Designation: E 812 – 91 (Reapproved 1997)

Standard Test Method for Crack Strength of Slow-Bend Precracked Charpy Specimens of High-Strength Metallic Materials[1]

This standard is issued under the fixed designation E 812; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method covers the determination of the crack strength σ_c of a Charpy-type specimen (see Fig. 1) containing a fatigue crack tested in slow bending. The nominal cross-sectional dimensions of this specimen are identical to those given in Test Methods E 23 (Fig. 4A) for the standard Charpy test specimen. The crack strength will be sensitive to changes in the plane-strain fracture toughness providing the strength of the specimen is determined primarily by crack propagation and not by plastic instability.

1.2 *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 Force Verification of Testing Machines[2]

E 8 Test Methods for Tension Testing of Metallic Materials[2]

E 23 Test Methods for Notched Bar Impact Testing of Metallic Materials[2]

E 139 Practice for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials[2]

E 399 Test Method for Plane-Strain Fracture Toughness of Metallic Materials[2]

E 616 Terminology Relating to Fracture Testing[3]

3. Terminology

3.1 *Definition:*

3.1.1 *crack strength,* σ_c [FL^2]—the maximum value of the nominal (net-section) stress that a cracked specimen is capable of sustaining.

3.1.1.1 *Discussion*—See definition of nominal stress in Terminology E 616.

3.1.1.2 *Discussion*—Crack strength is calculated on the basis of the maximum load and the original cross-sectional area (net cross-section or ligament). Thus, it takes into account the original size of the crack but ignores any crack extension that may occur during the test.

3.1.1.3 *Discussion*—Crack strength is analogous to the ultimate tensile strength, as it is based on the ratio of the maximum load to the minimum cross-sectional area of the specimen at the start of the test.

4. Summary of Test Method

4.1 This test method employs a Charpy specimen provided with a sharp notch terminating in a fatigue crack tested in three-point bending using fixtures that minimize the contribution of friction forces to the measured applied load. The maximum load in the test is recorded and the crack strength is determined from this value and the original dimensions of the specimen using the simple-beam equation.

5. Significance and Use

5.1 The crack strength does not provide a quantitative measure of fracture resistance that could be used in the design of structures. However, experience with a number of high-strength alloys[2] has shown that the ratio of the crack strength to the 0.2 % tensile yield strength σ_c/σ_{YS} or to the tensile ultimate strength, σ_c/σ_{UT}, can be correlated with K_{Ic}/σ_{YS} or with K_{Ic}/σ_{UT}, respectively, where K_{Ic} is the plane-strain fracture toughness in accordance with Test Method E 399[4, 5]. The lower-strength limits of useful correlations established by the presently available data are: for steel $\sigma_{YS} = 1378$ MPa (200 ksi), for aluminum alloys $\sigma_{YS} = 275.6$ MPa (40 ksi), and for titanium alloys $\sigma_{YS} = 826$ MPa (120 ksi). Correlations of this type can be useful for the following purposes:

5.1.1 In research and development of materials, to study the effects of such variables as composition, heat treatment,

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[1] This test method is under the jurisdiction of ASTM Committee E-8 on Fracture Testing and is the direct responsibility of Subcommittee E08.02 on Standards and Terminology.

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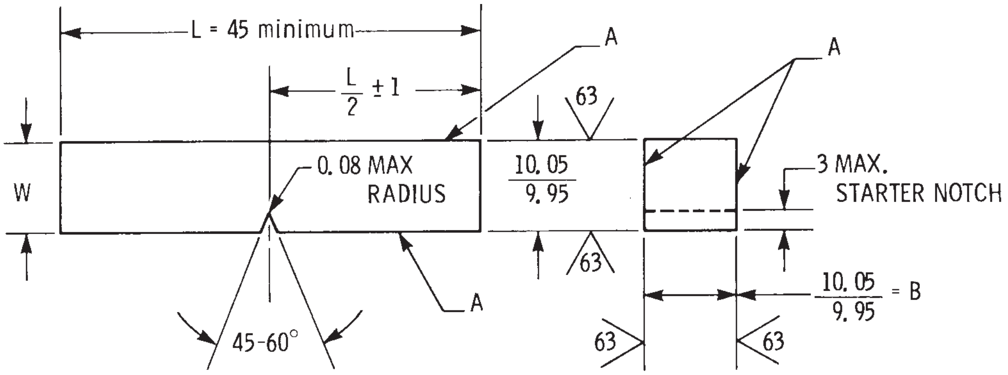
[2] *Annual Book of ASTM Standards*, Vol 03.01.

