Designation: E647 – 15$^{\varepsilon 1}$

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.

ε^1 NOTE—Table X1.1 was editorially corrected in July 2016.

1. Scope

1.1 This test method[2] covers the determination of fatigue crack growth rates from near-threshold to K_{max} controlled instability. 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/crack closure may significantly influence the fatigue crack growth rate data, particularly at low stress-intensity factors and low stress ratios, although such variables are not incorporated into the computation of 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:

	Section
Referenced Documents	2
Terminology	3
Summary of Use	4
Significance and Use	5
Apparatus	6
Specimen Configuration, Size, and Preparation	7
Procedure	8
Calculations and Interpretation of Results	9
Report	10
Precision and Bias	11
Special Requirements for Testing in Aqueous Environments	Annex A4
Guidelines for Use of Compliance to Determine Crack Size	Annex A5
Guidelines for Electric Potential Difference Determination of Crack Size	Annex A6
Recommended Data Reduction Techniques	Appendix X1
Recommended Practice for Determination of Fatigue Crack Opening Force From Compliance	Appendix X2
Guidelines for Measuring the Growth Rates Of Small Fatigue Cracks	Appendix X3
Recommended Practice for Determination Of ACR-Based Stress-Intensity Factor Range	Appendix X4

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

The Compact Specimen	Annex A1
The Middle Tension Specimen	Annex A2
The Eccentrically-Loaded Single Edge Crack Tension Specimen	Annex A3

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

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[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.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

E4 Practices for Force Verification of Testing Machines

E6 Terminology Relating to Methods of Mechanical Testing

E8/E8M Test Methods for Tension Testing of Metallic Materials

E338 Test Method of Sharp-Notch Tension Testing of High-Strength Sheet Materials (Withdrawn 2010)[4]

E399 Test Method for Linear-Elastic Plane-Strain Fracture Toughness K_{Ic} 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 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.

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

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

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

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

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

3.2.4 *fatigue cycle*—See *cycle.*

3.2.5 *force cycle*—See *cycle.*

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

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

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

3.2.8 *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.

3.2.9 *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 $P_{\max}$.

3.2.10 *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.

3.2.11 *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 $R \leq 0$.

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

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

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

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

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

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

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

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

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

3.2.14.3 *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.

3.2.14.4 *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 *applied-K curve*—a curve (a fixed-force or fixed-displacement crack-extension-force curve) obtained from a

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[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] The last approved version of this historical standard is referenced on www.astm.org.

fracture mechanics analysis for a specific specimen configuration. The curve relates the stress-intensity factor to crack size and either applied force or displacement.

3.3.1.1 *Discussion*—The resulting analytical expression is sometimes called a K calibration and is frequently available in handbooks for stress-intensity factors.

3.3.2 *fatigue crack growth threshold, ΔK_{th}* [$FL^{-3/2}$]—that asymptotic value of ΔK at which da/dN approaches zero. 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. The procedure for determining this *operational ΔK_{th}* is given in 9.4.

3.3.2.1 *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).

3.3.3 *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.

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

3.3.4.1 *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:

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

3.3.5 *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.

3.3.6 *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, d a/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 (**1**)[5] and (**2**).

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 d a/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 significant when test specimens are removed from materials that embody residual stress fields; for example weldments or complex shape forged, extruded, cast or machined thick sections, where full stress relief is not possible, or worked parts having complex shape forged, extruded, cast or machined thick sections where full stress relief is not possible or worked parts having intentionally-induced residual stresses. Specimens taken from such products that contain residual stresses will likewise themselves contain residual stress. While extraction of the specimen and introduction of the crack starting slot in itself partially relieves and redistributes the pattern of residual stress, the remaining magnitude can still cause significant error in the ensuing test result. Residual stress is superimposed on the applied cyclic stress and results in actual crack-tip maximum and minimum stress-intensities that are different from those based solely on externally applied cyclic forces or displacements. For example, crack-clamping resulting from far-field

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

3D residual stresses may lead to partly compressive stress cycles, and exacerbate the crack closure effect, even when the specimen nominal applied stress range is wholly tensile. Machining distortion during specimen preparation, specimen location and configuration dependence, irregular crack growth during fatigue precracking (for example, unexpected slow or fast crack growth rate, excessive crack-front curvature or crack path deviation), and dramatic relaxation in crack closing forces (associated with specimen stress relief as the crack extends) will often indicate influential residual stress impact on the measured da/dN versus ΔK result. (**3**,**4**) Noticeable crack-mouth-opening displacement at zero applied force is indicative of residual stresses that can affect the subsequent fatigue crack growth property measurement.

