INTERNATIONAL STANDARD

ISO 12737

Second edition
2005-08-01

Metallic materials — Determination of plane-strain fracture toughness

Matériaux métalliques — Détermination du facteur d'intensité de contrainte critique

Reference number
ISO 12737:2005(E)

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Published in Switzerland

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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 document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 12737 was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 4, *Toughness testing — Fracture (F), Pendulum (P), Tear (T)*.

This second edition cancels and replaces the first edition (ISO 12737:1996), which has been technically revised. It includes the changes in Draft Amendement 1:2004, *Recommendations relating to specimen test temperature and crack-plane orientation*.

Metallic materials — Determination of plane-strain fracture toughness

1 Scope

This International Standard specifies the ISO method for determining the plane-strain fracture toughness of homogeneous metallic materials using a specimen that is notched and precracked by fatigue, and subjected to slowly increasing crack displacement force.

2 Normative references

The following referenced documents are indispensable for the application 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 7500-1:2004, *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 document, the following terms and definitions apply.

3.1
plane-strain stress intensity factor
K_I
magnitude of the elastic stress field at the tip of a crack subjected to opening mode displacement (mode I)

NOTE It is a function of applied force and test specimen size, geometry, and crack length, and has the dimensions of force times length$^{-3/2}$.

3.2
plane-strain fracture toughness
K_{Ic}
measure, by the operational procedure of this method, of a material's resistance to crack extension when the state of stress near the crack tip is predominantly plane strain and plastic deformation is limited

NOTE It is the critical value of K_I at which significant crack extension occurs on increasing load with high constraint to plastic deformation.

3.3
crack-plane orientation
method for relating the plane and direction of crack extension to the characteristic directions of the product

NOTE A hyphenated code is used wherein the letter(s) preceding the hyphen represent(s) the direction normal to the crack plane, and the letter(s) following the hyphen represent(s) the anticipated direction of crack extension (see Figure 1). For wrought metals, the letter X always denotes the direction of principal deformation (maximum grain flow in the product), the letter Y the direction of least deformation, and the letter Z the direction normal to the X-Y plane. If specimen directions do not coincide with the product's characteristic directions, then two letters are used to denote the normal to the crack plane and/or the expected direction of crack extension [see Figure 1 b)]. If there is no grain flow direction (as in a casting), reference axes may be arbitrarily assigned but must be clearly identified.

