Designation: E399 – 09$^{\varepsilon 2}$

Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness K_{Ic} of Metallic Materials[1]

This standard is issued under the fixed designation E399; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

ε^1 NOTE—Eq A3.4, Eq A4.4, Eq A5.4, and Eq A6.11 were editorially corrected in May 2010.
ε^2 NOTE—11.2 and 11.4 were editorially corrected in December 2010.

1. Scope

1.1 This test method covers the determination of fracture toughness (K_{Ic}) of metallic materials under predominantly linear-elastic, plane-strain conditions using fatigue precracked specimens having a thickness of 1.6 mm (0.063 in.) or greater[2] subjected to slowly, or in special (elective) cases rapidly, increasing crack-displacement force. Details of test apparatus, specimen configuration, and experimental procedure are given in the Annexes.

NOTE 1—Plane-strain fracture toughness tests of thinner materials that are sufficiently brittle (see 7.1) can be made using other types of specimens (**1**).[3] There is no standard test method for such thin materials.

1.2 This test method is divided into two parts. The first part gives general recommendations and requirements for K_{Ic} testing. The second part consists of Annexes that give specific information on displacement gage and loading fixture design, special requirements for individual specimen configurations, and detailed procedures for fatigue precracking. Additional annexes are provided that give specific procedures for beryllium and rapid-force testing.

1.3 General information and requirements common to all specimen configurations:

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1.4 Specific requirements related to test apparatus:

Double-Cantilever Displacement Gage	Annex A1
Testing Fixtures	Annex A2
Bend Specimen Loading Fixture	Annex A2.1
Compact Specimen Loading Clevis	Annex A2.2

1.5 Specific requirements related to individual specimen configurations:

Bend Specimen *SE(B)*	Annex A3
Compact Specimen *C(T)*	Annex A4
Disk-Shaped Compact Specimen *DC(T)*	Annex A5
Arc-Shaped Tension Specimen *A(T)*	Annex A6
Arc-Shaped Bend Specimen *A(B)*	Annex A7

[1] This test method is under the jurisdiction of ASTM Committee E08 on Fatigue and Fracture and is the direct responsibility of Subcommittee E08.07 on Fracture Mechanics.

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[2] For additional information relating to the fracture toughness testing of aluminum alloys, see Practice B645.

[3] The boldface numbers in parentheses refer to the list of references at the end of this standard.

1.6 Specific requirements related to special test procedures:

Fatigue Precracking KIc Specimens	Annex A8
Hot-Pressed Beryllium Testing	Annex A9
Rapid-Force Testing	Annex A10

1.7 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[4]

B909 Guide for Plane Strain Fracture Toughness Testing of Non-Stress Relieved Aluminum Products

B645 Practice for Linear-Elastic Plane–Strain Fracture Toughness Testing of Aluminum Alloys

E4 Practices for Force Verification of Testing Machines

E8/E8M Test Methods for Tension Testing of Metallic Materials

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E337 Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)

E456 Terminology Relating to Quality and Statistics

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

E1820 Test Method for Measurement of Fracture Toughness

E1823 Terminology Relating to Fatigue and Fracture Testing

E1921 Test Method for Determination of Reference Temperature, T_o, for Ferritic Steels in the Transition Range

3. Terminology

3.1 *Definitions:Terminology* E1823 *is applicable to this test method*:

3.1.1 *stress-intensity factor, K, K_I, K_{II}, K_{III} [$FL^{-3/2}$]*—magnitude of the ideal-crack-tip stress field (a stress-field singularity), for a particular mode of crack displacement, in a homogeneous, linear-elastic body.

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

3.1.1.2 Values of *K* for modes I, II, and III are given as:

$$K_I = \lim_{r\to 0} [\sigma_{yy}(2\pi r)^{1/2}] \quad (1)$$

$$K_{II} = \lim_{r\to 0} [\tau_{xy}(2\pi r)^{1/2}] \quad (2)$$

$$K_{III} = \lim_{r\to 0} [\tau_{yz}(2\pi r)^{1/2}] \quad (3)$$

where *r* is the distance directly forward from the crack tip to the location where the significant stress is calculated.

3.1.2 *plane-strain fracture toughness, K_{Ic} [$FL^{-3/2}$]* —the crack-extension resistance under conditions of crack-tip plane strain in Mode I for slow rates of loading under predominantly linear-elastic conditions and negligible plastic-zone adjustment. The stress intensity factor, K_{Ic}, is measured using the operational procedure (and satisfying all of the validity requirements) specified in Test Method E399, that provides for the measurement of crack-extension resistance at the onset (2% or less) of crack extension and provides operational definitions of crack-tip sharpness, onset of crack extension, and crack-tip plane strain.

3.1.2.1 See also definitions of crack-extension resistance, crack-tip plane strain, and mode in Terminology E1823.

3.1.3 *crack plane orientation*—identification of the plane and direction of crack extension in relation to the characteristic directions of the product. A hyphenated code defined in Terminology E1823 is used wherein the letter(s) preceding the hyphen represents the direction normal to the crack plane and the letter(s) following the hyphen represents the anticipated direction of crack extension (see Fig. 1).

3.1.3.1 *Wrought Products*—the fracture toughness of wrought material depends on, among other factors, the orientation and propagation direction of the crack in relation to the material's anisotropy, which depends, in turn, on the principal directions of mechanical working and grain flow. Orientation of the crack plane shall be identified wherever possible. In addition, product form shall be identified (for example, straight-rolled plate, cross-rolled plate, pancake forging, and so forth) along with material condition (for example, annealed, solution treated plus aged, and so forth). The user shall be referred to product specifications for detailed processing information.

