



Standard Practice for Constant-Amplitude, Axial, Tension-Tension Cyclic Fatigue of Advanced Ceramics at Ambient Temperatures¹

This standard is issued under the fixed designation C 1361; 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 practice covers the determination of constant-amplitude, axial tension-tension cyclic fatigue behaviour and performance of advanced ceramics at ambient temperatures to establish “baseline” cyclic fatigue performance. This practice builds on experience and existing standards in tensile testing advanced ceramics at ambient temperatures and addresses various suggested test specimen geometries, specimen fabrication methods, testing modes (load, displacement, or strain control), testing rates and frequencies, allowable bending, and procedures for data collection and reporting. This practice does not apply to axial cyclic fatigue tests of components or parts (that is, machine elements with non uniform or multiaxial stress states).

1.2 This practice applies primarily to advanced ceramics that macroscopically exhibit isotropic, homogeneous, continuous behaviour. While this practice applies primarily to monolithic advanced ceramics, certain whisker- or particle-reinforced composite ceramics as well as certain discontinuous fibre-reinforced composite ceramics may also meet these macroscopic behaviour assumptions. Generally, continuous fibre-reinforced ceramic composites (CFCCs) do not macroscopically exhibit isotropic, homogeneous, continuous behaviour and application of this practice to these materials is not recommended.

1.3 The values stated in SI units are to be regarded as the standard and are in accordance with Practice E 380.

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.* Refer to Section 7 for specific precautions.

2. Referenced Documents

2.1 ASTM Standards:

C 1145 Terminology on Advanced Ceramics²

C 1273 Test Method for Tensile Strength of Monolithic Advanced Ceramics at Ambient Temperatures²

C 1322 Practice for Fractography and Characterization of Fracture Origins in Advanced Ceramics²

E 4 Practices for Force Verification of Testing Machines³

E 6 Terminology Relating to Methods of Mechanical Testing³

E 83 Practice for Verification and Classification of Extensometers³

E 337 Test Method for Measured Humidity with Psychrometer (the Measurement of Wet-and Dry-Bulb Temperatures)⁴

E 380 Practice for Use of International System of Units (SI) (the Modernized Metric System)⁵

E 467 Practice for Verification of Constant Amplitude Dynamic Loads in an Axial Load Fatigue Testing Machine³

E 468 Practice for Presentation of Constant Amplitude Fatigue Test Results for Metallic Materials³

E 739 Practice for Statistical Analysis of Linear or Linearized Stress-Life (S-N) and Strain-Life (ε-N) Fatigue Data³

E 1012 Practice for Verification of Specimen Alignment Under Tensile Loading³

E 1150 Definitions of Terms Relating to Fatigue³

2.2 Military Handbook:

MIL-HDBK-790 Fractography and Characterization of Fracture Origins in Advanced Structural Ceramics⁶

3. Terminology

3.1 **Definitions**—Definitions of terms relating to advanced ceramics, cyclic fatigue, and tensile testing as they appear in Terminology C 1145, Definitions E 1150, and Terminology E 6, respectively, apply to the terms used in this practice. Selected terms with definitions follow with the appropriate source given in parenthesis. Additional terms are also defined in 3.2.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 **advanced ceramic, n**—a highly engineered, high performance predominately non-metallic, inorganic, ceramic material having specific functional attributes. (See Terminology C 1145.)

3.2.2 **axial strain** $[LL^{-1}]$, **n**—the average longitudinal

¹ This practice is under the jurisdiction of ASTM Committee C-28 on Advanced Ceramics and is the direct responsibility of Subcommittee C28.01 on Properties and Performance.

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² Annual Book of ASTM Standards, Vol 15.01

³ Annual Book of ASTM Standards, Vol 3.01.

⁴ Annual Book of ASTM Standards, Vol 11.03.

⁵ Annual Book of ASTM Standards, Vol 14.02.

⁶ Available from Army Research Laboratory-Materials Directorate, Aberdeen Proving Ground, MD 21005.

strains measured at the surface on opposite sides of the longitudinal axis of symmetry of the specimen by two strain-sensing devices located at the mid length of the reduced section. (See Practice E 1012.)

3.2.3 *bending strain* [LL^{-1}], n —the difference between the strain at the surface and the axial strain. In general, the bending strain varies from point to point around and along the reduced section of the specimen. (See Practice E 1012.)

3.2.4 *constant amplitude loading*, n —in cyclic fatigue loading, a loading in which all peak loads are equal and all of the valley loads are equal. (See Definitions E 1150.)

3.2.5 *cyclic fatigue*, n —the process of progressive localized permanent structural change occurring in a material subjected to conditions that produce fluctuating stresses and strains at some point or points and that may culminate in cracks or complete fracture after a sufficient number of fluctuations. (See Definitions E 1150.) See Fig. 1 for nomenclature relevant to cyclic fatigue testing.

3.2.5.1 *Discussion*—In glass technology static tests of considerable duration are called static fatigue tests, a type of test generally designated as stress-rupture.

3.2.5.2 *Discussion*—Fluctuations may occur both in load and with time (frequency) as in the case of random vibration.

