INTERNATIONAL

Designation: E1820 – 23a

Standard Test Method for Measurement of Fracture Toughness[1]

This standard is issued under the fixed designation E1820; 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 procedures and guidelines for the determination of fracture toughness of metallic materials using the following parameters: *K, J*, and CTOD (δ). Toughness can be measured in the *R*-curve format or as a point value. The fracture toughness determined in accordance with this test method is for the opening mode (Mode I) of loading.

NOTE 1—Until this version, K_{Ic} could be evaluated using this test method as well as by using Test Method E399. To avoid duplication, the evaluation of K_{Ic} has been removed from this test method and the user is referred to Test Method E399.

1.2 The recommended specimens are single-edge bend, [SE(B)], compact, [C(T)], and disk-shaped compact, [DC(T)]. All specimens contain notches that are sharpened with fatigue cracks.

1.2.1 Specimen dimensional (size) requirements vary according to the fracture toughness analysis applied. The guidelines are established through consideration of material toughness, material flow strength, and the individual qualification requirements of the toughness value per values sought.

NOTE 2—Other standard methods for the determination of fracture toughness using the parameters *K, J*, and CTOD are contained in Test Methods E399, E1290, and E1921. This test method was developed to provide a common method for determining all applicable toughness parameters from a single test.

1.3 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.

1.4 *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.*

1.5 *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:*[2]

E4 Practices for Force Calibration and Verification of Testing Machines

E8/E8M Test Methods for Tension Testing of Metallic Materials

E21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials

E23 Test Methods for Notched Bar Impact Testing of Metallic Materials

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

E1290 Test Method for Crack-Tip Opening Displacement (CTOD) Fracture Toughness Measurement (Withdrawn 2013)[3]

E1823 Terminology Relating to Fatigue and Fracture Testing

E1921 Test Method for Determination of Reference Temperature, T_0, for Ferritic Steels in the Transition Range

E1942 Guide for Evaluating Data Acquisition Systems Used in Cyclic Fatigue and Fracture Mechanics Testing

E2298 Test Method for Instrumented Impact Testing of Metallic Materials

2.2 *ASTM Data Sets:*[4]

E1820/1–DS1(2016) Standard data set 1 to evaluate computer algorithms for evaluation of J_{Ic} using Annex 9 of E1820

E1820/2–DS2(2020) Standard data set 2 to evaluate computer algorithms for evaluation of J_{Ic} using Annex 9 of E1820

E1820/3–DS3(2020) Standard data set 3 to evaluate computer algorithms for evaluation of J_{Ic} using Annex 9 of E1820

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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 E08.07 on Fracture Mechanics.

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

[4] These data sets are available for download from ASTM at https://www.astm.org/get-involved/technical-committees/adhoc-e08.html

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

E1820/4–DS4(2020) Standard data set 4 to evaluate computer algorithms for evaluation of J_{Ic} using Annex 9 of E1820
E1820/5–DS5(2020) Standard data set 5 to evaluate computer algorithms for evaluation of J_{Ic} using Annex 9 of E1820
E1820/6–DS6(2020) Standard data set 6 to evaluate computer algorithms for evaluation of J_{Ic} using Annex 9 of E1820
E1820/7–DS7(2020) Standard data set 7 to evaluate computer algorithms for evaluation of J_{Ic} using Annex 9 of E1820
E1820/8–DS8(2020) Standard data set 8 to evaluate computer algorithms for evaluation of J_{Ic} using Annex 9 of E1820
E1820/9–DS9(2020) Standard data set 9 to evaluate computer algorithms for evaluation of J_{Ic} using Annex 9 of E1820

3. Terminology

3.1 Terminology E1823 is applicable to this test method. Only items that are exclusive to Test Method E1820, or that have specific discussion items associated, are listed in this section.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *compliance [LF^{-1}], n*—the ratio of displacement increment to force increment.

3.2.2 *crack opening displacement (COD) [L], n*—force-induced separation vector between two points at a specific gage length. The direction of the vector is normal to the crack plane.

3.2.2.1 *Discussion—In this practice, displacement,* v, is the total displacement measured by clip gages or other devices spanning the crack faces.

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

3.2.4 *crack-extension force, G [FL^{-1} or FLL^{-2}], n*—the elastic energy per unit of new separation area that is made available at the front of an ideal crack in an elastic solid during a virtual increment of forward crack extension.

3.2.5 *crack-tip opening displacement (CTOD), δ [L], n*—crack displacement resulting from the total deformation (elastic plus plastic) at variously defined locations near the original (prior to force application) crack tip.

