Designation: E647 – 23a

Standard Test Method for Measurement of Fatigue Crack Growth Rates[1]

This standard is issued under the fixed designation E647; 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[2] covers the determination of fatigue crack growth rates from near-threshold (see region I in Fig. 1) to K_{max} controlled instability (see region III in Fig. 1.) Results are expressed in terms of the crack-tip stress-intensity factor range (ΔK), defined by the theory of linear elasticity.

1.2 Several different test procedures are provided, the optimum test procedure being primarily dependent on the magnitude of the fatigue crack growth rate to be measured.

1.3 Materials that can be tested by this test method are not limited by thickness or by strength so long as specimens are of sufficient thickness to preclude buckling and of sufficient planar size to remain predominantly elastic during testing.

1.4 A range of specimen sizes with proportional planar dimensions is provided, but size is variable to be adjusted for yield strength and applied force. Specimen thickness may be varied independent of planar size.

1.5 The details of the various specimens and test configurations are shown in Annex A1 – Annex A3. Specimen configurations other than those contained in this method may be used provided that well-established stress-intensity factor calibrations are available and that specimens are of sufficient planar size to remain predominantly elastic during testing.

1.6 Residual stress as well as a variety of shielding effects such as crack closure may significantly influence the interpretation of fatigue crack growth rate data, particularly at low stress-intensity factors and low force ratios (**1, 2**).[3] None of these variables are incorporated into the classical computation of applied ΔK.

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

1.8 This test method is divided into two main parts. The first part gives general information concerning the recommendations and requirements for fatigue crack growth rate testing. The second part is composed of annexes that describe the special requirements for various specimen configurations, special requirements for testing in aqueous environments, and procedures for non-visual crack size determination. In addition, there are appendices that cover techniques for calculating da/dN, determining fatigue crack opening force, and guidelines for measuring the growth of small fatigue cracks. General information and requirements common to all specimen types are listed as follows:

1.9 Special requirements for the various specimen configurations appear in the following order:

1.10 *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.*

1.11 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the*

[1] This test method is under the jurisdiction of ASTM Committee E08 on Fatigue and Fracture and is the direct responsibility of Subcommittee E08.06 on Crack Growth Behavior.

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[2] For additional information on this test method see RR: E24 – 1001. Available from ASTM Headquarters, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

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

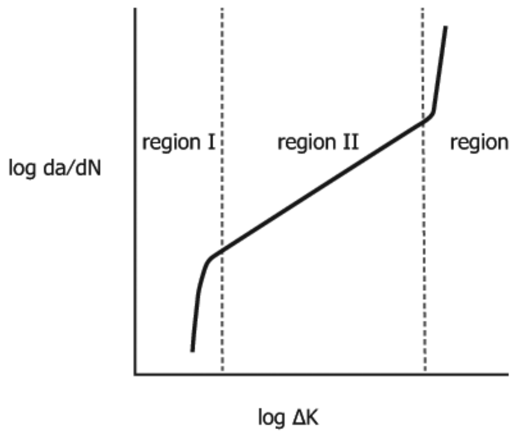

FIG. 1 Defined Regions of a Typical Fatigue Crack Growth Rate Curve

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]

E4 Practices for Force Calibration and Verification of Testing Machines

E6 Terminology Relating to Methods of Mechanical Testing

E8/E8M Test Methods for Tension Testing of Metallic Materials

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

E467 Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System

E561 Test Method for K_R Curve Determination

E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application

E1820 Test Method for Measurement of Fracture Toughness

E1823 Terminology Relating to Fatigue and Fracture Testing

3. Terminology

3.1 The terms used in this test method are given in Terminology E6, and Terminology E1823. Wherever these terms are not in agreement with one another, use the definitions given in Terminology E1823 which are applicable to this test method.

3.2 *Definitions:*

3.2.1 *crack extension, Δa* [L]—an increase in crack size.

3.2.2 *crack size, a*[L], *n*—a linear measure of a principal planar dimension of a crack. This measure is commonly used in the calculation of quantities descriptive of the stress and displacement fields and is often also termed crack length or depth.

3.2.2.1 *Discussion*—In fatigue testing, crack length is the physical crack size. See *physical crack size* in Terminology E1823.

