Designation: E561 – 23

Standard Test Method for K_R Curve Determination[1]

This standard is issued under the fixed designation E561; 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 the resistance to fracture of metallic materials under Mode I loading at static rates using either of the following notched and precracked specimens: the middle-cracked tension M(T) specimen or the compact tension C(T) specimen. A K_R curve is a continuous record of toughness development (resistance to crack extension) in terms of K_R plotted against crack extension in the specimen as a crack is driven under an increasing stress intensity factor, K. (**1**)[2]

1.2 Materials that can be tested for K_R curve development are not limited by strength, thickness, or toughness, so long as specimens are of sufficient size to remain predominantly elastic to the effective crack extension value of interest.

1.3 Specimens of standard proportions are required, but size is variable, to be adjusted for yield strength and toughness of the materials.

1.4 Only two of the many possible specimen types that could be used to develop K_R curves are covered in this method.

1.5 The test is applicable to conditions where a material exhibits slow, stable crack extension under increasing crack driving force, which may exist in relatively tough materials under plane stress crack tip conditions.

1.6 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

1.7 *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.*

1.8 *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:*[3]

E4 Practices for Force Calibration and Verification of Testing Machines

E111 Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus

E399 Test Method for Linear-Elastic Plane-Strain Fracture Toughness of Metallic Materials

E1823 Terminology Relating to Fatigue and Fracture Testing

E3076 Practice for Determination of the Slope in the Linear Region of a Test Record

2.2 *Other Document:*

AISC Steel Construction Manual[4]

3. Terminology

3.1 *Definitions:*

3.1.1 Terminology E1823 is applicable to this method.

3.1.2 *effective modulus, E_{eff} [FL^{-2}]*—an elastic modulus that allows a theoretical (modulus normalized) compliance to match an experimentally measured compliance for an actual initial crack size a_o.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *apparent fracture toughness, K_{app} [$FL^{-3/2}$]*—The stress intensity factor, K, (under non-plane strain conditions of crack-tip stress) calculated using the initial crack size and the maximum force achieved during the test.

3.2.1.1 *Discussion*—K_{app} is an engineering estimate of toughness that can be used to calculate residual strength. K_{app} not only depends on the material, but also specimen type, size, and thickness and as such is not a material property

3.2.1.2 *Discussion*—K_{app} has been historically referred to as apparent plane-stress fracture toughness, however in practice it is used to describe apparent fracture toughness under non-plane

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

[3] 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.

[4] Available from American Institute of Steel Construction (AISC), One E. Wacker Dr., Suite 700, Chicago, IL 60601-1802, http://www.aisc.org.

***A Summary of Changes section appears at the end of this standard**

strain conditions, for example the transition region between plane-strain and plane-stress.

3.2.2 *applied-K curve—*a curve obtained from a fracture mechanics analysis for a specific structural (or specimen) configuration showing the relationship between crack size and stress-intensity factor with either a fixed force or a fixed displacement applied to the structure (or specimen).

3.2.2.1 *Discussion—*This is often plotted as a family of curves for different levels of fixed force or fixed displacement and superimposed on the K_R curve to predict stable crack extension and fracture instability for that configuration.

3.2.2.2 *Discussion—*This family of curves is often referred to as crack driving curves.

3.2.3 K_c *[FL$^{-3/2}$]—*The stress intensity factor, K_c, is measured as the value of K_R (the crack extension resistance under non-plane strain conditions of crack-tip stress) corresponding to the maximum force point in the test.

3.2.3.1 *Discussion—*K_c not only depends on the material, but also specimen type, size, and thickness, and as such is not a material property.

3.2.3.2 *Discussion—*K_c is the value of K_R at the tangency between the R-curve and the configuration-dependent applied-*K* curve.

3.2.3.3 *Discussion—*K_c has been historically referred to as plane-stress fracture toughness, however in practice it is used to describe fracture toughness under non-plane strain conditions, for example the transition region between plane-strain and plane-stress.

