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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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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.ch
Web www.iso.ch

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Contents

Page

Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 12135 was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 4, *Toughness testing — Fracture (F), Pendulum (P), Tear (T)*.

Annexes B, D and I form a normative part of this International Standard. Annexes A, C, E, F, G and H are for information only.

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

1 Scope

This International Standard 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.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 3785:1976, *Steel — Designation of test piece axes*

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

ISO 9513:1999, *Metallic materials — Calibration of extensometers used in uniaxial testing*

3 Terms and definitions

For the purposes of this International Standard the following terms and definitions apply.

3.1
stress intensity factor
K
magnitude of the elastic stress-field singularity for a homogeneous, linear-elastic body

NOTE 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 displacement of the crack surfaces normal to the original (undeformed) crack plane at the tip of the fatigue precrack

1) To be published. (Revision of ISO 7500-1:1999)

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, specific values of which, experimentally determined by this method of test (J_c, J_i, J_u,…), characterize fracture toughness under conditions of non-negligible crack-tip plasticity

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

3.7
pop-in
abrupt discontinuity in the force versus displacement record, featured as a sudden increase in displacement and, generally, a decrease in force

NOTE 1 Displacement and force subsequently increase beyond their values at pop-in.

NOTE 2 When conducting tests by this method, pop-ins may result from unstable crack extension 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 or J with stable crack extension

4 Symbols and designations

See Table 1.

Table 1 — Symbols and their designations

Symbol	Unit	Designation
a	mm	Nominal crack length (for the purposes of fatigue precracking, an assigned value less than a_o)
a_f	mm	Final crack length ($a_o + \Delta a$)
a_i	mm	Instantaneous crack length
a_m	mm	Length of machined notch
a_o	mm	Initial crack length
Δa	mm	Stable crack extension including blunting
Δa_{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
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
F_f	kN	Maximum fatigue precracking force
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	Fracture 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_o	MJ/m^2	J 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 $\sqrt{m}$	Stress intensity factor

Table 1 (*continued*)

Symbol	Unit	Designation
K_f	MPa $\sqrt{m}$	Maximum value of K during the final stages of fatigue precracking
K_{Ic}	MPa $\sqrt{m}$	Plane strain fracture toughness
K_Q	MPa $\sqrt{m}$	A provisional value of K_{Ic}
q	mm	Load-point displacement
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 specimen load-point displacement q at the load-line
U_e	J	Elastic component of U
U_p	J	Plastic component of U
V	mm	Notch-opening displacement
V_e	mm	Elastic component of V
V_p	mm	Plastic component of V
W	mm	Width of test specimen
z	mm	For bend and straight-notch compact specimens, the initial distance of the notch opening gauge measurement position from the notched edge of the specimen, either further from the crack tip [$+z$ in Figure 8b)] or closer to the crack tip ($-z$); or, for a stepped-notch compact specimen, the initial distance of the notch 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 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 cannot be measured (B = specimen thickness in mm)
δ_o	mm	δ uncorrected for stable crack extension
$\delta_{0,2BL}$	mm	Size insensitive fracture resistance δ at 0,2 mm crack extension offset from construction line (B = specimen thickness in mm)

Table 1 (*continued*)

Symbol	Unit	Designation
$\delta_{0,2\mathrm{BL}(B)}$	mm	Size sensitive fracture resistance δ at 0,2 mm stable crack extension offset from construction line (B = specimen thickness in mm)
ν	1	Poisson's ratio

NOTE 1 This is not a complete list of parameters. Only the main parameters are given here, 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 measure 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.

