Designation: E2760 – 19$^{\epsilon 1}$

Standard Test Method for Creep-Fatigue Crack Growth Testing[1]

This standard is issued under the fixed designation E2760; 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.

ε¹ NOTE—Section 3.2.18.4 was editorially corrected in July 2020.

1. Scope

1.1 This test method covers the determination of creep-fatigue crack growth properties of nominally homogeneous materials by use of pre-cracked compact type, C(T), test specimens subjected to uniaxial cyclic forces. It concerns fatigue cycling with sufficiently long loading/unloading rates or hold-times, or both, to cause creep deformation at the crack tip and the creep deformation be responsible for enhanced crack growth per loading cycle. It is intended as a guide for creep-fatigue testing performed in support of such activities as materials research and development, mechanical design, process and quality control, product performance, and failure analysis. Therefore, this method requires testing of at least two specimens that yield overlapping crack growth rate data. The cyclic conditions responsible for creep-fatigue deformation and enhanced crack growth vary with material and with temperature for a given material. The effects of environment such as time-dependent oxidation in enhancing the crack growth rates are assumed to be included in the test results; it is thus essential to conduct testing in an environment that is representative of the intended application.

1.2 Two types of crack growth mechanisms are observed during creep/fatigue tests: *(1)* time-dependent intergranular creep and *(2)* cycle dependent transgranular fatigue. The interaction between the two cracking mechanisms is complex and depends on the material, frequency of applied force cycles and the shape of the force cycle. When tests are planned, the loading frequency and waveform that simulate or replicate service loading must be selected.

1.3 Two types of creep behavior are generally observed in materials during creep-fatigue crack growth tests: creep-ductile and creep-brittle (**1**)[2]. For highly creep-ductile materials that have rupture ductility of 10 % or higher, creep strains dominate and creep-fatigue crack growth is accompanied by substantial time-dependent creep strains near the crack tip. In creep-brittle materials, creep-fatigue crack growth occurs at low creep ductility. Consequently, the time-dependent creep strains are comparable to or less than the accompanying elastic strains near the crack tip.

1.3.1 In creep-brittle materials, creep-fatigue crack growth rates per cycle or da/dN, are expressed in terms of the magnitude of the cyclic stress intensity parameter, ΔK. These crack growth rates depend on the loading/unloading rates and hold-time at maximum load, the force ratio, R, and the test temperature (see Annex A1 for additional details).

1.3.2 In creep-ductile materials, the average time rates of crack growth during a loading cycle, $(da/dt)_{avg}$, are expressed as a function of the average magnitude of the C_t parameter, $(C_t)_{avg}$ (**2**).

NOTE 1—The correlations between $(da/dt)_{avg}$ and $(C_t)_{avg}$ have been shown to be independent of hold-times (**2, 3**) for highly creep-ductile materials that have rupture ductility of 10 percent or higher.

1.4 The crack growth rates derived in this manner and expressed as a function of the relevant crack tip parameter(s) are identified as a material property which can be used in integrity assessment of structural components subjected to similar loading conditions during service and life assessment methods.

1.5 The use of this practice is limited to specimens and does not cover testing of full-scale components, structures, or consumer products.

1.6 This practice is primarily aimed at providing the material properties required for assessment of crack-like defects in engineering structures operated at elevated temperatures where creep deformation and damage is a design concern and are subjected to cyclic loading involving slow loading/unloading rates or hold-times, or both, at maximum loads.

1.7 This practice is applicable to the determination of crack growth rate properties as a consequence of constant-amplitude load-controlled tests with controlled loading/unloading rates or hold-times at the maximum load, or both. It is primarily concerned with the testing of C(T) specimens subjected to uniaxial loading in load control mode. The focus of the procedure is on tests in which creep and fatigue deformation

---

[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.

Current edition approved Nov. 1, 2019. Published January 2020. Originally approved in 2010. Last previous edition approved in 2016 as E2760–16. DOI: 10.1520/E2760-19E01.

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

and damage is generated simultaneously within a given cycle. It does not cover block cycle testing in which creep and fatigue damage is generated sequentially. Data which may be determined from tests performed under such conditions may characterize the creep-fatigue crack growth behavior of the tested materials.

1.8 This practice is applicable to temperatures and hold-times for which the magnitudes of time-dependent inelastic strains at the crack tip are significant in comparison to the time-independent inelastic strains. No restrictions are placed on environmental factors such as temperature, pressure, humidity, medium and others, provided they are controlled throughout the test and are detailed in the data report.

