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

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.

ε^1 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

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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 E08.06 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:

$$R = \frac{\text{minimum load}}{\text{maximum load}} = \frac{P_{min}}{P_{max}} \tag{1}$$

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:

$$\Delta P = P_{max} - P_{min} \tag{2}$$

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

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[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 of the creep zone size (**7**). There is considerable experimental evidence that the C_t parameter which extends the *C* (t)-integral* concept into small-scale and the transition creep regime, correlates uniquely with creep crack growth rate in the entire regime ranging from small-scale to extensive creep regimes (**5**).

3.2.20.3 *Discussion*—For a specimen with a crack subject to constant force, P and under a small-scale-creep (**5**):

$$C_t = \frac{P\dot{V}_c}{BW}\,(f'/f) \tag{11}$$

and

$$f' = \frac{df}{d(a/W)} \tag{12}$$

3.2.21 *creep zone boundary*—the locus of points ahead of the crack tip where the equivalent strain caused by the creep deformation equals 0.002 (0.2 %) (**8**).

3.2.21.1 *Discussion*—Under small-scale creep conditions, the creep zone expansion with time occurs under self-similar manner for planar bodies (**9**), thus, the creep zone size, r_c, can be defined as the distance of the creep zone boundary from the crack tip at a fixed angle, θ, with respect to the crack plane. The rate of expansion of the creep zone size is designated as $\dot{r}_c(\theta)$.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *$(C_t)_{avg}$ parameter, $(C_t)_{avg}$ $[FL^{-1}T^{-1}]$*—the average value of the C_t parameter during the hold-time of the cycle and is given by (**1, 2**):

$$(C_t)_{avg} = \frac{1}{t_h}\int_0^{t_h} C_t\,dt \tag{13}$$

where:

t_h = hold-time at maximum load measured from the start of the hold period.

Eq 13 can also be written as:

$$(C_t)_{avg} = \frac{P_{max}(\Delta V_c)}{(BB_N)^{1/2}Wt_h}\,(f'/f) \tag{14}$$

where:

ΔV_c = the difference in the force-line displacement between the end and the start of the hold-time during a cycle (**1**).

3.3.1.1 *Discussion*—The value of $(C_t)_{avg}$ from Eq 14 is appropriate for small-scale creep regime but it's value is identical to the value of *C*(t)* for extensive creep conditions when the constitutive law described in section 3.2.18 is applicable.

3.3.2 *creep-fatigue crack growth rate behavior (CFCGR):*

for creep-ductile materials, this is a plot of the incremental, average time rate of crack growth, $(da/dt)_{avg}$, as a function of $(C_t)_{avg}$.

for creep-brittle materials, this is a plot of incremental crack growth rate per loading cycle, *da/dN*, as a function of the cyclic stress intensity factor, Δ*K*, for constant temperature, hold-time, and force ratio, *R*.

3.3.3 *transition time, t_T [T]*—time required for extensive creep conditions to develop in a cracked body (**9**). For specimens, this is typically the time required for the creep deformation zone to spread through a substantial portion of the uncracked ligament, or in the region that is under the influence of a crack in the case of a finite crack in a semi-infinite medium.

3.3.3.1 *Discussion*—An estimate of transition time for materials that creep according to the power-law can be obtained from the following equation(**9**):

$$t_T = \frac{K^2(1-\nu^2)}{E(n+1)C^*} \tag{15}$$

where:

ν = Poisson's ratio, and

n = secondary creep exponent as in Eq 9.

3.3.4 *force-line compliance (C_{FL})*—the elastic displacement in the specimen along the force-line divided by the force. This value is uniquely related to the normalized crack size of the specimen.

3.3.5 *force line displacement rate due to creep, $\dot{V}_c$ $[LT^1]$*—rate of increase of the force-line displacement due to creep strains.

