



BSI Standards Publication

Metallic materials — Unified method of test for the determination of quasistatic fracture toughness

National foreword

This British Standard is the UK implementation of ISO 12135:2021. It supersedes BS 7448-1:1991 and BS 7448-4:1997, which are withdrawn.

The UK participation in its preparation was entrusted to Technical Committee ISE/101/4, Toughness testing.

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

[BS 7448-1:1991](#), *Fracture mechanics toughness tests — Part 1: Method for determination of K_{IC} , critical CTOD and critical J values of metallic materials*, and [BS 7448-4:1997](#), *Fracture mechanics toughness tests — Part 4: Method for determination of fracture resistance curves and initiation values for stable crack extension in metallic materials*, have not undergone revision since their publication. BSI Technical Committee ISE/101/04, which is responsible for those standards, decided to work with ISO to revise and update ISO 12135:2016 rather than update those British Standards. This approach is consistent with the decision, taken some years previously, to work with ISO to publish [BS EN ISO 15653:2018](#), *Metallic materials — Method of test for the determination of quasistatic fracture toughness of welds*, which was based on [BS 7448-2:1997](#), *Fracture mechanics toughness tests — Part 2: Method for determination of K_{IC} , critical CTOD and critical J values of welds in metallic materials* (now withdrawn). BS ISO 12135:2021 now provides a unified standard, bringing together both single point and resistance curve fracture toughness testing of homogeneous metallic materials. This makes sense technically because, without prior knowledge, it is not possible to know how the test material will behave. In addition, BS ISO 12135:2021 now complements BS EN ISO 15653:2018 on weldment testing (which BS 7448-1:1991 and BS 7448-4:1997 did not).

The 2021 edition of ISO 12135, in addition to updating the 2016 edition, now incorporates many of the revisions requested by BSI Technical Committee ISE/101/04 and includes conclusions from research into fracture toughness testing since the 1990s. In general, the methods of specimen preparation and testing remain the same as in BS 7448-1:1991 and BS 7448-4:1997, with the possible exception of the fatigue precracking requirements. However, the lower limit of the initial fracture toughness testing rate has been reduced from 0,5 MPam^{0,5} s⁻¹ to 0,3 MPam^{0,5} s⁻¹.

The main changes relate largely to the methods used to analyse the test results. These include better-defined fatigue precracking requirements, which are intended to minimize the risk of overestimating fracture toughness. When the fatigue crack front straightness requirement cannot be achieved, the application of modification techniques, described in BS EN ISO 15653:2018, is now permitted. There is a slight relaxation in the way that crack front straightness is calculated. Now, the difference between the central seven- and nine-point weighted average should not exceed 10 % a_0 . In addition, the formulae for calculating crack tip opening displacement (CTOD) have been revised based on research carried out in the UK and Japan. The new formulae are still based on the concept that the specimen rotates around a hinge point located ahead of the crack tip but recognize that CTOD depends on the material yield to tensile strength ratio. The formulae in BS 7448-1:1991 and BS 7448-4:1997 tend to overestimate CTOD for materials that exhibit high strain hardening (i.e. a low yield to tensile strength ratio). This means that CTOD values for these materials calculated according to the

new formulae will be lower than when calculated according to the old formulae. However, CTOD values for low strain-hardening materials will remain largely unchanged. The formulae for calculating J -integral are unchanged but have been supplemented to include using crack-mouth opening displacement in addition to load-line displacement.

Furthermore, BS ISO 12135:2021 now incorporates five informative annexes that supplement or are additional to those in either BS 7448-1:1991 or BS 7448-4:1997.

[Annex A](#) describes the determination of δ_i and J_i using scanning electron microscopy.

[Annex C](#) provides detailed examples of what can be included in the test report.

[Annex D](#) contains stress intensity factor and compliance formulae.

[Annex F](#) describes the derivation of pop-in formulae.

[Annex H](#) describes in detail single-specimen methods for determining CTOD and J -integral R -curves using partial unloading compliance and electrical resistance methods.

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Metallic materials — Unified method of test for the determination of quasistatic fracture toughness

*Matériaux métalliques — Méthode unifiée d'essai pour la
détermination de la ténacité quasi statique*



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

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).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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 164, *Mechanical testing of metals*, Subcommittee SC 4, *Fatigue, fracture and toughness testing*.

This third edition cancels and replaces the second edition (ISO 12135:2016), which has been technically revised.

The main changes compared to the previous edition are as follows:

- formulae to calculate CTOD have been replaced with those based on rigid rotation assumption throughout; replacing the previous *R*-curve formulae based on CTOD from *J*. CTOD formulae for SENBs are now those based on recent research to include the material yield to tensile strength ratio in the CTOD formulae;
- the determination of *J* directly from displacement defined in terms of CMOD has been included, in addition to the methods based on load line displacement;
- where fatigue precrack straightness requirements cannot be met due to internal residual stresses, the application of modification techniques, originally developed for weld specimens, is now permitted;
- the rotation correction factor for compact specimens has been revised with a new formula;
- editorial changes have been made to improve consistency of terms and definitions used throughout the document.

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.

This corrected version of ISO 12135:2021 incorporates the following corrections:

- in [Figure 6 a\)](#) the envelope tip angle was corrected from 60° to 30°;

- in [7.3.1](#), [Formula \(35\)](#) was corrected, with the addition of " Δ " before " a ", to read: $J = \left[\frac{F \cdot S}{(B \cdot B_N)^{0,5} W^{1,5}} g_1 \left(\frac{a_0}{W} \right) \right]^2 \cdot \frac{1-v^2}{E} + \frac{\eta_p U_p}{B_N (W-a_0)} \left[1 - \frac{\gamma_p \cdot \Delta a}{(W-a_0)} \right]$;
- in [7.3.2](#), [Formula \(38\)](#) was corrected, with the deletion of "+ z ", to read: $\delta = \left[\frac{F \cdot S}{(B \cdot B_N)^{0,5} W^{1,5}} g_1 \left(\frac{a_0}{W} \right) \right]^2 \frac{1-v^2}{mR_{p0,2} E} + \frac{(1-r_p) \Delta a + r_p B_N}{(1-r_p) \Delta a + r_p B_N + a_0} \cdot V_p$;
- in [7.3.2](#), [Formula \(43\)](#) was corrected, with the deletion of "+ z ", to read: $\delta = \left[\frac{F}{(B \cdot B_N \cdot W)^{0,5}} g_2 \left(\frac{a_0}{W} \right) \right]^2 \cdot \frac{1-v^2}{2R_{p0,2} E} + \frac{0,54 \Delta a + 0,46 (W-a_0)}{0,54 (a_0 + \Delta a) + 0,46 W} \cdot V_p$;
- in [Table C.3](#) the small " v " was corrected to capital " V ";
- in [Annex D](#), [Formula \(D.7\)](#) was corrected, with the replacement of $1 - \left(\frac{a}{W} \right)^2$ with $\left(1 - \frac{a}{W} \right)^2$, to read: $g_4 \left(\frac{a}{W} \right) = \frac{15,8}{\left(1 - \frac{a}{W} \right)^2} \left\{ 0,121 + 1,21 \frac{a}{W} - 0,159 \left(\frac{a}{W} \right)^2 - 1,47 \left(\frac{a}{W} \right)^3 + 1,30 \left(\frac{a}{W} \right)^4 \right\}$;
- in [Annex H](#), [Formula \(H.13\)](#) was corrected, with the replacement of " g_6 " with " g_4 ", to read: coefficient $\lambda = \frac{g_4 \left(\frac{a_0}{W} \right)}{g_4 \left(\frac{a_{0,est}}{W} \right)}$ and the function to read: $g_4 \left(\frac{a}{W} \right)$.

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Metallic materials — Unified method of test for the determination of quasistatic fracture toughness

1 Scope

This document specifies methods for determining fracture toughness in terms of K , δ , J and R -curves for homogeneous metallic materials subjected to quasistatic loading. Specimens are notched, precracked by fatigue and tested under slowly increasing displacement. The fracture toughness is determined for individual specimens at or after the onset of ductile crack extension or at the onset of ductile crack instability or unstable crack extension. In cases where cracks grow in a stable manner under ductile tearing conditions, a resistance curve describing fracture toughness as a function of crack extension is measured. In some cases in the testing of ferritic materials, unstable crack extension can occur by cleavage or ductile crack initiation and growth, interrupted by cleavage extension. The fracture toughness at crack arrest is not covered by this document. Special testing requirements and analysis procedures are necessary when testing weldments, and these are described in [ISO 15653](#) which is complementary to this document.

Statistical variability of the results strongly depends on the fracture type, for instance, fracture toughness associated with cleavage fracture in ferritic steels can show large variation. For applications that require high reliability, a statistical approach can be used to quantify the variability in fracture toughness in the ductile-to-brittle transition region, such as that given in ASTM E1921. However, it is not the purpose of this document to specify the number of tests to be carried out nor how the results of the tests are to be applied or interpreted.

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 3785](#), *Metallic materials — Designation of test specimen axes in relation to product texture*

[ISO 7500-1](#), *Metallic materials — Calibration and verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Calibration and verification of the force-measuring system*

[ISO 9513](#), *Metallic materials — Calibration of extensometer systems used in uniaxial testing*

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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 stress intensity factor

K

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

Note 1 to entry: The stress intensity factor is a function of applied force, crack length, specimen size and specimen geometry.