NOTE 2—The term *inelastic* is used herein to refer to all nonelastic strains. The term *plastic* is used herein to refer only to time-independent (that is non-creep) component of inelastic strain.

1.9 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.

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

1.11 *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:*[3]

E4 Practices for Force Verification of Testing Machines
E83 Practice for Verification and Classification of Extensometer Systems
E139 Test Methods for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E220 Test Method for Calibration of Thermocouples By Comparison Techniques
E399 Test Method for Linear-Elastic Plane-Strain Fracture Toughness of Metallic Materials
E467 Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System
E647 Test Method for Measurement of Fatigue Crack Growth Rates
E1457 Test Method for Measurement of Creep Crack Growth Times in Metals
E1823 Terminology Relating to Fatigue and Fracture Testing
E2714 Test Method for Creep-Fatigue Testing

3. Terminology

3.1 Terminology related to fatigue and fracture testing contained in Terminology E1823 is applicable to this test method. Additional terminology specific to this standard is detailed in section 3.3. For clarity and easier access within this document some of the terminology in Terminology E1823 relevant to this standard is repeated below (see Terminology E1823, for further discussion and details).

3.2 *Definitions:*

3.2.1 *crack-plane orientation*—direction of fracture or crack extension relation to product configuration. This identification is designated by a hyphenated code with the first letter(s) representing the direction normal to the crack plane and the second letter(s) designating the expected direction of crack propagation.

3.2.2 *crack size, a [L]*—principal lineal dimension used in the calculation of fracture mechanics parameters for through-thickness cracks.

3.2.2.1 *Discussion*—In the C(T) specimen, a is the average measurement from the line connecting the bearing points of force application. This is the same as the physical crack size, a_p where the subscript p is always implied.

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

3.2.3 *specimen thickness, B [L]*—distance between the parallel sides of the specimen.

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

3.2.5 *specimen width, W [L]*—the distance from a reference position (for example, the front edge of a bend specimen or the force line of a compact specimen) to the rear surface of the specimen.

3.2.6 *force, P [F]*—the force applied to a test specimen or to a component.

3.2.7 *maximum force,* P_{max} *[F]—in fatigue*, the highest algebraic value of applied force in a cycle. By convention, tensile forces are positive and compressive forces are negative.

3.2.8 *minimum force,* P_{min} *[F]—in fatigue*, the lowest algebraic value of applied force in a cycle. By convention, tensile forces are positive and compressive forces are negative.

3.2.9 *force ratio (also stress ratio), R— in fatigue*, the algebraic ratio of the two loading parameters of a cycle. The most widely used ratio is as follows:

$$R = \frac{\text{minimum load}}{\text{maximum load}} = \frac{P_{min}}{P_{max}} \quad (1)$$

3.2.10 *force range, ΔP [F]—in fatigue loading*, the algebraic difference between the successive valley and peak forces (positive range or increasing force range) or between successive peak and valley forces (negative or decreasing force range). In constant amplitude loading, the range is given as follows:

$$\Delta P = P_{max} - P_{min} \quad (2)$$

3.2.11 *stress intensity factor,* $K, K_1, K_2, K_3, K_I, K_{II}, K_{III}$ $[FL^{-3/2}]$—the magnitude of the mathematically ideal crack tip

---

[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.

stress field (a stress-field singularity) for a particular mode in a homogeneous, linear-elastic body.

3.2.11.1 *Discussion*—For a C(T) specimen subjected to Mode I loading, K is calculated by the following equation:

$$K = \frac{P}{(BB_N)^{1/2} W^{1/2}} f(a/W) \tag{3}$$

$$f = \left[\frac{2 + a/W}{(1 - a/W)^{3/2}} \right] (0.886 + 4.64(a/W) - 13.32(a/W)^2 + 14.72(a/W)^3 - 5.6(a/W)^4) \tag{4}$$

3.2.12 *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}.

3.2.13 *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 0 when $R \leq 0$.

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

$$\Delta K = K_{max} - K_{min} \tag{5}$$

3.2.15 *yield strength, σ_{YS} [FL^{-2}]*—the stress at which the material exhibits a deviation from the proportionality of stress to strain at the test temperature. This deviation is expressed in terms of strain.

3.2.15.1 *Discussion*—For the purposes of this standard, the value of strain deviation from proportionality used for defining yield strength is 0.2 %.

3.2.16 *cycle—in fatigue*, one complete sequence of values of force that is repeated under constant amplitude loading. The symbol N used to indicate the number of cycles.