4. Significance and Use

4.1 Creep-fatigue crack growth testing is typically performed at elevated temperatures over a range of frequencies and hold-times and involves the sequential or simultaneous application of the loading conditions necessary to generate crack tip cyclic deformation/damage enhanced by creep deformation/damage or vice versa. Unless such tests are performed in vacuum or an inert environment, oxidation can also be responsible for important interaction effects relating to damage accumulation. The purpose of creep-fatigue crack growth tests can be to determine material property data for *(a)* assessment input data for the damage condition analysis of engineering structures operating at elevated temperatures, *(b)* material characterization, or *(c)* development and verification of rules for design and life assessment of high-temperature components subject to cyclic service with low frequencies or with periods of steady operation, or a combination thereof.

4.2 In every case, it is advisable to have complementary continuous cycling fatigue data (gathered at the same loading/unloading rate), creep crack growth data for the same material and test temperature(s) as per Test Method E1457, and creep-fatigue crack formation data as per Test Method E2714. Aggressive environments at high temperatures can significantly affect the creep-fatigue crack growth behavior. Attention must be given to the proper selection and control of temperature and environment in research studies and in generation of design data.

4.3 Results from this test method can be used as follows:

4.3.1 Establish material selection criteria and inspection requirements for damage tolerant applications where cyclic loading at elevated temperature is present.

4.3.2 Establish, in quantitative terms, the individual and combined effects of metallurgical, fabrication, operating temperature, and loading variables on creep-fatigue crack growth life.

4.4 The results obtained from this test method are designed for crack dominant regimes of creep-fatigue failure and should not be applied to cracks in structures with wide-spread creep damage. Localized damage in a small zone around the crack tip is permissible, but not in a zone that is comparable in size to the crack size or the remaining ligament size.

5. Functional Relationships

5.1 Empirical relationships that have been commonly used for description of creep-fatigue crack growth data are given in Annex A1. These relationships typically have limitations with respect to material types such as high temperature ferritic and austenitic steels (creep-ductile materials) versus nickel base alloys (typically creep-brittle materials). Therefore, original data should be reported to the greatest extent possible. Data reduction methods should be detailed along with assumptions. Sufficient information should be recorded and reported to permit analysis, interpretation, and comparison with results for other materials analyzed using currently popular methods.

6. Apparatus

6.1 *Testing Machine*—Tests shall be conducted using a servo-controlled tension-compression fatigue machine that has been verified in accordance with Practices E4 and Practice E467. Hydraulic and electromechanical machines are acceptable. The complete loading system comprising force transducer, specimen clevises and test specimen shall have lateral rigidity and be capable of executing the prescribed cycle in force control. It shall be possible to measure the response variable, extension, to the required tolerances. Further, auxiliary equipment for measuring crack size as a function of cycles to the required tolerances shall be available as part of the apparatus.

6.2 *Force Transducer:*

6.2.1 The force transducer shall be designed for tension-compression fatigue testing and shall have high axial and lateral rigidity. Its capacity shall be sufficient to measure the axial forces applied during the test to an accuracy better than 1 % of the reading. The force transducer and its associated electronics shall comply with Practices E4 and Practice E467.

6.2.2 The force transducer shall be temperature compensated and not have zero drift nor sensitivity variation greater than 0.002 % of the full scale per degree Celsius. During test, the force transducer shall be maintained at a temperature within its temperature compensation range. Force transducers are subject to thermal drift in zero point and sensitivity and may be permanently damaged by temperatures in excess of 50°C. Suitable cooling arrangements include forced air cooling of fins at the outer ends of the loading bars or water cooling coils or jackets. Care should be taken to ensure that force transducer calibration and force train alignment are not affected by the presence of the cooling devices.

6.3 *Alignment of Grips*—It is important that attention be given to achieving good alignment in the force-line through careful machining of all gripping fixtures. The length of the force train should be chosen with proper attention to the height of the furnace for heating the test specimen. The loading train should incorporate cooling arrangements to limit heat transfer from the hot zone to the testing machine and in particular the force transducer.

6.4 *Heating Apparatus:*

6.4.1 The apparatus for, and method of, heating the specimens should provide the temperature control necessary to satisfy the requirements in section 9.6.4, without manual adjustments more frequently than once in each 24-h period after force application.