3.2 crack-tip opening displacement

δ
relative opening displacement of the crack surfaces normal to the original (undeformed) crack plane at the tip of the fatigue precrack, evaluated using the rotation point formula

3.3 *J*-integral

line or surface integral that encloses the crack front from one crack surface to the other and characterizes the local stress-strain field at the crack tip

3.4
 J
loading parameter, equivalent to the *J*-integral (3.3), the specific values of which, experimentally determined by this method of test (J_c , J_i , J_w ,...), characterize fracture toughness under elastic-plastic conditions

3.5 stable crack extension

crack extension which stops or would stop when the applied displacement is held constant as a test progresses under displacement control

3.6 unstable crack extension

abrupt crack extension occurring with or without prior *stable crack extension* (3.5)

3.7 pop-in

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

Note 1 to entry: Displacement and force subsequently increase beyond their values at pop-in.

Note 2 to entry: When conducting tests by this method, pop-ins can result from *unstable crack extension* (3.6) in the plane of the precrack and are to be distinguished from discontinuity indications arising from: i) delaminations or splits normal to the precrack plane; ii) roller or pin slippage in bend or compact specimen load trains, respectively; iii) improper seating of displacement gauges in knife edges; iv) ice cracking in low-temperature testing; v) electrical interference in the instrument circuitry of force and displacement measuring and recording devices.

3.8 crack extension resistance curves

R-curves

variation in δ (3.2) or J (3.4) with *stable crack extension* (3.5)

4 Symbols and abbreviated terms

Symbol	Unit	Designation
a	mm	Nominal crack length (for the purposes of fatigue precracking, an assigned value less than a_0)
a_f	mm	Final crack length ($a_0 + \Delta a$)
a_i	mm	Instantaneous crack length
a_m	mm	Length of machined notch
a_0	mm	Initial crack length

NOTE 1 This is not a complete list of parameters. Only the main parameters are given, other parameters are referred to in the text.

NOTE 2 The values of all parameters used in calculations are assumed to be those measured or calculated for the temperature of the test, unless otherwise specified.

Symbol	Unit	Designation
Δa	mm	Stable crack extension including blunting
$\Delta a_{\max}$	mm	Crack extension limit for δ or J controlled crack extension
B	mm	Specimen thickness
B_N	mm	Specimen net thickness between side grooves
C	m/N	Specimen elastic compliance
CMOD	mm	Crack-mouth opening displacement, V
CTOD	mm	Crack tip opening displacement, δ
E	GPa	Modulus of elasticity at the pertinent temperature
F	kN	Applied force
F_c	kN	Applied force at the onset of unstable crack extension or pop-in when Δa is less than 0,2 mm offset from the construction line (Figure 2)
F_d	kN	Force value corresponding to the intersection of the test record with the secant line (Figure 18)
F_f	kN	Maximum fatigue precracking force
F_L	kN	Limiting collapse load estimated for a given specimen type
F_m	kN	Maximum force for a test which exhibits a maximum force plateau preceding fracture with no significant prior pop-ins (Figure 2)
F_Q	kN	Provisional force value used for the calculation of K_Q
F_u	kN	Applied force at the onset of unstable crack extension or pop-in when Δa is equal to or greater than the 0,2 mm offset from the construction line (Figure 2)
J	MJ/m ²	Experimental equivalent to the J -integral
$J_{c(B)}$	MJ/m ²	Size sensitive fracture resistance J at onset of unstable crack extension or pop-in when stable crack extension is less than 0,2 mm offset from the construction line (B = specimen thickness in mm)
J_g	MJ/m ²	J at upper limit of J -controlled crack extension
J_i	MJ/m ²	Size-insensitive fracture resistance J at initiation of stable crack extension
$J_{m(B)}$	MJ/m ²	Size sensitive fracture resistance J at the first attainment of a maximum force plateau for fully plastic behaviour (B = specimen thickness in mm)
$J_{\max}$	MJ/m ²	Limit of J - R material behaviour defined by this method of test
$J_{u(B)}$	MJ/m ²	Size sensitive fracture resistance J at the onset of unstable crack extension or pop-in when the event is preceded by stable crack extension equal to or greater than 0,2 mm offset from the construction line (B = specimen thickness in mm)
$J_{uc(B)}$	MJ/m ²	Size sensitive fracture resistance J at the onset of unstable crack extension or pop-in when stable crack extension cannot be measured (B = specimen thickness in mm)
J_0	MJ/m ²	J unclassified, and uncorrected for stable crack extension
$J_{0,2BL}$	MJ/m ²	Size insensitive fracture resistance J at 0,2 mm stable crack extension offset from the construction line
$J_{0,2BL(B)}$	MJ/m ²	Size sensitive fracture resistance J at 0,2 mm stable crack extension offset from the construction line (B = specimen thickness in mm)
K	MPa m ^{0,5}	Stress intensity factor
K_f	MPa m ^{0,5}	Maximum value of K during the final stage of fatigue precracking
K_{Ic}	MPa m ^{0,5}	Plane strain linear elastic fracture toughness
$K_{J0,2BL}$	MPa m ^{0,5}	Plane strain linear elastic fracture toughness equivalent to $J_{0,2BL}$
K_Q	MPa m ^{0,5}	A provisional value of K_{Ic}

NOTE 1 This is not a complete list of parameters. Only the main parameters are given, other parameters are referred to in the text.

NOTE 2 The values of all parameters used in calculations are assumed to be those measured or calculated for the temperature of the test, unless otherwise specified.

Symbol	Unit	Designation
M	—	Where M appears as a superscript designation (such as J^M or δ^M), it indicates that residual stress modification techniques have been applied to the specimen prior to test.
q	mm	Load-line displacement. q equals V in compact specimens (Figure 14).
R_m	MPa	Ultimate tensile strength perpendicular to crack plane at the test temperature
$R_{p0,2}$	MPa	0,2 % offset yield strength perpendicular to crack plane at the test temperature
S	mm	Span between outer loading points in a three-point bend test
T	°C	Test temperature
U	J	Area under plot of force F versus crack-mouth opening displacement V , or load-line displacement q
U_e	J	Elastic component of U
U_p	J	Plastic component of U (Figure 20)
V	mm	In bend specimens, V is the crack-mouth opening displacement (CMOD), which is the opening displacement at the notch edges (Figure 13). In compact specimens, the opening displacement, V , is determined at the load-line. V equals q in compact specimens (Figure 14).
V_e	mm	Elastic component of V
V_g	mm	Displacement measured by clip gauges mounted on knife edges at a distance z from the crack -mouth. Where integral knife edges are used, $V_g=V$ (Figure 13).
V_p	mm	Plastic component of V
W	mm	Width of the test specimen
z	mm	For bend and straight-notch compact specimens, z is the initial distance of the crack-mouth opening gauge measurement position from the notched edge of the specimen, either further from the crack tip [$+z$ in Figure 8 b)] or closer to the crack tip ($-z$); or, for a stepped-notch compact specimen, z is the initial distance of the crack-mouth opening gauge measurement position either beyond ($+z$) or before ($-z$) the initial load-line.
δ	mm	Crack-tip opening displacement (CTOD)
$\delta_c(B)$	mm	Size sensitive fracture resistance δ at the onset of unstable crack extension or pop-in when stable crack extension is less than 0,2 mm crack offset from the construction line (B = specimen thickness in mm)
δ_g	mm	δ at the limit of δ -controlled crack extension
δ_i	mm	Fracture resistance δ at initiation of stable crack extension
$\delta_m(B)$	mm	Size sensitive fracture resistance δ at the first attainment of a maximum force plateau for fully plastic behaviour (B = specimen thickness in mm)
δ_{max}	mm	Limit of δ - R curve defined by this method of test
$\delta_u(B)$	mm	Size sensitive fracture resistance δ at the onset of unstable crack extension or pop-in when the event is preceded by stable crack extension equal to or greater than 0,2 mm offset from the construction line (B = specimen thickness in mm)
$\delta_{uc}(B)$	mm	Size sensitive fracture resistance δ at the onset of unstable crack extension or pop-in when stable crack extension Δa cannot be measured (B = specimen thickness in mm)
δ_0	mm	δ unclassified, and uncorrected for stable crack extension
$\delta_{0,2BL}$	mm	Size insensitive fracture resistance δ at 0,2 mm crack extension offset from construction line
$\delta_{0,2BL}(B)$	mm	Size sensitive fracture resistance δ at 0,2 mm stable crack extension offset from construction line (B = specimen thickness in mm)
η_p	—	Dimensionless function of geometry used to calculate J
ν	—	Poisson's ratio

NOTE 1 This is not a complete list of parameters. Only the main parameters are given, other parameters are referred to in the text.

NOTE 2 The values of all parameters used in calculations are assumed to be those measured or calculated for the temperature of the test, unless otherwise specified.

5 General requirements

5.1 General

The fracture toughness of metallic materials can be characterized in terms of either specific (single point) values (see [Clause 6](#)), or a continuous curve relating fracture resistance to crack extension over a limited range of crack extension (see [Clause 7](#)). The procedures and parameters used to determine fracture toughness vary depending upon the level of plasticity realized in the test specimen during the test. Under any given set of conditions, however, any one of the fatigue-precracked test specimen configurations specified in this method may be used to measure any of the fracture toughness parameters considered. In all cases, tests are performed by applying slowly increasing displacements to the test specimen and measuring the forces and displacements realized during the test. The forces and displacements are then used in conjunction with certain pre-test and post-test specimen measurements to determine the fracture toughness that characterizes the material's resistance to crack extension. Details of the test specimens and general information relevant to the determination of all fracture parameters are given in this method. A flow-chart illustrating the way this method can be used is presented in [Figure 1](#). Characteristic types of force versus displacement records obtained in fracture toughness tests are shown in [Figure 2](#).

