Designation: E399 − 22

Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness 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 U.S. Department of Defense.

1. Scope

1.1 This test method covers the determination of fracture toughness (K_{Ic} and optionally K_{Isi}) 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. Two procedures are outlined for using the experimental data to calculate fracture toughness values:

1.1.1 The K_{Ic} test procedure is described in the main body of this test standard and is a mandatory part of the testing and results reporting procedure for this test method. The K_{Ic} test procedure is based on crack growth of up to 2 % percent of the specimen width. This can lead to a specimen size dependent rising fracture toughness resistance curve, with larger specimens producing higher fracture toughness results.

1.1.2 The K_{Isi} test procedure is described in Appendix X1 and is an optional part of this test method. The K_{Isi} test procedure is based on a fixed amount of crack extension of 0.5 mm, and as a result, K_{Isi} is less sensitive to specimen size than K_{Ic}. This less size-sensitive fracture toughness, K_{Isi}, is called size-insensitive throughout this test method. Appendix X1 contains an optional procedure for reinterpreting the force-displacement test record recorded as part of this test method to calculate the additional fracture toughness value, K_{Isi}.

NOTE 1—Plane-strain fracture toughness tests of materials thinner than 1.6 mm (0.063 in.) 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 testing and includes specific requirements for the K_{Ic} test procedure. 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, and the K_{Isi} test procedure, which provides an optional additional analysis procedure for the test data collected as part of the K_{Ic} test procedure.

1.3 General information and requirements common to all specimen configurations:

[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.

1.4 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

1.6 Specific requirements related to special test procedures:

Fatigue Precracking K_{Ic} and K_{Isi} Specimens	Annex A8
Hot-Pressed Beryllium Testing	Annex A9
Rapid-Force Testing	Annex A10
Determination of K_{Isi}	Appendix X1

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.9 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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 Calibration and 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
E647 Test Method for Measurement of Fatigue Crack Growth Rates
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_0, for Ferritic Steels in the Transition Range
E1942 Guide for Evaluating Data Acquisition Systems Used in Cyclic Fatigue and Fracture Mechanics Testing
E3076 Practice for Determination of the Slope in the Linear Region of a Test Record

[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.

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:

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

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

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

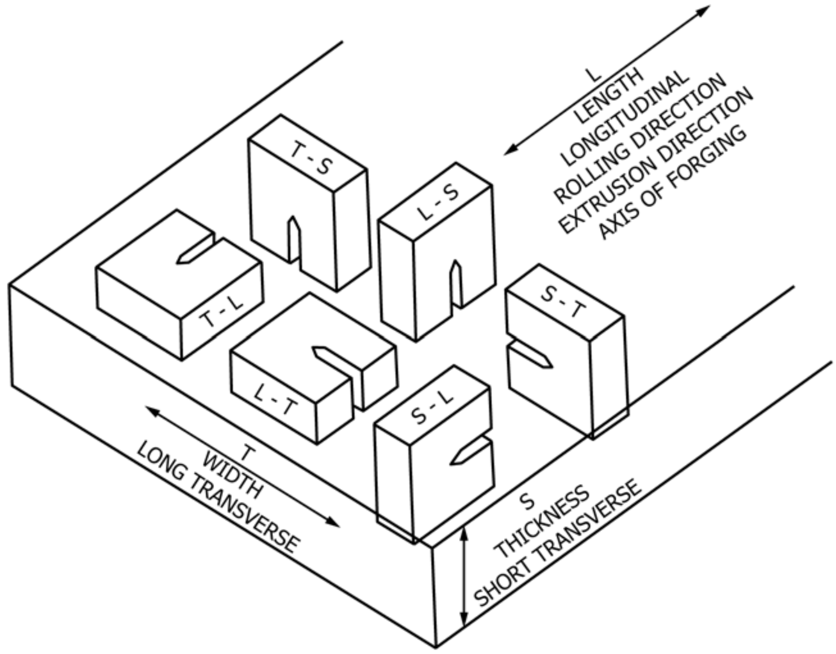
where *r* is the distance directly forward from the crack tip to the location where the significant stress is calculated.

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.

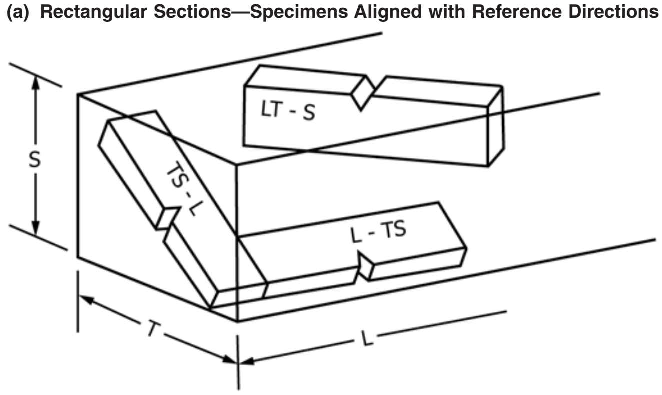
3.1.2.1 See also definitions of crack-extension resistance, crack-tip plane strain, and mode in Terminology E1823.

3.1.3 *crack mouth opening displacement (CMOD), V_m* [L]—crack opening displacement resulting from the total deformation (elastic plus plastic), measured under force at the location on a crack surface that has the largest displacement per unit force.

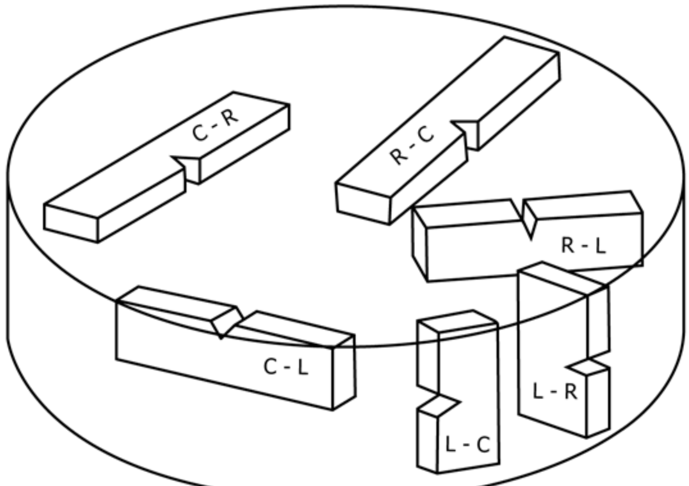
3.1.4 *crack plane orientation*—identification of the plane and direction of crack extension in relation to the characteristic directions of the product. A hyphenated code defined in Terminology E1823 is used wherein the letter(s) preceding the hyphen represents the direction normal to the crack plane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



(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