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Standard Test Method for Elevated Temperature Tensile Creep Strain, Creep Strain Rate, and Creep Time-to-Failure for Advanced Monolithic Advanced Ceramics[1]

This standard is issued under the fixed designation C1291; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of tensile creep strain, creep strain rate, and creep time-to-failure for advanced monolithic ceramics at elevated temperatures, typically between 1073 and 2073 K. A variety of test specimen geometries are included. The creep strain at a fixed temperature is evaluated from direct measurements of the gage length extension over the time of the test. The minimum creep strain rate, which may be invariant with time, is evaluated as a function of temperature and applied stress. Creep time-to-failure is also included in this test method.

1.2 This test method is for use with advanced ceramics that behave as macroscopically isotropic, homogeneous, continuous materials. While this test method is intended for use on monolithic ceramics, whisker- or particle-reinforced composite ceramics as well as low-volume-fraction discontinuous fiber-reinforced composite ceramics may also meet these macroscopic behavior assumptions. Continuous fiber-reinforced ceramic composites (CFCCs) do not behave as macroscopically isotropic, homogeneous, continuous materials, and application of this test method to these materials is not recommended.

1.3 The values in SI units are to be regarded as the standard (see IEEE/ASTM SI 10). The values given in parentheses are mathematical conversions to inch-pound units that are provided for information only and are not considered standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C1145 Terminology of Advanced Ceramics
C1273 Test Method for Tensile Strength of Monolithic Advanced Ceramics at Ambient Temperatures
E4 Practices for Force Verification of Testing Machines
E6 Terminology Relating to Methods of Mechanical Testing
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
E230 Specification and Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples
E639 Test Method for Measuring Total-Radiance Temperature of Heated Surfaces Using a Radiation Pyrometer (Withdrawn 2011)[3]
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application
IEEE/ASTM SI 10 American National Standard for Use of the International System of Units (SI): The Modern Metric System

[1] This test method is under the jurisdiction of ASTM Committee C28 on Advanced Ceramics and is the direct responsibility of Subcommittee C28.01 on Mechanical Properties and Performance.

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

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

3. Terminology

3.1 *Definitions*—The definitions of terms relating to creep testing, which appear in Section E of Terminology E6 shall apply to the terms used in this test method. For the purpose of this test method only, some of the more general terms are used with the restricted meanings given as follows.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *axial strain, ε_a, ~~[nd]~~,[L/L], n*—average of the strain measured on diametrically opposed sides and equally distant from the test specimen axis.

3.2.2 *bending strain, ε_b ~~[nd]~~,[L/L], n*—difference between the strain at the surface and the axial strain.

3.2.2.1 *Discussion*—

In general, it varies from point to point around and along the gage length of the ~~specimen.~~test [specimen.~~E1012~~] **E1012**

3.2.3 *creep-rupture test, n*—test in which progressive test specimen deformation and the time-to-failure are measured. In general, deformation is greater than that developed during a creep test.

3.2.4 *creep strain, ε, ~~[nd]~~,[L/L], n*—time dependent strain that occurs after the application of ~~load~~force which is thereafter maintained constant. Also known as engineering creep strain.

3.2.5 *creep test, n*—test that has as its objective the measurement of creep and creep rates occurring at stresses usually well below those that would result in fast fracture.

3.2.5.1 *Discussion*—

Since the maximum deformation is only a few percent, a sensitive extensometer is required.

3.2.6 *creep time-to-failure, t_f, ~~[s]~~,[T], n*—time required for a test specimen to fracture under constant ~~load~~force as a result of creep.

3.2.6.1 *Discussion*—

This is also known as creep rupture time.

3.2.7 *gage length, l, ~~[m]~~,[L], n*—original distance between fiducial markers on or attached to the test specimen for determining elongation.

3.2.8 *maximum bending strain, ε_{bmax}, ~~[nd]~~,[L/L], n*—largest value of bending strain along the gage length. It can be calculated from measurements of strain at three circumferential positions at each of two different longitudinal positions.

3.2.9 *minimum creep strain rate, ε_{min}, ~~[s~~[T^{-1}], n*—minimum value of the strain rate prior to test specimen failure as measured from the strain-time curve. The minimum creep strain rate may not necessarily correspond to the steady-state creep strain rate.