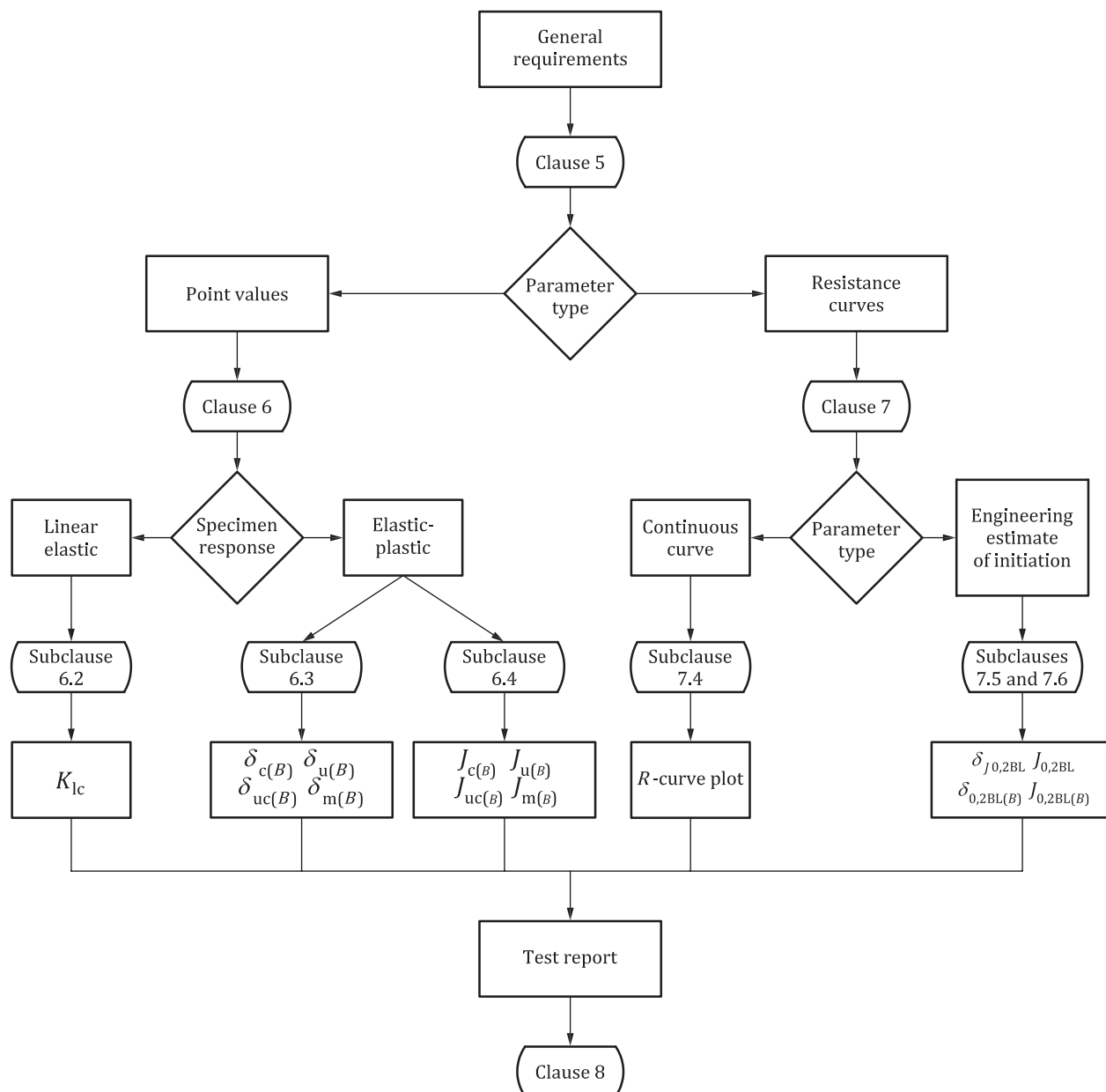
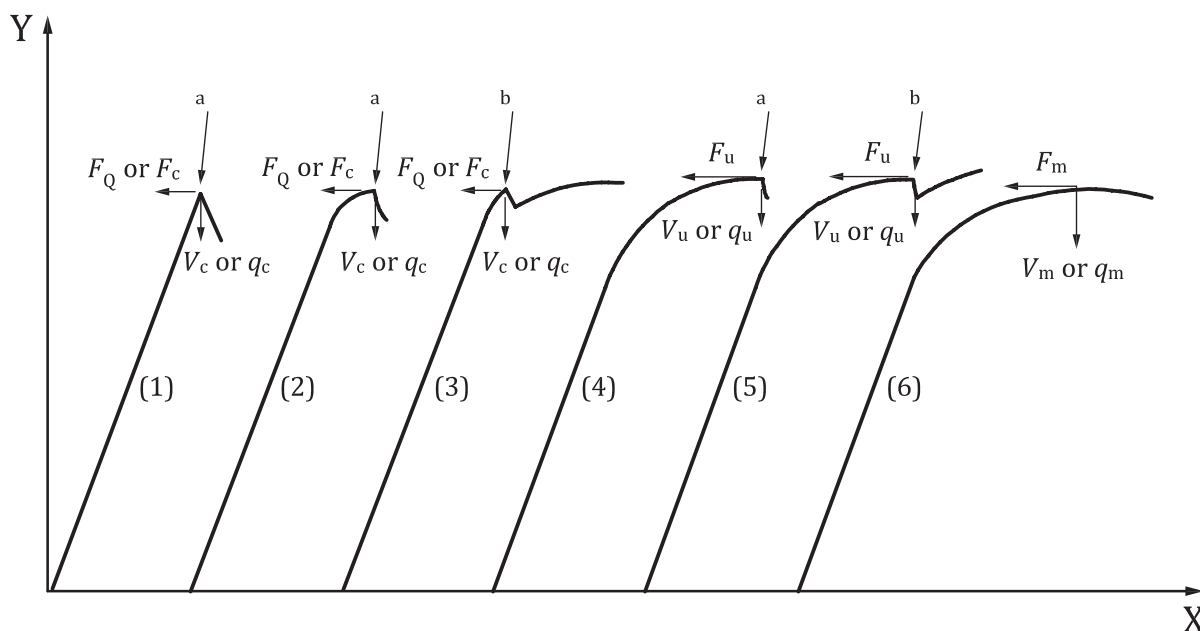


Figure 1 — General flowchart showing how to use the standard method of test

**Key**

X crack-mouth opening displacement (V) or load-line displacement (q)

Y force (F)

NOTE 1 The classifications of F_c , F_u and F_m are described in 6.3.1 and 6.4.1.

NOTE 2 Pop-in behaviour is a function of the material toughness and parameters of the test setup such as the testing machine/specimen compliance and the recorder response rate.

a Fracture.

b Pop-in.

Figure 2 — Characteristic types of force versus displacement records in fracture tests

5.2 Fracture parameters

Specific (point) values of fracture toughness are determined from individual specimens to define the onset of unstable crack extension or describe stable crack extension.

NOTE K_{Ic} characterizes the resistance to extension of a sharp crack so that i) the state of stress near the crack front closely approximates plane strain, and ii) the crack tip plastic zone is small compared with the specimen crack size, thickness and ligament ahead of the crack.

K_{Ic} is considered a size-insensitive measurement of fracture toughness under the above conditions. Certain test criteria shall be met in order to qualify measurements of K_{Ic} .

The parameters δ_c , J_c , δ_u , J_u , δ_{uc} and J_{uc} also characterize the resistance of a material to unstable extension of a sharp crack. However, these measurements are regarded as size-sensitive and as such characterize only the specimen thickness tested. The specimen thickness is thus noted in millimetre units in parentheses appended to the parameter symbol when reporting a test result.

When stable crack extension is extensive, a test procedure and fracture toughness measurement shall be performed as specified in Clause 7. Stable crack extension is characterized either in terms of crack tip opening displacement $\delta_{0,2BL}$ and fracture toughness $J_{0,2BL}$ parameters, or of a continuous δ - and J -resistance curve. The values $\delta_{0,2BL}$ and $J_{0,2BL}$, regarded as specimen size insensitive, are engineering estimates of the onset of stable crack extension, not to be confused with the actual initiation toughness δ_i and J_i . Measurement of δ_i and J_i is described in Annex A.

Two procedures are available for determining $\delta_{0,2BL}$ and $J_{0,2BL}$. The multiple specimen procedure requires several nominally identical specimens to be monotonically loaded, each to different amounts

of displacement. Measurements of force and displacement are made and recorded. Specimen crack fronts are marked (e.g. by heat tinting or post-test fatiguing) after testing, thus enabling measurement of stable crack extension on the specimen halves after each specimen is broken open. Post-test cooling of ferritic material specimens to ensure brittle behaviour can be helpful in preserving crack front markings prior to breaking open the specimens.

A minimum of six specimens is required by the multiple-specimen method. When material availability is limited, a single-specimen procedure based on either unloading compliance or the potential drop technique may be used. There is no restriction on the single-specimen procedure providing sufficient accuracy can be demonstrated. In all cases, certain criteria are to be met before $\delta_{0,2BL}$ or $J_{0,2BL}$ values and δ - or J -resistance curves are qualified by this standard method of test.

5.3 Fracture toughness symbols

Fracture toughness symbols identified in this document are given in [Table 1](#).

