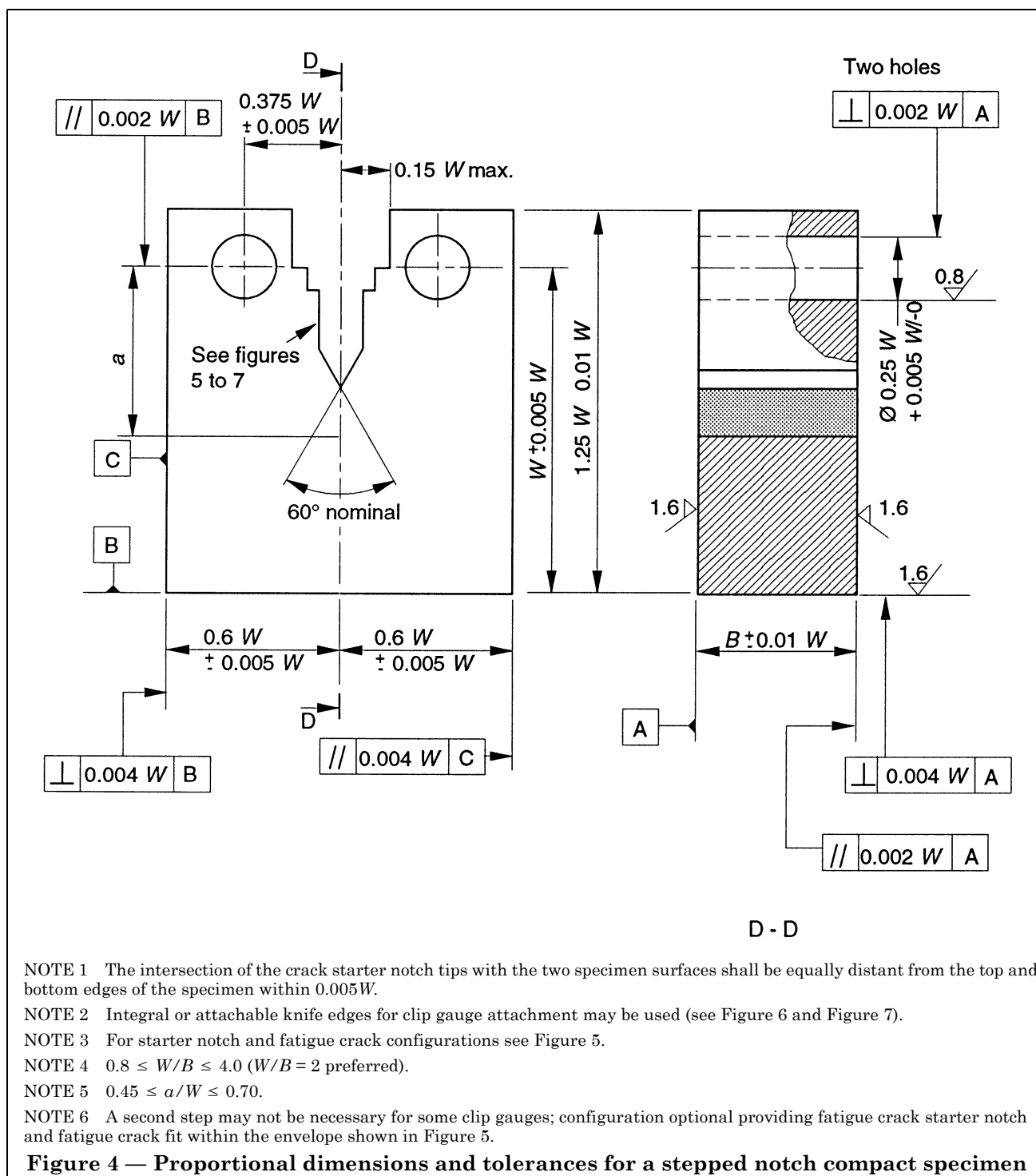
The choice of specimen design shall take into consideration any preference for δ or J R-curve testing and the crack orientation to be used in the test (see 7.2).