3.2.10 *slow crack growth, v, ~~[m/s]~~,[L/T], n*—subcritical crack growth (extension) which may result from, but is not restricted to, such mechanisms as environmentally assisted stress corrosion, diffusive crack growth, or other mechanisms. **C1145**

3.2.11 *steady-state creep, ε_{ss}, ~~[nd]~~,[L/L], n*—stage of creep wherein the creep rate is constant with time.

3.2.11.1 *Discussion*—

Also known as secondary creep.

3.2.12 *stress corrosion, n*—environmentally induced degradation that initiates from the exposed surface.

3.2.12.1 *Discussion*—

Such environmental effects commonly include the action of moisture, as well as other corrosive species, often with a strong temperature dependence.

3.2.13 *tensile creep strain, ε_t, ~~[nd]~~,[L/L], n*—creep strain that occurs as a result of a uniaxial tensile-applied stress.

4. Significance and Use

4.1 Creep tests measure the time-dependent deformation under ~~load~~force at a given temperature, and, by implication, the ~~load-carrying~~force-carrying capability of the material for limited deformations. Creep-rupture tests, properly interpreted, provide a measure of the ~~load-carrying~~force-carrying capability of the material as a function of time and temperature. The two tests

~~compliment~~complement each other in defining the ~~load-carrying~~force-carrying capability of a material for a given period of time. In selecting materials and designing parts for service at elevated temperatures, the type of test data used will depend on the criteria for ~~load-carrying~~force-carrying capability that best defines the service usefulness of the material.

4.2 This test method may be used for material development, quality assurance, characterization, and design data generation.

4.3 High-strength, monolithic ceramic materials, generally characterized by small grain sizes (<50 µm) and bulk densities near their theoretical density, are candidates for load-bearing structural applications at elevated temperatures. These applications involve components such as turbine blades which are subjected to stress gradients and multiaxial stresses.

4.4 Data obtained for design and predictive purposes ~~should~~shall be obtained using any appropriate combination of test methods that provide the most relevant information for the applications being considered. It is noted here that ceramic materials tend to creep more rapidly in tension than in compression (**1, 2, 3**).[4] This difference results in time-dependent changes in the stress distribution and the position of the neutral axis when tests are conducted in flexure. As a consequence, deconvolution of flexural creep data to obtain the constitutive equations needed for design cannot be achieved without some degree of uncertainty concerning the form of the creep equations, and the magnitude of the creep rate in tension vis-a-vis the creep rate in compression. Therefore, creep data for design and life prediction ~~should~~shall be obtained in both tension and compression, as well as the expected service stress state.

5. Interferences

5.1 *Time-Dependent Phenomena*—Other time-dependent phenomena, such as stress corrosion and slow crack growth, can interfere with determination of the creep behavior.

5.2 *Chemical Interactions with the Testing Environment*—The test environment (vacuum, inert gas, ambient air, etc.) including moisture content (for example, % relative humidity (RH)) may have a strong influence on both creep strain rate and creep rupture life. In particular, materials susceptible to slow crack growth failure will be strongly influenced by the test environment. Surface oxidation may be either active or passive and thus will have a direct effect on creep behavior by changing the material's properties. Testing ~~must~~shall be conducted in environments that are either representative of service conditions or inert to the materials being tested depending on the performance being evaluated. A controlled gas environment with suitable effluent controls ~~must~~shall be provided for any material that evolves toxic vapors.

5.3 *Test Specimen Surfaces*—Surface preparation of test specimens can introduce machining flaws that may affect the test results. Machining damage imposed during test specimen preparation will most likely result in premature failure of the test specimen but may also introduce flaws that can grow by slow crack growth. Surface preparation can also lead to residual stresses which can be released during the test. Universal or standardized methods of surface preparation do not exist. It ~~should~~shall be understood that final machining steps may or may not negate machining damage introduced during earlier phases of machining which tend to be rougher.

5.4 *Test Specimen/Extensometer Chemical Incompatibility*—The strain measurement techniques described herein generally rely on physical contact between extensometer components (contacting probes or optical method flags) and the test specimen so as to measure changes in the gage section as a function of time. Flag attachment methods and extensometer contact materials ~~must~~shall be chosen with care to ensure that no adverse chemical reactions occur during testing. Normally, this is not a problem if test specimen/probe materials that are mutually chemically inert are employed (for example, SiC probes on Si_3N_4 test specimens). The user must be aware that impurities or second phases in the flags or test specimens may be mutually chemically reactive and could influence the results.