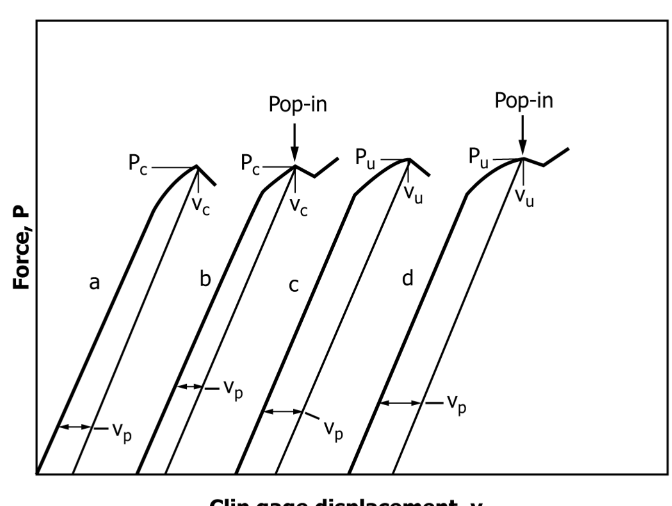
3.2.5.1 *Discussion—In this test method*, CTOD is the displacement of the crack surfaces normal to the original (unloaded) crack plane at the tip of the fatigue precrack, a_o. In this test method, CTOD is calculated at the original crack size, a_o, from measurements made from the force versus displacement record.

3.2.5.2 *Discussion—In CTOD testing*, δ_{Ic} [*L*] is a value of CTOD near the onset of slow stable crack extension, here defined as occurring at $\Delta a_p = 0.2$ mm (0.008 in.) + $0.7\delta_{Ic}$.

3.2.5.3 *Discussion—In CTOD testing*, δ_c [*L*] is the value of CTOD at the onset of unstable crack extension (see 3.2.36) or pop-in (see 3.2.22) when $\Delta a_p < 0.2$ mm (0.008 in.) + $0.7\delta_c$. δ_c corresponds to the force P_c and clip-gage displacement v_c (see Fig. 1). It may be size-dependent and a function of test specimen geometry.

3.2.5.4 *Discussion—In CTOD testing*, δ_u [*L*] is the value of CTOD at the onset of unstable crack extension (see 3.2.36) or pop-in (see 3.2.22) when the event is preceded by Δa_p >0.2 mm (0.008 in.) + $0.7\delta_u$. The δ_u corresponds to the force P_u and the clip gage displacement v_u (see Fig. 1). It may be size-dependent and a function of test specimen geometry. It can be useful to define limits on ductile fracture behavior.

3.2.5.5 *Discussion—In CTOD testing,* δ_c^* *[L]* characterizes the CTOD fracture toughness of materials at fracture instability prior to the onset of significant stable tearing crack extension. The value of δ_c^* determined by this test method represents a measure of fracture toughness at instability without significant stable crack extension that is independent of in-plane dimensions. However, there may be a dependence of toughness on thickness (length of crack front).



NOTE 1—Construction lines drawn parallel to the elastic loading slope to give v_p, the plastic component of total displacement, v_g.

NOTE 2—In curves b and d, the behavior after pop-in is a function of machine/specimen compliance, instrument response, and so forth.

FIG. 1 Types of Force versus Clip gage Displacement Records

3.2.6 *dial energy, KV [FL]*—absorbed energy as indicated by the impact machine encoder or dial indicator, as applicable.

3.2.7 *dynamic stress intensity factor, K_{Jd}*—The dynamic equivalent of the stress intensity factor K_J, calculated from J using the equation specified in this test method.

3.2.8 *effective thickness, B_e [L] , n*—for side-grooved specimens $B_e = B - (B - B_N)^2/B$. This is used for the elastic unloading compliance measurement of crack size.

3.2.9 *effective yield strength, σ_Y [FL^{-2}], n*—an assumed value of uniaxial yield strength that represents the influence of plastic yielding upon fracture test parameters.

3.2.9.1 *Discussion*—It is calculated as the average of the 0.2 % offset yield strength σ_{YS}, and the ultimate tensile strength, σ_{TS} as follows:

$$\sigma_Y = \frac{\sigma_{YS} + \sigma_{TS}}{2} \quad (1)$$

3.2.9.2 *Discussion*—In estimating σ_Y, influences of testing conditions, such as loading rate and temperature, should be considered.

3.2.9.3 *Discussion*—The dynamic effective yield strength, σ_{Yd}, is the dynamic equivalent of the effective yield strength.

