Designation: E 1737 – 96

Standard Test Method for *J*-Integral Characterization of Fracture Toughness[1]

This standard is issued under the fixed designation E 1737; 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.

1. Scope

1.1 This test method covers the determination of fracture toughness as characterized by the *J*-integral. Three toughness properties are identified which vary with the amount of crack extension present at test termination: (*a*) instability without significant prior crack extension (J_c); (*b*) onset of stable crack extension (J_{Ic}); (*c*) stable crack growth resistance curve (*J-R*).[2] A fourth quantity (J_u) not currently interpretable as a toughness property may be measured at fracture instability following stable crack extension. The method applies specifically to geometries that contain notches and flaws that are sharpened with fatigue cracks. The recommended specimens are generally bend-type specimens that contain deep initial cracks. The loading rate is slow and environmentally assisted cracking is assumed to be negligible.

1.1.1 The recommended specimens are the pin-loaded compact (C(T)), the single, edge bend (SE(B)), and the pin-loaded disk-shaped compact (DC(T)) specimen. All specimens have in-plane dimensions of constant proportionality for all sizes.

1.1.2 Specimen dimensions are functions of the ratio of *J*-integral to the material effective yield strength, thus the specimen design details must be based on known or estimates mechanical properties.

1.1.3 The objective of this test method is to set forth a method and to specify limitations for testing prescribed bend-type specimens that will result in *J*-integral fracture toughness values of materials that will be geometry insensitive.

1.1.4 The single specimen elastic compliance method is detailed herein, but other techniques for measuring crack length are permissible if they equal or exceed the accuracy requirements of this test method. For example, a dc electric potential method is described in Annex A5.

1.1.5 A multiple specimen technique for J_{Ic} measurement requiring five or more identically prepared specimens tested to different crack extensions and displacements is presented in Annex A4.

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

1.3 *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:*

E 4 Practices for Load Verification of Testing Machines[3]

E 399 Test Method for Plane-Strain Fracture Toughness of Metallic Materials[3]

E 616 Terminology Relating to Fracture Testing[3]

3. Terminology

3.1 Terminology E 616 is applicable to this test method.

3.2 *Definitions:*

3.2.1 *effective thickness* $B_e[L]$—for compliance-based crack extension measurements $B_e = B - (B - B_N)^2/B$.

3.2.2 *effective yield strength,* $\sigma_Y[FL^{-2}]$—an assumed value of uniaxial yield strength that represents the influence of plastic yielding upon fracture test parameters.

NOTE 1—σ is calculated as the average of the 0.2 % offset yield strength σ_{YS}, and the ultimate tensile strength σ_{TS}, for example:

$$\sigma_Y = \frac{\sigma_{YS} + \sigma_{TS}}{2}$$

NOTE 2—In estimating σ_Y, the influence of testing conditions, such as loading rate and temperature, should be considered.

3.2.3 *estimated crack extension,* $\Delta a[L]$—an increase in estimated crack size ($\Delta a = a - a_{oq}$).

3.2.4 *estimated crack size* $a[L]$—the distance from a reference plane to the observed crack front developed from measurements of elastic compliance or other methods. The reference plane depends on the specimen form, and it is normally taken to be either the boundary, or a plane containing either the load line or the centerline of a specimen or plate. The reference plane is defined prior to specimen deformation.

3.2.5 J_c, $J[FL^{-1}]$—a value of J (the crack extension resistance under conditions of crack-tip plane strain) at fracture instability prior to the onset of significant stable crack extension.

3.2.6 J_{Ic}, $J[FL^{-1}]$—a value of J (the crack extension resistance under conditions of crack tip plane strain) near the onset of stable crack extension as specified in this test method.

3.2.7 J_u, $J[FL^{-1}]$—a value of J measured at fracture instability after the onset of significant stable crack extension. It may be size dependent and a function of test specimen geometry.

3.2.8 *J-integral,* $J[FL^{-1}]$—a mathematical expression, a

[1] This test method is under the jurisdiction of ASTM Committee E-8 on Fatigue and Fracture and is the direct responsibility of Subcommittee E08.08 on Elastic-Plastic Fracture Mechanics Technology.

Current edition approved March 10, 1996. Published May 1996.

[2] Information on *R*-curve round-robin data is available from ASTM as a research report. Request RR: E24-1011.

[3] *Annual Book of ASTM Standards,* Vol 03.01.

line or surface integral over a path that encloses the crack front from one crack surface to the other, used to characterize the local stress-strain field around the crack front. See Terminology E 616 for further discussion.

3.2.9 *J-R curve*—a plot of resistance to stable crack extension, Δa or Δa_p.

DISCUSSION—In this test method, the *J-R* curve is a plot of the far-field *J*-integral versus physical crack extension (Δa_p) or estimated crack extension (Δa). It is recognized that the far-field value of *J* may not represent the stress-strain field local to a growing crack.

3.2.10 *net thickness, $B_N[L]$*—distance between the roots of the side grooves in side-grooved specimens.

3.2.11 *original crack size, $a_o[L]$*—the physical crack size at the start of testing.

