~~Designation:E 1457–00~~ Designation: E1457 – 07$^{\varepsilon 2}$

Standard Test Method for Measurement of Creep Crack Growth ~~Rates~~Times in Metals[1]

~~This standard is issued under the fixed designation E 1457; 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.~~

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ε^1 NOTE—Equation 6 was editorially corrected in August 2008.
ε^2 NOTE—Equation A2.3 was editorially corrected in October 2009.

1. Scope

~~1.1This test method covers the determination of creep crack growth rates in metals at elevated temperature using compact type, *C(T)*, (see Fig. 1) specimens subjected to static or quasi-static loading conditions. The time rate of crack growth,~~

1.1 This test method covers the determination of creep crack growth (CCG) in metals at elevated temperatures using pre-cracked specimens subjected to static or quasi-static loading conditions. The time (CCI), $t_{0.2}$ to an initial crack extension $\delta a_i = 0.2$ mm from the onset of first applied force and creep crack growth rate, $\dot{a}$ ~~(t) or *da/dt* is expressed in terms of the magnitude of crack growth rate relating parameters, $C^*(t)$,~~ *or da/dt* is expressed in terms of the magnitude of creep crack growth relating parameters, C^* or *K*. With C^* defined as the steady state determination of the crack tip stresses derived in principal from *C*(t)* and C_t or *K.*

~~1.1.1The choice of the crack growth rate relating parameter, $C^*(t)$, C_t, or *K* depends on the material behavior. Two types of material behavior are generally observed during creep crack growth tests; creep-ductile and creep-brittle. In creep ductile materials, creep crack growth is accompanied by substantial time-dependent creep strains at the crack tip and the crack growth rate is correlated by $C^*(t)$ and/or C_t~~ t (~~**1-4**~~**1-14**).[2] ~~In creep-brittle materials, creep crack growth occurs at low creep ductility. Consequently, the time-dependent creep strains are comparable to or dominated by accompanying elastic strains local to the crack tip. Under such steady state creep-brittle conditions, *K* is chosen as the correlating parameter **(5**~~**The crack growth derived in this manner is identified as a material property which can be used in modeling and life assessment methods (15-25).**

~~1.1.2In creep ductile materials, extensive creep occurs when the entire uncracked ligament undergoes creep deformation. Such conditions are distinct from the conditions of small-scale creep and transition creep **(4, 6**~~

1.1.1 The choice of the crack growth correlating parameter C^*, *C*(t)*, C_t, or *K* depends on the material creep properties, geometry and size of the specimen. Two types of material behavior are generally observed during creep crack growth tests; creep-ductile **(1-14)** ~~. In the case of extensive creep, the region dominated by creep deformation is significant in size in comparison to the crack size and to the uncracked ligament size. In small-scale-creep only a small region of the uncracked ligament near the crack tip experiences creep deformation. The creep crack growth rate in the extensive creep region is correlated by the $C^*(t)$-integral. The~~ *and creep-brittle* **(26-37)**. *In creep ductile materials, where creep strains dominate and creep crack growth is accompanied by substantial time-dependent creep strains at the crack tip, the crack growth rate is correlated by the steady state definitions of* C_t~~*, parameter correlates the creep crack growth rate in the small-scale creep and the transition creep regions and reduces, by definition, to C*(t) in the extensive creep region* **(4**~~t or *C*(t)* , defined as C^* (see 1.1.4). In creep-brittle materials, creep crack growth occurs at low creep ductility. Consequently, the time-dependent creep strains are comparable to or dominated by accompanying elastic strains local to the crack tip. Under such steady state creep-brittle conditions, C_t or *K* could be chosen as the correlating parameter **(8-14)**.

~~1.1.3Only steady-state creep crack growth rate behavior is covered by this method. During steady state, a unique correlation exists between $\dot{a}$ and the appropriate crack growth rate relating parameter. Transient crack growth conditions occur in the early stages of crack growth tests for the whole range of creep brittle/ductile behavior which is excluded by this method.~~

~~1.1.4The state-of-stress at the crack tip may have an influence on the creep crack growth behavior and can cause crack-front tunneling in plane-sided specimens. Specimen size and geometry also will affect the state-of-stress at the crack tip and are~~

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[1] This test method is under the jurisdiction of ASTM Committee E08 on ~~Fracture~~ Fatigue and Fracture and is the direct responsibility of Subcommittee E08.06 on Crack Growth Behavior.

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

~~important factors in determining crack growth rate.~~

~~1.1.5The recommended specimen is the standard compact tension specimen *C(T)* with *B/W* =0.5 and pin loaded in tension under constant loading conditions, Fig. 1. The specimen configuration has fixed planar dimensional proportionality with an initial normalized crack size, a_o /W, of 0.45 to 0.55. Side-grooved specimens are recommended to promote uniform crack extension across the thickness of the specimen (7~~

1.1.2 In any one test, two regions of crack growth behavior may be present (**9, 10**). The initial transient region where elastic strains dominate and creep damage develops and in the steady state region where crack grows proportionally to time. Steady-state creep crack growth rate behavior is covered by this standard. In addition specific recommendations are made in 11.7 as to how the transient region should be treated in terms of an initial crack growth period. During steady state, a unique correlation exists between *da/dt* and the appropriate crack growth rate relating parameter.

1.1.3 In creep ductile materials, extensive creep occurs when the entire uncracked ligament undergoes creep deformation. Such conditions are distinct from the conditions of small-scale creep and transition creep (**1-7**). In the case of extensive creep, the region dominated by creep deformation is significant in size in comparison to both the crack length and the uncracked ligament sizes. In small-scale-creep only a small region of the uncracked ligament local to the crack tip experiences creep deformation.

1.1.4 The creep crack growth rate in the extensive creep region is correlated by the $C^*(t)$-integral. The C_t parameter correlates the creep crack growth rate in the small-scale creep and the transition creep regions and reduces, by definition, to $C^*(t)$ in the extensive creep region (**5**). Hence in this document the definition C^* is used as the relevant parameter in the steady state extensive creep regime whereas $C^*(t)$ and/or C_t are the parameters which describe the instantaneous stress state from the small scale creep, transient and the steady state regimes in creep. The recommended functions to derive C^* for the different geometries is shown in Annex A1 is described in Annex A2.