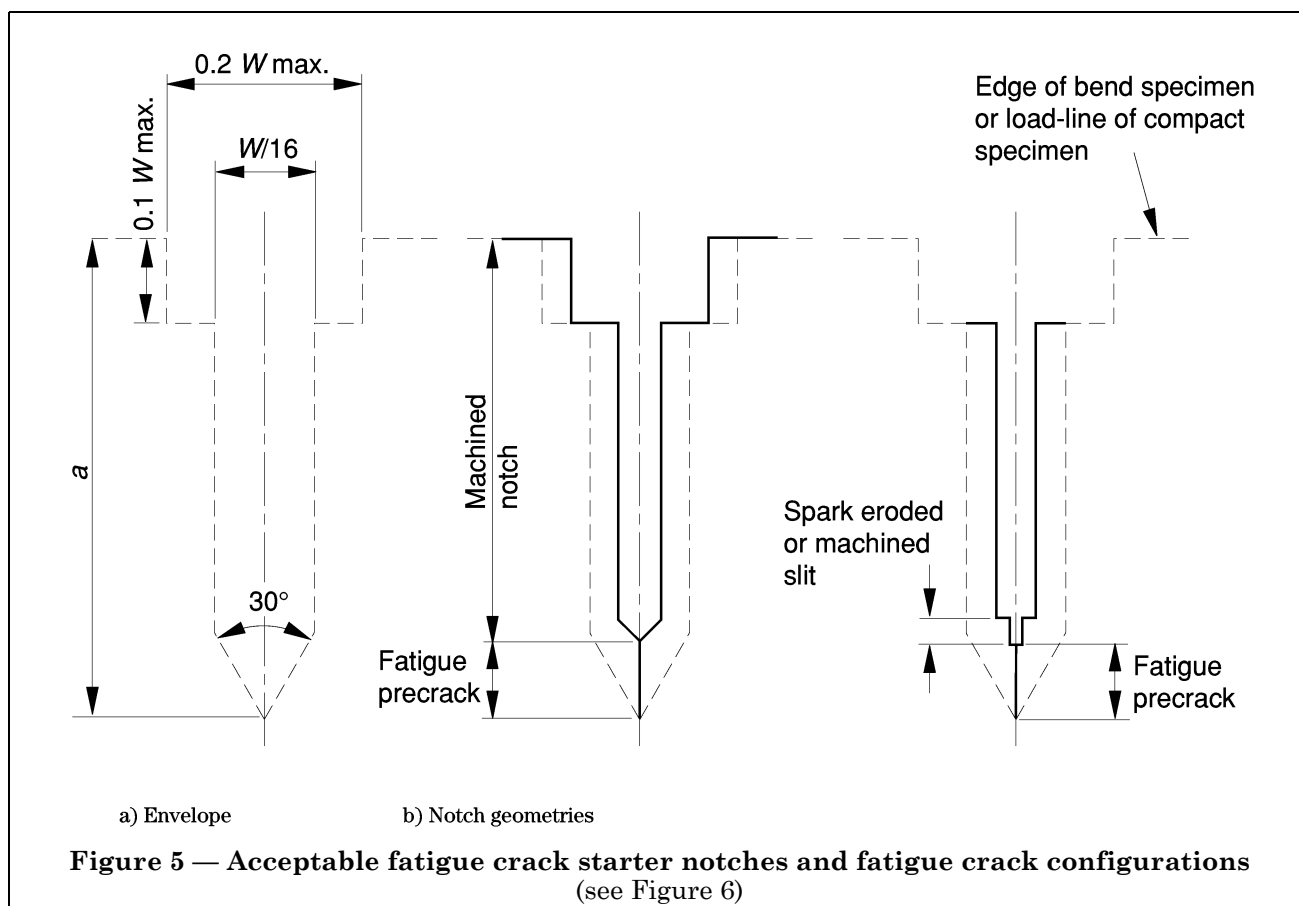
NOTE All three designs (see Figure 2 to Figure 4) are suitable for the determination of δ R-curves. Determination of J R-curves requires the measurement of load-line displacement (q). The stepped notch compact specimen (see Figure 4) allows direct measurement of load-line displacement (q). Methods for measuring load-line displacement directly and indirectly are outlined in Annex C for the bend specimen (see Figure 2). Straight notch compact specimens require the establishment of a relationship between load-line and notch opening displacement (see Annex C).

