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Metallic materials—Determination of plane-strain fracture toughness

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Foreword

This translation has been made based on the original Japanese Industrial Standard established by the Minister of International Trade and Industry through deliberations at Japanese Industrial Standards Committee in accordance with the Industrial Standardization Law:

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Metallic materials—Determination of plane-strain fracture toughness

Introduction This Japanese Industrial Standard has been prepared based on ISO 12737, *Metallic materials—Determination of plane-strain fracture toughness* issued in 1996 as the first edition without changing the technical contents.

1 Scope This Standard specifies the 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 standards contain provisions which, through reference in this text, constitute provisions of this Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Standard are encouraged to investigate the possibility of applying the most recent edition of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 7500-1 : 1986 *Metallic materials—Verification of static uniaxial testing machines—Part 1 : Tensile testing machines*

ISO 9513 : 1989 *Metallic materials—Verification of extensometers used in uniaxial testing*

3 Definitions For the purposes of this Standard, the following 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). 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 Fig. 1). For wrought metals, the letter X always denotes the principal direction of grain flow, Z the direction of principal working force, and Y the direction normal to the X-Z 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 Fig. 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.

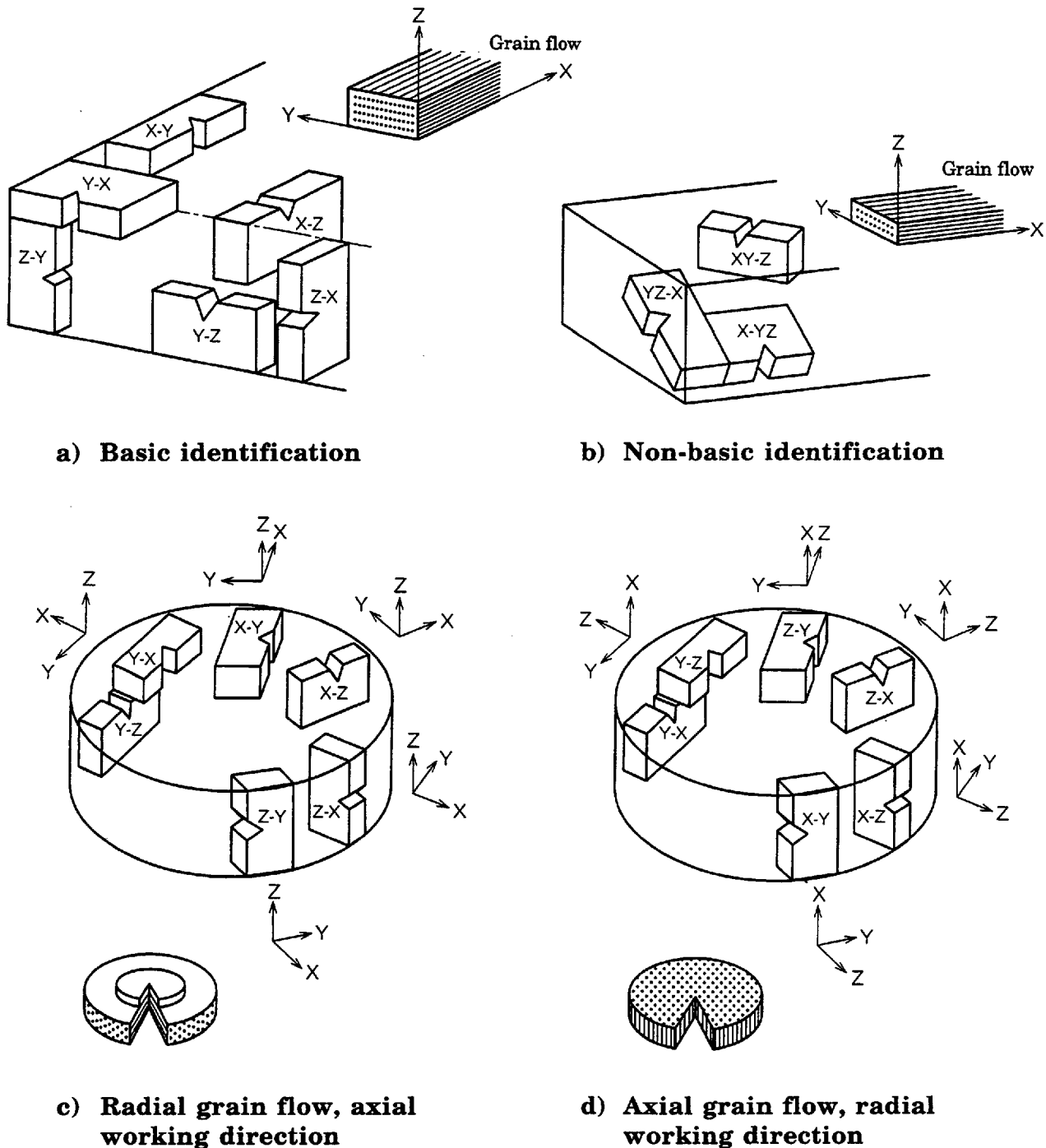


Fig. 1 Crack plane identification

4 Symbols and designations For the purposes of this Standard the following symbols apply (see also Figs. 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 Fig. 4)
F_5	kN	Particular value of F (see Fig. 4)
K_t	MPa·m ^{1/2} 1)	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
1) 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.

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_{1C} 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_1 values less than K_{1C} . Crack extension under cyclic or sustained loads can be influenced by temperature and environment. Therefore when K_{1C} 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_{1C} will be determined in a particular test.

6 Apparatus

6.1 Testing machine and load 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 load and displacement for subsequent analysis. The combination of load-sensing device and recording system shall permit the force F_Q (as defined in clause 10) to be determined from the test record to $\pm 1\%$.

6.2 Fatigue cracking machine When possible, the fatigue machine and load-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 $\pm 2.5\%$. 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 $\pm 5^\circ\text{C}$. Response of the gauge shall correspond to the calibration apparatus to $\pm 0.003\text{ mm}$ for displacements up to 0.3 mm and $\pm 1\%$ 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 Annex E) and similar gauges are commercially available.