~~1.1.6Residual stresses can influence the measurement of crack growth properties (8~~

1.1.5 An engineering definition of an initial crack extension size δa_i is used in order to quantify the initial period of crack development. This distance is given as 0.2 mm. It has been shown (**38-40**) ~~. The effect can be significant when test coupons are taken from material that characteristically embodies residual stress fields; for example weldments, and/or thick cast, forged, extruded, products and product shapes where full stress relief is impractical. Specimens taken from such products that contain residual stresses will likewise themselves contain residual stresses. Extraction of specimens in itself partially relieves and redistributes the residual stress pattern, however, the remaining magnitude can still cause significant effects in the ensuing test. Residual stress is superimposed on applied stress and results in crack-tip stress intensity that is different from that based solely on externally applied forces or displacements. Distortion during specimen machining often indicates the presence of residual stresses. No allowance is included in this standard for dealing with residual stresses.~~ that this period which exists at the start of the test could be a substantial period of the test time. During this early period the crack tip undergoes damage development as well as redistribution of stresses prior reaching steady state. Recommendation is made to correlate this initial crack growth period defined as $t_{0.2}$ at $\delta a_i = 0.2$ mm with the steady state C^* when the crack tip is under extensive creep and with K for creep brittle conditions. The values for C^* and K should be calculated at the final specified crack size defined as $a_o + \delta a_i$ where a_o initial size of the starter crack.

1.1.6 The recommended specimens for CCI and CCG testing is the standard compact tension specimen C(T) (see Fig. A1.1) which is pin-loaded in tension under constant loading conditions. The clevis setup is shown in Fig. A1.2 (see 7.2.1 for details). Additional geometries which are valid for testing in this procedure are shown in Fig. A1.3. These are the C-ring in tension CS(T), middle tension M(T), single notch tension SEN(T), single notch bend SEN(B), and double edge notch bend tension DEN(T). In Fig. A1.3, the specimens' side-grooving position for measuring displacement at the force-line (FLD) crack mouth opening displacement (CMOD) and also and positions for the potential drop (PD) input and output leads are shown. Recommended loading for the tension specimens is pin-loading. The configurations, size range and initial crack size and their extent of side-grooving are given in Table A1.1 of Annex A1, (**40-44**). Specimen selection will be discussed in 5.9.

1.1.7 ~~Specimen configurations other than the *C(T)* specimen tested under constant load may involve validity requirements different from those presently specified in this test method. Nevertheless, use of geometries other than *C(T)* are permitted by this method provided data are compared to data obtained from *C(T)* specimens. Other specimens used in creep crack growth testing include the Single Edge Notch Bend *(SENB)* specimen, Single Edge Notch Tension *(SENT)* specimen, Middle Cracked Tension *M(T)* specimen.~~ The state-of-stress at the crack tip may have an influence on the creep crack growth behavior and can cause crack-front tunneling in plane-sided specimens. Specimen size, geometry, crack length, test duration and creep properties will affect the state-of-stress at the crack tip and are important factors in determining crack growth rate. A recommended size range of test specimens and their side-grooving are given in Table A1.1 in Annex A1. It has been shown that for this range the cracking rates do not vary for a range of materials and loading conditions (**40-44**). Suggesting that the level of constraint, for the relatively short term test durations (less than one year), does not vary within the range of normal data scatter observed in tests of these geometries. However it is recommended that, within the limitations imposed on the laboratory, that tests are performed on different geometries, specimen size, dimensions and crack size starters. In all cases a comparison of the data from the above should be made by testing the standard *C(T)* specimen where possible. It is clear that increased confidence in the materials crack growth data can be produced by testing a wider range of specimen types and conditions as described above.

1.1.8 Material inhomogenities, residual stresses and material degradation at temperature, specimen geometry and low-force long duration tests (mainly greater that one year) can influence the rate of crack growth properties **(39-47)**. In cases where residual stresses exist, the effect can be significant when test specimens are taken from material that characteristically embodies residual stress fields or the damaged material. For example weldments, and/or thick cast, forged, extruded, components, plastically bent components and complex component shapes where full stress relief is impractical. Specimens taken from such component that contain residual stresses will likewise contain residual stresses which may have altered is their extent and distribution due to specimen fabrication. Extraction of specimens in itself partially relieves and redistributes the residual stress pattern; however, the remaining magnitude can still cause significant effects in the ensuing test. Residual stress is superimposed on applied stress and results in crack-tip stress intensity that is different from that based solely on externally applied forces or displacements. Distortion during specimen machining can also indicate the presence of residual stresses.

1.1.9 Stress relaxation of the residual stresses due to creep and crack extension should also be taken into consideration. No specific allowance is included in this standard for dealing with these variations. However the method of calculating C^* presented in this document which used the specimen's creep displacement rate to estimate C^* inherently takes into account the effects described above as reflected by the instantaneous creep strains that have been measured. However extra caution should still be observed with the analysis of these types of tests as the correlating parameters K and C^* shown in Annex A2 even though it is expected that stress relaxation at high temperatures could in part negate the effects due to residual stresses.

1.1.10 Specimen configurations and sizes other than those listed in Table A1.1 which are tested under constant force will involve further validity requirements. This is done by comparing data from recommended test configurations. Nevertheless, use of other geometries are applicable by this method provided data are compared to data obtained from standard specimens (as identified in Table A1.1) and the appropriate correlating parameters have been validated.

1.2 The values stated in SI units are to be regarded as the standard. The inch-pound units given in parentheses are for information only.

1.3 *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:*~~ *Scope of Material Properties Data Resulting from This Standard*

2.1 This test method covers the determination of initial creep crack extension (CCI) times and growth (CCG) in metals at elevated temperature using pre-cracked specimens subjected to static or quasi-static loading conditions. The metallic materials investigated range from creep-ductile to creep-brittle conditions.

2.2 The crack growth rate $\dot{a}$ or *da/dt* is expressed in terms of the magnitude of CCG rate relating parameters, $C^*(t)$, C_t or K. The resulting output derived as $\dot{a}$ v C^* (as the steady state formulation of $C^*(t)$, C_t for creep-ductile materials or as $\dot{a}$ v K (for creep-brittle materials) is deemed as material property for CCG.

2.3 In addition for CCI derivation of crack extension time $t_{0.2}$ v C^* (for creep-ductile materials) or $t_{0.2}$ v K (for creep-brittle materials) can also be used as a material property for the purpose of modeling and remaining life assessment.

2.4 The output from these results can be used as 'Benchmark' material properties data which can subsequently be used in crack growth numerical modeling, in component design and remaining life assessment methods.