5.5 *Test Specimen Bending*—Bending in uniaxial tensile tests can cause extraneous strains or promote accelerated rupture times. Since maximum or minimum stresses will occur at the surface where strain measurements are made, bending may introduce either an over or under measurement of axial strain, if the measurement is made only on one side of the tensile test specimen. Similarly, bending stresses may accentuate surface oxidation and may also accentuate the severity of surface flaws.

5.6 *Temperature Variations*—Creep strain is often related to temperature through an exponential function. Thus fluctuations in test temperature or change in temperature profile along the length of the test specimen in real time can cause fluctuations in strain measurements or changes in creep rate.

6. Apparatus

6.1 *~~Load Testing~~Force Test Machine:*

6.1.1 ~~Specimens~~ Test specimens may be loaded in any suitable ~~testing~~test machine provided that uniform, direct loading can be maintained. The ~~testing~~test machine must maintain the desired constant ~~load~~force on the test specimen regardless of test specimen deformation with time, either through dead-weight loading or through active ~~load~~force control. The force measuring

[4] The boldface numbers in parentheses refer to the list of references at the end of this test method.

system can be equipped with a means for retaining readout of the force, or the force can be recorded manually. The accuracy of the ~~testing~~test machine ~~must~~shall be in accordance with Practices E4.

6.1.2 *Allowable Bending*—Allowable bending, as defined in Practice E1012, ~~should~~shall not exceed 5 %. This is based on the same assumptions as those for tensile strength testing (see ~~Ref~~Ref. ~~**4**,~~**(4),** for example). It ~~should~~shall be noted that unless percent bending is monitored until the end-of-test condition has been reached, there will be no record of percent bending for each test specimen. The testing system alignment including the test machine, gripping devices (as described in 6.2), and ~~load train~~ load-train couplers (as described in 6.3), must be verified using the procedure detailed in the appendix such that the percent bending does not exceed 5 at a mean stress equal to one half the anticipated test stress. This verification ~~must~~shall be conducted at a minimum at the beginning and the end of each test series. An additional verification of alignment is recommended, although not required, at the middle of the test series. Either a dummy or actual test specimen may be used. Tensile test specimens used for alignment verification ~~should~~shall be equipped with a recommended eight separate longitudinal strain gages to determine bending contributions from both eccentric and angular misalignment of the grip heads. (Although it is possible to use a minimum of six separate longitudinal strain gages for test specimens with circular cross sections, eight strain gages are recommended here for simplicity and consistency in describing the technique for both circular and rectangular cross sections.) If dummy test specimens are used for alignment verification, they ~~should~~shall have the same geometry and dimensions as the actual test specimens as well as an elastic modulus that closely matches that of the test material to ensure similar axial and bending stiffness characteristics.

6.2 *Gripping Devices:*

6.2.1 Various types of gripping devices may be used to transmit the measured ~~load~~force applied by the ~~testing~~test machine to the test specimens. The brittle nature of advanced ceramics requires a uniform interface between the grip components and the gripped section of the test specimen. Line or point contacts and nonuniform pressure can produce Hertzian-type stresses leading to crack initiation and fracture of the test specimen in the gripped section. Gripping devices can be classed generally as those employing active and those employing passive grip interfaces as discussed in the following sections. Regardless of the type of gripping device chosen, it ~~must~~shall be consistent with the thermal requirements imposed on it by the elevated temperature nature of creep testing. This requirement may preclude the use of some material combinations and gripping designs.

6.2.1.1 *Active Grip Interfaces*—Active grip interfaces require a continuous application of a mechanical, hydraulic, or pneumatic force to transmit the ~~load~~force applied by the test machine to the test specimen. Generally, these types of grip interfaces cause a ~~load~~force to be applied normal to the surface of the gripped section of the test specimen. Transmission of the uniaxial ~~load~~force applied by the test machine is then accomplished by friction between the test specimen and the grip faces. Thus, important aspects of active grip interfaces are uniform contact between the gripped section of the test specimen and the grip faces, and constant coefficient of friction over the ~~grip/specimen interface.~~interface between the test specimen and grip.