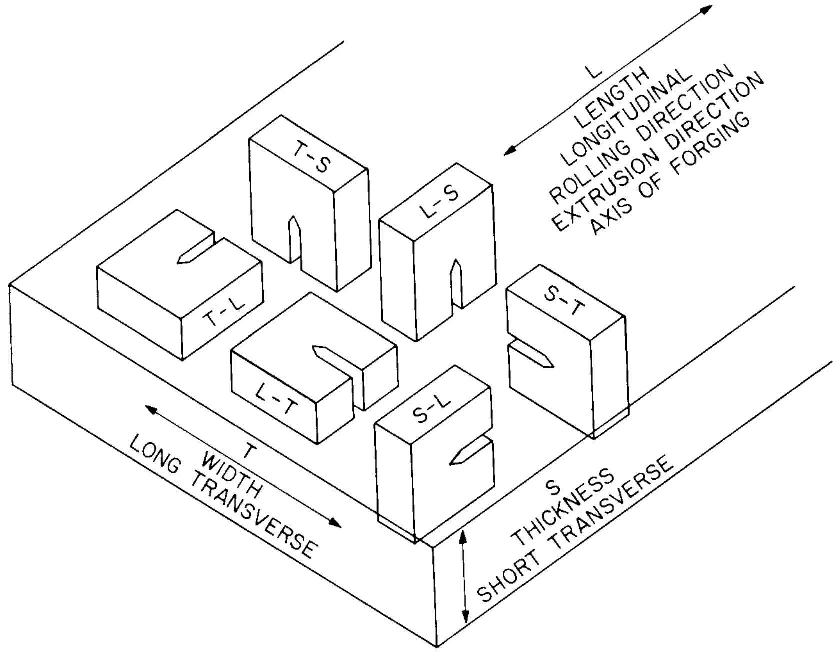
3.1.3.2 For rectangular sections, the reference directions are identified as in Fig. 1(a) and Fig. 1(b), which give examples for rolled plate. The same system is used for sheet, extrusions, and forgings with nonsymmetrical grain flow.

L = direction of principal deformation (maximum grain flow)
T = direction of least deformation
S = third orthogonal direction

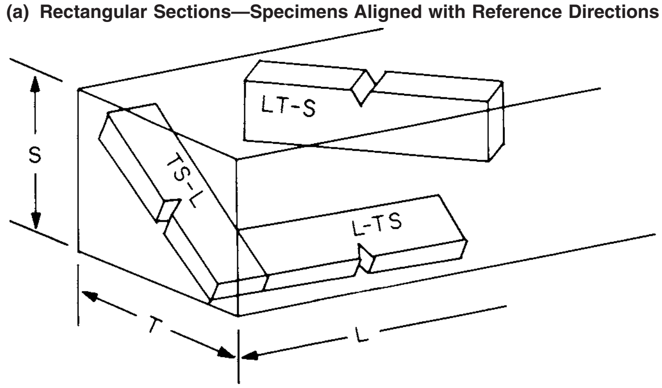
3.1.3.3 Using the two-letter code, the first letter designates the direction normal to the crack plane, and the second letter the expected direction of crack propagation. For example, in Fig. 1(a), the T-L specimen fracture plane normal is in the width direction of a plate and the expected direction of crack propagation is coincident with the direction of maximum grain flow (or longitudinal) direction of the plate.

3.1.3.4 For specimens tilted in respect to two of the reference axes as in Fig. 1(b), crack plane orientation is identified by a three-letter code. The designation L-TS, for example, indicates the crack plane to be perpendicular to the principal deformation (L) direction, and the expected fracture direction to be intermediate between T and S. The designation TS-L means that the crack plane is perpendicular to a direction

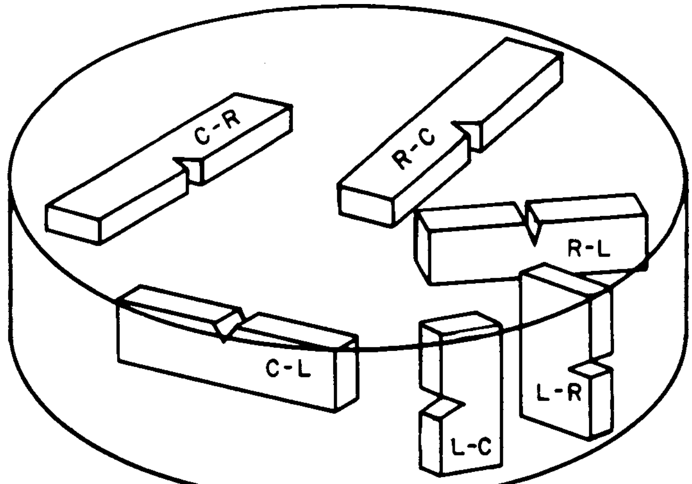
[4] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.



(a) Rectangular Sections—Specimens Aligned with Reference Directions



(b) Rectangular Sections—Specimens Not Aligned with Reference Directions



(c) Cylindrical Bars and Tubes

L = direction of maximum grain flow
R = radial direction
C = circumferential or tangential direction

FIG. 1 Crack Plane Identification