3.2.10 *general yield force, P_{gy} [F]*—in an instrumented impact test, applied force corresponding to general yielding of the specimen ligament. It corresponds to F_{gy}, as used in Test Method E2298.

3.2.11 *J-integral, J [FL^{-1}], n*—a mathematical expression, a line or surface integral that encloses the crack front from one crack surface to the other, used to characterize the local stress-strain field around the crack front.

3.2.11.1 *Discussion*—The *J*-integral expression for a two-dimensional crack, in the *x-z* plane with the crack front parallel to the *z*-axis, is the line integral as follows:

$$J = \int_{\Gamma} \left(W dy - \bar{T} \cdot \frac{\partial \bar{u}}{\partial x} ds \right) \quad (2)$$

where:

W	=	loading work per unit volume or, for elastic bodies, strain energy density,
Γ	=	path of the integral, that encloses (that is, contains) the crack tip,
ds	=	increment of the contour path,
$\bar{T}$	=	outward traction vector on ds,
$\bar{u}$	=	displacement vector at ds,
x, y, z	=	rectangular coordinates, and
$\bar{T} \cdot \frac{\partial \bar{u}}{\partial x} ds$	=	rate of work input from the stress field into the area enclosed by Γ.

3.2.11.2 *Discussion*—The value of *J* obtained from this equation is taken to be path-independent in test specimens commonly used, but in service components (and perhaps in test specimens) caution is needed to adequately consider loading interior to Γ such as from rapid motion of the crack or the service component, and from residual or thermal stress.

3.2.11.3 *Discussion*—In elastic (linear or nonlinear) solids, the *J*-integral equals the crack-extension force, *G*. (See *crack extension force*.)

3.2.11.4 *Discussion*—In elastic (linear and nonlinear) solids for which the mathematical expression is path independent, the *J*-integral is equal to the value obtained from two identical bodies with infinitesimally differing crack areas each subject to stress. The parameter *J* is the difference in work per unit difference in crack area at a fixed value of displacement or, where appropriate, at a fixed value of force (**1**)[5].

3.2.11.5 *Discussion*—The dynamic equivalent of J_c is $J_{cd,X}$, with X = order of magnitude of *J*-integral rate.

3.2.12 *J_c [FL^{-1}]* —The property J_c determined by this test method characterizes the fracture toughness of materials at fracture instability prior to the onset of significant stable tearing crack extension. The value of J_c determined by this test method represents a measure of fracture toughness at instability without significant stable crack extension that is independent of in-plane dimensions; however, there may be a dependence of toughness on thickness (length of crack front).

3.2.13 *J_u [FL^{-1}]*—The quantity J_u determined by this test method measures fracture instability after the onset of significant stable tearing crack extension. It may be size-dependent and a function of test specimen geometry. It can be useful to define limits on ductile fracture behavior.

3.2.13.1 *Discussion*—The dynamic equivalent of J_u is $J_{ud,X}$, with X = order of magnitude of *J*-integral rate.

3.2.14 *J-integral rate, $\dot{J}$ [$FL^{-1}T^{-1}$]*—derivative of J with respect to time.

3.2.15 *machine capacity, MC [FL]*—maximum available energy of the impact testing machine.

3.2.16 *maximum force, P_{max} [F]*—in an instrumented impact test, maximum value of applied force. It corresponds to F_m, as used in Test Method E2298.

3.2.17 *net thickness, B_N [L], n*—distance between the roots of the side grooves in side-grooved specimens.

3.2.18 *original crack size, a_o [L] , n*—the physical crack size at the start of testing.

3.2.18.1 *Discussion*—In this test method, a_{oq} is used to denote original crack size estimated from compliance.

3.2.19 *original remaining ligament, b_o [L], n*—distance from the original crack front to the back edge of the specimen, that is ($b_o = W - a_o$).

3.2.20 *physical crack size, a_p[L] , n*—the distance from a reference plane to the observed crack front. This distance may represent an average of several measurements along the crack front. The reference plane depends on the specimen form, and it is normally taken to be either the boundary, or a plane containing either the load-line or the centerline of a specimen or plate. The reference plane is defined prior to specimen deformation.

3.2.21 *plane-strain fracture toughness, J_{Ic} [FL^{-1}], K_{JIc} [$FL^{-3/2}$] , n*—the crack-extension resistance under conditions of crack-tip plane-strain.

3.2.21.1 *Discussion*—For example, in Mode I for slow rates of loading and substantial plastic deformation, plane-strain fracture toughness is the value of the *J*-integral designated J_{Ic} [FL^{-1}] as measured using the operational procedure (and

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