[3] Discontinued 1996; see *1995 Annual Book of ASTM Standards*, Vol 03.01.

[4] Succop, G., and Brown, W. F., Jr., “Estimation of K_{Ic} from Slow Bend Precracked Charpy Specimen Strength Ratios,” *Developments in Fracture Mechanics Test Method Standardization, ASTM-STP 632,* 1977.

[5] “Rapid Inexpensive Tests for Determining Fracture Toughness,” National Materials Advisory Board, National Academy of Sciences, NMAB 328, Washington, DC, 1976.



NOTE 1—All dimensions are in millimetres.
NOTE 2—*A* surfaces shall be perpendicular or parallel as applicable to within 0.025 mm TIR.
NOTE 3—Crack starter shall be perpendicular to specimen length and thickness to within ±2°.

FIG. 1 Dimensions of Precracked Charpy Specimen

mechanical processing, etc., where a ranking of materials in terms of their plane-strain fracture toughness K_{Ic} may be useful.

5.1.2 For specifications of acceptance and manufacturing quality control and for service evaluation to compare the resistance to plane-strain fracture of a number of materials that are otherwise suitable for an application; provided that a "calibration relation" can be established between σ_c and K_{Ic} over a range of toughness of interest.[3]

5.1.3 The variation of crack strength with testing temperature may be useful in establishing transition temperatures.

5.2 When using the crack strength of any of the preceding purposes, it is important that certain precautions be kept in mind.

5.2.1 The sensitivity of the crack strength to changes in the plane-strain fracture toughness will decrease as the toughness approaches a value sufficient to cause the crack strength to be determined by the plastic limit load. Available data obtained at room temperature for various materials[3] indicate that useful sensitivity of σ_c/σ_{YS} to changes in K_{Ic}/σ_{YS} is maintained up to values of σ_c/σ_{YS} of about 2.0. On the average, for high-strength metallic materials, this limitation will correspond to a value of K_{Ic}/σ_{YS} of approximately 0.12 $m^{1/2}$ (0.6 in.$^{1/2}$).

5.2.2 There is no assurance that a calibration relation established for one class of materials will be equally useful for another class of materials or that changes in the processing of a given material will not alter the calibration relation. Therefore, when it is desired to closely estimate K_{Ic} from such a relation, this relation should be carefully established over the range of plane-strain fracture toughness of interest for a particular alloy condition.

5.2.3 Calibration relations should not be extrapolated.

5.2.4 The crack strength of some materials will be sensitive to the rate of loading and loading rates should be confined to the range given in 8.3.2.

5.2.5 The crack strength will be influenced by the testing temperature and calibration relations may change with testing temperature.

6. Apparatus

6.1 *Tension-Testing Machine*, conforming to the requirements of Practices E 4.

6.2 *Bend-Test Fixture*—The procedure involves testing of the specimen in three-point bending. The bend test fixture should provide support rollers that are free to rotate and move apart slightly during loading (for example, see the Test Method E 399 bend test fixture for general principles of design). The nominal span between support rollers shall be 40 mm (1.57 in.). If the diameter of the support rollers is between 7.5 mm (0.30 in.) and 10 mm (0.39 in.) there will be negligible change in span during deformation of the specimen.

6.3 *Temperature Control and Measurement*—For tests at temperatures other than ambient, any suitable means may be used to cool or heat the specimen providing the region including the notched and cracked section can be maintained within ±2°C (±3.6°F) of the desired temperature during the course of the test.

6.3.1 Temperatures shall be measured with calibrated thermocouples used in conjunction with potentiometers or millivoltmeters. Such measurements are subject to various errors particularly at elevated temperatures and reference should be made to Practice E 139 for a discussion of errors encountered in elevated temperature testing.

6.3.2 The temperature-measuring apparatus should be calibrated periodically against standards traceable to the National Bureau of Standards in order to ensure the accuracy specified in 6.3 can be achieved.