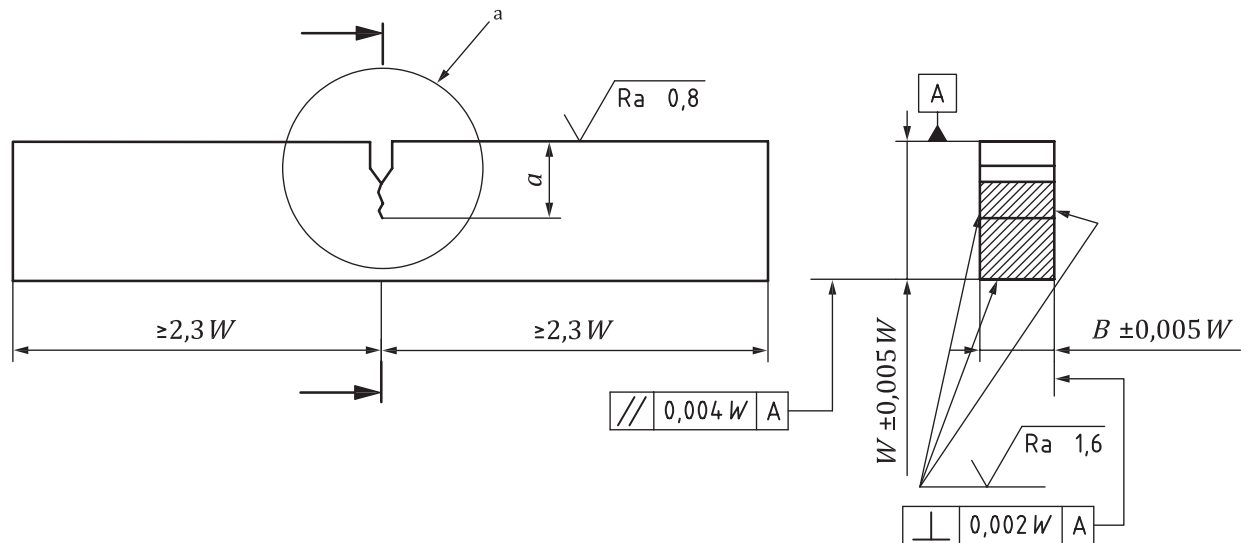
Table 1 — Fracture toughness symbols

Parameter	Size insensitive quantities	Size sensitive quantities (specific to thickness B tested)	Qualifying limits to R -curves
K	K_{Ic} $K_{J\ 0,2BL}$		
δ	δ_i $\delta_{0,2BL}$	$\delta_{c(B)}$ $\delta_{0,2BL(B)}$ $\delta_{u(B)}, \delta_{uc(B)}, \delta_{m(B)}$	$\delta_g, \delta_g(\Delta a_{max})$
J	J_i $J_{0,2BL}$	$J_{c(B)}$ $J_{0,2BL(B)}$ $J_{u(B)}, J_{uc(B)}, J_{m(B)}$	$J_g, J_g(\Delta a_{max})$

5.4 Test specimens

5.4.1 Specimen configuration and size

Dimensions and tolerances of specimens shall conform to [Figures 3](#) to [5](#).



The intersection of the crack starter notch tips with the two specimen surfaces shall be equally distant from the top and bottom edges of the specimen to within 0,005 W .

NOTE 1 Integral or attachable knife edges for clip gauge attachment can be used (see [Figures 8](#) and [9](#)).

NOTE 2 For starter notch and fatigue crack configuration, see [Figure 6](#).

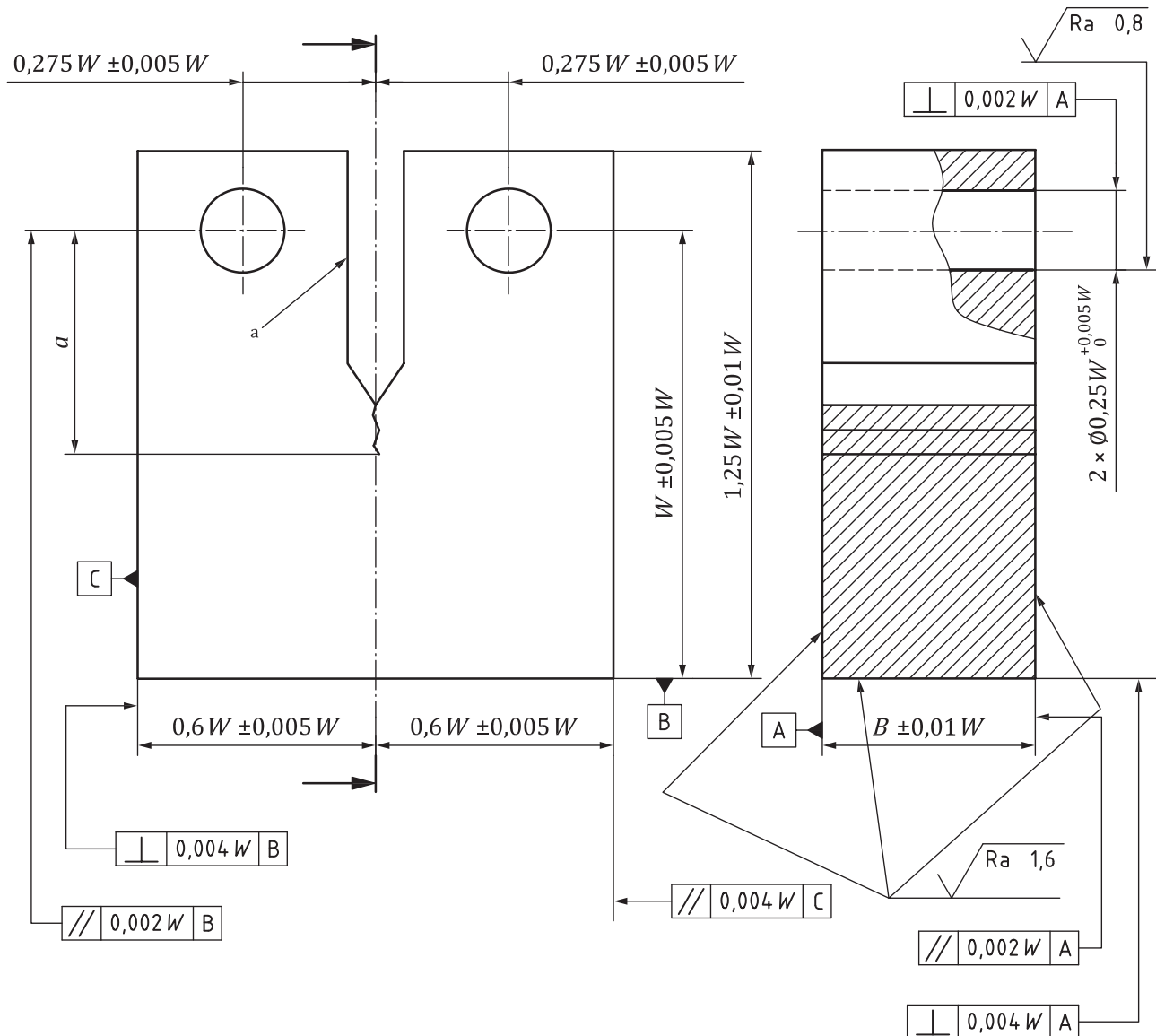
NOTE 3 $1,0 \leq W/B \leq 4,0$ ($W/B = 2$ preferred).

NOTE 4 $0,45 \leq a/W \leq 0,70$. For K_{Ic} determination, $0,45 \leq a/W \leq 0,55$.

NOTE 5 Surface roughness R_a in micrometres.

^a See [Figures 6](#) to [8](#) and [5.4.2.3](#).

Figure 3 — Proportional dimensions and tolerances for bend specimen



The intersection of the crack starter notch tips with the two specimen surfaces shall be equally distant from the top and bottom edges of the specimen to within $0,005 W$.

NOTE 1 Integral or attachable knife edges for clip gauge attachment can be used (see Figures 8 and 9).

NOTE 2 For starter notch and fatigue crack configuration, see Figure 6.

NOTE 3 $0,8 \leq W/B \leq 4,0$ ($W/B = 2$ preferred).

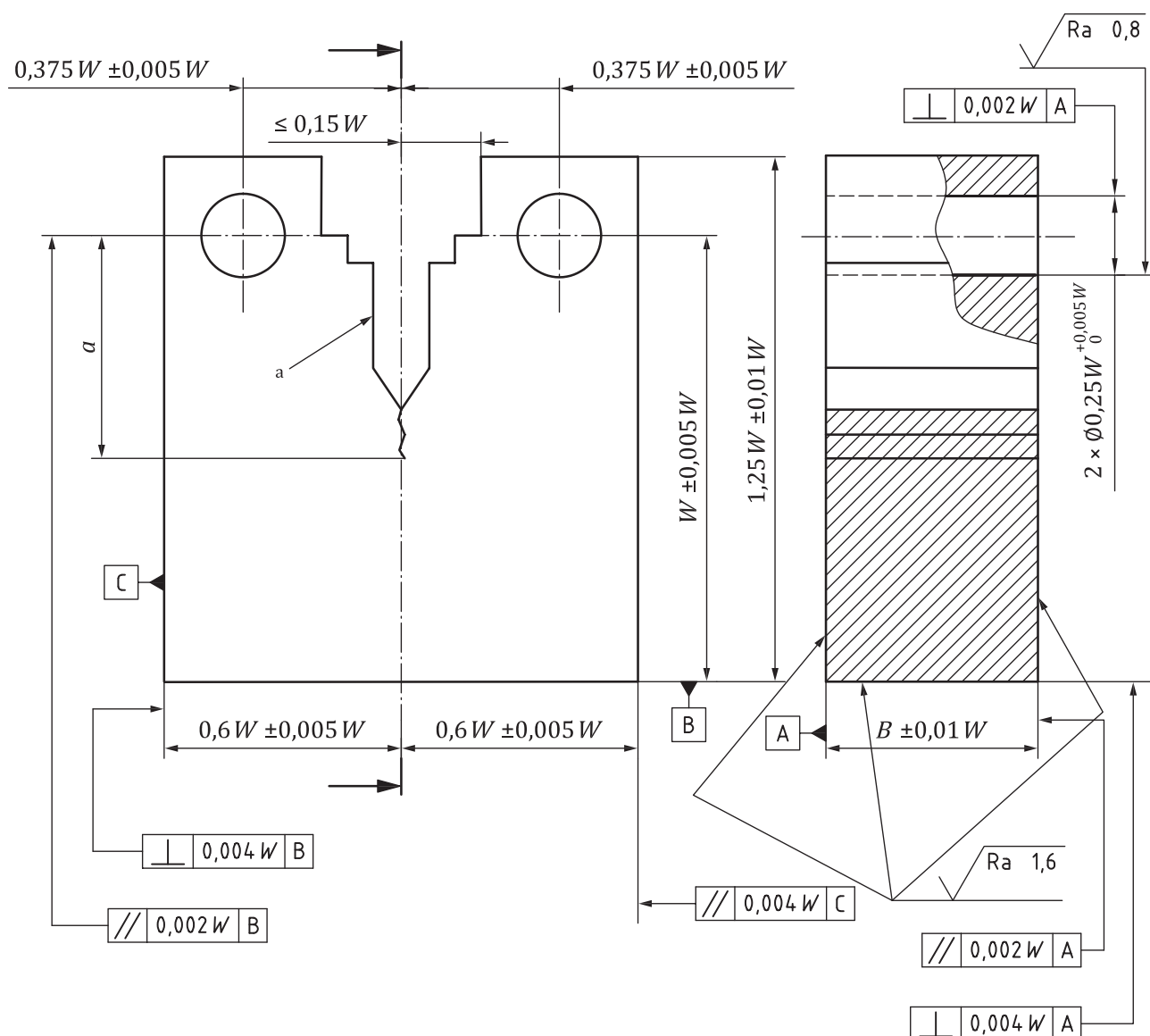
NOTE 4 $0,45 \leq a/W \leq 0,70$. For K_{Ic} determination, $0,45 \leq a/W \leq 0,55$.