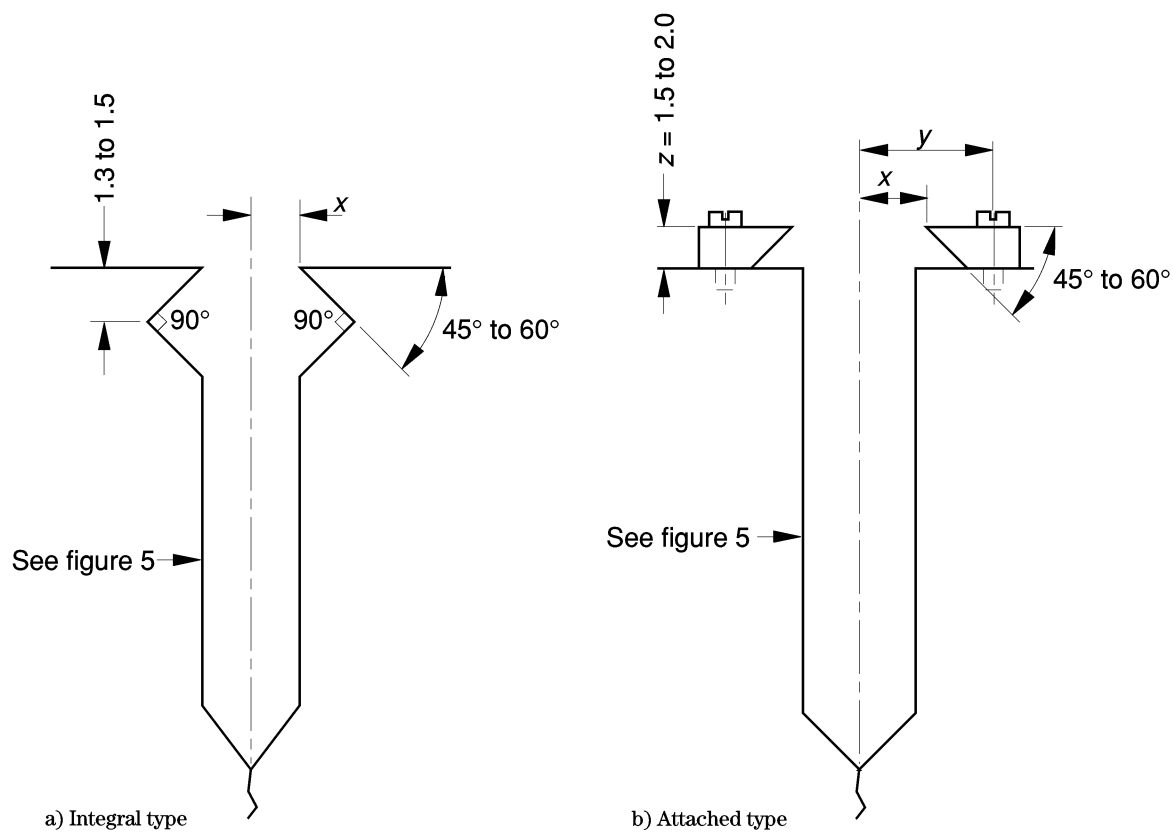












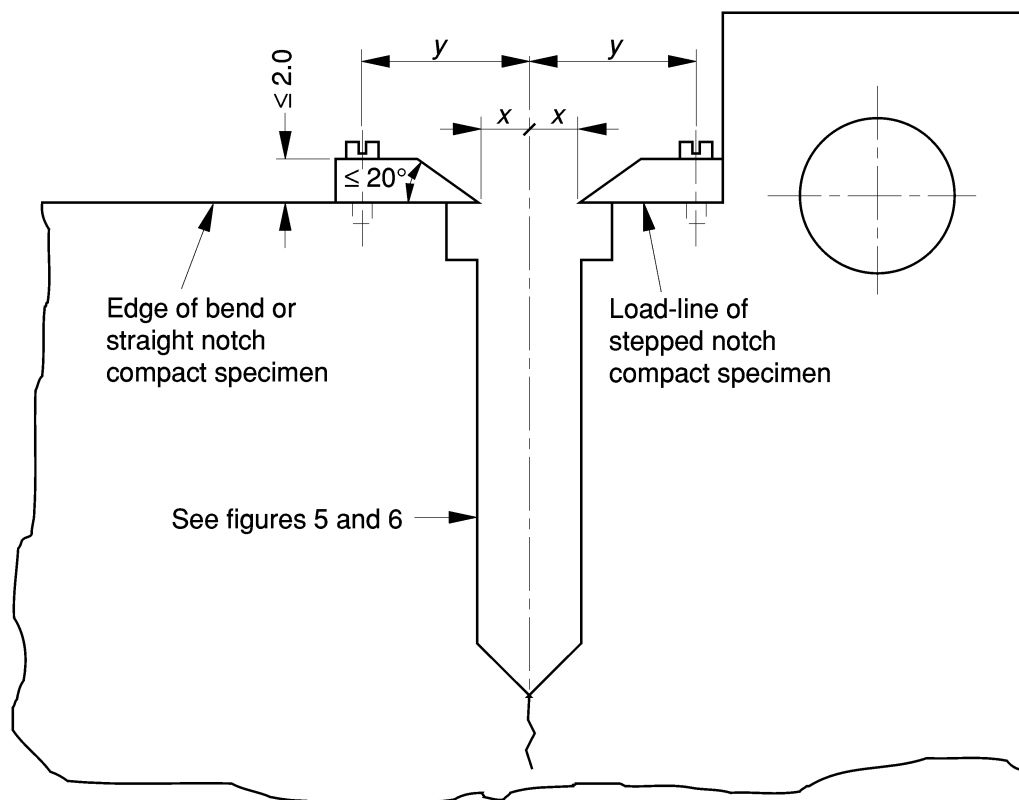
For $2x$ see 6.1.2

$2y + \text{screw thread diameter} \leq W/2$

All linear dimensions are in millimetres

NOTE If the knife edges are glued or similarly attached to the edges of the specimen, $2y$ = distance between extreme points of attachment.

Figure 6 — Outward pointing knife edges and corresponding notch geometries (see Figure 7)



For $2x$ see 6.1.2

$2y + \text{screw thread diameter} \leq W/2$

All linear dimensions are in millimetres

NOTE 1 If the knife edges are glued or similarly attached to the edges of the specimen, $2y$ = distance between extreme points of attachment.

NOTE 2 If razor blades are used instead of inward pointing knife edges, the displacement will normally be measured at a point half the razor blade thickness above the load line (see 9.2.4).

Figure 7 — Inward pointing knife edges and corresponding notch geometries (see Figure 6)