4. Summary of Test Method

4.1 During slow-stable fracturing, the developing crack extension resistance K_R is equal to the applied stress intensity factor *K*. The crack is driven forward by continuously or incrementally increasing force or displacement. Measurements are made periodically for determination of the effective crack size and for calculation of *K* values, which are individual data points that define the K_R curve for the material under those test conditions.

4.2 The crack starter is a low-stress-level fatigue crack.

4.3 The method covers two techniques for determination of effective crack size: *(1)* direct measurement of the physical crack size which is then adjusted for the developing plastic zone size, and *(2)* compliance measurement techniques that yield the effective crack size directly. Methods of measuring crack extension and of making plastic-zone corrections to the physical crack size are prescribed. Expressions for the calculation of crack-extension force K_R are given. Criteria for determining if the specimen conditions are predominantly elastic are provided.

5. Significance and Use

5.1 The K_R curve characterizes the resistance to fracture of materials during slow, stable crack extension and results from the growth of the plastic zone ahead of the crack as it extends from a fatigue precrack or sharp notch. It provides a record of the toughness development as a crack is driven stably under increasing applied stress intensity factor *K*. For a given material, K_R curves are dependent upon specimen thickness, temperature, and strain rate. The amount of valid K_R data generated in the test depends on the specimen type, size, method of loading, and, to a lesser extent, testing machine characteristics.

5.2 For an untested geometry, the K_R curve can be matched with the applied-K curves (crack driving curves) to estimate the degree of stable crack extension and the conditions necessary to cause unstable crack propagation (**2**). In making this estimate, K_R curves are regarded as being independent of initial crack size a_o and the specimen configuration in which they are developed. For a given material, material thickness, and test temperature, K_R curves appear to be a function of only the effective crack extension Δa_e (**3**).

5.2.1 To predict crack behavior and instability in a component, a family of applied-K curves is generated by calculating *K* as a function of crack size for the component using a series of force, displacement, or combined loading conditions. The K_R curve may be superimposed on the family of applied-K curves as shown in Fig. 1, with the origin of the K_R curve coinciding with the assumed initial crack size a_o. The intersection of the applied-K curves with the K_R curve shows the expected effective stable crack extension for each loading condition. The applied-K curve that develops tangency with the K_R curve defines the critical loading condition that will cause the onset of unstable fracture under the loading conditions used to develop the applied-K curves.

5.2.2 Conversely, the K_R curve can be shifted left or right in Fig. 1 to bring it into tangency with applied-K curve to determine the initial crack size that would cause crack instability under that loading condition.

5.3 If the *K*-gradient (slope of the applied-K curve) of the specimen chosen to develop the K_R curve has negative characteristics (see Note 1), as in a displacement-controlled test condition, it may be possible to drive the crack until a maximum or plateau toughness level is reached (**4, 5, 6**). When a specimen with positive *K*-gradient characteristics (see Note

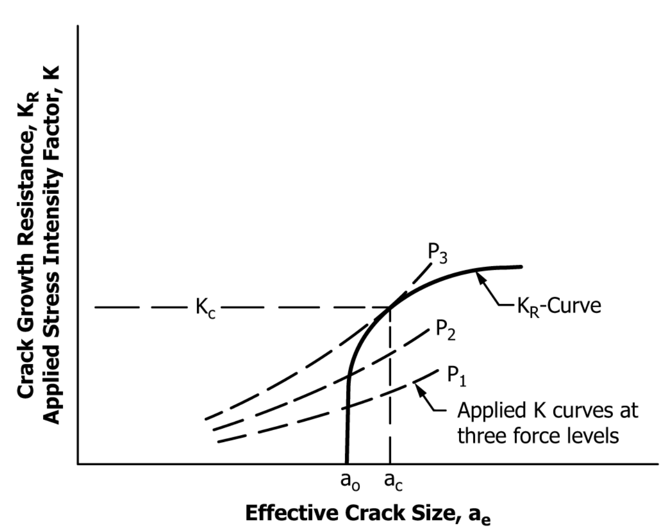

FIG. 1 Schematic Representation of K_R curve and Applied *K* Curves to Predict Instability; K_c, P_3, a_c, Corresponding to an Initial Crack Size, a_o