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Standard Test Method for Determination of Slow Crack Growth Parameters of Advanced Ceramics by Constant Stress Flexural Testing (Stress Rupture) at Ambient Temperature[1]

This standard is issued under the fixed designation C1576; 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 standard test method covers the determination of slow crack growth (SCG) parameters of advanced ceramics by using constant stress flexural testing in which time to failure of flexure test specimens is determined in *four-point* flexure as a function of constant applied stress in a given environment at ambient temperature. In addition, test specimen fabrication methods, test stress levels, data collection and analysis, and reporting procedures are addressed. The decrease in time to failure with increasing applied stress in a specified environment is the basis of this test method that enables the evaluation of slow crack growth parameters of a material. The preferred analysis in the present method is based on a power law relationship between crack velocity and applied stress intensity; alternative analysis approaches are also discussed for situations where the power law relationship is not applicable.

NOTE 1—The test method in this standard is frequently referred to as "static *fatigue*" or stress-rupture testing (**1-3**)[2] in which the term "*fatigue*" is used interchangeably with the term "slow crack growth." To avoid possible confusion with the "*fatigue*" phenomenon of a material that occurs exclusively under cyclic loading, as defined in Terminology E1823, this test method uses the term "constant stress testing" rather than "static *fatigue*" testing.

1.2 This test method applies primarily to monolithic advanced ceramics that are macroscopically homogeneous and isotropic. This test method may also be applied to certain whisker- or particle-reinforced ceramics as well as certain discontinuous fiber-reinforced composite ceramics that exhibit macroscopically homogeneous behavior. Generally, continuous fiber ceramic composites do not exhibit macroscopically isotropic, homogeneous, continuous behavior, and the application of this test method to these materials is not recommended.

1.3 This test method is intended for use with various test environments such as air, other gaseous environments, and liquids.

1.4 The values stated in SI units are to be regarded as the standard and in accordance with IEEE/ASTM SI 10 Standard.

1.5 *This test method may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns 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:*[3]

C1145 Terminology of Advanced Ceramics
C1161 Test Method for Flexural Strength of Advanced Ceramics at Ambient Temperature
C1322 Practice for Fractography and Characterization of Fracture Origins in Advanced Ceramics
C1368 Test Method for Determination of Slow Crack Growth Parameters of Advanced Ceramics by Constant Stress-Rate Strength Testing at Ambient Temperature
C1465 Test Method for Determination of Slow Crack Growth Parameters of Advanced Ceramics by Constant Stress-Rate Flexural Testing at Elevated Temperatures
E4 Practices for Force Verification of Testing Machines
E6 Terminology Relating to Methods of Mechanical Testing
E112 Test Methods for Determining Average Grain Size
E337 Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)
E399 Test Method for Linear-Elastic Plane-Strain Fracture Toughness K_{Ic} of Metallic Materials
E1823 Terminology Relating to Fatigue and Fracture Testing

3. Terminology

3.1 *Definitions:*

[1] This practice 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] The boldface numbers in parentheses refer to a list of references at the end of this standard.

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

3.1.1 The terms described in Terminology C1145, Terminology E6, and Terminology E1823 are applicable to this test standard. Specific terms relevant to this test method are as follows:

3.1.2 *advanced ceramic, n*—a highly engineered, high performance, predominately non-metallic, inorganic, ceramic material having specific functional attributes. **C1145**

3.1.3 *constant applied stress,* $\sigma[FL^{-2}]$*, n*—a constant maximum flexural stress applied to a specified beam test specimen by using a constant static force with a test machine or a test fixture.

3.1.4 *'constant applied stress-time to failure' diagram*—a plot of constant applied stress against time to failure. Constant applied stress and time to failure are both plotted on logarithmic scales.

3.1.5 *'constant applied stress-time to failure' curve*—a curve fitted to the values of time to failure at each of several applied stresses.

NOTE 2—In the ceramics literature, this is often called a "static fatigue" curve.