3.2.3 *cycle—in fatigue,* under constant amplitude loading, the force variation from the minimum to the maximum and then to the minimum force.

3.2.3.1 *Discussion*—In spectrum loading, the definition of cycle varies with the counting method used.

3.2.3.2 *Discussion*—In this test method, the symbol N is used to represent the number of cycles.

3.2.4 *fatigue-crack-growth rate, da/dN,* [*L/cycle*]—the rate of crack extension under fatigue loading, expressed in terms of crack extension per cycle.

3.2.5 *fatigue cycle*—See *cycle*.

3.2.6 *force cycle*—See *cycle.*

3.2.7 *force range, ΔP* [F]—*in fatigue*, the algebraic difference between the maximum and minimum forces in a cycle expressed as:

$$\Delta P = P_{max} - P_{min} \tag{1}$$

3.2.8 *force ratio (also called stress ratio), R—in fatigue*, the algebraic ratio of the minimum to maximum force (stress) in a cycle, that is, $R = P_{min}/P_{max}$.

3.2.9 *maximum force, P_{max}* [F]—*in fatigue*, the highest algebraic value of applied force in a cycle. Tensile forces are considered positive and compressive forces negative.

3.2.10 *maximum stress-intensity factor, K_{max}* [$FL^{-3/2}$]—*in fatigue*, the maximum value of the stress-intensity factor in a cycle. This value corresponds to P_{max}.

3.2.11 *minimum force, P_{min}* [F]—*in fatigue*, the lowest algebraic value of applied force in a cycle. Tensile forces are considered positive and compressive forces negative.

3.2.12 *minimum stress-intensity factor, K_{min}* [$FL^{-3/2}$]*—in fatigue*, the minimum value of the stress-intensity factor in a cycle. This value corresponds to P_{min} when R > 0 and is taken to be zero when R ≤ 0.

3.2.13 *notch height, h* [L]—the distance between the parallel faces of the machined notch prior to specimen deformation.

3.2.14 *stress cycle*—See **cycle** in Terminology E1823.

3.2.15 *stress-intensity factor, K, K_1, K_2, K_3 [$FL^{-3/2}$]*—See Terminology E1823.

3.2.15.1 *Discussion*—In this test method, mode 1 is assumed and the subscript 1 is everywhere implied.

3.2.16 *stress-intensity factor range, ΔK [$FL^{-3/2}$]—in fatigue*, the variation in the stress-intensity factor in a cycle, that is

$$\Delta K = K_{max} - K_{min} \tag{2}$$

3.2.16.1 *Discussion*—The loading variables R, ΔK, and K_{max} are related in accordance with the following relationships:

$$\Delta K = (1 - R)K_{max} \text{ for } R \geq 0, \text{ and} \tag{3}$$

$$\Delta K = K_{max} \text{ for } R \leq 0.$$

[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.

3.2.16.2 *Discussion*—These operational stress-intensity factor definitions do not include local crack-tip effects; for example, crack closure, residual stress, and blunting.

3.2.16.3 *Discussion*—While the operational definition of ΔK states that ΔK does not change for a constant value of K_{max} when $R \leq 0$, increases in fatigue crack growth rates can be observed when R becomes more negative. Excluding the compressive forces in the calculation of ΔK does not influence the material's response since this response (da/dN) is independent of the operational definition of ΔK. For predicting crack-growth lives generated under various R conditions, the life prediction methodology must be consistent with the data reporting methodology.

3.2.16.4 *Discussion*—An alternative definition for the stress-intensity factor range, which utilizes the full range of R, is $\Delta K_{fr} = K_{max} - K_{min}$. (In this case, K_{min} is the minimum value of stress-intensity factor in a cycle, regardless of R.) If using this definition, in addition to the requirements of 10.1.13, the value of R for the test should also be tabulated. If comparing data developed under $R \leq 0$ conditions with data developed under $R > 0$ conditions, it may be beneficial to plot the da/dN data versus K_{max}.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *fatigue crack growth threshold, ΔK_{th}* $[FL^{-3/2}]$—that asymptotic value of ΔK at which da/dN approaches zero.

3.3.1.1 *Discussion*—For most materials an *operational*, though arbitrary, definition of ΔK_{th} is given as that ΔK which corresponds to a fatigue crack growth rate of 10^{-10} m/cycle.