NOTE 5 Alternative pin hole diameter, $\phi 0,188 W^{+0,004 W}_0$.

NOTE 6 Surface roughness R_a in micrometres.

^a See Figures 6 to 8 and 5.4.2.3.

Figure 4 — Proportional dimensions and tolerances for straight-notch compact specimen



The intersection of the crack starter notch tips with the two specimen surfaces shall be equally distant from the top and bottom edges of the specimen to within $0,005 W$.

Second step may not be necessary for some clip gauges; configuration optional providing fatigue crack starter notch and fatigue crack fit within the envelope represented in [Figure 6](#).

NOTE 1 Integral or attachable knife edges for clip gauge attachment can be used (see [Figures 8](#) and [9](#)).

NOTE 2 For starter notch and fatigue crack configuration, see [Figure 6](#).

NOTE 3 $0,8 \leq W/B \leq 4,0$ ($W/B = 2$ preferred).

NOTE 4 $0,45 \leq a/W \leq 0,70$. For K_{Ic} determination, $0,45 \leq a/W \leq 0,55$.

NOTE 5 Alternative pin hole diameter, $\phi 0,188 W^{+0,004 W}_0$. When this pin size is used, notch opening can be increased to $0,21 W$ maximum.

NOTE 6 Surface roughness R_a in micrometres.

^a See [Figures 6](#) to [8](#).

Figure 5 — Proportional dimensions and tolerances for stepped-notch compact specimen

The choice of specimen design shall take into consideration the likely outcome of the test (see [Figure 1](#)), any preference for δ or J fracture toughness values, the crack plane orientation of interest ([Annex B](#)) and the quantity and condition of test material available.

NOTE 1 All specimen designs ([Figures 3](#) to [5](#)) are suitable for determining K_{Ic} , δ and J values, although there are special procedural requirements for J values calculated from measurements made away from the load line. [Table 2](#) provides guidance on specimen size for K_{Ic} measurement.

Table 2 — Minimum recommended thickness for K_{Ic} testing

	$\frac{R_{p0,2}}{E}$	B mm
$0,005\ 0 \leq$	$\frac{R_{p0,2}}{E} < 0,005\ 7$	75
$0,005\ 7 \leq$	$\frac{R_{p0,2}}{E} < 0,006\ 2$	63
$0,006\ 2 \leq$	$\frac{R_{p0,2}}{E} < 0,006\ 5$	50
$0,006\ 5 \leq$	$\frac{R_{p0,2}}{E} < 0,006\ 8$	44
$0,006\ 8 \leq$	$\frac{R_{p0,2}}{E} < 0,007\ 1$	38
$0,007\ 1 \leq$	$\frac{R_{p0,2}}{E} < 0,007\ 5$	32
$0,007\ 5 \leq$	$\frac{R_{p0,2}}{E} < 0,008\ 0$	25
$0,008\ 0 \leq$	$\frac{R_{p0,2}}{E} < 0,008\ 5$	20
$0,008\ 5 \leq$	$\frac{R_{p0,2}}{E} < 0,010\ 0$	13
$0,010\ 0 \leq$	$\frac{R_{p0,2}}{E}$	7

NOTE 2 When crack-mouth opening displacement V_g is measured on the load line as shown in [Figure 14 b](#)), $V = q = V_g$ for the stepped-notch compact specimen (see [Figure 5](#)). The stepped-notch specimen is thus equally useful for the determination of values of K_{Ic} , δ and J .

NOTE 3 For both the bend and compact configurations, a specimen width-to-thickness ratio (W/B) of 2 is preferred, but values ranging from 1 to 4 for bend specimens and from 0,8 to 4 for compact specimens are allowed. Evidence suggests that specimen proportions of $W/B = 4$ yield slightly higher R -curves than the lesser proportions of $W/B = 2$.

5.4.2 Specimen preparation

5.4.2.1 Material condition

Specimens shall be machined from material in the final heat treated and/or mechanically worked condition.

NOTE 1 In the exceptional circumstance where a material cannot be machined in its final heat treated condition, such final heat treatment can be carried out after machining, provided that the specimen's required dimensions and tolerances, shape, and surface finishes are met, and that full account is taken of the effects of specimen dimensions on the metallurgical condition induced by certain heat treatments, for example, water quenching of steels.

NOTE 2 Residual stresses can influence the measurement of quasistatic fracture toughness. The effect can be significant when test coupons are taken from material that characteristically embodies residual stress fields; e.g. weldments, complex shapes, such as die forgings, stepped extrusions, castings where full stress relief is not possible, or parts with intentionally-induced residual stresses. Specimens taken from such products that contain residual stresses likewise themselves contain residual stress. While extraction of the specimen in itself partially relieves and redistributes the pattern of residual stress, the remaining magnitude can affect the test result. Residual stress is superimposed on applied stress and results in actual crack-tip stress intensity that is different from that based solely on externally applied forces or displacements. Distortion during specimen machining, specimen configuration dependence, and irregular crack extension during fatigue precracking (such as excessive crack front curvature or out-of-plane growth) often indicates influential residual stresses. Crack-mouth opening displacement at zero applied force (crack closure effect) is indicative of residual stresses that can affect the subsequent fracture toughness measurement. Methods for dealing with residual stresses in samples taken from weldments are described in [ISO 15653](#).

5.4.2.2 Crack plane orientation

The orientation of the crack plane shall be

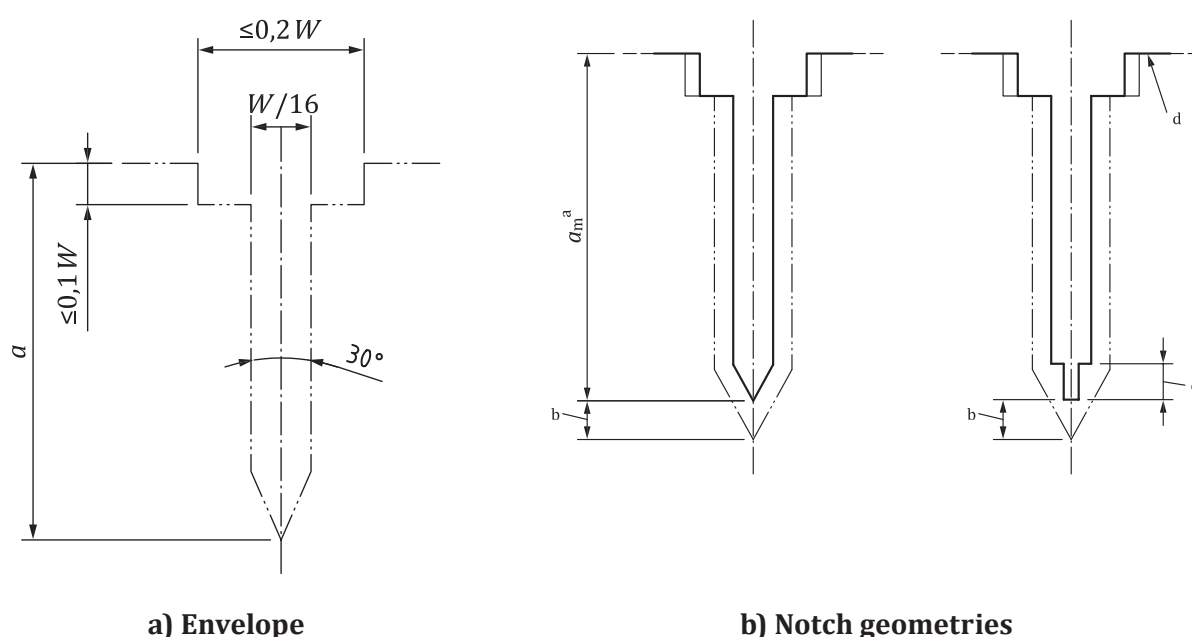
- decided before machining,
- identified in accordance with the coordinate systems in [Annex B](#) and [ISO 3785](#),
- then recorded along with other specimen and material information. An example test report is provided in [C.1](#).