~~(*1*) For cylindrical specimens, a one-piece split collet arrangement acts as the grip interface (**4, 5**). Generally, close tolerances are required for concentricity of both the grip and specimen diameters. In addition, the diameter of the gripped section of the specimen and the unclamped, open diameter of the grip faces must be within similarly close tolerances to promote uniform contact at the specimen/grip interface. Tolerances will vary depending on the exact configuration used.~~

(1) For cylindrical test specimens, a one-piece split collet arrangement acts as the grip interface (**4, 5**). Generally, close tolerances are required for concentricity of both the grip and test specimen diameters. In addition, the diameter of the gripped section of the test specimen and the unclamped, open diameter of the grip faces shall be within similarly close tolerances to promote uniform contact at the test specimen/grip interface. Tolerances will vary depending on the exact configuration used.

(2) For flat test specimens, flat-face, wedge-grip faces act as the grip interface. Generally, close tolerances are required for the flatness and parallelism as well as wedge angle of the grip faces. In addition, the thickness, flatness, and parallelism of the gripped section of the test specimen shall be within similarly close tolerances to promote uniform contact at the test specimen/grip interface. Tolerances will vary depending on the exact configuration used.

~~(*2*) For flat specimens, flat-face, wedge-grip faces act as the grip interface. Generally, close tolerances are required for the flatness and parallelism as well as wedge angle of the grip faces. In addition, the thickness, flatness, and parallelism of the gripped section of the specimen must be within similarly close tolerances to promote uniform contact at the specimen/grip interface. Tolerances will vary depending on the exact configuration used.~~

6.2.1.2 *Passive Grip Interfaces*—Passive grip interfaces transmit the ~~load~~force applied by the test machine to the test specimen through a direct mechanical link. Generally, these mechanical links transmit the test ~~loads~~forces to the test specimen by means of geometrical features of the test specimens such as button-head fillets, shank shoulders, or holes in the gripped head. Thus, the important aspect of passive grip interfaces is uniform contact between the gripped section of the test specimen and the grip faces.

~~(*1*) For cylindrical specimens, a multi-piece split collet arrangement acts as the grip interface at button-head fillets of the specimen (**6**). Because of the limited contact area at the specimen/grip interface, soft, deformable metallic collets may be used to transfer the axial load to the exact geometry of the specimen. In some cases, tapered collets may be used to transfer the axial load to the shank of the specimen rather than into the button-head radius (**6**). Generally, moderate tolerances on the collet height must be maintained to promote uniform axial-loading at the specimen/grip interface. Tolerances will vary depending on the exact configuration used.~~

(1) For cylindrical test specimens, a multi-piece split collet arrangement acts as the grip interface at button-head fillets of the test specimen (**6**). Because of the limited contact area at the test specimen/grip interface, soft, deformable metallic collets may be

used to transfer the axial force to the exact geometry of the test specimen. In some cases, tapered collets may be used to transfer the axial force to the shank of the test specimen rather than into the button-head radius (**6**). Generally, moderate tolerances on the collet height shall be maintained to promote uniform axial-loading at the test specimen/grip interface. Tolerances will vary depending on the exact configuration used.

(2) For flat test specimens, pins or pivots act as grip interfaces at either the shoulders of the test specimen shank (**7, 8**) or at holes in the gripped test specimen head (**9, 10**). Generally, close tolerances of shoulder radii and grip interfaces are required to promote uniform contact along the entire test specimen/grip interface as well as to provide for non-eccentric loading. Generally, very close tolerances are required for longitudinal coincidence of the pin and the hole centerlines.

~~(2) For flat specimens, pins or pivots act as grip interfaces at either the shoulders of the specimen shank (**7, 8**) or at holes in the gripped specimen head (**9, 10**). Generally, close tolerances of shoulder radii and grip interfaces are required to promote uniform contact along the entire specimen/grip interface as well as to provide for non-eccentric loading. Generally, very close tolerances are required for longitudinal coincidence of the pin and the hole centerlines.~~

6.3 *~~Load~~Load-Train Couplers:*

6.3.1 Various types of devices ~~(load train~~ (load-train couplers) may be used to attach the active or passive grip interface assemblies to the ~~testing machine.~~ test machine as discussed in Test Method C1273. The ~~load train~~ load-train couplers, in conjunction with the type of gripping device, play major roles in the alignment of the ~~load train~~ load-train and thus subsequent bending imposed on the test specimen. ~~Load train~~ Load-train couplers can be classified generally as fixed or non-fixed as discussed in the following sections. Note that the use of well-aligned fixed or self-aligned non-fixed couplers does not automatically guarantee low bending in the gage section of the tensile test specimen. Generally, well-aligned fixed or self-aligning non-fixed couplers provide for well-aligned ~~load trains,~~ load-trains, but the type and operation of grip interfaces as well as the as-fabricated dimensions of the tensile test specimen can add significantly to the final bending imposed on the gage section of the test specimen. Regardless of the type of load couplers chosen, they ~~must~~shall be consistent with the thermal requirements imposed on them by the elevated temperature nature of creep testing. These requirements may preclude the use of some material combinations and ~~load train~~ load-train designs.