3.4
notch opening displacement

V

displacement measured at or near the notch mouth

4 Symbols and designations

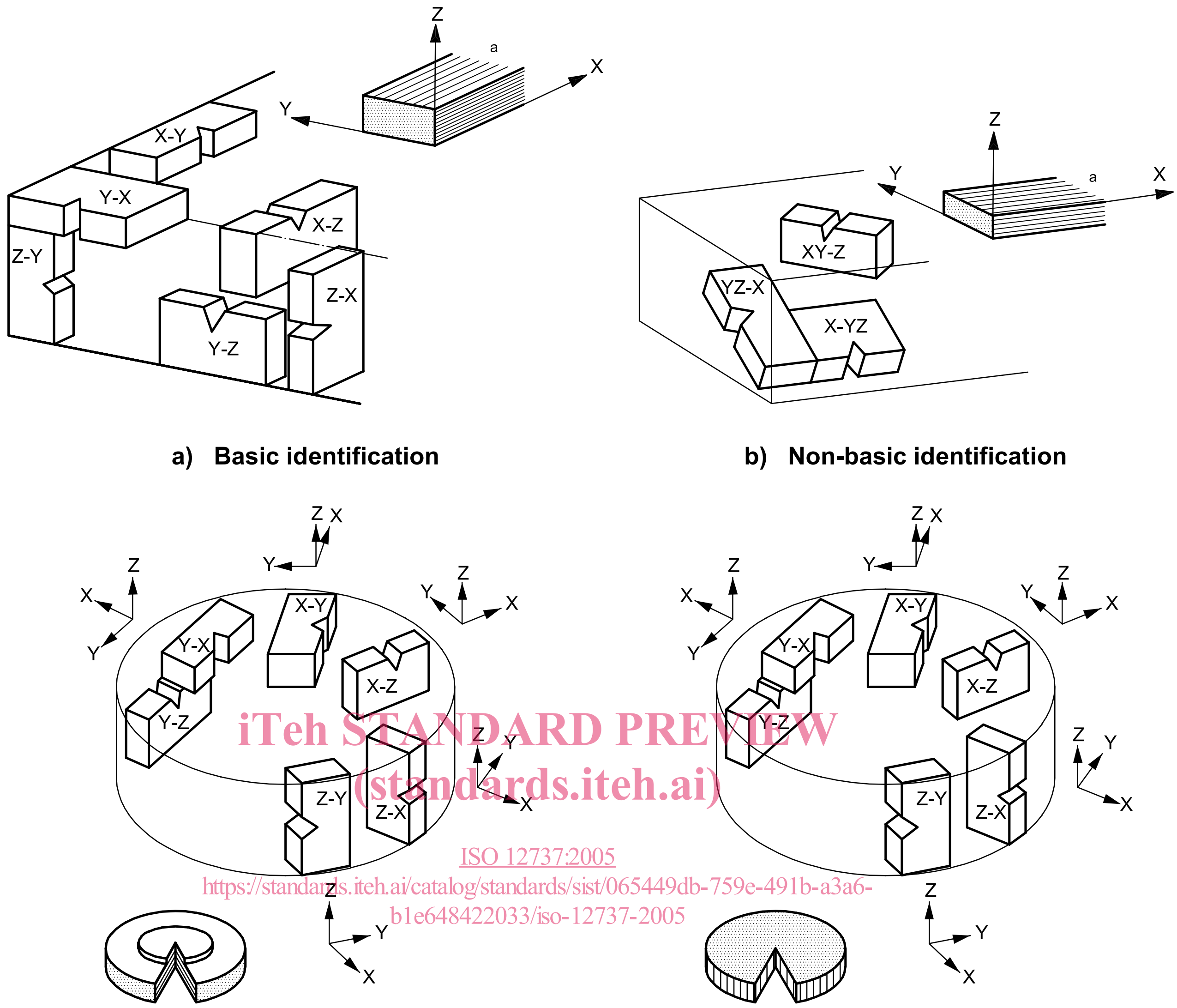
For the purposes of this International Standard, the following symbols apply (see also Figures 1, 2 and 4).

Symbol	Unit	Designation
a	mm	Crack length
B	mm	Specimen thickness
E	MPa	Young's modulus
F	kN	Applied force
F_Q	kN	Particular value of F (see Figure 4)
F_5	kN	Particular value of F (see Figure 4)
K_f	MPa·m $^{1/2}$ [a]	Maximum stress intensity factor during the final stage of fatigue cracking
K_Q	MPa·m $^{1/2}$	Provisional value of K_{Ic}
K_I	MPa·m $^{1/2}$	Opening mode stress intensity factor (mode I)
K_{Ic}	MPa·m $^{1/2}$	Critical value of K_I (plane-strain fracture toughness)
R	—	Ratio of minimum to maximum fatigue cracking force during any single cycle of fatigue operation
$R_{p0,2}$	MPa	0,2 % offset yield strength
S	mm	Span between outer loading points
V	mm	Notch opening displacement
W	mm	Width for bend specimen or effective width for compact specimen
ΔK_I	MPa·m $^{1/2}$	Difference between maximum and minimum values of K_I during any single cycle of fatigue operation

[a] 0,031 6 MPa·m$^{1/2}$ = 1 N·mm$^{-3/2}$ = 0,031 6 MN·m$^{-3/2}$.

5 Principle

This method covers the determination of the plane-strain fracture toughness (K_{Ic}) of metallic materials by increasing-force tests of fatigue-precracked test specimens. Details of the test specimens and experimental procedures are given in Annexes B and C. Force versus notch opening displacement is recorded autographically, or converted to digital form for accumulation in a computer information storage facility and subsequent processing. The force corresponding to 2 % apparent crack extension is established by a specified deviation from the linear portion of the test record. If certain validity requirements are satisfied, the value of K_{Ic} is calculated from this force.



a) **Basic identification**

b) **Non-basic identification**

c) **Radial grain flow, axial working direction**

d) **Axial grain flow, radial working direction**

[a] Grain flow.

