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Standard Practice for Determination of a Fracture Toughness of Steels Using Equivalent Energy Methodology[1]

This standard is issued under the fixed designation E 992; 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.

$^{\epsilon 1}$ NOTE—Editorial changes were made throughout in March 1989.

1. Scope

1.1 This practice covers the determination of the fracture toughness (*K-EE*) of a steel by testing fatigue-cracked bend or compact specimens and interpreting the load displacement curves according to equivalent energy methodology.

1.2 The practice is limited to the analyses of test results from the standard bend and compact specimens of Test Method E 399, with exception noted in 7.2 (see Figs. 1 and 2). Size may be a variable.

1.3 Values stated in inch-pound units are to be regarded as the standard. SI units are provided for information only.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems 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:*

A 533/A 533M Specification for Pressure Vessel Plates, Alloy Steel, Quenched and Tempered, Manganese-Molybdenum and Manganese-Molybdenum-Nickel[2]

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

E 6 Terminology Relating to Methods of Mechanical Testing[3]

E 8 Test Methods of Tension Testing of Metallic Materials[3]

E 83 Practice for Verification and Classification of Extensometers[3]

E 337 Test Method for Measuring Humidity with a Psychrometer (The Measurement of Wet- and Dry-Bulb Temperatures)[4]

E 338 Method of Sharp-Notch Tension Testing of High-Strength Sheet Materials[3]

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

E 561 Practice for *R*-Curve Determination[3]

E 616 Terminology Relating to Fracture Testing[3]

E 813 Test Method for J_{Ic}, a Measure of Fracture Toughness[3]

3. Terminology

3.1 Terminology E 616 is applicable to this practice.

3.2 *Definition:*

3.2.1 *fracture toughness*—a generic term for measures of resistance to extension of a crack.

3.3 *Description of Term Specific to This Standard:*

3.3.1 *equivalent energy fracture toughness, K-EE* ($FL^{-3/2}$)—the crack extension resistance determined by the procedure specified in this practice.

Discussion—The thickness, (*B*), of the standard specimen from which the result is obtained should be identified in quoting the result. For specimens thicker than the standard specimens (see 7.2), both *B* and *W* should be specified. See specimen designation code in Terminology E 616.

4. Summary of Practice

4.1 This practice involves tension or three-point bend testing of notched specimens that have been precracked in fatigue in accordance with Test Method E 399. Load versus displacement is measured autographically to maximum load by means of a displacement gage which spans the notch. The calculated value, designated *K-EE*, is determined from the load-displacement curve using the area to maximum load with exceptions noted in Section 9. Nonlinearity in the load-displacement curve to maximum load may occur indicating significant amounts of plasticity or stable ductile tearing, or both. However, there is no guarantee that crack initiation has occurred at maximum load.

4.2 Background application information concerning the basis for the development of this practice is given in Refs **(1)** through **(10)**.[5]

5. Significance and Use

5.1 This practice provides reduction of data from tests run in accordance with Test Method E 399 that fail to meet the validity criteria of that standard; but will, nonetheless, produce a fracture toughness measurement, *K-EE*. If the data satisfy the validity criteria of Test Method E 399, they can and should be used to calculate values of K_{Ic}.

5.2 The *K-EE* measurement provides an economical and

[1] This practice is under the jurisdiction of ASTM Committee E-24 on Fracture Testing and is the direct responsibility of Subcommittee E24.03 on Alternative Fracture Test Methods.

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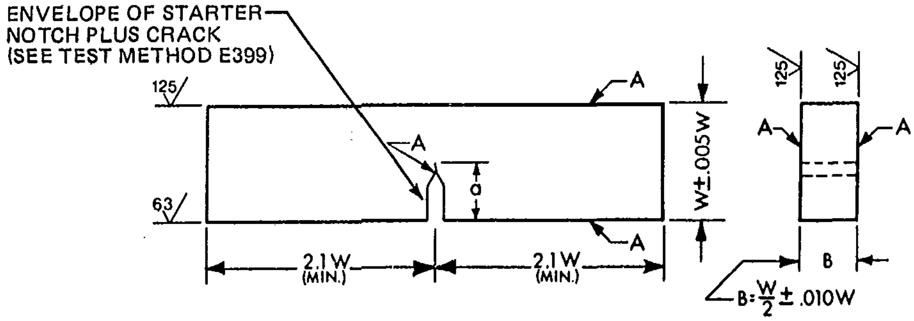
[2] *Annual Book of ASTM Standards*, Vol 01.04.

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

[4] *Annual Book of ASTM Standards*, Vol 11.03.