NOTE 3—In this test method, a_{oq} is the initial crack length estimated by elastic compliance.

3.2.12 *original uncracked ligament, $b_o[L]$*—distance from the original crack front to the back edge of the specimen, that is:

$$b_o = W - a_o$$

3.2.13 *physical crack extension, $\Delta a_p[L]$*—an increase in physical crack size ($\Delta a_p = a_p - a_o$).

3.2.14 *physical crack size, $a_p[L]$*—the distance from a reference plane to the observed crack front. This distance may represent an average of several measurements along the crack front. The reference plane depends on the specimen form, and it is normally taken to be either the boundary, or a plane containing either the load line or the centerline of a specimen or plate. The reference plane is defined prior to specimen deformation.

3.2.15 *precrack load, $P_M[F]$*—the allowable precrack load.

3.2.16 *remaining ligament, $b[L]$*—distance from the physical crack front to the back edge of the specimen, that is:

$$b = W - a_p$$

3.2.17 *specimen span, $S[L]$*—distance between specimen supports for the SE(B) specimen.

3.2.18 *specimen thickness, $B[L]$*—the side to side dimension of the specimen being tested.

3.2.19 *specimen width, $W[L]$*—a physical dimension on a test specimen measured from a reference position such as the front edge in a bend specimen or the load line in the compact specimen to the back edge of the specimen.

4. Summary of Test Method

4.1 This test method involves three-point bend loading or pin loading of fatigue precracked specimens and determination of *J* as a function of crack growth. Load versus load-line displacement is recorded. The *J*-integral is determined and plotted against estimated or physical crack growth, Δa or Δa_p, within specified limits of crack growth. The resulting data reflect the material's resistance to crack growth.

4.2 For J_c determination, *J* is evaluated from a load-displacement record which is terminated by fracture instability prior to significant stable crack extension. The value of J_c determined by this test method represents a measure of fracture toughness at instability without significant stable crack extension that is independent of in-plane dimensions. However, there may be a dependence of toughness on thickness which is equivalent to length of crack front.

4.3 For J_{Ic} determination, the *J* versus crack growth behavior is approximated with a best fit power law relationship. A construction line is drawn, approximating crack tip stretch effects. The construction line is calculated from material flow properties or determined experimentally. Draw an offset line parallel to the construction line but offset by 0.2 mm. The intersection of this line and the power law fit defines J_{Ic}, provided the requirements of this test method are satisfied.

4.4 For *J-R* curve determination, this test method describes a single specimen technique. The *J-R* curve consists of a plot of *J* versus crack extension, in the region of *J*-controlled growth, and is size independent provided that the requirements of this test method are satisfied. For the procedure described in this test method, crack length and crack extension are determined from elastic compliance measurements. These measurements are taken on a series of unloading/reloading segments spaced along the load-versus-displacement record. Other methods such as dc electric potential can be used to estimate crack length and crack extension.

4.5 An alternative, multi-specimen technique can be used to obtain J_{Ic}. This technique requires five or more identically prepared specimens tested to different crack opening displacements. This technique uses optical measurements of crack extension on the fracture surfaces after the test.

4.6 Supplemental information about the background of this test method and the rationale for many of the technical requirements of this test method are contained in Ref **(1)**.[4]

5. Significance and Use

5.1 The *J*-integral values measured by this test method characterize the toughness of ductile materials that lack sufficient size and thickness to be tested for K_{Ic} in accordance with the requirements of Test Method E 399.

5.1.1 The *J*-integral values can be used as indexes of material toughness for alloy design, materials processing, materials selection and specification, and quality assurance.

5.1.2 The *J*-integral value for most structural metals is independent of testing speed in the quasi-static regime. The value becomes a function of testing speed in the dynamic regime. Cyclic loads or environmental attack under sustained stress, or both, can cause additional contributions to crack extension. Therefore, the application of *J*-integral values in design of service components should be made with full cognizance of service conditions.

5.1.3 *J*-integral values can be used to evaluate materials in terms that can be significant to design, and for evaluation of materials with flaws.

5.1.4 This test method is applicable for a wide range of ductile engineering materials. However, there are high ductility, high toughness materials for which this test method is not applicable. The prescribed procedure may result in unsatisfactory results when applied to materials with extremely high tearing resistance because crack growth due to physical tearing of the material may be virtually indistin-

[4] The boldface numbers in parentheses refer to the references at the end of this test method.

guishable from extensive crack tip blunting.

5.2 The *J-R* curve characterizes, within the limits set forth in this test method, the resistance of metallic materials to slow stable crack growth after initiation from a pre-existing fatigue crack.