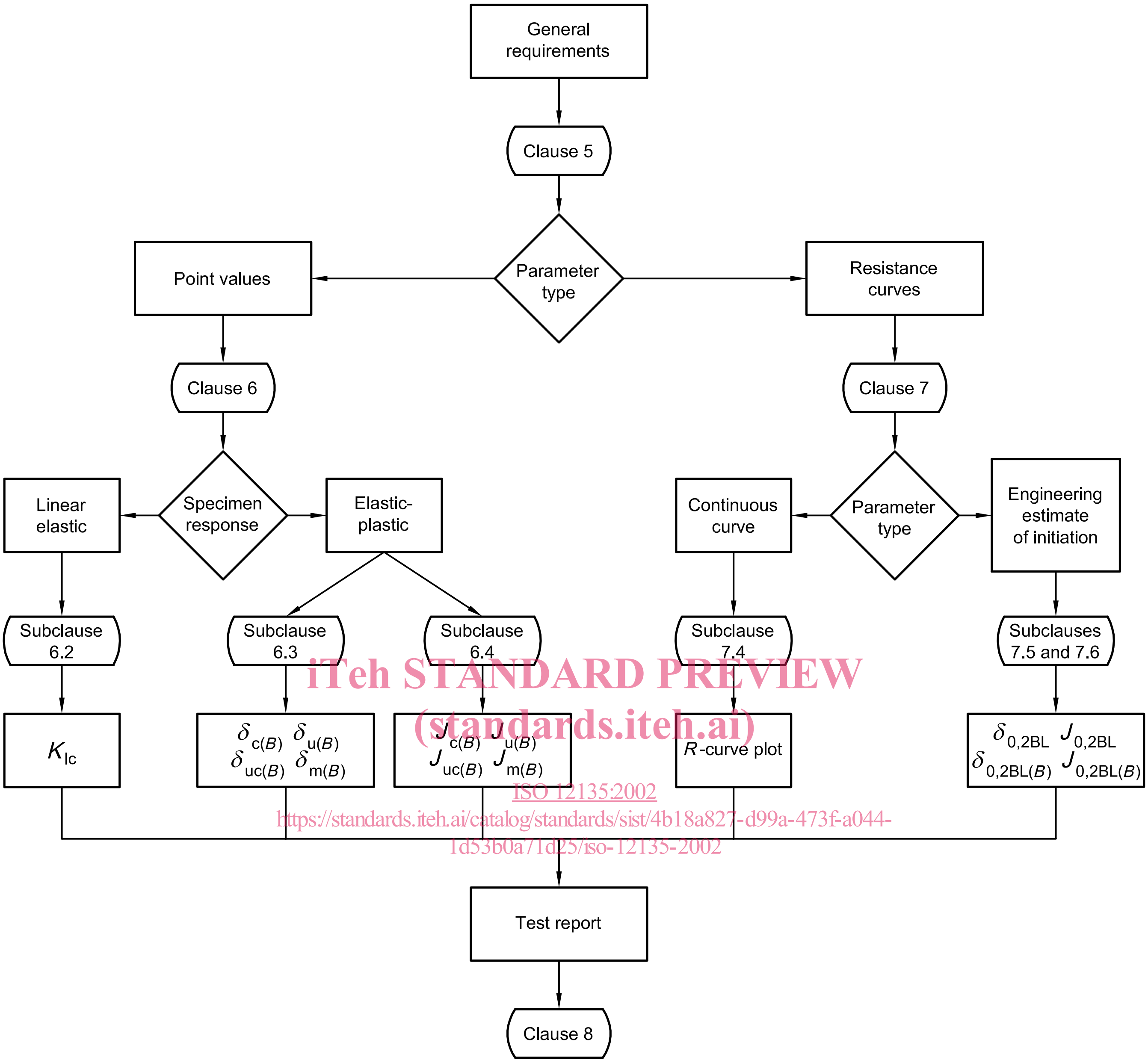
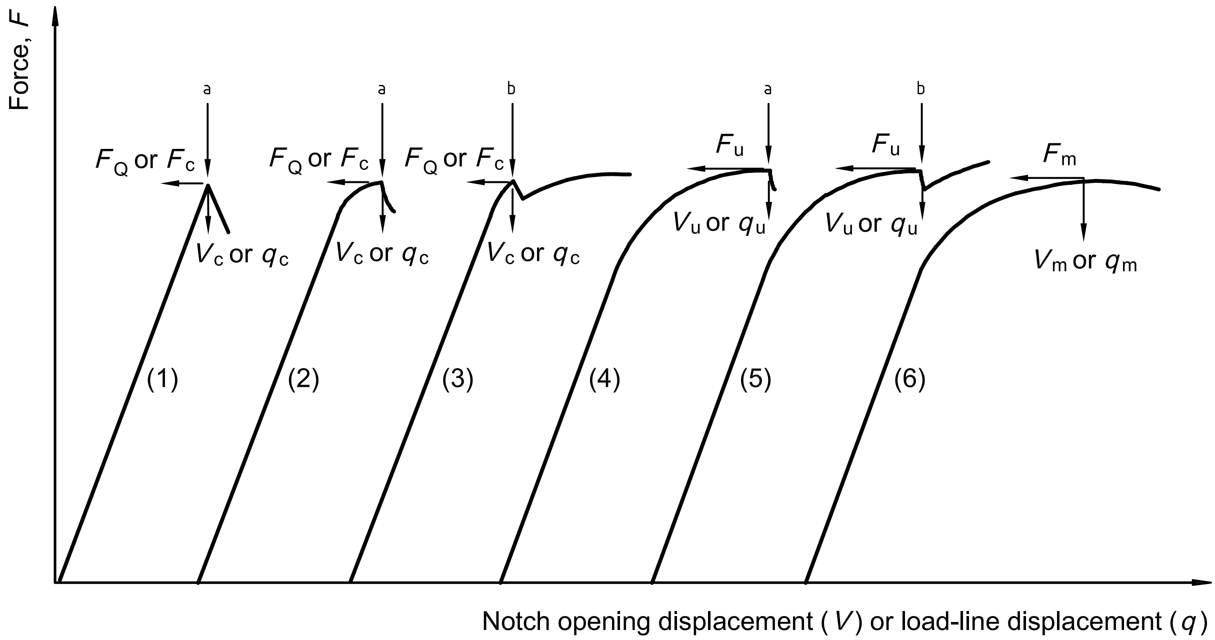