3. Referenced Documents

3.1 *ASTM Standards:*[3]

E4 Practices for Force Verification of Testing Machines
E74 Practice ~~for~~of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines
E83 Practice for Verification and Classification of Extensometer Systems
E139 ~~Practice~~ Test Methods for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials
E220 Test Method for Calibration of Thermocouples ~~by~~By Comparison Techniques
E399 Test Method for Linear-Elastic Plane-Strain Fracture Toughness K_{Ic} of Metallic Materials
E647 Test Method for Measurement of Fatigue Crack Growth Rates
E1820~~Standard Test Method for Measurement of Fracture Toughness~~
813 Test Method for JIc, A Measure of Fracture Toughness
E1152 Test Method for Determining-J-R-Curves
E1820 Test Method for Measurement of Fracture Toughness
E1823 ~~Terminology Relating to Fracture Testing~~~~[3]~~

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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* ~~, Vol 03.01.~~volume information, refer to the standard's Document Summary page on the ASTM website.

~~3.~~Terminology Relating to Fatigue and Fracture Testing

4. Terminology

~~3.1*Definitions*:~~

~~3.1.1Terminology related to fracture testing contained in Terminology E 1823E 1823 is applicable to this test method.~~

~~3.2*Definitions of Terms Specific to This Standard:*~~

~~3.2.1C*(t)—Integral, C*(t) [FL^{-1}~~

4.1 Terminology related to fracture testing contained in Terminology E1823 is applicable to this test method. Additional terminology specific to this standard is detailed in 4.2. For clarity and easier access within this document some of the terminology in E1823 relevant to this standard is repeated below (see Terminology E1823, for further discussion and details).

4.1.1 *crack-plane orientation*—an identification of the plane and direction of fracture test specimen in 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.

4.1.2 *J-integral, J* $[FL^{-1}]$—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 field around the crack front.

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

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

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

4.1.6 *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.

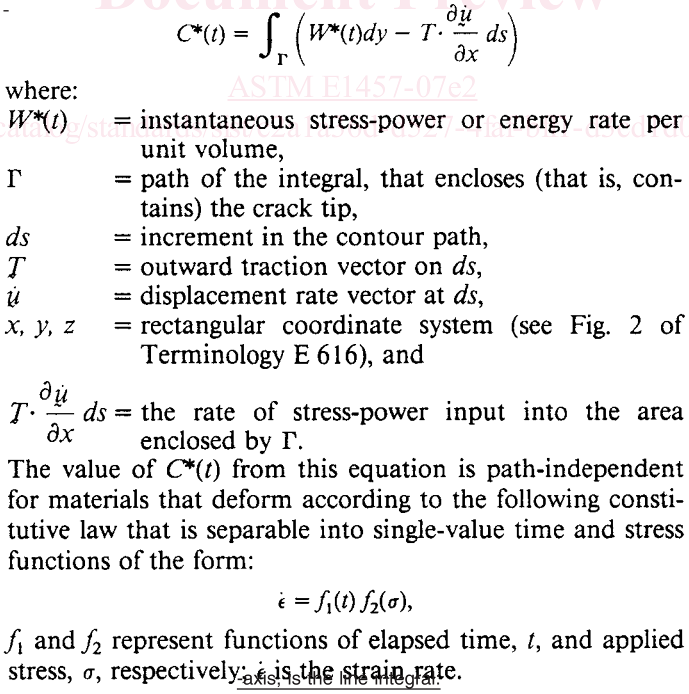
4.1.7 *stress intensity factor, K* $[FL^{-3/2}]$—the magnitude of the ideal crack tip stress field (a stress-field singularity) for Mode 1 in a homogeneous, linear-elastic body.

4.1.8 *yield strength,* σ_{YS} $[FL^{-2}]$—the stress at which the material exhibits a deviation equal to a strain of 0.02 % offset from the proportionality of stress to strain.

4.2 *Definitions of Terms Specific to This Standard:*

4.2.1 C*(t)-integral, C*(t) $[FL^{-1}T$ ~~$^{-1}$~~$^{-1}$~~], a~~ $]$—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.

~~3.2.1.1~~4.2.1.1 *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:~~



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

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,
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 (see Fig. 2 of Terminology E 616), and
$T \cdot \frac{\partial \dot{u}}{\partial x} ds$ = the rate of stress-power input into the area enclosed by Γ.

The value of $C^*(t)$ from this equation is path-independent for materials that deform according to the following constitutive law that is separable into single-value time and stress functions of the form:

$$\dot{\epsilon} = f_1(t) f_2(\sigma),$$

f_1 and f_2 represent functions of elapsed time, t, and applied stress, σ, respectively; $\dot{\epsilon}$ is the strain rate.

-axis, is the line integral:

$$C^*(t)=\int_\Gamma \left(W^*(t)dy - T \cdot \frac{\partial \dot{u}}{\partial x} ds \right) \quad (1)$$

W*(t)

Γ

ds
T
$\dot{u}$
x, y, z

~~3.2.1.2~~

$$T \cdot \frac{\partial \dot{u}}{\partial x} \partial s \tag{2}$$

is the rate of stress-power input into the area enclosed by Γ across the elemental length *ds*. The value of $C^*(t)$ from this equation is path-independent for materials that deform according to the following constitutive laws that may be separated into single-value time and stress functions or strain and stress functions of the forms:

$$\dot{\varepsilon} = f_1(t) f_2(\sigma) \tag{3}$$

$$\dot{\varepsilon} = f_3(\varepsilon) f_4(\sigma) \tag{4}$$

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.

4.2.1.2 *Discussion*—For materials exhibiting creep deformation for which the above equation is path-independent, the ~~$C^*(t)$-integral~~$C^*(t)$-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.

~~3.2.1.3~~4.2.1.3 *Discussion*—The value of C~~$*(t)$~~ $*(t)$ corresponding to the steady-state conditions is called C~~$_s$~~*. Steady-state is said to have been achieved when a fully developed creep stress distribution has been produced around the crack tip.

~~3.2.2C_t—Parameter,~~

4.2.1.4 *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. This behavior is observed as 'tails' at the early stages of crack growth. This standard deals with this region as the initial crack extension period defined as time, $t_{0.2}$, measured for an initial crack growth of 0.2 mm after first loading (see 11.8.8 for further details).

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

~~3.2.2.1~~*]*—a parameter equal to the value obtained from the difference in stress-power from two identical bodies with infinitesimally differing crack areas at a fixed value of time increment and displacement rate, or a fixed time increment applied force. This applies for any arbitrary constitutive law.