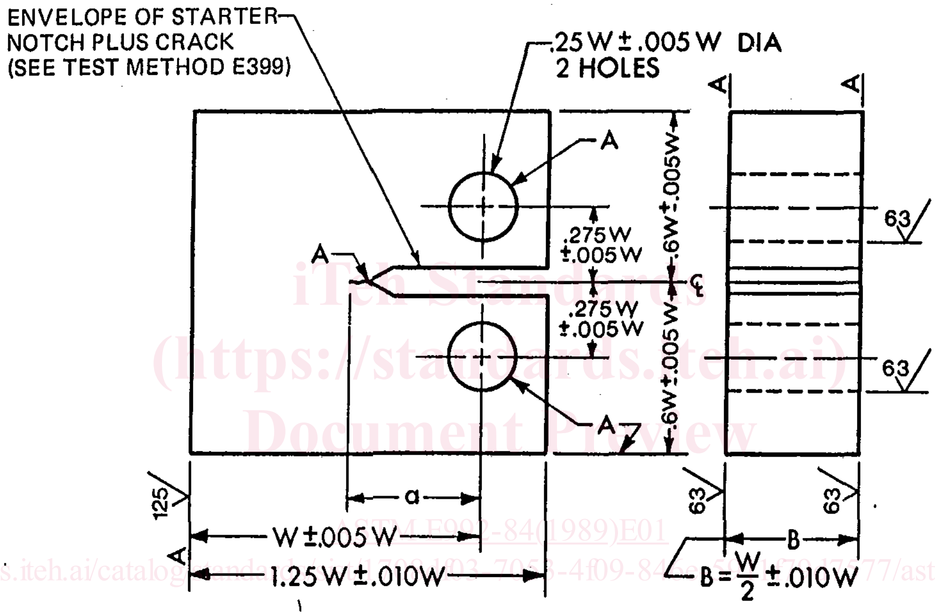
[5] The boldface numbers in parentheses refer to the references at the end of this practice.



NOTE 1—A surface shall be perpendicular and parallel as applicable within 0.001 *W*TIR

NOTE 2—Crack starter notch shall be perpendicular to specimen surfaces to within ±2°.

FIG. 1 Bend Specimen—Standard Proportions and Tolerances



NOTE 1—A surface shall be perpendicular and parallel as applicable within 0.002 *W*TIR.

NOTE 2—The intersection of the crack starter notch tips with the two specimen surfaces shall be equally distant from the top and bottom edges of the specimen within 0.005 *W*.

FIG. 2 Compact Specimen—Standard Proportions and Tolerances

simple method of determining fracture toughness values from specimens that are relatively small. This practice is applicable to assessing toughness in a limited region or to materials of limited thickness and availability (for example: welds, heat-affected zones, and nozzle-corner materials).

5.3 The a/W restriction as defined in Test Method E 399 is relaxed and is more in keeping with Practice E 561. Tables are provided in this practice for $0.45 \leq a/W \leq 0.75$.

5.4 There is no restriction on specimen size in this practice; however, since the maximum measuring capacity is size dependent, some knowledge of this dependence and the magnitude of acceptable toughness is desirable. Guidance in this area based on experience is provided in Section 7.

6. Apparatus

6.1 This practice involves testing of notched specimens that have been precracked in fatigue. Load versus displacement across the notch is recorded autographically. Testing may be done in various machines having load-sensing devices meeting requirements of Practices E 4. Use the grips and fixtures as described in Test Method E 399.

6.2 *Displacement Gage*—The displacement gage output must indicate accurately the relative displacement of two precisely located gage positions spanning the crack notch. In testing small specimens the gage recommended in Test Method E 399 may have a sufficient linear working range; however, in testing larger specimens, displacements may be of such magnitude that gages with greater working ranges may be needed; in this case Practice E 561 applies. However, an accuracy of 1 % of the value over the working range of the gage is recommended.

7. Specimen Configuration, Dimensions, and Preparation

7.1 *Specimen Size*—There is no specimen size limitation in this practice. However, in the very tough regime, small specimens may produce values considerably less than *K-EE* obtained from larger specimens. For less tough materials, the *K-EE* values may be less size dependent. Guidance as to maximum anticipated results as a function of specimen size is given in Table 1 which is based on estimates of related Charpy impact upper shelf energy (**11**).

7.2 *Specimen*—This practice is limited to the standard bend and compact specimens of Test Method E 399 (see Figs. 1 and 2) with the exception that the relative thickness of the specimens may be greater than those specified in Test Method E 399. A crack length, (a), nominally equal to no less than half the specimen width, (W), is recommended (that is, $a/W > 0.50$, see Figs. 1 and 2); however, values of a/W up to 0.75 are acceptable. The crack starter, fatigue precracking, and instrumentation procedures of Test Method E 399 apply.