Figure 1 — Crack-plane identification

The property K_{Ic} characterizes the resistance of a material to fracture in the presence of a sharp crack under severe tensile constraint, such that

a) the state of stress near the crack front approaches plane strain, and

b) the crack-tip plastic zone is small compared to the crack size, specimen thickness, and ligament ahead of the crack.

K_{Ic} is believed to represent a lower limiting value of fracture toughness in the environment and at the temperature of test.

Cyclic or sustained loads can cause crack extension at K_I values less than K_{Ic}. Crack extension under cyclic or sustained loads can be influenced by temperature and environment. Therefore, when K_{Ic} is applied to the design of service components, differences between laboratory test and field conditions should be considered.

With plane-strain fracture toughness testing, there can be no advance assurance that a valid K_{Ic} will be determined in a particular test.

6 Apparatus

6.1 Testing machine and force measurement

The testing machine shall be calibrated in accordance with ISO 7500-1 and shall be of at least grade 1. The testing machine shall have provisions for autographic recording of the force applied to the specimen; alternatively, a computer data acquisition system may be used to record force and displacement for subsequent analysis. The combination of force-sensing device and recording system shall permit the force F_Q (as defined in Clause 10) to be determined from the test record to ± 1 %.

6.2 Fatigue cracking machine

When possible, the fatigue machine and force-indicating device shall be calibrated statically in accordance with ISO 7500-1 and shall have a grade of at least 2. If the machine cannot be calibrated statically, the applied force shall be known to ± 2,5 %. Careful alignment of the specimen and fixturing is necessary to encourage straight fatigue cracks. The fixturing shall be such that the stress distribution is uniform across the specimen thickness and symmetrical about the plane of the prospective crack.

6.3 Displacement gauge

The displacement-gauge electrical output shall represent the relative displacement (V) of two precisely located gauge positions spanning the notch mouth. The design of the displacement gauge and knife edges shall allow free rotation of the points of contact between the gauge and the specimen.

The displacement gauge shall be calibrated in accordance with 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 during the time the gauge is in use. Periodic verification of greater frequency may be required, depending on use and agreement between contractual parties.

Verification of the gauge shall be performed at the temperature of test to ± 5 °C. The response of the gauge shall correspond to the calibration apparatus to ± 0,003 mm for displacements up to 0,3 mm, and ± 1 % for higher values.

The determination of an absolute displacement value is not necessary since only changes in displacement are used in this method. Two proven designs of displacement gauge are given in [1] and [2] (see Bibliography) and similar gauges are commercially available.

6.4 Testing fixtures

The bend test shall be performed using a fixture designed to minimize friction effects by allowing the support rollers to rotate and translate slightly as the specimen is loaded, thus achieving rolling contact. A design suitable for testing bend specimens is shown in Figure D.1.

A loading clevis suitable for testing compact specimens is shown in Figure D.2.

7 Test specimen size, configuration and preparation

7.1 Specimen size

In order for a result to be considered valid according to this method, the specimen thickness (B), crack length (a) and ligament length ($W - a$) must all be not less than $2{,}5(K_{Ic}/R_{p0,2})^2$, where $R_{p0,2}$ is the 0,2 % offset yield strength of the material in the environment and at the temperature of test. Meeting this requirement cannot be ensured in advance, thus specimen dimensions should be conservatively established for the first test in a series. If the form of the available material is such that it is not possible to obtain a test specimen with thickness, crack length and ligament length equal to or greater than $2{,}5(K_{Ic}/R_{p0,2})^2$, then it is not possible to make a valid K_{Ic} measurement according to this method.

7.2 Recommended specimen proportions

7.2.1 Recommended specimens

The recommended specimens are shown in Figures B.1 and C.1. Width (W) is nominally twice the thickness (B). Crack length (a) is between 0,45 and 0,55 times the width.

7.2.2 Alternative proportions

In certain cases, it may be necessary or desirable to use specimens having W/B ratios other than 2, and alternative proportions are allowed (see Annex B or C). Specimens having alternative proportions shall nevertheless have the same crack length-to-width (a/W) ratio as the recommended specimens.