Figure 1 — General flowchart showing how to use the standard method of test



NOTE 1 F_Q is the maximum force used in the determination of a provisional K_{Ic} (see Figure 16).

NOTE 2 F_c, F_u and F_m correspond to either δ_c, δ_u and δ_m respectively, or J_c, J_u and J_m respectively.

NOTE 3 Pop-in behaviour is a function of the testing machine/specimen compliance and the recorder response rate.

[a] Fracture.

[b] Pop-in.

Figure 2 — Characteristics 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 a measurement 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, 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 steel specimens to ensure brittle behaviour may 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 International Standard are given in Table 2.

Table 2 — Fracture toughness symbols

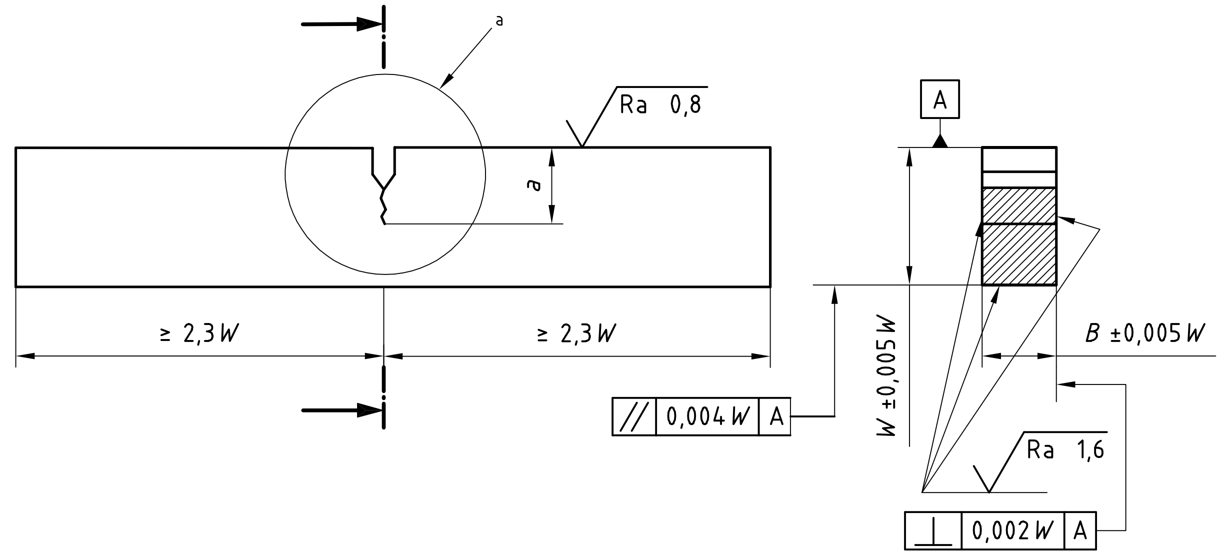
Parameter	Size insensitive quantities	Size sensitive quantities (specific to thickness B tested)	Qualifying limits to R-curves
K	K_{Ic}		
δ	δ_i $\delta_{0,2BL}$	$\delta_{c(B)}$ $\delta_{0,2BL(B)}$ $\delta_{u(B)}$, $\delta_{uc(B)}$, $\delta_{m(B)}$	δ_g, $\delta_g(\Delta a_{max})$
J	J_i $J_{0,2BL}$	$J_{c(B)}$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

Surface roughness values in micrometres



NOTE 1 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 2 Integral or attachable knife edges for clip gauge attachment may be used (see Figures 8 and 9).

NOTE 3 For starter notch and fatigue crack configuration, see Figure 6.