3.2.6 *cyclic fatigue life*, N_f —the number of loading cycles of a specified character that a given specimen sustains before failure of a specified nature occurs. (See Definitions E 1150.)

3.2.7 *cyclic fatigue limit*, S_f [FL^{-2}], n —the limiting value of the median cyclic fatigue strength as the cyclic fatigue life, N_f , becomes very large. (for example, $N > 10^6$ - 10^7). (See Definitions E 1150)

3.2.7.1 *Discussion*—Certain materials and environments preclude the attainment of a cyclic fatigue limit. Values tabulated as cyclic fatigue limits in the literature are frequently (but not always) values of S_f at 50 % survival at N_f cycles of stress in which the mean stress, S_m , equals zero.

3.2.8 *cyclic fatigue strength* S_N , [FL^{-2}], n —the limiting value of the median cyclic fatigue strength at a particular cyclic fatigue life, N_f . (See Definitions E 1150.)

3.2.9 *gage length*, [L], n —the original length of that portion of the specimen over which strain or change of length is determined. (See Terminology E 6.)

3.2.10 *load ratio*, n —in cyclic fatigue loading, the algebraic ratio of the two loading parameters of a cycle; the most widely

used ratios (see Definitions E 1150):

$$R = \frac{\text{minimum load}}{\text{maximum load}} \text{ or } R = \frac{\text{valley load}}{\text{peak load}}$$

and:

$$A = \frac{\text{load amplitude}}{\text{mean load}} \text{ or } A = \frac{(\text{maximum load} - \text{minimum load})}{(\text{maximum load} + \text{minimum load})}$$

3.2.11 *maximum stress*, S_{max} [FL^{-2}], n —the maximum applied stress during cyclic fatigue

3.2.12 *mean stress*, S_{max} [FL^{-2}], n —the average applied stress during cyclic fatigue such that

$$S_m = \frac{S_{max} + S_{min}}{2} \quad (1)$$

3.2.13 *minimum stress*, S_{min} [FL^{-2}], n —the minimum applied stress during cyclic fatigue

3.2.14 *modulus of elasticity* [FL^{-2}], n —the ratio of stress to corresponding strain below the proportional limit. (See Terminology E 6.)

3.2.15 *percent bending*, n —the bending strain times 100 divided by the axial strain. (See Practice E 1012.)

3.2.16 *S-N diagram*, n —a plot of stress versus the number of cycles to failure. The stress can be maximum stress, S_{max} , minimum stress, S_{min} , stress range, ΔS or S_r , or stress amplitude, S_a . The diagram indicates the S-N relationship for a specified value of S_m , A , R and a specified probability of survival. For N , a log scale is almost always used, although a linear scale may also be used. For S , a linear scale is usually used, although a log scale may also be used. (See Definitions E 1150 and Practice E 468.)

3.2.17 *slow crack growth*, n —sub-critical crack growth (extension) that may result from, but is not restricted to, such mechanisms as environmentally-assisted stress corrosion or diffusive crack growth.

3.2.18 *stress amplitude*, S_a [FL^{-2}], n —the difference between the mean stress and the maximum or minimum stress such that

$$S_a = \frac{S_{max} - S_{min}}{2} = S_{max} - S_m = S_m - S_{min} \quad (2)$$

3.2.19 *stress range*, ΔS or S_r [FL^{-2}], n —the difference between the maximum stress and the minimum stress such that $\Delta S = S_r = S_{max} - S_{min}$

3.2.20 *tensile strength* [FL^{-2}], n —the maximum tensile stress which a material is capable of sustaining. Tensile strength is calculated from the maximum load during a tension test carried to rupture and the original cross-sectional area of the specimen. (See Terminology E 6.)

3.2.21 *time to failure*, t_f [t], n —total elapsed time from test initiation to test termination required to reach the number of cycles to failure.

4. Significance and Use

4.1 This practice may be used for material development, material comparison, quality assurance, characterization, reliability assessment, and design data generation.

4.2 High-strength, monolithic advanced ceramic materials are generally characterized by small grain sizes ($< 50 \mu m$) and

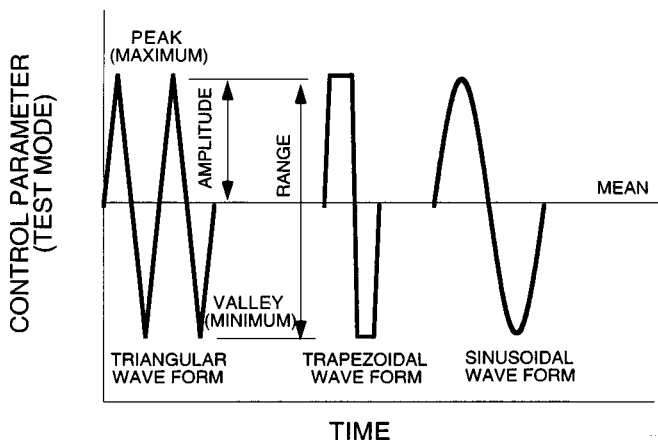


FIG. 1 Cyclic Fatigue Nomenclature and Wave Forms

bulk densities near the theoretical density. These materials are candidates for load-bearing structural applications requiring high degrees of wear and corrosion resistance, and high-temperature strength. Although flexural test methods are commonly used to evaluate strength of advanced ceramics, the non uniform stress distribution in a flexure specimen limits the volume of material subjected to the maximum applied stress at fracture. Uniaxially-loaded tensile strength tests may provide information on strength-limiting flaws from a greater volume of uniformly stressed material.