6.4.2 Heating shall be by an electric resistance or radiation furnace with the specimen in air at atmospheric pressure unless other media are specifically agreed upon in advance.

6.5 *Displacement Gage for the Measurement of the Force Line Displacement During the Test:*

6.5.1 Continuous force-line displacement measurement is needed to evaluate the magnitude of $(C_t)_{avg}$ as a function of creep-fatigue cycles during the test in creep-ductile materials. Displacement measurements must be made on the force-line. As a guide, the displacement gage should have a working range no more than twice the displacement expected during the test. Accuracy of the gage should be within ±1 % of the full working range of the gage. In calibration, the maximum deviation of the individual data points from the fit to the data shall not exceed ±1 % of the working range.

NOTE 3—Thermal effects, particularly thermal gradients, can change extensometer output and must be minimized. It is good practice to keep the body of the extensometer outside the furnace unless it is designed to withstand the test temperature.

6.5.2 Knife edges are recommended for friction-free seating of the gage. Parallel alignment of the knife edges must be maintained to within ±1°.

6.5.3 The displacement along the force-line may be directly measured by attaching the entire clip gage assembly to the specimen and placing the whole assembly in the furnace. Alternatively, the displacements can be transferred outside the furnace with ceramic rods. In the latter procedure, the transducer is placed outside the furnace. Other designs that can measure displacements to the same levels of accuracy may also be used.

6.5.4 The extensometer used shall be suitable for measuring force-line displacements over long periods during which there shall be minimal drift, slippage and instrument hysteresis. Extensometers used for measurement shall be suitable for dynamic measurements over periods of time, i.e. should have a rapid response and with a low hysteresis (not greater than 0.1 % of extensometer output). Strain gauge, capacitance gauge, DCDT or LVDT type transducers are generally used and should be calibrated according to Practice E83. The extensometer should meet the requirements of Grade B2 or better as specified by Practice E83.

6.6 *Crack Monitoring:*

6.6.1 A direct current (DCPD) or alternating current (ACPD) electrical potential-drop crack monitoring system must be used. Further details on the attachment of the input and output electrical leads and measurement procedures are given in Annex A2.

NOTE 4—It is good practice to electrically insulate the test specimen (or loading grips) from the test machine loading frame and ancillary equipment in order to avoid unstable potential drop recordings associated with earth loops. However, it is not essential to do so. The contact resistance between the loading pin holes and the pins can provide sufficient electrical insulation.

6.6.2 The DCPD or ACPD system should be capable of reliably resolving crack extensions of at least ±0.1 mm at the test temperature.

6.7 *Temperature Measurement and Control*—Test specimen temperature shall be measured using Class 1 thermocouples in contact with the test specimen surface in the region near the crack plane. In all cases involving the use of thermocouples, it is essential to ensure that intimate thermal contact is achieved between test specimen and thermocouple without affecting the properties of the test specimen. When using furnace heating, thermocouple beads shall be shielded from direct radiation.

NOTE 5—For long duration creep-fatigue tests, the use of Type K thermocouples above 400°C is not recommended. Their use for short duration tests (<500 h) at temperatures up to 600°C is possible, but their re-use is not recommended in these circumstances. Similarly, Type N thermocouples may be used for short duration tests (<500 h) at temperatures up to 800°C, with their re-use not being recommended without recalibration.

6.8 *Cycle Counter*—Standard practice should be to record all cycles in a data acquisition system. As a minimum, a digital device should be used to record the number of cycles applied to the test specimen. Five digits are required. For tests lasting less than 10 000 cycles, individual cycles shall be counted. For longer tests, the device shall have a resolution better than 1 % of the actual life.

6.9 *Data Recording*—An automatic digital recording system should be used which is capable of collecting and simultaneously processing the force, force-line displacement, DCPD or ACPD and temperature data as a function of time and cycles. The sampling frequency of the data shall be sufficient to ensure correct definition of the loading cycle. In particular, it should be sufficient to identify values of load and extension at taming points in the loading diagram, e.g. at cycle maxima and minima, and start and end of hold-time values.