4.2.1.6 *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 3.2.1~~ t is path-independent and is appropriate to small-scale creep and the transition creep regimes and is identical to $C^*(t)$ for extensive creep conditions when the constitutive law described in 4.2.1 applies.

~~3.2.2.2~~

4.2.1.7 *Discussion*—Under small-scale creep conditions, C~~$*(t)$~~ $*(t)$ 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 (see section 3.2.3 for definition).~~ boundary. Under these circumstances, $C_t$is related uniquely to the rate of expansion of the creep zone size ~~**(9, 10**~~**(10-12)**. There is considerable experimental evidence that the $C_t$parameter ~~**(4, 7,**~~ **(5, 8, 10)** ~~which extends the $C^*(t)$-integral concept into the small-scale creep and the transition creep regimes and is equal to $C^*(t)$ in the extensive creep regime, correlates uniquely with creep crack growth rate in the entire regime ranging from small-scale to extensive creep regime.~~

~~3.2.3*creep zone boundary*—the creep zone boundary is defined as the locus of points ahead of the crack front where the equivalent strain caused by the creep deformation equals 0.002 (0.2%) **(11**~~**correlates uniquely with creep crack growth rate in the entire regime ranging from small-scale to extensive creep regime.**

4.2.2 *creep zone boundary, r_c*—the locus of points ahead of the crack front where the equivalent strain caused by the creep deformation equals 0.002 (0.2 %) **(13)**.

~~3.2.3.1~~

4.2.2.1 *Discussion*—Under small-scale creep conditions, the creep zone expansion with time occurs in a self-similar manner ~~**(6**~~**(7)** thus, the creep zone size, r_c, can be defined as the distance to the creep zone boundary from the crack tip at a fixed angle θ with respect to the crack plane.

~~3.2.4*crack size*—a [L]-in this test method, the physical crack size is represented as~~

4.2.3 *crack size, a [L]*—in this test method, the physical crack size is represented as a_p. The subscript, p, is everywhere implied ~~(see Terminology E 1823E 1823).~~

~~3.2.5*crack-plane orientation*—an identification of the plane and direction of a crack growth test specimen in 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 (see Terminology E 1823E 1823 for further discussion).~~

~~3.2.6*creep crack growth behavior*—a plot of the time rate of crack growth, *da/dt*, as a function of $C^*(t)$,~~ *p*. The subscript, *p*, is everywhere implied (see Terminology E1823). a_o is defined as the initial crack size.

4.2.4 *creep crack growth (CCG) rate*—a plot of the incremental time rate of crack growth, $\dot{a}$ or *da/dt*, as a function of $C^*(t)$, C_t, or *K*.

~~3.2.7*J-integral,* $J(FL^{-1})$—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 field around the crack front (see Terminology E 1823E 1823, for further discussion).~~

~~3.2.8*load-line displacement due to creep,* V_c[L]—additional displacement at the loading pins due to the crack that is directly associated with the accumulation of creep strains.~~

~~3.2.8.1~~

4.2.5 *force-line displacement due to creep, elastic and plastic strain, V [L]*—the total displacement measured at the loading pins (V^{FLD}) due to the initial force placed on the specimen and the subsequent crack extension that is associated with the accumulation of creep strains during tests. It can also be defined as the displacement at the crack mouth opening (V^{CMOD}). The details of these two methods for deriving the displacement rates are described in 11.4.

4.2.5.1 *Discussion*~~—In creeping bodies, additional loadpoint displacement caused by crack, *V*, can be partitioned into an instantaneous part,~~ *—In creeping bodies, the total displacement V*, at either V^{FLD} or V^{CMOD} can be partitioned into an instantaneous elastic part V_i~~,~~ and a time-dependent creep part, *e*, a plastic part, V_e~~.~~

~~(1) $V = Vip$, and a time-dependent creep part V_c where:~~

~~(5) $V = Ve + Vp + Vc$~~

~~(1) $V = Vip$, and a time-dependent creep part V_c where:~~

~~(5) $V = Ve + Vp + Vc$~~

~~3.2.8.2*Discussion*—the symbol for the rate of load-line displacement related to creep is called~~ *E1457-07E02_5*

The corresponding symbols for the rates of force-line displacement components shown in Eq 5 are given respectively as $\dot{V}$, $\dot{V}_e$, $\dot{V}_p$, $\dot{V}_c$. *This information is used to derive the parameter* C^*. See Section 11.

~~3.2.9*net thickness,* $B_N[L]$—distance between the roots of the side grooves in side grooved specimens.~~

~~3.2.10*original crack size* a_o *(L)*—the physical crack size at the start of testing.~~

~~3.2.11*specimen thickness, B[L]*—distance between sides of the specimen.~~

~~3.2.12*specimen width, W[L]*—distance from the reference plane to the back surface of the specimen. The reference plane in *C(T)* specimens is the plane normal to the sides containing the load-line.~~

~~3.2.13*stress intensity factor,* $K[FL^{-3/2}]$—the magnitude of the ideal crack tip stress field (a stress-field singularity) for Mode 1 in a homogeneous, linear-elastic body (see Terminology E 1823E 1823, for further discussion).~~

~~3.2.14~~

4.2.5.2 *Discussion*—For the set of specimens in Annex A1, Table A1.1 for creep ductile material where creep strains dominate and in which test times are longer (usually >1000 h), the elastic and plastic displacement rate components are small compared to the creep and therefore it is recommended to use the total displacement rate $\dot{V}$ assuming that $\dot{V}_c \approx \dot{V}$ to derive the steady state C^*. See Section 11 for detailed discussion.

4.2.6 *initial crack extension increment (CCI) after full force-up,* δa_i *[L]*—the recommended time taken to crack extension of $\delta a_i = 0.2$ mm after first application of force for defining a crack growth period $t_{0.2}$ in hours as a function of $C^*(t)$, C_t, or *K* value taken. at crack length $a_o + \delta a_i$ 0.2 mm.

4.2.7 *initial crack time to 0.2 mm,* $t_{0.2}$ *[T]*—the time to $\delta a_i = 0.2$ mm (0.008 in.) of crack extension δa by creep after full loading. This size is chosen as the limit of accuracy set for crack extension measurements in laboratory geometries.

