INTERNATIONAL

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Standard Test Method for Crack-Tip Opening Displacement (CTOD) Fracture Toughness Measurement[1]

This standard is issued under the fixed designation E 1290; 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 the determination of critical crack-tip opening displacement (CTOD) values at one or more of several crack extension events. These CTOD values can be used as measures of fracture toughness for metallic materials, and are especially appropriate to materials that exhibit a change from ductile to brittle behavior with decreasing temperature. This test method applies specifically to notched specimens sharpened by fatigue cracking. The recommended specimens are three-point bend [SE(B)] compact [C(T)], or arc-shaped bend [A(B)] specimens. The loading rate is slow and influences of environment (other than temperature) are not covered. The specimens are tested under crosshead or clip gage displacement controlled loading.

1.1.1 The recommended specimen thickness, B, for the SE(B) and C(T) specimens is that of the material in thicknesses intended for an application. For the A(B) specimen, the recommended depth, W, is the wall thickness of the tube or pipe from which the specimen is obtained. Superficial surface machining may be used when desired.

1.1.2 For the recommended three-point bend specimens [SE(B)], width, W, is either equal to, or twice, the specimen thickness, B, depending upon the application of the test. (See 4.3 for applications of the recommended specimens.) For SE(B) specimens the recommended initial normalized crack size is $0.45 \leq a_o/W \leq 0.70$. The span-to-width ratio (S/W) is specified as 4.

1.1.3 For the recommended compact specimen [C(T)] the initial normalized crack size is $0.45 \leq a_o/W \leq 0.70$. The half-height-to-width ratio (H/W) equals 0.6 and the width to thickness ratio W/B is specified to be 2.

1.1.4 For the recommended arc-shaped bend [A(B)] specimen, B is one-half the specimen depth, W. The initial normalized crack size is $0.45 < a_o/W < 0.70$. The span to width ratio, S/W, may be either 3 or 4 depending on the ratio of the inner to outer tube radius. For an inner radius, r_1, to an outer radius, r_2, ratio of > 0.6 to 1.0, a span to width ratio, S/W, of 4 may be used. For r_1/r_2 *ratios from 0.4 to 0.6, an S/W of 3 may be used.*

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:* [2]

E 4 Practices for Force Verification of Testing Machines
E 8 Test Methods for Tension Testing of Metallic Materials
E 399 Test Method for Plane-Strain Fracture Toughness of Metallic Materials
E 1820 Test Method for Measurement of Fracture Toughness
E 1823 Terminology Relating to Fatigue and Fracture Testing

3. Terminology

3.1 Terminology E 1823 is applicable to this test method.

3.2 *Definitions:*

3.2.1 *crack tip opening displacement, (CTOD),* $\delta[L]$—the crack displacement due to elastic and plastic deformation at variously defined locations near the original (prior to an application of force) crack tip.

3.2.1.1 *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 CTOD testing, δ_c[L] is the value of CTOD at the onset of unstable brittle crack extension (see 3.2.13) or pop-in (see 3.2.7) when $\Delta a_p < 0.2$ mm (0.008 in.). The force P_c and the clip gage displacement v_c, for δ_c are indicated in Fig. 1.

In CTOD testing, δ_u[L] is the value of CTOD at the onset of unstable brittle crack extension (see 3.2.13) or pop-in (see 3.2.7) when the event

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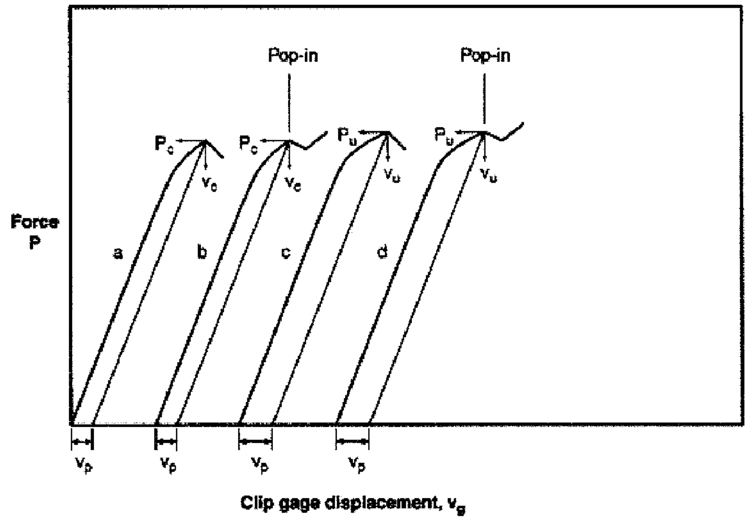
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.