5.1.5 The growth rate of small fatigue cracks can differ noticeably from that of long cracks at given ΔK values. Use of long crack data to analyze small crack growth often results in non-conservative life estimates. The small crack effect may be accentuated by environmental factors. Cracks are defined as being small when 1) their length is small compared to relevant microstructural dimension (a continuum mechanics limitation), 2) their length is small compared to the scale of local plasticity (a linear elastic fracture mechanics limitation), and 3) they are merely physically small (<1 mm). Near-threshold data established according to this method should be considered as representing the materials' steady-state fatigue crack growth rate response emanating from a long crack, one that is of sufficient length such that transition from the initiation to propagation stage of fatigue is complete. Steady-state near-threshold data, when applied to service loading histories, may result in non-conservative lifetime estimates, particularly for small cracks (**5-7**).

5.1.6 Crack closure can have a dominant influence on fatigue crack growth rate behavior, particularly in the near-threshold regime at low stress ratios. This implies that the conditions in the wake of the crack and prior loading history can have a bearing on the current propagation rates. The understanding of the role of the closure process is essential to such phenomena as the behavior of small cracks and the transient crack growth rate behavior during variable amplitude loading. Closure provides a mechanism whereby the cyclic stress intensity near the crack tip, ΔK_{eff}, differs from the nominally applied values, ΔK. This concept is of importance to the fracture mechanics interpretation of fatigue crack growth rate data since it implies a non-unique growth rate dependence in terms of ΔK, and R (**8**).[6]

NOTE 3—The characterization of small crack behavior may be more closely approximated in the near-threshold regime by testing at a high stress ratio where the anomalies due to crack closure are minimized.

5.2 This test method can serve the following purposes:

5.2.1 To establish the influence of fatigue crack growth on the life of components subjected to cyclic loading, provided data are generated under representative conditions and combined with appropriate fracture toughness data (for example, see Test Method E399), defect characterization data, and stress analysis information (**9**, **10**).

NOTE 4—Fatigue crack growth can be significantly influenced by load history. During variable amplitude loading, crack growth rates can be either enhanced or retarded (relative to steady-state, constant-amplitude growth rates at a given ΔK) depending on the specific loading sequence. This complicating factor needs to be considered in using constant-amplitude growth rate data to analyze variable amplitude fatigue problems (**11**).

5.2.2 To establish material selection criteria and inspection requirements for damage tolerant applications.

5.2.3 To establish, in quantitative terms, the individual and combined effects of metallurgical, fabrication, environmental, and loading variables on fatigue crack growth.

6. Apparatus

6.1 *Grips and Fixtures*—Grips and fixturing required for the specimens outlined in this method are described in the appropriate specimen annex.

6.2 *Alignment of Grips*—It is important that attention be given to achieving good alignment in the force train through careful machining of all gripping fixtures. Misalignment can cause non-symmetric cracking, particularly for critical applications such as near-threshold testing, which in turn may lead to invalid data (see Sec. 8.3.4, 8.8.3). If non-symmetric cracking occurs, the use of a strain-gaged specimen to identify and minimize misalignment might prove useful. One method to identify bending under tensile loading conditions is described in Practice E1012. Another method which specifically addresses measurement of bending in pin-loaded specimen configurations is described in Ref (**12**). For tension-compression loading the length of the force train (including the hydraulic actuator) should be minimized, and rigid, non-rotating joints should be employed to reduce lateral motion in the force train.

NOTE 5—If compliance methods are used employing displacement gages similar to those described in Test Methods E399, E1820, or E561, knife edges can be integrally machined or rigidly affixed to the test sample (either fastened, bonded, or welded) and must be geometrically compatible with the displacement device such that line contact is maintained throughout the test.

7. Specimen Configuration, Size, and Preparation

7.1 *Standard Specimens*—Details of the test specimens outlined in this method are furnished as separate annexes to this method. Notch and precracking details for the specimens are given in Fig. 1.