6.3.2 *Fixed ~~Load Train~~ Load-Train Couplers*—Fixed couplers may incorporate devices that require either a one-time, pretest alignment adjustment of the ~~load train~~ load-train which remains constant for all subsequent tests or an *in situ*, pretest alignment of the ~~load train~~ load-train which is conducted separately for each test specimen and each test. Such devices (**11, 12**) usually employ angularity and concentricity adjusters to accommodate inherent ~~load train~~ load-train misalignments. Regardless of which method is used, alignment verification ~~must~~shall be performed as discussed in 6.1.2.

6.3.3 *Non-Fixed ~~Load Train~~ Load-Train Couplers*—Non-fixed couplers may incorporate devices that promote self-alignment of the ~~load train~~ load-train during the movement of the crosshead or actuator. Generally, such devices rely upon freely moving linkages to eliminate applied moments as the ~~load train~~ load-train components are loaded. Knife edges, universal joints, hydraulic couplers, and air bearings are examples (**7, 11, 13, 14, 15**) of such devices. Although non-fixed load couplers are intended to be self-aligning and thus eliminate the need to evaluate the bending in the test specimen for each test, the operation of the couplers ~~must~~shall be verified as discussed in 6.1.2.

6.4 *Heating Apparatus:*

6.4.1 The apparatus for and method of heating the test specimens ~~must~~shall provide the temperature control necessary to satisfy the requirements specified in 6.4.2 without manual adjustments more frequent than once in each 24-h period after ~~load~~force application. It ~~must~~shall also satisfy the requirements of the testing environment in 6.4.3.

6.4.2 *Temperature*—The furnace ~~must~~shall be capable of maintaining the tensile test specimen temperature constant with time to 2 K. The temperature readout device ~~must~~shall have a resolution of 1 K or less. The furnace system ~~must~~shall be such that thermal gradients are minimal in the tensile test specimen so that no more than a 5-K differential exists in the test specimen gage length at temperatures up to 1773 K.

6.4.3 *Environment*—The furnace may have an air, inert, or vacuum environment as required. If an inert or vacuum chamber is used, and it is necessary to direct ~~load~~force through bellows, fittings, or seal, then it ~~must~~shall be verified that force losses or errors do not exceed 1 % of the applied force.

6.5 *Temperature Measuring Devices:*

6.5.1 The method of temperature measurement ~~must~~shall be sufficiently sensitive and reliable to ensure that the temperature of the test specimen is within the limits specified in 6.4.2. Depending on the temperature range being used, this can be accomplished with either calibrated thermocouples or pyrometers.

6.5.2 *Thermocouples:*

6.5.2.1 *Calibration*—The thermocouple(s) ~~must~~shall be calibrated in accordance with Test Method E220 and Specification and Tables E230.[5] For longer tests at higher temperatures, this ~~must~~shall be done both before the test is initiated and after the test is completed in order to determine the extent of thermocouple degradation and possible thermal drift during the test.

[5] Thermocouples ~~should~~shall be periodically checked since calibration may drift with usage or contamination.

6.5.2.2 *Accuracy*—The measurement of temperature ~~must~~shall be accurate to within 5 K. This includes the error inherent to the thermocouple and any error in the measuring instruments.[6,7]

6.5.2.3 *Extension Wire*—The appropriate thermocouple extension wire ~~must~~shall be used to connect a thermocouple to the furnace controller or temperature readout device, or both. Special attention ~~must~~shall be accorded to connecting the extension wire with the correct polarity.