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, etc.

FIG. 1 Types of Force Versus Clip Gage Displacement Records

is preceded by Δa_p> 0.2 mm (0.008 in.). The force P_u and the clip gage displacement v_u, for δ_u are indicated in Fig. 1.

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

3.2.2.1 *Discussion*—The calculation of σ_Y is the average of the 0.2 % offset yield strength (σ_{YS}), and the tensile strength (σ_{TS}), that is $(\sigma_{YS} + \sigma_{TS})/2$. Both σ_{YS} and σ_{TS} are determined in accordance with Test Methods E 8.

3.2.3 *original crack size, $a_o[L]$*—see Terminology E 1823.

3.2.4 *original uncracked ligament, $b_o[L]$*—the distance from the original crack front to the back surface of the specimen at the start of testing, $b_o = W - a_o$.

3.2.5 *physical crack extension, $\Delta a_p[L]$*—an increase in physical crack size, $\Delta a_p = a_p - a_o$.

3.2.6 *physical crack size, $a_p[L]$*—see Terminology E 1823.

3.2.6.1 *Discussion*—In CTOD testing, $a_p = a_o + \Delta a_p$.

3.2.7 *pop-in*—a discontinuity in the force versus clip gage displacement record. The record of a pop-in shows a sudden increase in displacement and, generally, a decrease in force. Subsequently, the displacement and force increase to above their respective values at pop-in.

3.2.8 *slow stable crack extension [L]*—a displacement controlled crack extension beyond the stretch zone width (see 3.2.12). The extension stops when the applied displacement is held constant.

3.2.9 *specimen span, S [L]*—the distance between specimen supports in a bend specimen.

3.2.10 *specimen thickness, B[L]*—see Terminology E 1823.

3.2.11 *specimen width, W [L]*—see Terminology E 1823.

3.2.12 *stretch zone width, SZW [L]*—the length of crack extension that occurs during crack-tip blunting, for example, prior to the onset of unstable brittle crack extension, pop-in, or slow stable crack extension. The SZW is in the same plane as the original (unloaded) fatigue precrack and refers to an extension beyond the original crack size.

3.2.13 *unstable brittle crack extension [L]*—an abrupt crack extension that occurs with or without prior stable crack extension in a standard test specimen under crosshead or clip gage displacement control.

4. Summary of Test Method

4.1 The objective of the test is to determine the value of CTOD at one of the following crack extension events. The values of CTOD may correspond to: δ_c, the onset of unstable brittle crack extension with no significant prior slow stable crack extension (see 3.2.1), or δ_u, the onset of unstable brittle crack extension following prior slow stable crack extension.

4.2 The test method involves crosshead or clip gage displacement controlled three-point bend loading or pin loading of fatigue precracked specimens. Force versus clip gage crack opening displacement is recorded, for example, Fig. 1. The forces and displacements corresponding to the specific events in the crack initiation and extension process are used to determine the corresponding CTOD values. For values of δ_c, and δ_u, the corresponding force and clip gage displacements are obtained directly from the test records.

4.3 The rectangular section bend specimen and the compact specimen are intended to maximize constraint and these are generally recommended for those through-thickness crack types and orientations for which such geometries are feasible. For the evaluation of surface cracks in structural applications for example, orientations T-S or L-S (Terminology E 1823), the square section bend specimen is recommended. Also for certain situations in curved geometry source material or welded joints, the square section bend specimen may be preferred. Square section bend specimens may be necessary in order to sample an acceptable volume of a discrete microstructure.

4.4 The arc-shaped bend specimen permits toughness testing in the C-R orientation (Terminology E 1823), for pipe or tube. This orientation is of interest since pipes and tubes under