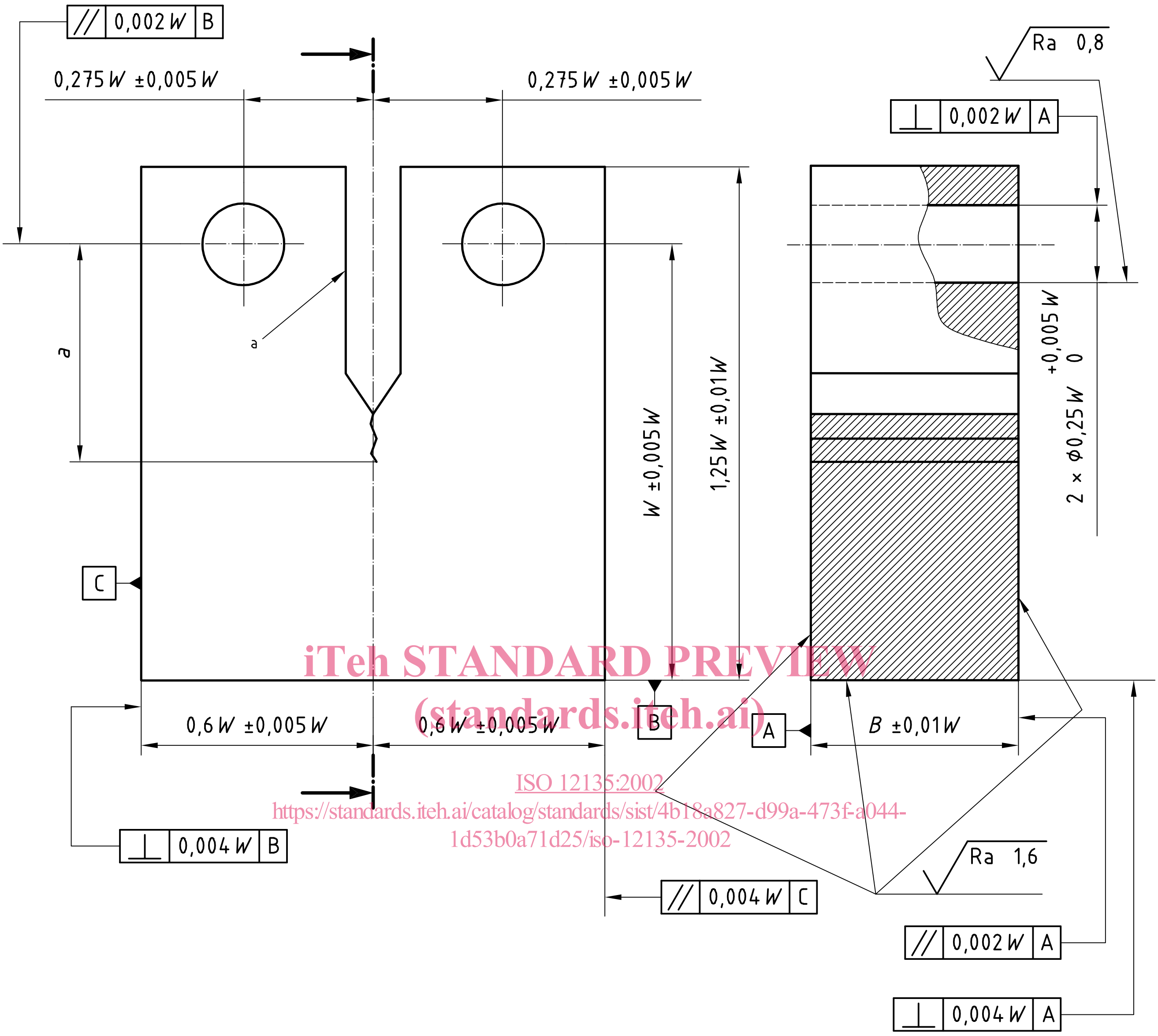
NOTE 4 $1,0 \leqslant W/B \leqslant 4,0$ ($W/B = 2$ preferred).

NOTE 5 $0,45 \leqslant a/W \leqslant 0,70$.

[a] See Figures 6 to 8 and 5.4.2.3.

Figure 3 — Proportional dimensions and tolerances for bend specimen

Surface roughness values in micrometres



NOTE 1 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 2 Integral or attachable knife edges for clip gauge attachment may be used (see Figures 8 and 9).

NOTE 3 For starter notch and fatigue crack configuration, see Figure 6.