3.2.17 *hold-time (t_h)—in fatigue*, the amount of time in the cycle where the controlled test variable (for example, force, strain, displacement) remains constant with time.

3.2.18 *C*(t)*—integral, *C*(t)* [$FL^{-1}T^{-1}$], 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 rate fields at any instant around the crack front in a body subjected to extensive creep conditions.

3.2.18.1 *Discussion*—The *C*(t)* expression for a two-dimensional crack, in the *x-z* plane with the crack front parallel to the *z*-axis, is the line integral (**4, 5**).

$$C^*(t) = \int_\Gamma \left(W^*(t) dy - T \cdot \frac{\partial \dot{u}}{\partial x} ds \right) \tag{6}$$

where:

$W^*(t)$ = instantaneous stress-power or energy rate per unit volume,
Γ = path of the integral, that encloses (that is, contains) the crack tip contour,
ds = increment in the contour path,
T = outward traction vector on ds,
$\dot{u}$ = displacement rate vector at ds,
x, y, z = rectangular coordinate system, and
$T \cdot \frac{\partial \dot{u}}{\partial x} ds$ = the rate of stress-power input into the area enclosed by Γ across the elemental length ds.

3.2.18.2 *Discussion*—The value of *C*(t)* from this equation is path-independent for materials that deform according to a constitutive law that may be separated into single-value time and stress functions or strain and stress functions of the forms (**1**):

$$\dot{\varepsilon} = f_1(t) f_2(\sigma) \tag{7}$$

$$\dot{\varepsilon} = f_3(\varepsilon) f_4(\sigma) \tag{8}$$

where, f_1–f_4 represent functions of elapsed time, t, strain, ε and applied stress, σ, respectively and $\dot{\varepsilon}$ is the strain rate.

3.2.18.3 *Discussion*—For materials exhibiting creep deformation for which the above equation is path-independent, the *C*(t)*-integral is equal to the value obtained from two, stressed, identical bodies with infinitesimally differing crack areas. This value is the difference in the stress-power per unit difference in crack area at a fixed value of time and displacement rate, or at a fixed value of time and applied force.

3.2.18.4 *Discussion*—The value of *C*(t)* corresponding to the steady-state conditions is called C^*. Steady-state is said to have been achieved when a fully developed creep stress distribution has been produced around the crack tip. This occurs when secondary creep deformation characterized by Eq 9 dominates the behavior of the specimen.

$$\dot{\varepsilon}_{ss} = A\sigma^n \tag{9}$$

3.2.18.5 *Discussion*—This steady state in C^* does not necessarily mean steady state crack growth rate. The latter occurs when steady state damage develops at the crack tip.

3.2.19 *force-line displacement due to creep, elastic, and plastic strain V [L]* —the total displacement measured at the loading pins (V^{LD}) due to the initial force placed on the specimen at any instant and due to subsequent crack extension that is associated with the accumulation of creep, elastic, and plastic strains in the specimen.

3.2.19.1 *Discussion*—The force-line displacement associated with just the creep strains is expressed as V_c.

3.2.19.2 *Discussion*—In creeping bodies, the total displacement at the force-line, V^{FLD}, can be partitioned into an instantaneous elastic part V_e, a plastic part, V_p, and a time-dependent creep part, V_c (**6**).

$$V \approx V_e + V_p + V_c \tag{10}$$

The corresponding symbols for the rates of force-line displacement components shown in Eq 10 are given respectively as $\dot{V}$, $\dot{V}_e$, $\dot{V}_p$, $\dot{V}_c$. This information is used to derive the parameters C^* and C_t.

3.2.20 *C_t parameter, C_t [$FL^{-1}T^{-1}$]*—parameter equal to the value obtained from two identical bodies with infinitesimally differing crack areas, each subjected to stress, as the difference in stress power per unit difference in crack area at a fixed value of time and displacement rate or at a fixed value of time and applied force for an arbitrary constitutive law (**5**).

3.2.20.1 *Discussion*—The value of C_t is path-independent and is identical to *C*(t)* for extensive creep conditions when the constitutive law described in section 3.1.18.2 of *C*(t)-integral* definition applies.

3.2.20.2 *Discussion*—Under small-scale creep conditions, *C*(t)* is not path-independent and is related to the crack tip stress and strain fields only for paths local to the crack tip and well within the creep zone boundary (**7**). Under these circumstances, C_t, is related uniquely to the rate of expansion