6.3.3 The temperature of the specimen during any test other than one at room temperature shall be measured by means of a thermocouple attached near the notched and cracked section. This thermocouple may be spot welded in place, however, the spot weld location should avoid the crack path. Requirements for cooling or heating the specimens prior to testing are discussed in Test Methods E 23 and should be followed in this method. In the case where the specimen and the test fixture is immersed in a liquefied gas maintained at its boiling point, no temperature measurement is required provided experience shows that the specimen achieves temperature equilibrium with the bath before the test begins.

NOTE 1—Care should be taken to ensure that the liquid or gaseous environment used to control the temperature of the specimen does not influence the crack strength through a chemical reaction with the metal.

6.3.4 It should be appreciated that the crack strength of some materials may be influenced by the time during which the specimen remains at an elevated test temperature.

7. Test Specimens, Dimensions, and Preparation

7.1 *Dimensions*—The precracked Charpy bend specimen is shown in Fig. 1. The crack length, *a*, (starter notch depth + fatigue crack length) is nominally equal to one half the specimen width, *W*, and shall lie within the range between 0.45 and 0.55 *W*.

7.1.1 The crack starter may consist of a V-notch having an included angle from 45 to 60° provided with a small radius at its tip. Experience has shown that a notch radius of less than 0.08 mm (0.003 in.) is usually necessary in order to facilitate the initiation of a fatigue crack at a low-stress intensity level.

7.2 *Fatigue Cracking*—In order to ensure a sufficiently sharp fatigue crack and to facilitate the production of this crack, the following procedure shall be followed:

7.2.1 The fatigue cracking shall be conducted with the specimen in the condition of heat treatment in which it is to be tested.

7.2.2 The method used for fatigue cracking shall be such that the crack extension direction is perpendicular to the notched face of the specimen. Cantilever bending or three-point bending may be used to produce fatigue cracks. Cantilever bending facilitates completely reversed loading ($R = -1$) which aids in starting and propagating the crack. For practical purposes, the *K* calibration for three-point bending may be used to estimate the stress-intensity factors.

NOTE 2—The expression given in Test Method E 399 for the *K* calibration in three-point bending may be rewritten in terms of the bending moment *M* as follows and used to compute the stress intensity in cantilever bending. Thus,

$$K = 4M/BW^{3/2}\ f(a/W) \qquad (1)$$

where:

M = bending moment, KN·cm (1bf·in.),

B = specimen thickness, cm (in.),

W = specimen width (depth), cm (in.), and

a = crack length as determined in 8.2.1, cm (in.).

To facilitate calculation of *K*, values of *f(a/W)* are tabulated below for specific values of *a/W*.

a/W	*f(a/W)*	*a/W*	*f(a/W)*
0.450	2.29	0.500	2.66
0.455	2.32	0.505	2.70
0.460	2.35	0.510	2.75
0.465	2.39	0.515	2.79
0.470	2.43	0.520	2.84
0.475	2.46	0.525	2.89
0.480	2.50	0.530	2.94
0.485	2.54	0.535	2.99
0.490	2.58	0.540	3.04
0.495	2.62	0.545	3.09
		0.550	3.14

7.2.3 The fatigue crack shall extend at least 1 mm (0.04 in.) beyond the tip of the crack starter notch. During at least the last 0.5 mm (0.02 in.) of fatigue cracking, the ratio of the maximum-stress intensity in fatigue to Young's modulus, $K_{f\,(\mathrm{max})}/E$ shall not exceed 0.0003 $\mathrm{m}^{½}$ (0.002 $\mathrm{in.}^{½}$).

7.2.4 When the fatigue cracking is conducted at a temperature T_1 and testing at a different temperature T_2, where $T_1 > T_2$, the $K_{f\,(\mathrm{max})}$ of the fatigue cycle should be that value determined in 7.2.4 above multiplied by $\sigma_{\mathrm{YS1}}/\sigma_{\mathrm{YS2}}$ where σ_{YS1} is the 0.2 % tensile yield strength at temperature T_1 and σ_{YS2} is the 0.2 % tensile yield strength at temperature T_2. Where $T_1 < T_2$ proceed as in 7.4.2.

8. Procedure

8.1 *Number of Tests*—When evaluating crack strength at a specific temperature it is recommended that at least three-replicate tests be made for each material condition.

8.2 *Specimen Measurement*—All specimen dimensions shall be within the tolerances shown in Fig. 1.