4.2.8 *transition time, t*~~$_T$~~*T [T]*~~—time required for extensive creep conditions to develop in a cracked body. For test specimens, this is typically the time required for the zone of creep deformation to spread through a substantial portion of the uncracked ligament, or in the region which is under the influence of a crack in the case of a finite crack in a semi-infinite medium.~~

~~3.2.15*yield strength,* $\sigma_{YS}[FL^{-2}]$ —the stress at which the material exhibits a deviation equal to a strain of .002 from the proportionality of stress to strain.~~

~~3.2.16*crack initiation period,* $t_o[T]$—the time prior to first 0.2 mm (.008 in) of crack extension by creep.~~

~~4.~~—time required for extensive creep conditions to develop in a cracked body. 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 which is under the influence of a crack in the case of a finite crack in a semi-infinite medium. This limit is employed to validate the steady state correlating parameter *C. See 11.8.1 for details.**

5. Summary of Test Method

~~4.1The objective of creep crack growth testing is the determination of the relationship between the time rate of crack growth, *da/dt*, due to creep and the applied value of the appropriate crack growth rate relating parameter as stated in 1.1.1. This test method~~

~~involves loading of sharply notched specimens or fatigue pre-cracked specimens heated to the test temperature by means of a suitable furnace. The applied force is either held constant with time or is changed slowly enough to be considered quasi-static. The crack size and load-line displacements are continuously recorded, digitally or autographically on strip-chart recorders, as a function of time. The temperature must be monitored to ensure that it remains constant within allowable limits during the test. If servomechanical loading systems are used to maintain constant force, or if tests are conducted under conditions other than constant force, a record of force versus time also must be maintained.~~

~~4.2The force, load-line displacement and crack size data are numerically processed as discussed later to obtain the crack growth rate versus $C^*(t)$,~~

5.1 The main objective of creep crack growth testing is the determination of the relationship between the time and rate of crack growth, *da/dt*, due to creep and the applied value of the appropriate crack growth rate relating parameter. In addition results for time to crack extension of 0.2 mm at force-up (CCI) as defined in 1.1.5 are also correlated from the experimental data. This test method involves loading of sharply notched by means of EDM or fatigue pre-cracked specimens (see 8.8), using the recommended geometries, heated to the test temperature by means of a suitable furnace. The applied force is either held constant with time or is changed slowly enough to be considered quasi-static. The temperature must be constantly monitored to ensure that it remains at the specified level within allowable limits during the test. If servo-mechanical loading systems are used to maintain constant force, or if tests are conducted under conditions other than constant force, a record of force versus time also must be maintained.

5.2 Three different loading methods are available for creep crack growth testing. Dead weight loading is the recommended method and is the most commonly used method for loading specimens. In addition, constant displacement **(26)** and constant displacement rate **(1-4, 36)** loading may also be used but are only recommended when working with extremely brittle materials. For tests conducted under conditions other than dead-weight loading, the user must compare the results and verify the analysis to data and analysis from tests performed under dead-weight loading conditions.

5.3 It is recommended to carry out long term tests (at least >1000 h and usually, if possible, between 5000 to 10 000 h) in order to reduce crack tip plasticity which would occur at higher forces and allow for steady state creep cracking to take place. Large forces should be avoided since this will induce either fast fracture or extensive deformation due to creep or plastic collapse and/or rupture, thus rendering the crack growth test as void. Data from fast test are usually not appropriate for life assessment purposes as they may not reflect the stress state of the component at the crack-tip.

5.4 The crack size and force-line displacements are continuously recorded, digitally or autographically on strip-chart recorders, as a function of time. The force, force-line displacement and crack size data are numerically processed as discussed later to obtain the crack growth rate versus $C^*(t)$, C_t or Krelationship.

~~4.3Three different loading methods are available for creep crack growth testing. Dead weight loading is highly recommended and is the most commonly used method for loading specimens. In addition, constant displacement **(12**~~

5.5 Data scatter that is usually present in creep crack growth experiments **(40, 42, 48, 49)**~~and constant displacement rate **(1, 3**~~**. This will indicate that more than one test should be performed to gain confidence in the results. The number of specimens to be tested is dependent on a number of factors (49)** ~~**loading may also be used but are only recommended when working with extremely brittle materials. For tests conducted under conditions other than dead-weight loading, the user must compare the results and verify the analysis to data and analysis from tests performed under dead-weight loading conditions.**~~

~~**5.**~~**such as the number of test variables (specimen type, size, dimension, crack size, force, CCI and CCG range and material batches) being considered. In general it is recommended for the range of conditions that a minimum of five tests at different forces should be performed to produce overlapping crack growth data over the region of CCG rate of interest. Additional repeat tests would be preferable, but not compulsory, to improve confidence in the derived data range.**

5.6 If the material exhibits such factors as irregular grain sizes and voids, weld (X-weld, HAZ) and other inhomogenities the minimum number of tests should be increased (see 5.5). Also, more tests should be performed if the material creep crack growth behavior exhibits increased scatter regardless of the reason for the variability. If there is insufficient material available or if there are other reasons which would restrict multiple testing then the results should be considered with increased caution.

5.7 In some cases crack growth information is needed for the initial start of the test where steady state cracking has not been reached. Also this period coincides with the limit of accuracy in crack growth measurement (recommended as 0.2 mm see 1.1.2 **(32)**). The data produced for (CCI) will therefore be one point per test (similar to uniaxial rupture tests). Hence more tests would be needed to accommodate the variability in the results. The minimum number of tests recommended will depend on the level of scatter, but should not be less than 5 tests which should also uniformly cover test times of interest.

5.8 *Specimen Selection*—For all cases attention must be given to the proper selection of specimen. The C(T) is always the primary choice as there is ample reference in the literature to the testing and analysis of this geometry.

5.9 The choice of specimen should reflect a number of factors. These priorities can be listed as follows:

5.9.1 Availability and the size of material prepared for testing indicates the number of specimens that can be tested.

5.9.2 Material creep ductility and stress sensitivity; for creep brittle specimens the C(T) is recommended.

5.9.3 Capacity of the test rig; the 3-point bend specimens and the C(T) specimens will typically take lower forces.

5.9.4 Type of loading (tension, bending, tension/bending) should be taken into consideration.

5.9.5 Compatibility with size and stress state of the specimen with the component under investigation.

5.9.6 Following a test if the crack front is substantially leading in the centre the indications are that constraint should be increased. If the crack front is substantially receding at the centre the opposite applies-This can be remedied by changing the size, thickness, side-grooving or the geometry of the specimen used for testing. See 8.3.

5.9.7 The length of time and temperature of testing; this will dictate the size, the applied force, initial crack size and side-grooving of the specimen.