7.1.1 For specimens removed from material for which complete stress relief is impractical (see 5.1.4), the effect of residual stresses on the crack propagation behavior can be minimized through the careful selection of specimen shape and size. By selecting a small ratio of specimen dimensions, B/W the effect of a through-the-thickness distribution of residual stresses acting perpendicular to the direction of crack growth can be reduced. This choice of specimen shape minimizes crack curvature or other crack front irregularities which confuse the calculation of both da/dN and ΔK. In addition, residual stresses acting parallel to the direction of crack growth can often produce clamping or opening moments about the crack-tip, which can also confound test results. This is particularly

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[6] Subcommittee E08.06 has initiated a study group activity on crack closure measurement and analysis. Reference (**8**) provides basic information on this subject.

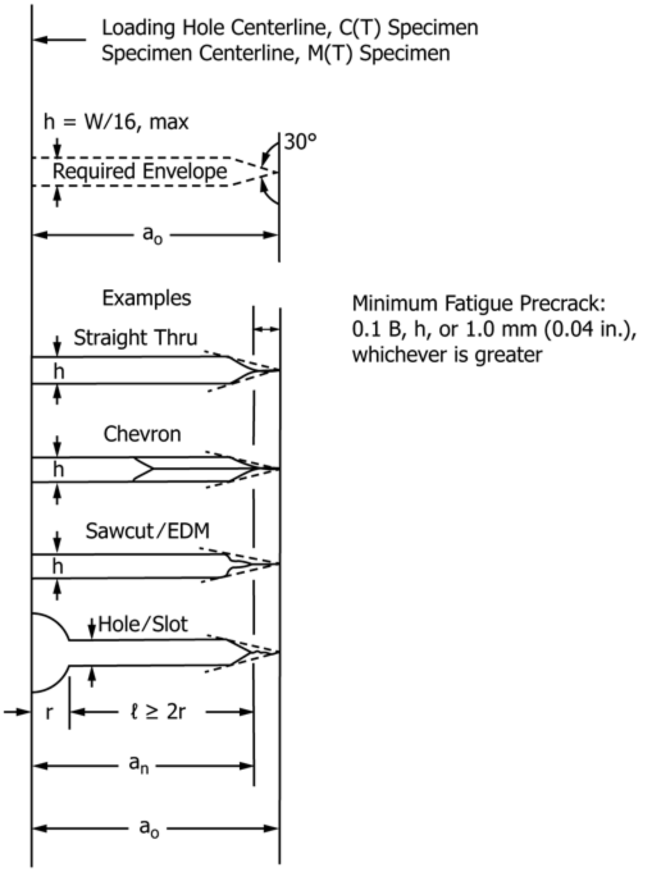

FIG. 1 Notch Details and Minimum Fatigue Precracking Requirements

true for deep edge-notched specimens such as the C(T), which can display significant crack-mouth movement during machining of the crack starter notch. In these instances it is useful to augment both specimen preparation and subsequent testing with displacement measurements as has been recommended for fracture toughness determination in non-stress-relieved products. (**13**) In most, but not all, of these cases, the impact of residual-stress-induced clamping on crack growth property measurement can be minimized by selecting a symmetrical specimen configuration, that is, the M(T) specimen. Alternately, there can be situations where the specimen is too constrained to result in measurable post-machining movement after sharp-notch introduction. If this is so, and the crack is small enough to be wholly embedded in a field of tension or compression, then the cyclic stress ratio operating at the crack-tip will be different from that calculated from the applied cyclic loads. At this time the only recourse is to test an alternate specimen configuration or sample location to check for uniqueness of the da/dN-ΔK relationship as a means to determine if residual stress is significantly biasing the measured result.

7.2 *Specimen Size*—In order for results to be valid according to this test method it is required that the specimen be predominantly elastic at all values of applied force. The minimum in-plane specimen sizes to meet this requirement are based primarily on empirical results and are specific to the specimen configuration as furnished in the appropriate specimen annex (**10**).

NOTE 6—The size requirements described in the various specimen annexes are appropriate for low-strain hardening materials ($\sigma_{ULT}/\sigma_{YS} \leq 1.3$) (**14**) and for high-strain hardening materials ($\sigma_{ULT}/\sigma_{YS} \geq 1.3$) under certain conditions of force ratio and temperature (**15, 16**) (where σ_{ULT} is the ultimate tensile strength of the material). However, under other conditions of force ratio and temperature, the requirements listed in the annexes appear to be overly restrictive-that is, they require specimen sizes which are larger than necessary (**17,18**). Currently, the conditions giving rise to each of these two regimes of behavior are not clearly defined.