NOTE Fracture toughness values depend on crack plane orientation and direction of crack extension in relation to the principal directions of mechanical working, grain flow and other anisotropy.

5.4.2.3 Machining

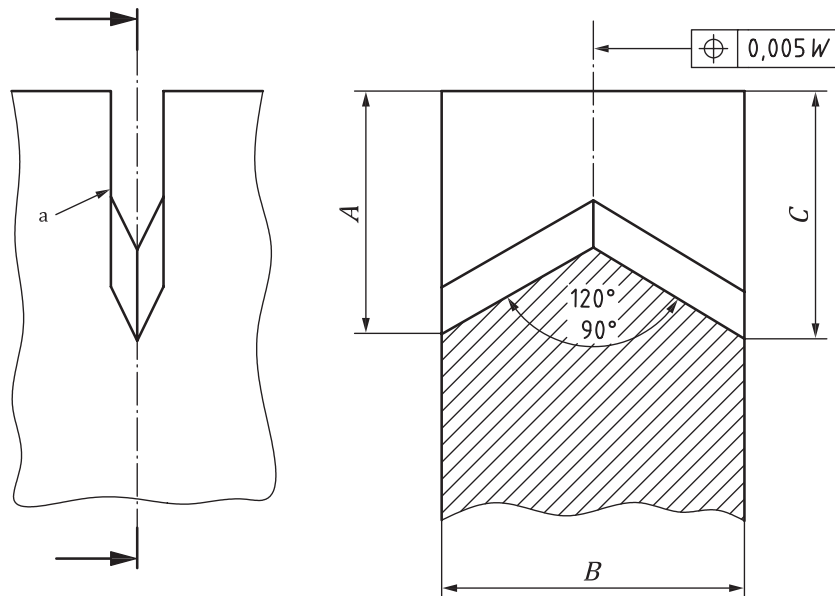
- a) The specimen notch profile shall not exceed the envelope, comprising machined notch and pre-crack, shown in [Figure 6](#). The root radius of a milled notch shall not be greater than 0,10 mm. Sawn, disk ground, or spark-eroded notches shall not have a width (at the tip) greater than 0,30 mm ([Figure 6](#)). The plane of the specimen notch shall be perpendicular to the specimen surfaces to within 2°.

Figure 6 — Acceptable fatigue crack envelope and crack starter notches (see Figures 7 and 8)



If fatigue crack initiation and/or propagation are a problem, a chevron notch configuration as shown in [Figure 7](#) may be used.

- a Machined notch, a_m .
- b Fatigue precrack.
- c Spark eroded or machined slit.
- d Edge of bend specimen or load-line of compact specimen.



Chevron notch root radii shall not exceed 0,25 mm.

NOTE 1 $A = C \pm 0,010 W$.

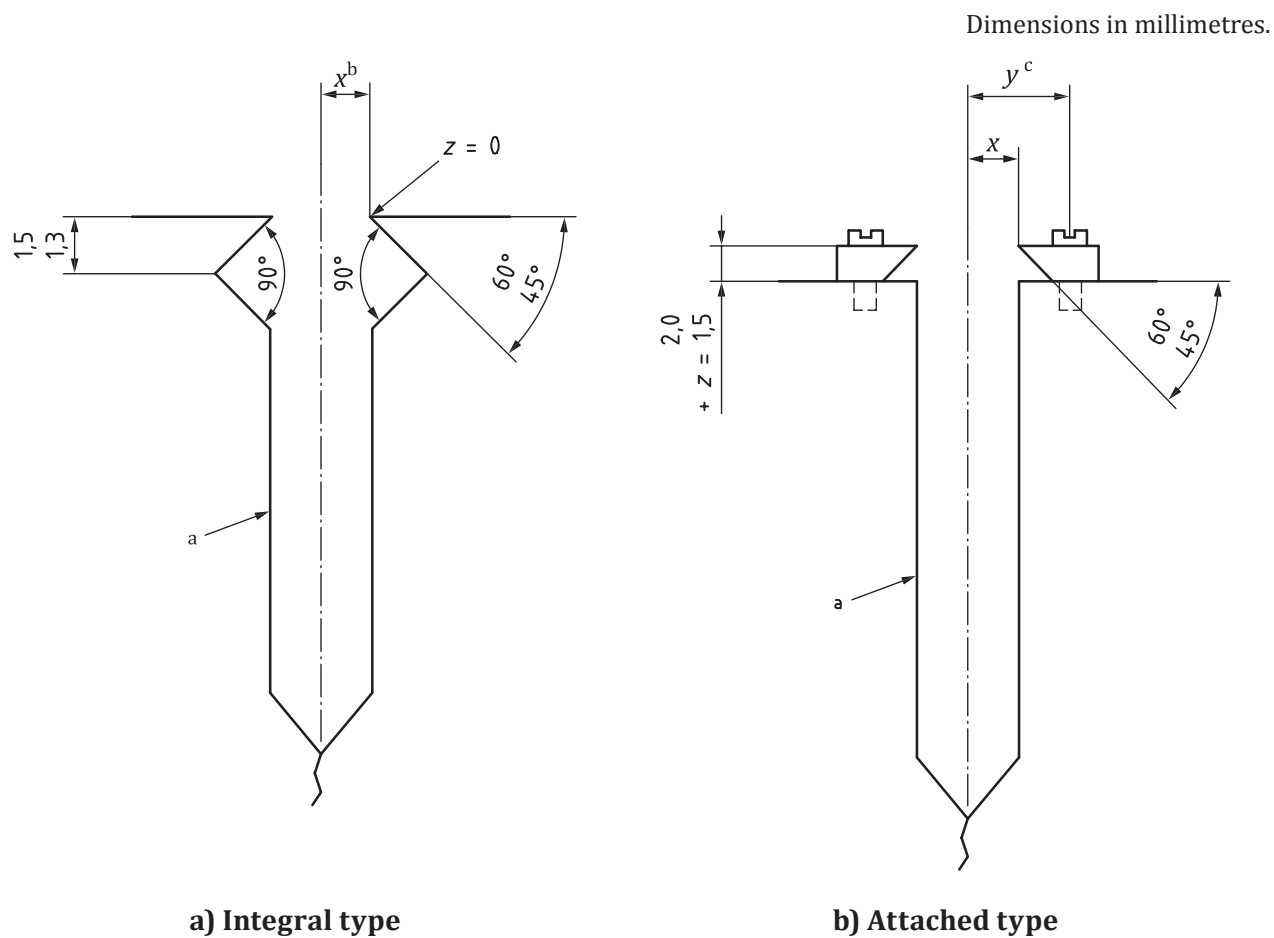
NOTE 2 Cutter tip angle 90° maximum.

NOTE 3 For the purposes of [8.2.2](#), a_m is the greater of A and C.

a See [Figure 6](#).

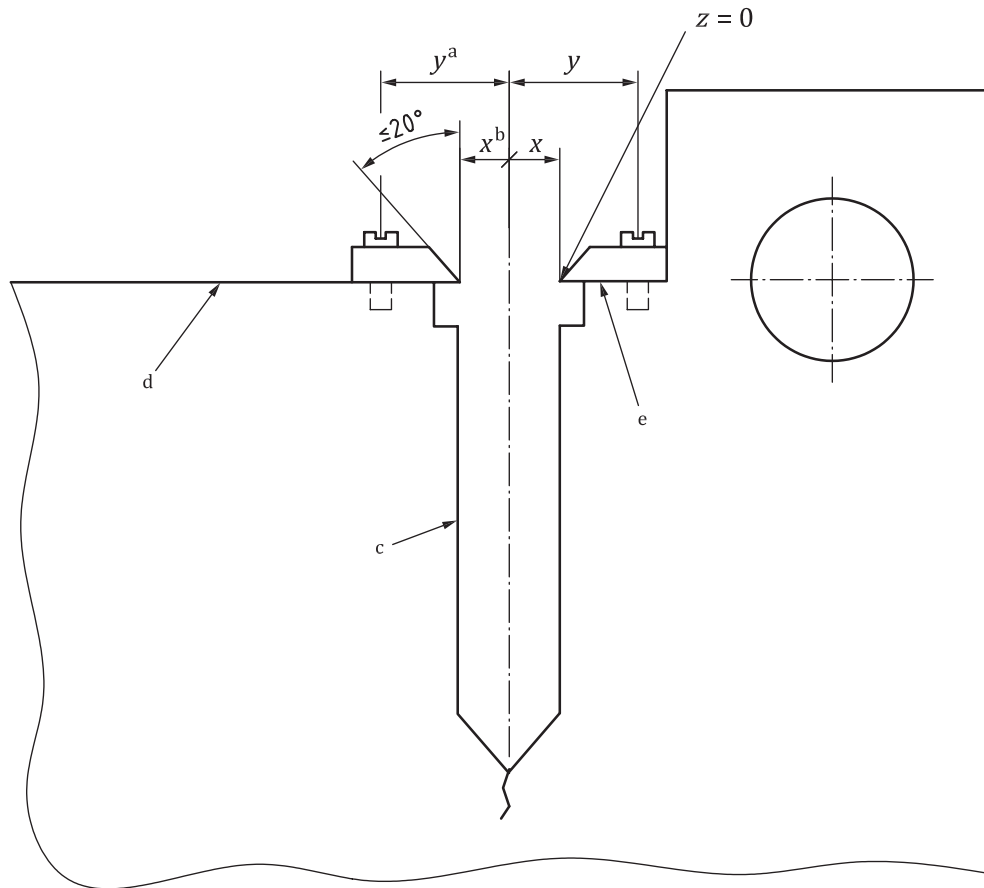
Figure 7 — Chevron notch

- b) Specimen knife edges may be integral or attached. Suitable designs are shown in [Figures 8](#) and [9](#). The dimension $2x$ in [Figures 8](#) and [9](#) shall be within the working range of the crack-mouth opening displacement gauge, and the knife edges shall be square with the specimen surfaces and parallel to each other to within 0,5°. For both types, the crack-mouth opening displacement gauge shall be free to rotate about the points of contact between the gauge and knife edge. Consequently, when inward-pointing knife edges or stiff razor blades are used, it may be necessary to use an enlarged crack-mouth as shown in [Figures 5](#), [6](#) and [9](#). The use of a knife edge/clip gauge for displacement measurement does not preclude the use of other schemes providing they meet the requirements and accuracy of this method. When side grooves are used (see [5.4.2.5](#)), it is recommended that the side grooving be carried out after fatigue precracking.