5.9.8 *Discussion*—It is unlikely that all conditions for material selection can be satisfied at any one time. The main priority is to produce a test environment for stable crack growth to occur under steady state conditions. Therefore compromises may need to be made. This document goes part of the way to assist the user in this choice by identifying specific detail of a number of geometries. The appropriate decision may, however, need expert advice in the relevant field or industry.

6. Significance and Use

~~5.1Creep~~6.1 Creep crack growth rate expressed as a function of ~~C*(t)-integral,~~ *the steady state* C~~*(t),~~* or *K*~~-~~characterizes the resistance of a material to crack growth under conditions of extensive creep deformation or under brittle creep conditions. Background information on the rationale for employing the fracture mechanics approach in the analyses of creep crack growth data is given in (**~~7~~8, ~~9~~10, ~~13, 14~~27-32**).

~~5.1.1Aggressive~~6.2 Aggressive environments at high temperatures can significantly affect the creep 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.

~~5.1.2Expressing~~ *6.2.1 Expressing CCI time,* $t_{0.2}$ and CCG rate, *da/dt* as a function of an appropriate ~~crack growth rate relating~~ fracture mechanics related parameter, as discussed in ~~section 1.1.1~~11.8~~,~~ generally provides results that are independent of specimen size and planar geometry for the same stress state at the crack tip for the range of geometries and sizes presented in this document (see Annex A1). Thus, the appropriate correlation will enable exchange and comparison of data obtained from a variety of specimen configurations and loading conditions. Moreover, this feature enables creep crack growth ~~rate~~ data to be utilized in the design and evaluation of engineering structures operated at elevated temperatures where creep deformation is a concern. The concept of similitude is assumed, implying that cracks of differing sizes subjected to the same nominal *C*~~*(t),~~ **(t),* C_t, or *K* will advance by equal increments of crack extension per unit time, provided the conditions for the validity for the ~~specific(s)~~specific crack growth rate relating ~~parameter(s)~~parameter are met. See 11.7 for details.

~~5.1.3The~~6.2.2 The effects of crack tip constraint arising from variations in specimen size, geometry and material ductility can influence $t_{0.2}$ and *da/dt*. For example, crack growth rates at the same value of *C*~~*(t),~~ **(t),* C_t in creep-ductile materials generally increases with increasing thickness. It is therefore necessary to keep the component dimensions in mind when selecting specimen thickness, geometry and size for laboratory testing.

~~5.1.4Different~~6.2.3 Different geometries as mentioned in ~~1.1.7~~1.1.6 may have different size requirements for obtaining geometry and size independent creep crack growth rate data. It is therefore necessary to account for these factors when comparing *da/dt* data for different geometries or when predicting component life using laboratory data. For these reasons, the scope of this standard is restricted to the use of ~~C(T)~~ *specimens* ~~*and a full set of*~~ *shown in Annex A1 and the validation* ~~*conditions*~~*criteria for* ~~*this specimen is specified. If other specimen geometries such as the ones mentioned in 1.1.7*~~ *these specimens are specified in 11.2.3 and 11.7. However if specimens other than the C(T) geometry are used for generating creep crack growth data, then the da/dt* data obtained ~~must~~ should, if possible, be compared against test data derived from the standard C(T) ~~tests.~~ tests in order to validate the data.

~~5.1.5Creep~~6.2.4 Creep cracks have been observed to grow at different rates at the beginning of tests compared with the rates at equivalent *C*~~*(t),~~ **(t),* C_t or *K*values for cracks that have sustained previous creep crack extension (**~~15~~(9, 10**). This region is identified as 'tail'. The duration of this transient condition, 'tail', varies with material and initially applied force level. These transients are due to rapid changes in the crack tip stress fields after initial elastic loading and/or due to an initial period during which a creep damage zone evolves at the crack tip and propagates in a self-similar fashion with further crack extension (**~~16~~9, 10**)~~.~~ ~~The steady-state crack extension which follows this period is characterized by a unique *da/dt* versus C*(t),~~ *. This region is separated from the steady-state crack extension which follows this period and is characterized by a unique da/dt* versus *C*(t),* C_t or *K* relationship. ~~The~~This transient region, especially in creep-brittle materials, can be present for a substantial fraction of the overall life (**~~17~~32**)~~. Criteria are provided in this standard to separate the transient and steady-state portions of creep crack growth.~~

~~5.2Results from this test method can be used as follows:~~

~~5.2.1Establish the influence of creep crack growth on component life under conditions of sustained loading at elevated temperature wherein creep deformation may occur provided that the experimental data are generated under representative loading and stress-state conditions and combined with appropriate fracture or plastic collapse criterion, defect characterization data, and stress analysis information (**18**~~**. Criteria are provided in this standard to quantify this region as an initial crack growth period (see 1.1.5) and to use it in parallel with the steady state crack growth rate data. See 11.8.8 for further details.**

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

6.3.1 Establish predictive models for crack incubation periods and growth using analytical and numerical techniques (**15-19**).

~~5.2.2Establish material selection criteria and inspection requirements for damage tolerant applications.~~

~~5.2.3Establish, in quantitative terms, the individual and combined effects of metallurgical, fabrication, operating temperature,~~

~~and loading variables on creep crack growth life.~~

~~5.3The results obtained from this test method are designed for crack dominant regimes of creep failure and should not be applied to cracks in structures with wide-spread creep damage around the crack. 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. Creep damage for the purposes here is defined by the presence of grain boundary cavitation.~~

~~6.~~

6.3.2 Establish the influence of creep crack development and growth on remaining component life under conditions of sustained loading at elevated temperatures wherein creeps deformation might occur **(20-25)**.

NOTE 1—For such cases, the experimental data must be generated under representative loading and stress-state conditions and combined with appropriate fracture or plastic collapse criterion, defect characterization data, and stress analysis information.

6.3.3 Establish material selection criteria and inspection requirements for damage tolerant applications.

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

6.4 The results obtained from this test method are designed for crack dominant regimes of creep failure and should not be applied to cracks in structures with wide-spread creep damage which effectively reduces the crack extension to a collective damage region. 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. Creep damage for the purposes here is defined by the presence of grain boundary cavitation. Creep crack growth is defined primarily by the growth of intergranular time-dependent cracks. Crack tip branching and deviation of the crack growth directions can occur if the wrong choice of specimen size, side-grooving and geometry is made (see 8.3). The criteria for geometry selection are discussed in 5.8.