7.2.3 Alternative specimen configurations (for information only)

By prior agreement, alternative specimen configurations and their associated methods of analysis may be used, provided that they be accepted as national standards for K_{Ic} testing by an ISO member body, including those standards which have the multiple purpose of measuring K_{Ic} along with J and/or CTOD (crack tip opening displacement) properties: e.g. [2] and [3].

7.2.4 Fatigue-crack starter notch

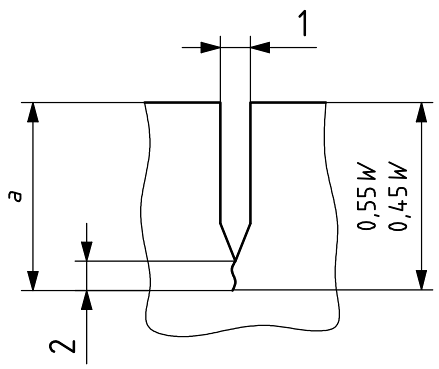
Two fatigue-crack starter notch configurations are shown in Figures 2 a) and 2 b). The suggested root radius for the straight-through slot terminating in a V-notch is 0,10 mm or less. For the chevron form of notch, the suggested root radius is 0,25 mm or less. The method of notch preparation is discretionary. The starter notch (plus fatigue crack) must lie within the envelope shown in Figure 2 c) (see Annex A).

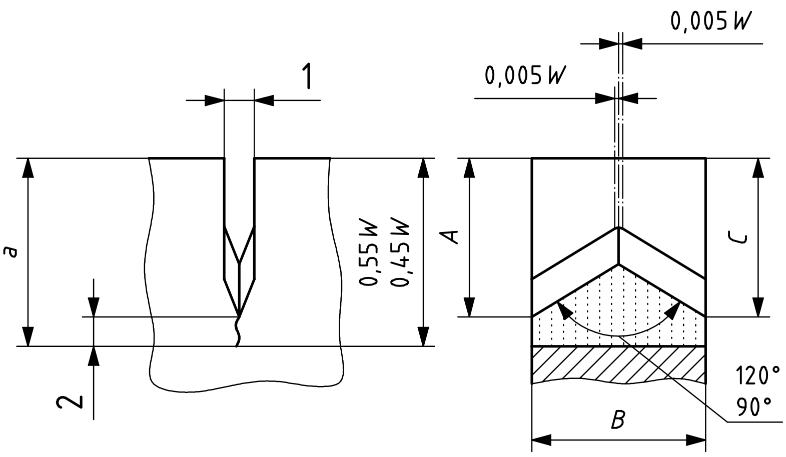
Two types of knife edges for attaching the displacement gauge are illustrated in Figure 3.

7.3 Specimen preparation and fatigue precracking

7.3.1 Material condition

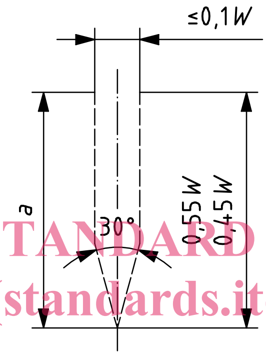
All specimens shall be tested in the finally heat-treated, mechanically-worked and environmentally-conditioned state. Normally, specimens shall also be machined in this final state. However, for material that cannot be machined in the final condition, the final treatment may be carried out after machining, provided that the required dimensions and tolerances on specimen size, shape and overall surface finish are met (see Figures B.1 and C.1), and that full account is taken of the effects of specimen size on metallurgical condition induced by certain heat treatments, e.g. water quenching of steels.





a) Straight-through notch

b) Chevron notch [c]



c) Envelope

Key

1 notch width [a]

2 fatigue crack [b]