- a See [Figure 6](#).
- b $2x$, see [5.4.2.3 b\)](#).
- c $2y + \text{screw thread diameter} \leq W/2$.

Figure 8 — Outward pointing knife edges and corresponding notch geometries



NOTE If razor blades are used instead of inward pointing knife edges, the displacement is normally measured at a point half the razor blade thickness above the load line (see 5.5.1).

- a $2y + \text{screw thread diameter} \leq W/2$.
- b $2x$, see 5.4.2.3 b).
- c See Figures 6 and 7.
- d Edge of bend or straight compact, or first step of stepped-notch compact specimen.
- e Load-line stepped compact.

Figure 9 — Inward-pointing attached knife edges and corresponding notch geometries
(see Figure 8)

5.4.2.4 Fatigue precracking

5.4.2.4.1 General

Fatigue precracking shall be performed on specimens machined from material in its finally heat treated, mechanically worked or environmentally conditioned state. Intermediate treatments between fatigue precracking and testing are acceptable only when such treatments are necessary to simulate the conditions of a specific structural application; such departure from recommended practice shall be explicitly reported.

The maximum fatigue precracking force during any stage of the fatigue precracking process shall be accurate to $\pm 2,5\%$.

Measured values of specimen thickness B and width W determined in accordance with 5.5.1 shall be recorded and used to determine the maximum fatigue precracking force F_f in accordance with 5.4.2.4.3 and 5.4.2.4.4.

The ratio of minimum-to-maximum force in the fatigue cycle shall be in the range 0 to 0,1 except that to expedite crack initiation one or more cycles of – 1,0 may be first applied.

5.4.2.4.2 Equipment and fixtures

Fixtures for fatigue precracking shall be carefully aligned and arranged so that loading is uniform through the specimen thickness B and symmetrical about the plane of the prospective crack.

5.4.2.4.3 Bend specimens

For three-point bend specimens, the maximum fatigue precracking force during the final 1,3 mm or 50 % of precrack extension, whichever is less, shall be the lower between [Formula \(1\)](#):

$$F_f = 0,8 \cdot \frac{B(W-a_0)^2}{S} \cdot R_{p0,2} \quad (1)$$

where $R_{p0,2}$ is the yield strength at the test temperature or the precracking temperature, whichever is the lower yield strength, and [Formula \(2\)](#):

$$F_f = \xi E \cdot \frac{(W \cdot B \cdot B_N)^{0,5}}{g_1(a_0/W)} \cdot \frac{W}{S} \cdot \frac{(R_{p0,2})_p}{(R_{p0,2})_t} \quad (2)$$

where $\xi = 1,6 \times 10^{-4} m^{0,5}$, $(R_{p0,2})_p$ and $(R_{p0,2})_t$ are the yield strengths at the precracking and test temperatures, respectively, and E is the modulus of elasticity at the test temperature or the precracking temperature, whichever is lower.

NOTE 1 For plane-sided specimens, $B_N = B$.

NOTE 2 Values of $g_1(a_0/W)$ are given in [Annex D](#).

NOTE 3 Additional fatigue precracking requirements are necessary when determining K_{Ic} , see [6.2.4](#).

5.4.2.4.4 Compact specimens

For compact specimens, the maximum fatigue precracking force during the final 1,3 mm or 50 % of precrack extension, whichever is less, shall be the lower between [Formula \(3\)](#):

$$F_f = 0,6 \cdot \frac{B(W-a_0)^2}{2W+a_0} \cdot R_{p0,2} \quad (3)$$

where $R_{p0,2}$ is the yield strength at the test temperature or the precracking temperature, whichever is the lower yield strength, and [Formula \(4\)](#):

$$F_f = \xi E \cdot \frac{(W \cdot B \cdot B_N)^{0,5}}{g_2(a_0/W)} \cdot \frac{(R_{p0,2})_p}{(R_{p0,2})_t} \quad (4)$$

where $\xi = 1,6 \times 10^{-4} m^{0,5}$, $(R_{p0,2})_p$ and $(R_{p0,2})_t$ are the yield strengths at the precracking and test temperatures, respectively, and E is the modulus of elasticity at the test temperature or the precracking temperature, whichever is lower.

NOTE 1 For plane-sided specimens, $B_N = B$.

NOTE 2 Values of $g_2(a_0/W)$ are given in [Annex D](#).

NOTE 3 Additional fatigue precracking requirements are necessary when determining K_{Ic} , see [6.2.4](#).

5.4.2.5 Side grooving

Specimens for the determination of point measurements of fracture toughness (e.g. K_{Ic} , δ_c , J_c) may be plane-sided or side-grooved. All specimens for R -curve testing shall be side grooved. Side grooves shall have equal depths and an included angle of 30° to 90° with a root radius of $(0,4 \pm 0,2)$ mm. The depth of side grooving, $B - B_N$, shall be no greater than $0,2B$. Side grooving shall be performed after fatigue precracking except for the case described in Note 2.

NOTE 1 With respect to fully plastic stable crack extension, side grooving of specimens can lower and flatten the R -curve compared to plane-sided specimens of the same nominal dimensions.

NOTE 2 As an aid to precracking some materials, shallow (i.e. less than 5 %) side grooves are allowed prior to fatigue precracking. After fatiguing, these side grooves are to be extended to their full depths.

It is recommended that side grooves with an included angle of 90° be used for austenitic steel specimens because of the large displacements that can occur at the back face of the specimens, producing partial, or complete closure of the side grooves.

5.5 Pre-test requirements

5.5.1 Pre-test measurements

The dimensions of specimens shall conform to [Figures 3 to 5](#). The measurement of thicknesses B and B_N , and width W shall be accurate to within $\pm 0,02$ mm or $\pm 0,2$ %, whichever is larger.

The specimen thickness B shall be measured before testing at a minimum of three equally-spaced positions along the intended crack extension path. The average of these measurements shall be taken as the thickness B . For side-grooved specimens, the specimen net thickness shall be measured between the side grooves at a minimum of three equally-spaced positions along the crack extension path. The average of these three measurements shall be taken as the net section thickness B_N .

The specimen width W shall be measured at a minimum of three equally-spaced positions across the specimen thickness on a line no further than 10 % of the nominal width away from the crack plane. The average of these measurements shall be taken as the width W . When straight-notch compact specimens are used, the dimension from specimen front face to back face (i.e. $1,25 W$) shall be measured.

When attached knife edges are used as shown in [Figure 8 b\)](#), the knife edge thickness z shall be measured. If razor blades are used as knife edges, the half thickness of these shall be taken as the dimension z .

NOTE When integral or attached knife edges are used as shown in [Figures 8 a\)](#) and [9](#), the dimension z is equal to zero.

5.5.2 Crack shape/length requirements

A fatigue crack shall be developed from the root of the machined notch of the specimen as follows. For all designs of specimen (see [Figures 3 to 5](#)), the ratio a_0/W shall be in the range of 0,45 to 0,70, except for K_{Ic} determination, when a_0/W shall be in the range of 0,45 to 0,55. The minimum fatigue crack extension shall be the larger of 1,3 mm or 2,5 % of the specimen width W . The notch plus fatigue crack shall be within the limiting envelope shown in [Figure 6](#).

5.6 Test apparatus

5.6.1 Calibration

Calibration of all measuring apparatus shall be traceable either directly or indirectly via a hierarchical chain to an accredited calibration laboratory.

5.6.2 Force application

The combination of force sensing and recording devices shall conform to [ISO 7500-1](#).

The test machine shall operate at a constant displacement rate.

A force measuring system of nominal capacity exceeding $1,2F_L$ shall be used, where

$$F_L = \frac{4}{3} \cdot \frac{B(W-a_0)^2}{S} \cdot R_m \quad (5)$$

for bend specimens, and

$$F_L = \frac{B(W-a_0)^2}{2W+a_0} \cdot R_m \quad (6)$$

for compact specimens.

5.6.3 Displacement measurement

The displacement gauge shall have an electrical output that represents crack-mouth opening displacement V between two precisely located gauge positions spanning the crack-mouth. The design of the displacement gauge (or transducer where appropriate), knife edges and specimen shall allow free rotation of the points of contact between the gauge and knife edges.

NOTE 1 Examples of two proven displacement gauge designs are given in References [3], [4] and [5], and similar gauges are commercially available.

NOTE 2 The measurement of load-line displacement q (see [5.7.1.3](#)) is described in [Annex E](#).

Displacement gauges for crack-mouth opening displacement and load-line displacement shall be calibrated with reference to [ISO 9513](#), as interpreted in relation to this method, and shall be of at least Class 1; however, calibration shall be performed at least weekly when the gauges are in use.