3.1.6 *test environment, n*—the aggregate of chemical species and energy that surrounds a test specimen. **E1823**

3.1.7 *test environmental chamber, n*—a container surrounding the test specimen that is capable of providing controlled local environmental condition. **C1368, C1465**

3.1.8 *flexural strength,* σ_f $[FL^{-2}]$*, n*—a measure of the ultimate strength of a specified beam test specimen in flexure determined at a given stress rate in a particular environment.

3.1.9 *fracture toughness, (critical stress intensity factor)* K_{IC} $[FL^{-3/2}]$*, n*—a generic term for measures of resistance to extension of a crack. **E1823, E399**

3.1.10 *inert flexural strength* $[FL^{-2}]$*, n*—the flexural strength of a specified beam as determined in an inert condition whereby no slow crack growth occurs.

NOTE 3—An inert condition may be obtained by using vacuum, low temperature, very fast test rate, or an inert environment such as silicone oil or high purity dry N_2.

3.1.11 *R-curve, n*—a plot of crack-extension resistance as a function of stable crack extension. **C1145**

3.1.12 *run-out, n*—a test specimen that does not fail before a prescribed test time.

3.1.13 *slow crack growth (SCG), n*—subcritical crack growth (extension) which may result from, but is not restricted to, such mechanisms as environmentally assisted stress corrosion or diffusive crack growth. **C1368, C1465**

3.1.14 *slow crack growth (SCG) parameters*—the parameters estimated as constants in the log (*time to failure*) versus log (*constant applied stress*), which represent a measure of susceptibility to slow crack growth of a material (see Appendix X1).

3.1.15 *stress intensity factor,* K_I $[FL^{-3/2}$*, n*—the magnitude of the ideal-crack-tip stress field stress field singularity) subjected to mode I loading in a homogeneous, linear elastic body. **E1823**

3.1.16 *time to failure,* t_f $[t]$*, n*—total elapsed time from test initiation to test specimen failure.

4. Significance and Use

4.1 The service life of many structural ceramic components is often limited by the subcritical growth of cracks. This test method provides an approach for appraising the relative slow crack growth susceptibility of ceramic materials under specified environments at ambient temperature. Furthermore, this test method may establish the influences of processing variables and composition on slow crack growth as well as on strength behavior of newly developed or existing materials, thus allowing tailoring and optimizing material processing for further modification. In summary, this test method may be used for material development, quality control, characterization, design code or model verification, and limited design data generation purposes.

NOTE 4—Data generated by this test method do not necessarily correspond to crack velocities that may be encountered in service conditions. The use of data generated by this test method for design purposes, depending on the range and magnitude of applied stresses used, may entail extrapolation and uncertainty.

4.2 This test method is related to Test Method C1368 ("constant stress-rate flexural testing"), however, C1368 uses constant stress rates to determine corresponding flexural strengths whereas this test method employs constant stress to determine corresponding times to failure. In general, the data generated by this test method may be more representative of actual service conditions as compared with those by constant stress-rate testing. However, in terms of test time, constant stress testing is inherently and significantly more time consuming than constant stress rate testing.

4.3 The flexural stress computation in this test method is based on simple elastic beam theory, with the assumptions that the material is isotropic and homogeneous, the moduli of elasticity in tension and compression are identical, and the material is linearly elastic. The grain size should be no greater than one-fiftieth (1⁄50) of the beam depth as measured by the mean linear intercept method (Test Methods E112). In cases where the material grain size is bimodal or the grain size distribution is wide, the limit should apply to the larger grains.

4.4 The test specimen sizes and test fixtures have been selected in accordance with Test Methods C1161 and C1368, which provides a balance between practical configurations and resulting errors, as discussed in Ref (**4, 5**).

4.5 The data are evaluated by regression of log applied stress versus log time to failure to the experimental data. The recommendation is to determine the slow crack growth parameters by applying the power law crack velocity function. For derivation of this, and for alternative crack velocity functions, see Appendix X1.

NOTE 5—A variety of crack velocity functions exist in the literature. A comparison of the functions for the prediction of long-term static fatigue data from short-term dynamic fatigue data (**6**) indicates that the exponential forms better predict the data than the power-law form. Further, the exponential form has a theoretical basis (**7-10**), however, the power law form is simpler mathematically. Both have been shown to fit short-term test data well.