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

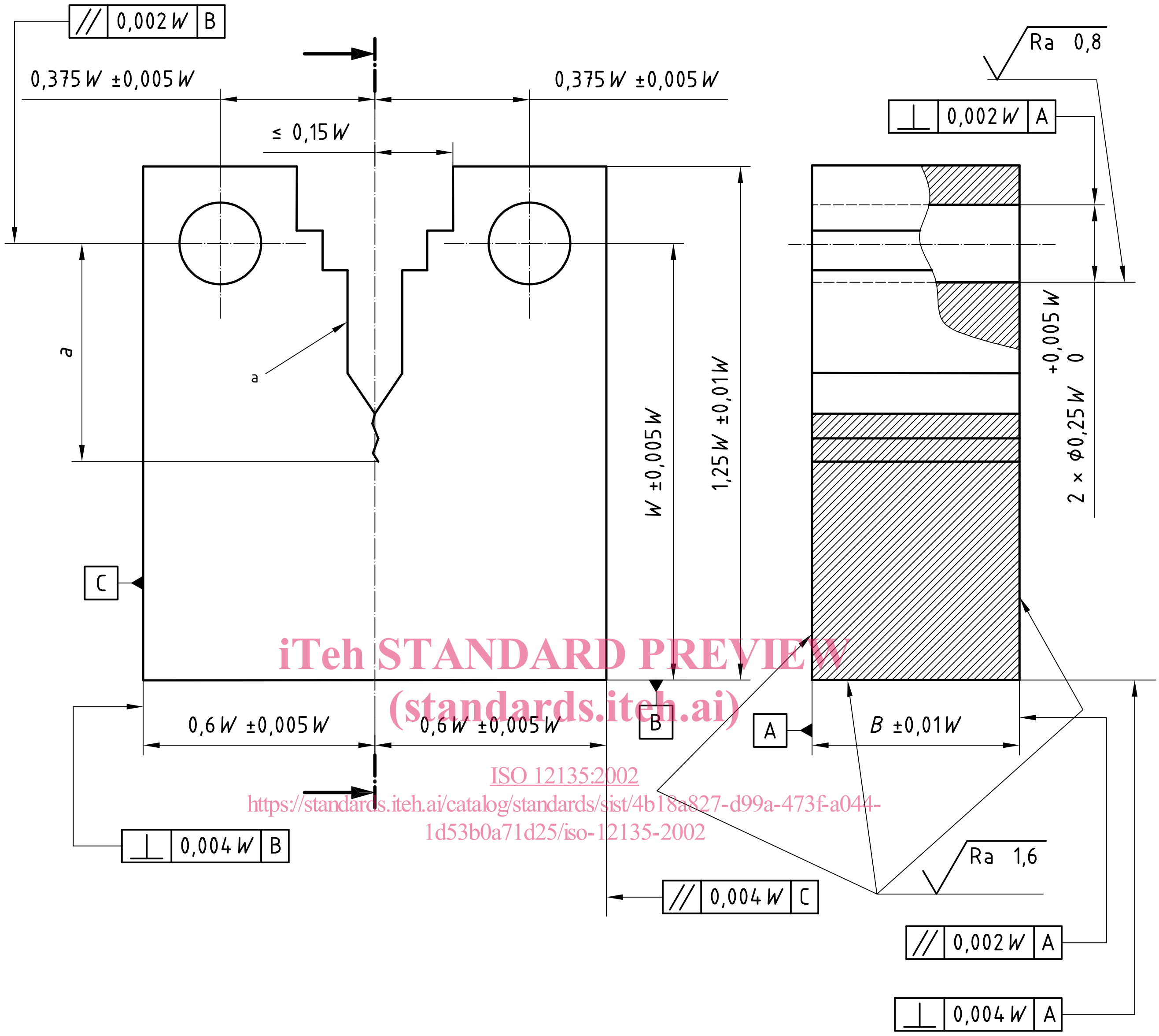
NOTE 5 $0,45 \leqslant a/W \leqslant 0,70$.

NOTE 6 Alternative pin hole diameter, $\varnothing\ 0,188\ W\ ^{+0,004W}_{0}$

[a] See Figures 6 to 8 and 5.4.2.3.

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

Surface roughness values in micrometres



NOTE 1 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 2 Integral or attachable knife edges for clip gauge attachment may be used (see Figures 8 and 9).

NOTE 3 For starter notch and fatigue crack configuration, see Figure 6.

NOTE 4 $0{,}8 \leqslant W/B \leqslant 4{,}0$ ($W/B = 2$ preferred).

NOTE 5 $0{,}45 \leqslant a/W \leqslant 0{,}70$

NOTE 6 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 7 Alternative pin hole diameter, $\varnothing\ 0{,}188\ W\ ^{+0{,}004W}_{\ 0}$. When this pin size in used, notch opening may be increased to 0,21 W maximum.

[a] See Figures 6 to 8.

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