7.2.1 An alternative size requirement may be employed for high-strain hardening materials as follows. The uncracked ligament requirement listed for the specific specimen geometry may be relaxed by replacing σ_{YS} with a higher, effective yield strength which accounts for the material strain hardening capacity. For purposes of this test method, this *effective* yield strength, termed flow strength, is defined as follows:

$$\sigma_{FS} = (\sigma_{YS} + \sigma_{ULT})/2 \tag{5}$$

However, it should be noted that the use of this alternative size requirement allows mean plastic deflections to occur in the specimen. These mean deflections under certain conditions, as noted previously, can accelerate growth rates by as much as a factor of two. Although these data will generally add conservatism to design or structural reliability computations, they can also confound the effects of primary variables such as specimen thickness (if B/W is maintained constant), force ratio, and possibly environmental effects. Thus, when the alternative size requirement is utilized, it is important to clearly distinguish between data that meet the yield strength or flow strength criteria. In this way, data will be generated that can be used to formulate a specimen size requirement of general utility.

7.3 *Notch Preparation*—The machined notch for standard specimens may be made by electrical-discharge machining (EDM), milling, broaching, or sawcutting. The following notch preparation procedures are suggested to facilitate fatigue precracking in various materials:

7.3.1 *Electric Discharge Machining*—$\rho < 0.25$ mm (0.010 in.) (ρ = notch root radius), high-strength steels ($\sigma_{YS} \geq 1175$ MPa/170 ksi), titanium and aluminum alloys.

7.3.2 *Mill or Broach*—$\rho \leq 0.075$ mm (0.003 in.), low or medium-strength steels ($\sigma_{YS} \leq 1175$ MPa/170 ksi), aluminum alloys.

7.3.3 *Grind*—$\rho \leq 0.25$ mm (0.010 in.), low or medium-strength steels.

7.3.4 *Mill or Broach*—$\rho \leq 0.25$ mm (0.010 in.), aluminum alloys.

7.3.5 *Sawcut*—Recommended only for aluminum alloys.

7.3.6 Examples of various machined-notch geometries and associated precracking requirements are given in Fig. 1 (see 8.3).

7.3.7 When residual stresses are suspected of being present (see 5.1.4), local displacement measurements made before and after machining the crack starter notch are useful for detecting the potential magnitude of the effect. A simple mechanical displacement gage can be used to measure distance between two hardness indentations at the mouth of the notch (**3, 13**). Limited data obtained during preparation of aluminum alloy C(T) specimens with the specimen width, W, ranging from 50-100 mm (2-4 in.) has shown that fatigue crack growth rates can be impacted significantly when these mechanical displacement measurements change by more than 0.05 mm (0.002 in.).(**4**)

8. Procedure

8.1 *Number of Tests*—At crack growth rates greater than 10^{-8} m/cycle, the within-lot variability (neighboring specimens) of da/dN at a given ΔK typically can cover about a factor of two (**19**). At rates below 10^{-8} m/cycle, the variability in da/dN may increase to about a factor of five or more due to increased sensitivity of da/dN to small variations in ΔK. This scatter may be increased further by variables such as microstructural differences, residual stresses, changes in crack tip geometry (crack branching) or near tip stresses as influenced for example by crack roughness or product wedging, force precision, environmental control, and data processing techniques. These variables can take on added significance in the low crack growth rate regime ($da/dN < 10^{-8}$ m/cycle). In view of the operational definition of the threshold stress-intensity (see 3.3.2 and 9.4), at or near threshold it is more meaningful to express variability in terms of $\Delta\ K$ rather than da/dN. It is good practice to conduct replicate tests; when this is impractical, multiple tests should be planned such that regions of overlapping da/dN versus ΔK data are obtained, particularly under both K-increasing and K-decreasing conditions. Since confidence in inferences drawn from the data increases with number of tests, the desired number of tests will depend on the end use of the data.

8.2 *Specimen Measurements*—The specimen dimensions shall be within the tolerances given in the appropriate specimen annex.