NOTE 6—At least 200 data points should be collected to define the loading and unloading segments of the cycle and an additional 100–200 data points should be collected to fully characterize hold-time duration.

NOTE 7—The simultaneous recording of servo position is also recommended to assist in the retrospective diagnosis of disturbances during test, e.g. extensometer slippage.

7. Test Specimen

7.1 The schematic and dimension of the C(T) specimen is shown in Fig. 1.

NOTE 8—The crack mouth geometry and dimensions and the machine notch and knife edge configuration may be varied from the one in Fig. 1 to adapt to the clip gage chosen for measuring force-line displacements.

7.2 The width-to-thickness ratio *W/B* for the C(T) specimen is recommended to be 4, nominally. Other *W/B* ratios, up to 8, may be used for thickness effect characterization or to reduce forces during the test; it is however important to note that the stress state may vary with thickness.

7.3 The initial crack size, a_0 (including a sharp starter notch or pre-crack), shall be at least 0.25 times the width, *W*, but no

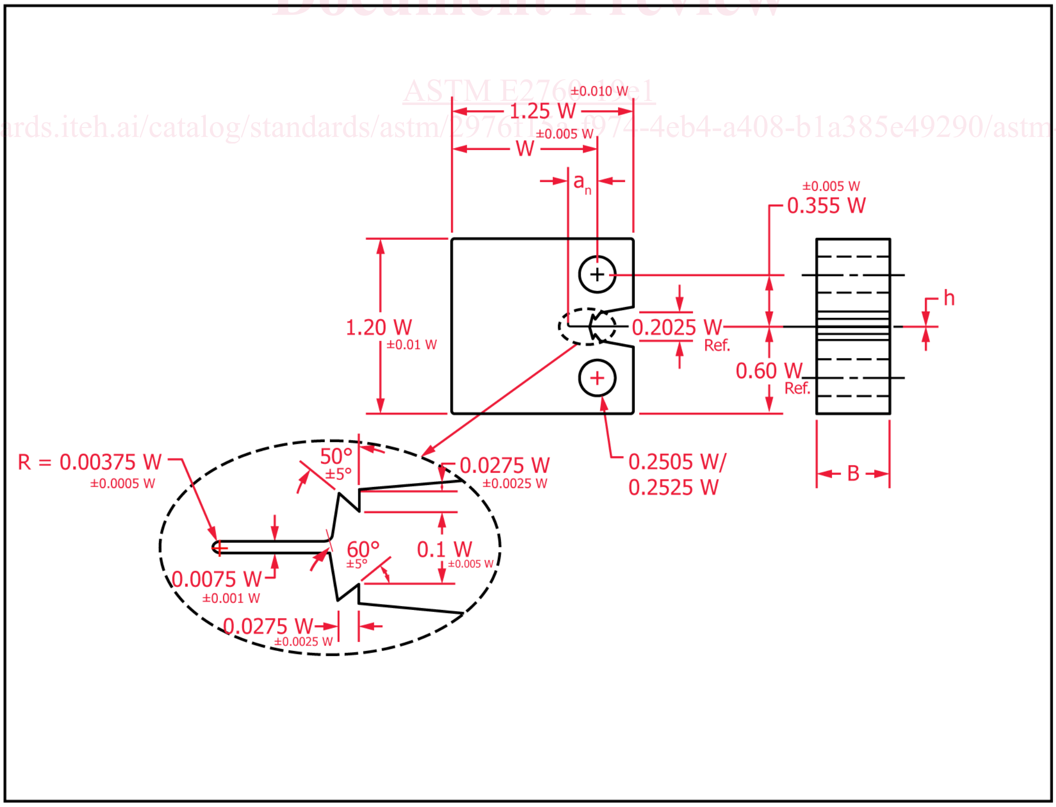

FIG. 1 Drawing of a C(T) Specimen Recommended for Creep-Fatigue Crack Growth Testing and the Details of the Machined Notch and the Knife-Edges for Securely Attaching the Extensometer