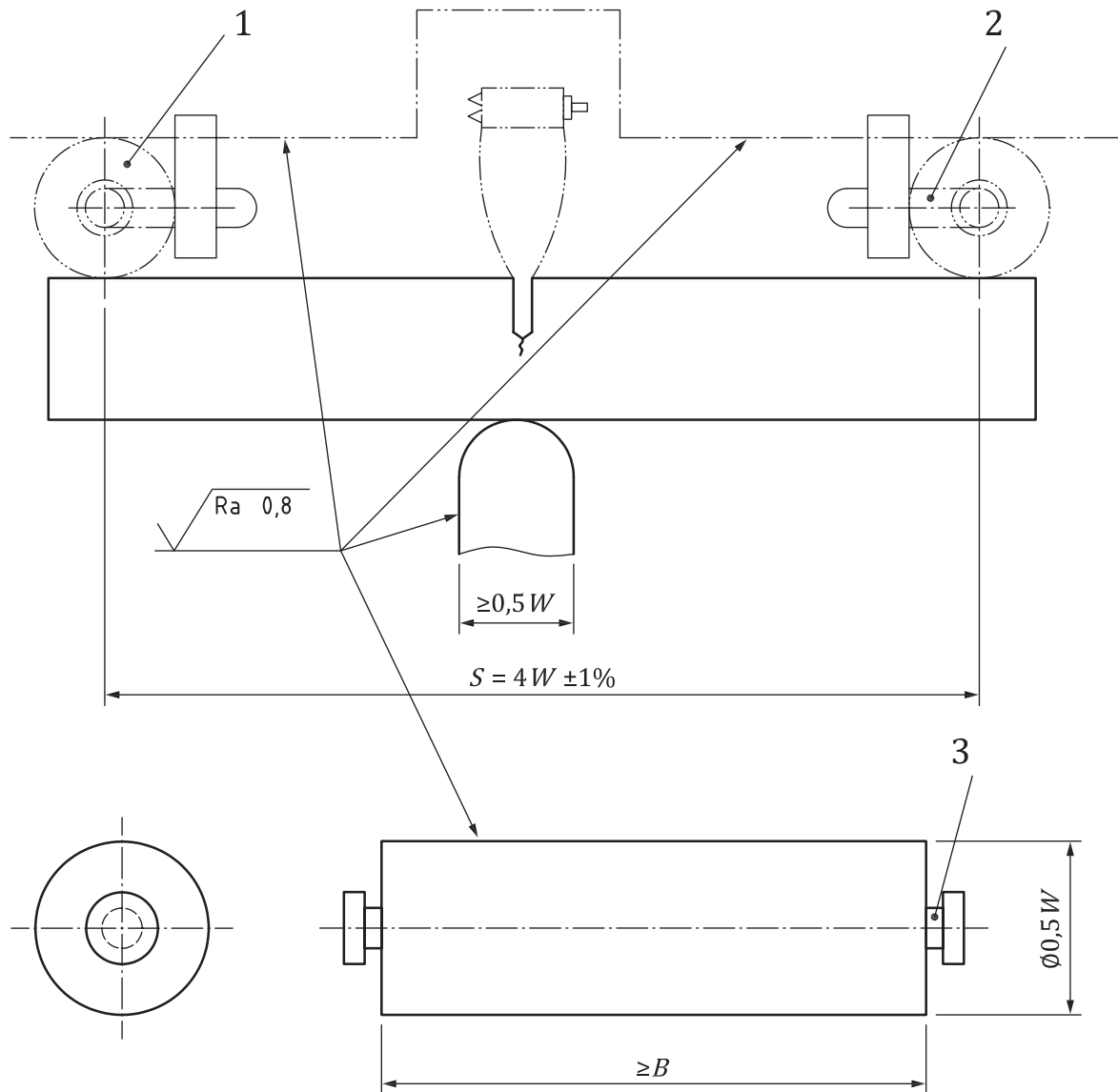
More frequent verification may be required depending on use and agreement between contractual parties.

The verification of the displacement gauge shall be performed at the test temperature $\pm 5^\circ\text{C}$, when technically possible, unless the temperature of the gauge is different from the temperature of the specimen during the test. In this latter case, the verification of the displacement gauge shall be performed at the temperature at which it is used $\pm 5^\circ\text{C}$. The response of the gauge shall be true to $\pm 0,003\text{ mm}$ for displacements up to $0,3\text{ mm}$, and $\pm 1\%$ thereafter. When the clip gauge is well-insulated from the specimen, an ambient temperature calibration is usually adequate; however, it should be demonstrated that the calibration is satisfactory for the test conditions.

5.6.4 Test fixtures

Three-point bend specimens shall be tested using a loading fixture designed to minimize friction by allowing the rollers to move outwards during loading (see [Figure 10](#)). The roller diameters shall be between W and $W/2$.

The loading fixture bearing surfaces shall have a hardness greater than 40 HRC (400 HV) or a yield strength of at least $1\,000\text{ MPa}$.



Roller details

Key

- 1 roller
- 2 rubber band or spring
- 3 bosses for rubber bands or springs

Roller pins and specimen contact surface of loading ram have to be parallel to each other to $\pm 0,002 W$.

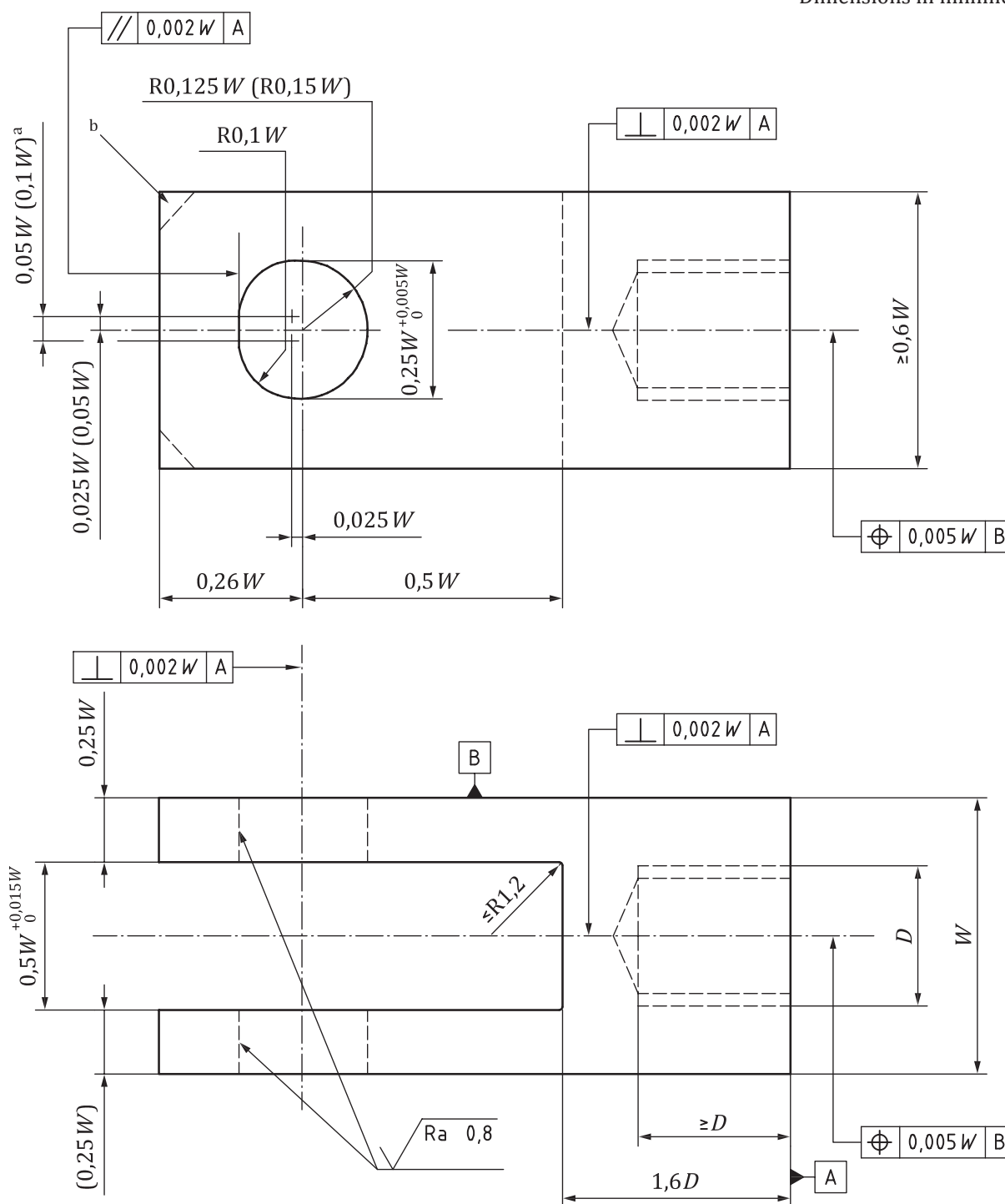
NOTE 1 Fixture and roller pin hardness ≥ 40 HRC.

NOTE 2 Surface roughness Ra in micrometres.

Figure 10 — Fixture for three-point bend tests

Compact specimens shall be loaded using a clevis and pin arrangement designed to minimize friction. The arrangement shall ensure alignment as the specimen is loaded in tension. Clevises for resistance-curve measurements shall have flat-bottomed holes (see [Figure 11](#)) so that the loading pins are free to roll throughout the test. Round-bottomed holes (see [Figure 12](#)) shall not be allowed for single specimen (unloading compliance) tests.

Dimensions in millimetres.



For specimens showing large displacements, clevis hole dimensions shall be enlarged to the values shown in brackets.

NOTE 1 Pin diameter = $0,24 W_{-0,005 W}^0$.

NOTE 2 Clevis and pin hardness ≥ 40 HRC.

NOTE 3 Surface roughness Ra in micrometres.

^a Loading flat. ^b Corners of clevis may be removed if necessary to accommodate clip gauge.

Figure 11 — Typical design of compact specimen clevis employing a flat hole to accommodate load-pin