8.3 *Fatigue Precracking*—The importance of precracking is to provide a sharpened fatigue crack of adequate size and straightness (also symmetry for the M(T) specimen) which ensures that *1*) the effect of the machined starter notch is removed from the specimen K-calibration, and *2*) the effects on subsequent crack growth rate data caused by changing crack front shape or precrack load history are eliminated.

8.3.1 Conduct fatigue precracking with the specimen fully heat treated to the condition in which it is to be tested. The precracking equipment shall be such that the force distribution is symmetrical with respect to the machined notch and K_{max}. during precracking is controlled to within ±5 %. Any convenient loading frequency that enables the required force accuracy to be achieved can be used for precracking. The machined notch plus the precrack must lie within the envelope, shown in Fig. 1, that has as its apex the end of the fatigue precrack. In addition the fatigue precrack shall not be less than $0.10B$, h, or 1.0 mm (0.040 in.), whichever is greater Fig. 1

8.3.2 The final K_{max} during precracking shall not exceed the initial K_{max} for which test data are to be obtained. If necessary, forces corresponding to higher K_{max} values may be used to initiate cracking at the machined notch. In this event, the force range shall be stepped-down to meet the above requirement. Furthermore, it is suggested that reduction in P_{max} for any of these steps be no greater than 20 % and that measurable crack extension occur before proceeding to the next step. To avert transient effects in the test data, apply the force range in each step over a crack size increment of at least $(3/\pi)\ (K'_{max}/\sigma_{YS})^2$, where K'_{max} is the terminal value of K_{max} from the previous forcestep. If P_{min}/P_{max} during precracking differs from that used during testing, see the precautions described in 8.5.1.

8.3.3 For the K-decreasing test procedure, prior loading history may influence near-threshold growth rates despite the precautions of 8.3.2. It is good practice to initiate fatigue cracks at the lowest stress intensity possible. Precracking growth rates less than 10^{-8} m/cycle are suggested. A compressive force, less than or equal to the precracking force, may facilitate fatigue precracking and may diminish the influence of the K-decreasing test procedure on subsequent fatigue crack growth rate behavior.

8.3.4 Measure the crack sizes on the front and back surfaces of the specimen to within 0.10 mm (0.004 in.) or $0.002W$, whichever is greater. For specimens where $W > 127$ mm (5 in.), measure crack size to within 0.25 mm (0.01 in.). If crack sizes measured on front and back surfaces differ by more than $0.25B$, the pre-cracking operation is not suitable and subsequent testing would be invalid under this test method. In addition for the M(T) specimen, measurements referenced from the specimen centerline to the two cracks (for each crack use the average of measurements on front and back surfaces) shall not differ by more than $0.025W$. If the fatigue crack departs more than the allowable limit from the plane of symmetry (see 8.8.3) the specimen is not suitable for subsequent testing. If the above requirements cannot be satisfied, check for potential problems in alignment of the loading system and details of the machined notch, or material-related problems such as residual stresses.

8.4 *Test Equipment*—The equipment for fatigue testing shall be such that the force distribution is symmetrical to the specimen notch.

8.4.1 Verify the force cell in the test machine in accordance with Practices E4 and E467. Conduct testing such that both ΔP and P_{max} are controlled to within ±2 % of the targeted values throughout the test.

8.4.2 An accurate digital device is required for counting elapsed cycles. A timer is a desirable supplement to the counter and provides a check on the counter. Multiplication factors (for example, ×10 or ×100) should not be used on counting devices when obtaining data at growth rates above 10^{-5} m/cycle since they can introduce significant errors in the growth rate determination.

8.5 *Constant-Force-Amplitude Test Procedure for $da/dN > 10^{-8}$ m/cycle*—This test procedure is well suited for fatigue crack growth rates above 10^{-8} m/cycle. However, it becomes increasingly difficult to use as growth rates decrease below 10^{-8} m/cycle because of precracking considerations (see 8.3.3). (A K-decreasing test procedure which is better suited for rates below 10^{-8} m/cycle is provided in 8.6.) When using the constant-force-amplitude procedure it is preferred that each specimen be tested at a constant force range (ΔP) and a fixed set of loading variables (stress ratio and frequency). However, this may not be feasible when it is necessary to generate a wide range of information with a limited number of specimens. When loading variables are changed during a test, potential problems arise from several types of transient phenomenon (**20**). The following test procedures should be followed to