7. Apparatus

~~6.1~~

7.1 *Testing Machine*~~:~~

~~6.1.1Dead-weight or servo-mechanical loading machines capable of maintaining a constant force or maintaining constant displacement rates in the range of 10~~—This standard does not recommend a specific type of testing equipment. It does however specify accuracy limits for the test equipment and suggestions for the types of equipment that could be used to achieve the accuracy limits specified.

7.1.1 Dead-weight or servo-mechanical loading machines capable of maintaining a constant force or maintaining constant displacement rates in the range of 10^{-5} to 1 mm/h can be used for creep crack growth testing. If servo-hydraulic machines are used under constant force conditions, the force must be monitored continuously and the variations in the indicated force must not exceed ±1.0 % of the nominal value at any time during the test. If either constant displacement rate or constant displacement is used, the indicated displacement must be within 1 % of the nominal value at any given time during the test.

~~6.1.2The~~7.1.2 The accuracy of the testing machine shall be within the permissible variation specified in Practice ~~E 4~~E4.

~~6.1.3If lever-type, dead-weight creep machines are used, it is preferable that they automatically maintain the lever arm in a horizontal position. If such a device is not available, the lever arm should be manually adjusted at such intervals so that the arm position at any time does not deviate from the horizontal by an amount leading to 1%, variation of force on the specimen.~~

~~6.1.4Precautions should be taken to ensure that the force on the specimen is applied as nearly axial as possible.~~

~~6.2*Grips and Fixtures for C(T) Specimens*:~~

~~6.2.1Clevis assemblies (see Fig. 2) shall be incorporated in the load train at both the top and bottom of the specimen to allow in-plane rotation as the specimen is loaded.~~

~~6.2.2Suggested proportions and critical tolerances of the clevis are given (see Fig. 2) in terms of the specimen width, *W*~~

7.1.3 If lever-type, dead-weight creep machines are used, it is preferable that they automatically maintain the lever arm in a horizontal position. If such a device is not available, the lever arm should be manually adjusted at such intervals so that the arm position at any time does not deviate from the horizontal by an amount leading to 1 %, variation of force on the specimen.

7.1.4 Precautions should be taken to ensure that the force on the specimen is applied as nearly axial as possible.

7.2 *Grips and Fixtures* for specimens listed in Annex A1: It is allowed to deviate from the recommended testing apparatus as long as the relevant accuracies and loading conditions are adhered to.

7.2.1 Clevis assemblies shall be incorporated in the force train at both the top and bottom of the specimen to allow in-plane rotation as the specimen is loaded. Fig. A1.2 shows an example for the clevis setup for the tension specimens shown in Fig. A1.3. The bend specimen will be simply a 3-point bend loading assembly.

7.2.2 Suggested proportions and critical tolerances of the fixtures shall be within the specified variation shown in Fig. A1.2. Note that surface finish does not have a major effect on creep crack growth and therefore a normal smooth finish to the specimen is sufficient.

7.2.3 The pin-to-hole clearances are designed to minimize friction thereby eliminating unacceptable end-movements that would invalidate the specimen calibrations for determining *K*, *J*, and *C*(t)*.

~~6.2.3The pin-to-hole clearances are designed to minimize friction thereby eliminating unacceptable end-movements that would invalidate the specimen calibrations for determining *K, J*, and *C**(*t*).~~

~~6.2.4The~~ 7.2.4 The material for the grips and pull rods should be chosen with due regard to test temperature and force level to be employed. Some elevated temperature materials currently being used include American Iron and Steel Institute (AISI) Grade 304 and 316 stainless steel, Grade A286 steel, nickel-based superalloys like alloy 718 or alloy X750. The loading pins are machined from A286 steel (or equivalent or better temperature resistant steel) and are heat treated such that they develop a high resistance to creep deformation and rupture.

~~6.3~~7.3 *Alignment of Grips*—It is important that attention be given to achieving good alignment in the ~~load train~~ force-line through careful machining of all gripping ~~fixtures (see Fig. 2 for machine tolerances).~~ fixtures. The length of the ~~load~~force train should be chosen with proper attention to the height of the furnace for heating the test specimen.

~~6.4~~7.4 *Heating Apparatus*:

~~6.4.1The~~7.4.1 The apparatus for, and method of, heating the specimens should provide the temperature control necessary to satisfy the requirements ~~of~~ in ~~9.2.2~~10.3, without manual adjustments more frequent than once in each 24-h period after ~~load~~force application.

~~6~~7.4.2 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.

NOTE ~~1—The~~ 2—The test conditions in which ~~the~~ tests are performed may have a considerable effect on the ~~results of the tests.~~ results. This is particularly true when properties are influenced by plasticity, environmental effects, oxidation or other types of corrosion.

~~6.5~~7.5 *Temperature-Measurement Apparatus*—The method of temperature measurement must be sufficiently sensitive and reliable to ensure that the specimen temperature is within the limits specified in ~~9.2.2~~10.3. For details of types of apparatus used see Specification ~~E 139~~E139.

~~6.6~~

7.6 *Displacement Gage*~~:~~

~~6.6.1Continuous displacement measurement is needed to evaluate the magnitude of *C*(t)* and~~ —*For the measurement of the FLD* or *CMOD* displacement during the test.

7.6.1 Continuous displacement measurement is needed to evaluate the magnitude of $C^*(t)$ and C_t at any time during the test. Displacement measurements must be made on the ~~load-line.~~force-line.

~~6.6.2As~~7.6.2 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.

~~6~~7.6.3 Knife edges are recommended for friction-free seating of the gage. Parallel alignment of the knife edges must be maintained to within ±1°.

~~6.6.4The~~7.6.4 The displacement along the ~~load-line~~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 a rod and tube assembly such as that shown in Figs. ~~3~~A1.4 and ~~4~~A1.5.

7.6.5 In the latter procedure, the transducer is placed outside the furnace. It is important to make the tube and rod from materials that are thermally stable and are from the same material to avoid erroneous readings caused by differences in thermal expansion coefficients. Other designs that can measure displacements to the same levels of accuracy may also be used.

~~6.7~~7.7 *Apparatus for Crack Size Measurement*—A crack size monitoring technique capable of reliably resolving crack extensions of at least ±0.1 mm ~~(0.004 in.)~~ at test temperature is recommended for creep crack growth measurements. Since crack extension across the thickness of the specimen is not always uniform, surface crack size measurements by optical means are not considered reliable as a primary method. Optical observation may be used as an auxiliary measurement method. The selected crack size measurement technique must be capable of measuring the average crack size across the thickness. The most commonly used technique for crack size measurement during creep crack growth testing is the electric potential technique that is described in Annex ~~A1~~A3.