6.5.2.4 *Degradation*—The integrity and degree of degradation of used bare thermocouples ~~must~~shall be verified before each test. At certain temperatures, oxidation and elemental diffusion of the thermocouple alloys will affect the electromotive force (EMF) of the thermocouple junctions. As a consequence, the EMF of a bare, used thermocouple will no longer correspond to the calibration values determined in the pristine condition. The indicated temperature will therefore be less than the actual temperature. This is a particular problem when the same thermocouple is used for both monitoring and control of temperature. Previously used bare thermocouples ~~must~~shall be replaced (with newly welded and annealed, or cut-back, rewelded, and annealed thermocouples) when calibration at the test temperature reveals an error of >2K. It is preferable to use fully sheathed thermocouples in order to minimize degradation.

6.5.3 *Pyrometers:*

6.5.3.1 *Calibration*—The pyrometer(s) ~~must~~shall be calibrated in accordance with Test Method E639.

6.5.3.2 *Accuracy*—The measurement of temperature ~~must~~shall be accurate to within 5 K. This shall include the error inherent to the pyrometer and any error in the measuring instruments.[6,7]

6.6 *Extensometers:*

6.6.1 The strain measuring equipment ~~must~~shall be capable of being used at elevated temperatures. The sensitivity and accuracy of the strain-measuring equipment ~~must~~shall be suitable to define the creep characteristics with the precision required for the application of the data.

6.6.2 *Calibration*—Extensometers ~~must~~shall be calibrated in accordance with Practice E83.

6.6.3 *Accuracy*—Extensometers with accuracies equivalent to the B-1 classification of extensometer systems specified in Practice E83 are suitable for use in high-temperature testing of ceramics. Results of analytical and empirical evaluations at elevated temperatures show that mechanical extensometers **(16)** can meet these requirements. Optical extensometers using flags have gage length uncertainties that will generally prevent them from achieving class B-1 accuracy **(17)**. Empirical evaluations at elevated temperature **(18)** show that these extensometers can yield highly repeatable creep data, however.

6.7 *Timing Apparatus*—For creep rupture tests, a timing apparatus capable of measuring the elapsed time between complete application of the ~~load~~force and the time at which fracture of the test specimen occurs to within 1 % of the elapsed time shall be employed.

7. Test Specimens and Sample

7.1 *Test Specimen Size:*

7.1.1 *Description*—The size and shape of test specimens ~~must~~shall be based on the requirements necessary to obtain representative samples of the material being ~~investigated.~~ investigated as discussed in Test Method C1273. The test specimen geometry shall be such that there is no more than a 5 % elastic stress concentration at the ends of the gage section. Typical shapes include square or rectangular cross-section dogbones and cylindrical button-head geometries, and are shown in Appendix X1. It is recommended, in accordance with Test Methods E139 and in the absence of additional information to the contrary, that the grip section be at least four times larger than the larger dimension of either width or thickness of the gage section.

7.1.2 *Dimensions*—Suggested dimensions for tensile creep test specimens that have been successfully used in previous investigations are given in Appendix X1. Cross-sectional tolerances are 0.05 mm. Parallelism tolerances on the faces of the test specimen are 0.03 mm. Various radii of curvature may be used to adjust the gage section or change the mounting configuration. Although these radii are expected to be larger, resulting in a smaller stress concentration, wherever possible, resort ~~should~~shall be made to a finite element analysis to determine the locations and intensities of stress concentrations in the new geometry.

7.2 *Test Specimen Preparation*—Depending on the intended application of the data, use one of the following test specimen preparation procedures:

7.2.1 *Application-matched Machining*—The test specimen ~~must~~shall have the same surface preparation as that specified for a component. Unless the process is proprietary, the report ~~must~~shall be specified about the stages of material removal, wheel grits, wheel bonding, and the amount of material removed per pass.

7.2.2 *Customary Procedure*—In instances where a customary machining procedure has been developed that is completely satisfactory for a class of materials (that is, it induces no unwanted surface damage or residual stresses), then this procedure shall be used. It shall be fully specified in the report.

7.2.3 *Standard Procedure*—In instances where 7.2.1 or 7.2.2 are not appropriate, then 7.2.3 will apply. This procedure will serve as the minimum requirements, but a more stringent procedure may be necessary.

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[6] Resolutions ~~should~~shall not be confused with accuracy. Beware of instruments that readout to 1°C (resolution), but have an accuracy of only 10 K or ½ % of full scale (½ % of 1200 K is 6 K).

[7] Temperature measuring instruments typically approximate the temperature-EMF tables, but with a few degrees of error.