8.2.1 Measure the thickness, *B*, to the nearest 0.025 mm (0.001 in.) at not less than two positions between the fatigue crack tip and the unnotched edge of the specimen and record the average value. Measure the depth *W* to the nearest 0.025 mm (0.001 in.) at two positions, one on each side of the crack starter notch and record the average value.

8.2.2 After fracture measure the initial notch plus fatigue crack length, *a*, to the nearest 0.5 % at the following three positions: at the center of the crack front and midway between the center and the intersection of the crack front with the specimen surfaces. Use the average of these three measurements as the crack length in the calculation of σ_c (see 9.1). If the difference between any two of the crack length measurements exceeds 10 % of the average, or if part of the crack front is closer to the machined notch root than 5 % of the average, the specimen should be discarded. Also, if the length of either surface trace of the crack is less than 80 % of the average crack length, as defined above, the specimen should be discarded.

8.3 *Bend Testing*—Set up the bend-test fixture so that the line of action of the applied load shall pass midway between the support roll centers within 1 mm (0.04 in.). Measure the span (distance between the support-roll centers) within 1 % and record this value as *S*. This value should fall between 38 mm (1.5 in.) and 42 mm (1.65 in.).

8.3.1 Locate the specimen with the crack tip midway between the roll centers to within 1 mm (0.040 in.), and square to the roll axes within 2°. Check the parallelism between the top face of the specimen and the loading roller by sighting the gap between these surfaces just before contact is made. As a small load is applied light in this gap should extinguish simultaneously across the thickness of the specimen. If this condition is not met, the loading roller should be suitably adjusted.

8.3.2 Load the specimen at a rate between 0.05 kN/s and 0.26 kN/s (700 lbf/min and 3600 lbf/min) until the maximum load is reached and record this value as P_{max}.

NOTE 3—It is desirable to follow the load change carefully because specimens having low toughness will break abruptly and no slow decrease in load beyond the maximum will be observed.

9. Calculation and Interpretation of Results

9.1 Calculate the crack strength of the specimen in MPa or ksi from the measured value of $P_{\max}$ and the initial dimensions of the specimen as follows:

$$\sigma_c = \frac{1.5\, P_{\max}{}^{S}}{B\,(W - a)^2} \qquad (2)$$

where:

$P_{\max}$ = maximum load sustained by the specimen as determined in 8.3.2, N or lbf,
B = thickness of the specimen as determined in 8.2.1, mm or in.,
S = span as determined in 8.3, mm or in.,
W = depth of the specimen as determined in 8.2.1, mm or in., and
a = initial notch plus fatigue crack length as determined in 8.2.2, mm or in.

9.2 *Crack Plane Orientation*—The crack strength of a material often depends on the orientation and direction of propagation of the crack in relation to the anisotropy of the material, which in turn depends on the principal directions of mechanical working or grain flow. Reference should be made to Test Method E 399 for a description of the system used to designate crack plane orientation and crack propagation directions for cracked bend specimens.

9.3 *Fracture Appearance*—The appearance of the fracture may furnish valuable supplementary information. A means for describing the fracture appearance of cracked bend specimens is given in Test Method E 399 and may be used to characterize the fracture appearance of the precracked Charpy specimens.

10. Report

10.1 The report shall include the following for each specimen tested:

10.1.1 All dimensions listed in 9.1,

10.1.2 The maximum load $P_{\max}$,

10.1.3 The crack strength, σ_c,

10.1.4 Test temperature,

10.1.5 The estimated maximum stress intensity, stress intensity range, and number of cycles spent during the final 0.5 mm (0.02 in.) of fatigue cracking unless all fatigue cracking conforms to the requirements of 7.2.3 and that is so stated,

10.1.6 Crack plane orientation in accordance with Test Method E 399,

10.1.7 Fracture appearance in accordance with Test Method E 399, and

10.1.8 0.2 % tensile yield strength and tensile ultimate strength at the test temperature and their sources, in accordance with Test Methods E 8.

11. Precision and Bias

11.1 *Precision*—At present the available data are not of a type that permits a meaningful analysis of precision of the crack strength as determined by this test method.

11.2 *Bias*—There is no accepted "standard" value for the crack strength of any material. In the absence of such a true value, any statement concerning the bias of the crack strength is meaningless.