8. Procedure

8.1 Follow appropriate section of Test Method E 399. In setting up the displacement coordinate of the autographic plots, make sufficient allowance for measuring loads and displacements for extensive plasticity and ductile tearing, or both. Stopping the test and rescaling the coordinates are acceptable practices but may be inconvenient for analysis. For many materials one method for selecting the displacement per inch (25 mm) of pen travel is to divide the thickness by 100, for example, a compact specimen having a width of 4 in. (102 mm) [B = 2.0 in. (51 mm)], select 0.02 in./in. (0.5 mm/mm) of pen travel; for width of 1 in. (25 mm) [B = 0.5 in. (13 mm)], select 0.005 in./in. (0.13 mm/mm) of travel [0.010 in./in. (0.25 mm/mm) also is adequate].

8.2 Continue the test to well past maximum load whenever fracture instability does not occur to ensure that the maximum load can be identified.

8.3 Unloading compliance procedures are compatible with this practice (see Practice E 561 and Test Method E 813).

TABLE 1 Estimated Maximum of *K-EE* Values as a Function of Specimen Size Based on Charpy Impact Upper Shelf Energy

Thickness of Standard Specimen B, in. (mm)	Charpy Impact Upper Shelf Energy ft·lbf (J)		
	50 (69)	100 (136)	150 (204)
	K-EE Values,[A] ksi $\sqrt{in.}$ (MPa $\sqrt{m}$)		
½ (13)	175 (190)	225 (250)	250 (275)
1 (25)	175 (190)	250 (275)	300 (330)
2 (50)	200 (220)	275 (300)	325 (360)
4 (100)	200 (220)	300 (330)	400 (440)

[A] Judged to be accurate within ±25 ksi· $\sqrt{in.}$ (28 MPa· $\sqrt{m}$).

9. Calculation and Interpretation

9.1 *Interpretation of Test Record*—The calculation equations for *K-EE* are the same as those in Test Method E 399 with one exception. The exception is the definition of the load used in the K_Q equations of Test Method E 399. In this practice, the load designated here by P_E (instead of P_Q as in Test Method E 399) is defined as follows. P_E is the load obtained by extending the linear portion of the load-displacement curve until the area under the linear portion equals the area to the maximum load sustained by the specimen without instability. Caution is recommended when interpreting data obtained in the toughness transition region. Guidance on obtaining P_E is given in 9.2.

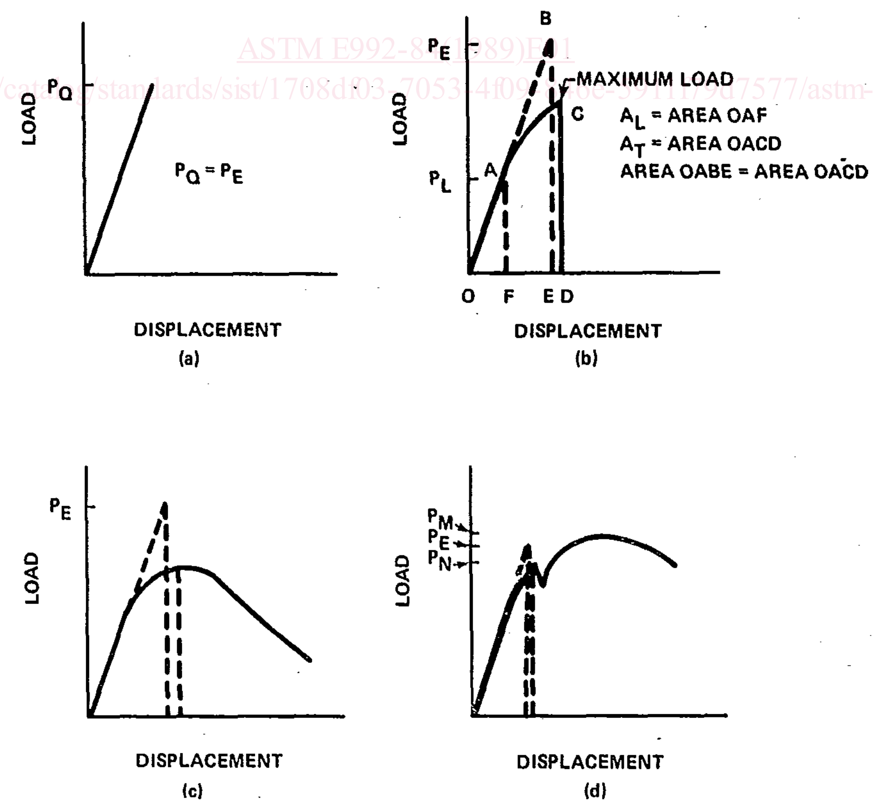


FIG. 3 Sketches Illustrating the Determination of P_E