NOTE ~~2—The~~ 3—The crack size measurement precision is herein defined as the standard deviation of the mean value of crack size determined for a set of replicate measurements.

~~6.8~~7.8 *Room Temperature Control*—The ambient temperature in the room should be sufficiently constant so that the specimen temperature variations do not exceed the limits stated in ~~9.2.2~~10.3.5.

~~6.9~~

7.9 *Timing Apparatus*—Suitable means for recording and measuring elapsed time to within 1 % of the elapsed time should be provided.

~~7.Specimen Configuration, Dimensions, and Preparation~~

~~7.1*Specimen Configuration*:~~

~~7.1.1The configuration of the standard *C(T)* specimen is shown in Fig. 1~~

8. Specimen Configuration

8.1 The schematic and dimension of the standard C(T) specimen and the additional specimens are shown in Fig. A1.3.

~~7.1.2The crack starter slot width for the compact specimens shall lie within the envelope shown in Fig. 5~~

8.2 The configurations and size range of all the geometries are given in Table A1.1.

~~7.1.3The width-to-thicknes ratio, *W/B*, recommended is 2, nominally. Other *W/B* ratios, up to 8, may be used for thickness effect characterization; it is however important to note that the stress state may vary with thickness.~~

~~7.1.4The initial crack size, a_o(including a sharp starter notch or pre-crack), shall be at least 0.45 times the width, *W*, but no greater than 0.55 times the width. This may be varied within the above interval depending on the selected load level for testing and the desired test duration.~~

~~7.2To meet crack front straightness requirements imposed in 10.2.2, side-grooved specimens may be required. The depth of required side grooves for a particular material might only be found by trial and error but a total reduction of 20% has been found to work well for many materials. However, for extremely creep-ductile materials, a total side-groove reduction of up to 40 % may be needed to produce straight crack fronts. Any included angle of side groove less than 90° is allowed. Root radius shall be ≤ 0.4 ± 0.2 mm (0.016 ± 0.008 in.). In order to produce nearly-straight pre-crack fronts, it is desirable, but not a requirement, to have the pre-cracking done prior to side-groove machining operation.~~

~~7.3~~

8.2.1 Crack opening slot is the machined crack width. For C(T) specimens it can be as much as 0.1 *a/W* for the rest of the geometries, which have shorter crack starters it is recommended to have an opening of 0.05 *a/W*.

8.2.2 The width-to-thickness ratio *W/B* for the C(T) specimen is recommended to be 2, nominally. Other *W/B* ratios, up to 8, may be used for thickness effect characterization; it is however important to note that the stress state may vary with thickness (see 1.1.7 and 5.9).

8.2.3 The initial crack size, a_o (including a sharp starter notch or pre-crack), shall be at least 0.45 times the width, *W*, but no greater than 0.55*W*. This may be varied within the stated interval depending on the selected force level for testing and the desired test duration.

8.3 *Side-Grooving*—In most cases 20 % side-grooving is sufficient to meet crack front straightness requirements (see 5.9, 6.2.2, and 8.4). However more or less side-grooving in specimens may be required depending on the ductility and crack growth behavior of the material. The depth of required side-grooves for a particular material might only be found by trial and error but a total reduction of 20 % has been found to work well for many materials. However, for extremely creep-ductile materials, a total side-groove reduction of up to 40 % may be needed to produce straight crack fronts. Any included angle of side groove less than 90° is allowed. Root radius shall be ≤ 0.4 ± 0.2 mm in order to produce nearly-straight pre-crack fronts; it is desirable, but not a requirement, to have the pre-cracking done prior to side-groove machining operation.

8.4 *Specimen Size*~~— There are no specific size requirements imposed in this method. However, specimen size must be chosen with consideration to the capacity of the loading system, being able to fit the specimen into the heating furnace with sufficient room for attaching the necessary extensometers, and providing sufficient ligament size for growing the crack in a stable fashion to permit collection of crack growth data.~~

~~7.4~~*—There are no specific size requirements imposed in this method but considerations due to constraint effects should be taken into account. Also specimen size must be chosen with consideration to the material availability, capacity of the loading system, being able to fit the specimen into the heating furnace with sufficient room for attaching the necessary extensometers, and providing sufficient ligament size for growing the crack in a stable fashion to permit collection of crack growth data (see also 1.1.7, 1.1.10, 5.9).*

8.5 *Specimen Measurements*—The specimen dimensions are given in Fig. A1.3 and Table A1.1. They shall be machined within the machining tolerances given in Fig. A1.1 and the dimensions should be measured before and after the test.

8.6 *Notch Preparation*~~—The machined notch for the test specimens may be made by electrical-discharge machining (EDM), milling, broaching, or saw cutting. Associated precracking requirements are shown in Fig. 5~~—The machined notch for the test specimens (see 8.2.1) may be made by electrical-discharge machining (EDM), milling, broaching, or saw cutting. It is recommended that the last 0.1 *a/W* of the crack be machined using electro discharge machining (EDM) of a width of 0.1 mm. This will allow easier pre-cracking or further crack tip sharpening by EDM to the final crack starter size prior testing. See Note in Fig. A1.3.

~~7.5*Specimen Measurements*—The specimen dimensions shall be within the tolerances given in Fig. 1~~

8.7 Associated pre-cracking requirements are discussed in 8.8.

~~7.6*Precracking*—Fatigue pre-cracking is recommended for most situations. However a narrow slit induced by an electro-discharge machine (EDM) can also be used as a crack starter. For example EDM is preferable for some creep-brittle materials such as intermetallics (**19**~~

8.8 *Pre-Cracking*—EDM or Fatigue pre-cracking are two methods used to introduce a sharp crack tip starter. It is recommended, using electro-discharge machine (EDM) method, that a narrow slit (of 0.1 mm width) should be introduced to produce a sharp and even crack starter. Fatigue pre-cracking could be performed as long as it can be ascertained that the final crack front will be straight and flat and does not deviate from the crack plane. EDM is preferable for some creep-brittle materials such as inter-metallics (**26**) ~~due to difficulties in growing cracks with straight fronts. Both methods of pre-cracking are described.~~

~~7.6.1*EDM pre-crack*—The width of the EDM pre-crack shall not exceed 0.1 mm. Precautions must be taken to avoid any over-heating, however localized, which may alter the microstructure of the material near the crack tip.~~

~~7.6.2*Fatigue pre-cracking*—Specimens may also be pre-cracked at room temperature or at a temperature between ambient and~~