3.3.1.2 *Discussion*—The procedure for determining this *operational ΔK_{th}* is given in 9.4.

3.3.1.3 *Discussion*—The intent of this definition is not to define a true threshold, but rather to provide a practical means of characterizing a material's fatigue crack growth resistance in the near-threshold regime. Caution is required in extending this concept to design (see 5.1.5).

3.3.2 *fatigue crack growth rate, da/dN or Δa/ΔN, [L]—in fatigue*, the rate of crack extension caused by fatigue loading and expressed in terms of average crack extension per cycle.

3.3.3 *normalized K-gradient, C = (1/K).* dK/da $[L^{-1}]$—the fractional rate of change of K with increasing crack size.

3.3.3.1 *Discussion*—When C is held constant the percentage change in K is constant for equal increments of crack size. The following identity is true for the normalized K-gradient in a constant force ratio test:

$$\frac{1}{K}\cdot\frac{dK}{da} = \frac{1}{K_{max}}\cdot\frac{dK_{max}}{da} = \frac{1}{K_{min}}\cdot\frac{dK_{min}}{da} = \frac{1}{\Delta K}\cdot\frac{d\Delta K}{da} \quad (4)$$

3.3.4 *K-decreasing test*—a test in which the value of C is nominally negative. In this test method K-decreasing tests are conducted by shedding force, either continuously or by a series of decremental steps, as the crack grows.

3.3.5 *K-increasing test*—a test in which the value of C is nominally positive. For the standard specimens in this method the constant-force-amplitude test will result in a K-increasing test where the C value increases but is always positive.

4. Summary of Test Method

4.1 This test method involves cyclic loading of notched specimens which have been acceptably precracked in fatigue. Crack size is measured, either visually or by an equivalent method, as a function of elapsed fatigue cycles and these data are subjected to numerical analysis to establish the rate of crack growth. Crack growth rates are expressed as a function of the stress-intensity factor range, ΔK, which is calculated from expressions based on linear elastic stress analysis.

5. Significance and Use

5.1 Fatigue crack growth rate expressed as a function of crack-tip stress-intensity factor range, da/dN versus ΔK, characterizes a material's resistance to stable crack extension under cyclic loading. Background information on the ration-ale for employing linear elastic fracture mechanics to analyze fatigue crack growth rate data is given in Refs **(3)** and **(4)**.

5.1.1 In innocuous (inert) environments fatigue crack growth rates are primarily a function of ΔK and force ratio, R, or K_{max} and R (Note 1). Temperature and aggressive environments can significantly affect da/dN versus ΔK, and in many cases accentuate R-effects and introduce effects of other loading variables such as cycle frequency and waveform. Attention needs to be given to the proper selection and control of these variables in research studies and in the generation of design data.

NOTE 1—ΔK, K_{max}, and R are not independent of each other. Specification of any two of these variables is sufficient to define the loading condition. It is customary to specify one of the stress-intensity parameters (ΔK or K_{max}) along with the force ratio, R.

5.1.2 Expressing da/dN as a function of ΔK provides results that are independent of planar geometry, thus enabling exchange and comparison of data obtained from a variety of specimen configurations and loading conditions. Moreover, this feature enables da/dN versus ΔK data to be utilized in the design and evaluation of engineering structures. The concept of similitude is assumed, which implies that cracks of differing lengths subjected to the same nominal ΔK will advance by equal increments of crack extension per cycle.

5.1.3 Fatigue crack growth rate data are not always geometry-independent in the strict sense since thickness effects sometimes occur. However, data on the influence of thickness on fatigue crack growth rate are mixed. Fatigue crack growth rates over a wide range of ΔK have been reported to either increase, decrease, or remain unaffected as specimen thickness is increased. Thickness effects can also interact with other variables such as environment and heat treatment. For example, materials may exhibit thickness effects over the terminal range of da/dN versus ΔK, which are associated with either nominal yielding (Note 2) or as K_{max} approaches the material fracture toughness. The potential influence of specimen thickness should be considered when generating data for research or design.

NOTE 2—This condition should be avoided in tests that conform to the specimen size requirements listed in the appropriate specimen annex.

5.1.4 Residual stresses can influence fatigue crack growth rates, the measurement of such growth rates and the predictability of fatigue crack growth performance. The effect can be