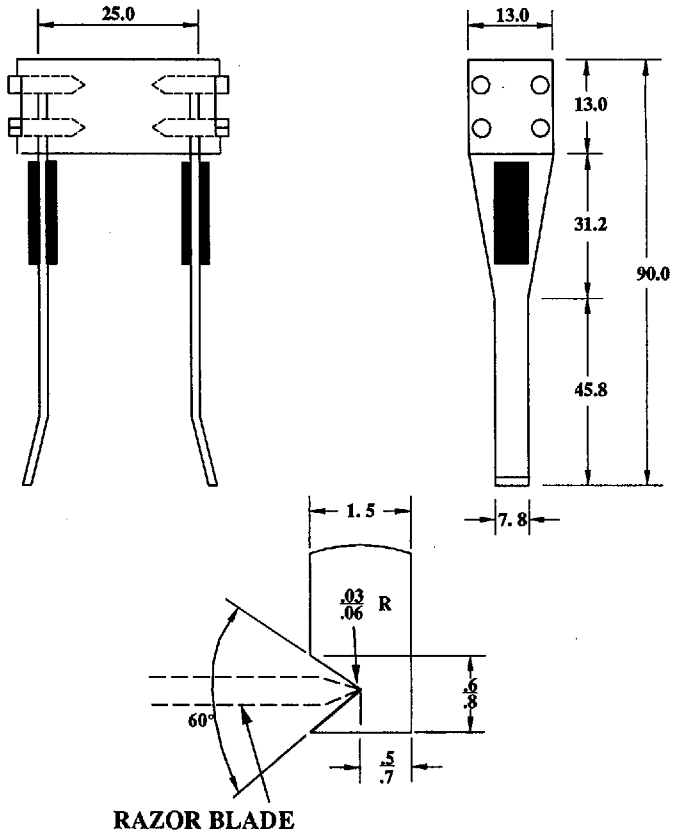
5.2.1 The *J-R* curve can be used to assess the significance of cracks in structural details in the presence of ductile tearing, with awareness of the difference that may exist between laboratory test and field conditions.

5.3 J_{Ic}, as determined by this test method, characterizes the toughness of materials near the onset of stable crack extension from a preexisting fatigue crack.

5.3.1 J_{Ic} and J_c values may be converted to their equivalents in terms of stress-intensity factor, K_I (**2**), if dominant elastic conditions for the application can be demonstrated. The K_I values from J_{Ic} correspond to the material toughness near the onset of stable crack extension in a dominant linear elastic stress field that contains a preexisting crack. The K_I values from J_c correspond to the material toughness near the onset of unstable crack extension in a dominant linear elastic stress field containing a preexisting crack. The J_{Ic} and J_c values according to this test method cannot be used to obtain K_{Ic} values according to Test Method E 399.

5.4 The value of J_c determined by this test method represents a measure of fracture toughness at instability without significant stable crack extension that is independent of in-plane dimensions. However, there may be a dependence of toughness on thickness, equivalent to a dependence on crack front length.

5.4.1 Values of J_c, may exhibit considerable variability and statistical techniques may be required in their interpretation and application.



NOTE—All dimensions are in millimetres.

FIG. 1 Clip Gage Design for a 8.0-mm (0.3-in.) and More Working Range

6. Apparatus

6.1 Measurements of applied load and load-line displacement are needed to determine the total energy absorbed by the specimen. Load versus load-line displacement may be recorded digitally for processing by computer or autographically with an *x-y* plotter.

6.2 Test fixtures for each specimen type are described in the applicable annex.

6.3 *Displacement Gage:*

6.3.1 Displacement measurements are needed for two purposes: to determine *J* from the measured area under the load-displacement record and, for the elastic compliance method, to estimate crack extension, Δa, from elastic compliance calculations.

6.3.2 In compact specimens, displacement measurements on the load line are recommended. As a guide, select a displacement gage that has a working range of not more than twice the displacement expected during the test. When the expected displacement is less than 3.75 mm (0.15 in.), the gage recommended in Test Method E 399 may be used. When a greater working range is needed, an enlarged gage such as the one shown in Fig. 1 is recommended. Accuracy shall be within ±1 % of the full working range. In calibration the maximum deviation of the individual data points from a fit to the data shall be less than ±1 %, or ±0.2 % of the working range of the gage when using the elastic compliance method. Knife edges are recommended for friction-free seating of the gage. Maintain parallel alignment of the knife edges within ±1°.

6.3.3 The single edge bend specimen may require two displacement gages. A load-line displacement measurement is required for *J* computation. A crack mouth opening displacement gage may be used to estimate crack size using the elastic compliance technique. The gage shall meet the requirements of 6.3.2. Accuracy of the load-line displacement gage shall be within ±1 % of the full working range. In calibration, the maximum deviation of the individual data points from a fit to the data shall be less than ±1 %, or ±0.2 % of the working range of the gage when using the gage for compliance measurements. Direct methods for load-line displacement measurement are described in Refs (**3—6**). If a remote transducer is used for load-line displacement measurement, care shall be taken to exclude the elastic displacement of the load train measurement and elastic and inelastic deformations at the load points (**7**).

6.3.4 For the elastic compliance method, the suggested minimum digital signal resolution for displacement should be one part in 32 000 of the transducer signal range (*V*), and signal stability should be four parts in 32 000 of the transducer signal range (*V*) measured over a 10-min period. Signal noise should be less than two parts in 32 000 of the transducer signal range (*V*).

6.3.5 If an autographic method with expanded scales is used for elastic compliance measurements, displacement signal sensitivity is required which produces approximately