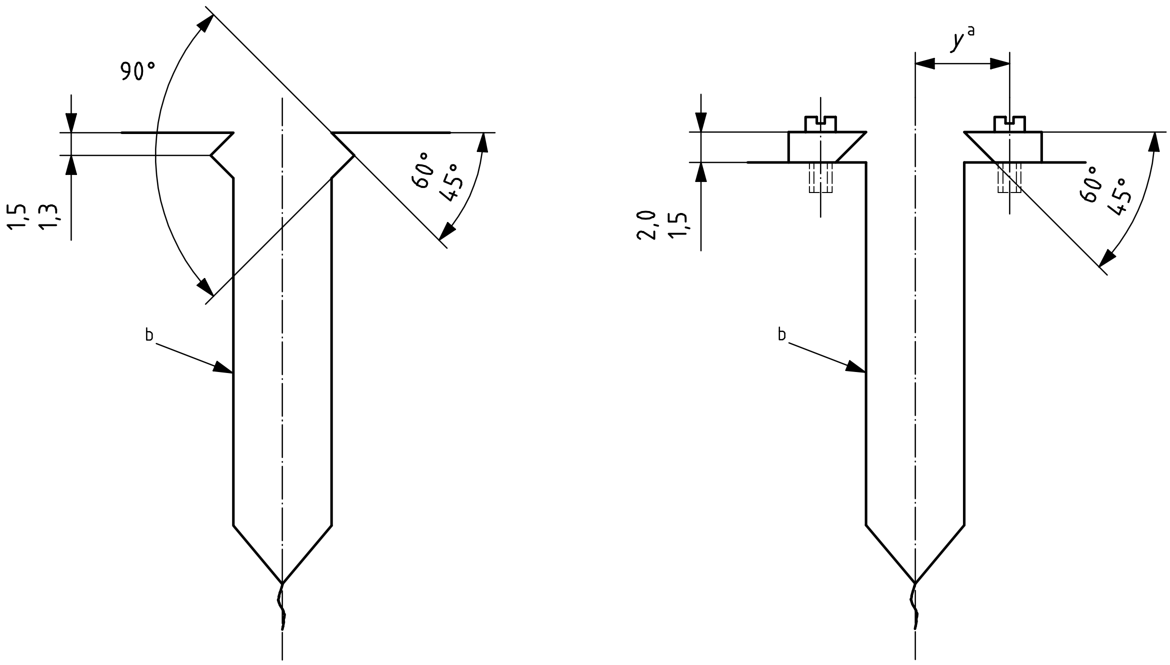
[a] The crack starter notch shall be perpendicular to specimen surfaces to ± 2°. Notch width shall not exceed 0,1W but shall not be less than 1,6 mm.

[b] For straight-through notch: suggested notch root radius 0,10 mm maximum. Cutter tip angle 90° maximum. Fatigue crack extension on each surface of specimen shall be at least 0,025W or 1,3 mm, whichever is greater.

[c] For chevron notch: suggested notch root radius 0,25 mm maximum. Cutter tip angle 90° maximum, A = C within ± 0,01W. Fatigue crack shall emerge on both surfaces of specimen.

Figure 2 — Crack starter notches and maximum permissible notch/crack envelope

Dimensions in millimetres



a) **Integral type** b) **Attached type**

Knife edges shall be square with specimen surfaces and parallel to ± 0,5°.

[a] $2y$ plus the diameter of screw thread shall not exceed $W/2$. If knife edges are glued or similarly attached to the edge of the specimen, dimension $2y$ shall correspond to the distance between extreme points of attachment.

[b] See Figure 2.

Figure 3 — Knife edge detail

7.3.2 Crack-plane orientation

The fracture toughness of a material is usually dependent on the orientation and direction of propagation of the crack in relation to the principal directions of metal working, grain flow or otherwise-produced texture. Orientation of the crack plane shall be decided before machining (see 7.3.3), identified in accordance with the prescribed coordinate systems (see 3.3) and recorded (see Clause 11).

7.3.3 Machining

Specimen sizes, shapes, dimensional tolerances and surface finishes shall be as given in Figures B.1 and C.1.

7.3.4 Fatigue precracking

Fatigue precracking normally shall be done at room temperature with the specimen in the finally heat-treated, mechanically-worked or environmentally-conditioned state in which it is to be tested. Different fatigue precracking temperatures and intermediate thermal/mechanical/environmental treatments between fatigue precracking and testing shall be used only when such treatments are necessary to simulate the conditions for a specific structural application, and required dimensions and tolerances on specimen size and shape can be maintained. Such fatigue precracking shall be performed according to the requirements of Annex A.