4.3 Cyclic fatigue by its nature is a probabilistic phenomenon as discussed in STP 91A and STP 588.**(1,2)**⁷ In addition, the strengths of advanced ceramics are probabilistic in nature. Therefore, a sufficient number of specimens at each testing condition is required for statistical analysis and design, with guidelines for sufficient numbers provided in STP 91A, **(1)** STP 588, **(2)** and Practice E 739. The many different tensile specimen geometries available for cyclic fatigue testing may result in variations in the measured cyclic fatigue behavior of a particular material due to differences in the volume or surface area of material in the gage section of the specimens.

4.4 Tensile cyclic fatigue tests provide information on the material response under fluctuating uniaxial tensile stresses. Uniform stress states are required to effectively evaluate any non-linear stress-strain behavior which may develop as the result of cumulative damage processes (for example, microcracking, cyclic fatigue crack growth, etc.).

4.5 Cumulative damage processes due to cyclic fatigue may be influenced by testing mode, testing rate (related to frequency), differences between maximum and minimum load (R or A), effects of processing or combinations of constituent materials, or environmental influences, or both. Other factors that influence cyclic fatigue behaviour are: void or porosity content, methods of specimen preparation or fabrication, specimen conditioning, test environment, load or strain limits during cycling, wave shapes (that is, sinusoidal, trapezoidal, etc.), and failure mode. Some of these effects may be consequences of stress corrosion or sub critical (slow) crack growth which can be difficult to quantify. In addition, surface or near-surface flaws introduced by the specimen fabrication process (machining) may or may not be quantifiable by conventional measurements of surface texture. Therefore, surface effects (for example, as reflected in cyclic fatigue reduction factors as classified by Marin **(3)**) must be inferred from the results of numerous cyclic fatigue tests performed with specimens having identical fabrication histories.

4.6 The results of cyclic fatigue tests of specimens fabricated to standardized dimensions from a particular material or selected portions of a part, or both, may not totally represent the cyclic fatigue behavior of the entire, full-size end product or its in-service behavior in different environments.

4.7 However, for quality control purposes, results derived from standardized tensile test specimens may be considered indicative of the response of the material from which they were taken for given primary processing conditions and post-processing heat treatments.

4.8 The cyclic fatigue behavior of an advanced ceramic is dependent on its inherent resistance to fracture, the presence of flaws, or damage accumulation processes, or both. There can be significant damage in the specimen without any visual evidence such as the occurrence of a macroscopic crack. This can result in a specific loss of stiffness and retained strength. Depending on the purpose for which the test is being conducted, rather than final fracture, a specific loss in stiffness or retained strength may constitute failure. In cases where fracture occurs, analysis of fracture surfaces and fractography, though beyond the scope of this practice, are recommended.

5. Interferences

5.1 Test environment (vacuum, inert gas, ambient air, etc.) including moisture content (for example, relative humidity) may have an influence on the measured cyclic fatigue behavior. In particular, the behavior of materials susceptible to slow crack growth fracture will be strongly influenced by test environment and testing rate. Conduct tests to evaluate the mechanical cyclic fatigue behaviour of a material in inert environments to minimize slow crack growth effects. Conversely, conduct tests in environments or at test modes and rates representative of service conditions to evaluate material performance under use conditions, or both. Regardless of whether testing is conducted in uncontrolled ambient air or controlled environments, monitor and report relative humidity and temperature at a minimum at the beginning and end of each test, and hourly if the test duration is greater than 1 h. Testing at humidity levels greater than 65 % relative humidity (RH) is not recommended.

5.2 While cyclic fatigue in ceramics is sensitive to environment at any stress level **(4)** environment has been shown to have a greater influence on cyclic fatigue at higher loads (that is, loads greater than the threshold for static fatigue **(5)**). In this regime, the number of cycles to failure may be influenced by test frequency and wave form. Tests performed at low frequency with wave forms having plateaus may decrease the cycles to failure since the material is subject to maximum tensile stresses (that is, similar to static fatigue) for longer periods of time during each cycle. Conversely, at lower stress levels the cycles to failure are usually not influenced by frequency or wave form, except as noted in 4.3.

5.3 In many materials, amplitude of the cyclic wave form is a primary contributor to the cyclic fatigue behavior. However, in ceramics the maximum stress intensity factor may be the primary contributor of the cyclic fatigue behaviour. Nonetheless, the choice of load ratio, R or A , can have a pronounced effect on the cyclic fatigue behavior of the material. A load ratio of $R=1$ (maximum equal to minimum) constitutes a constant load test with no fluctuation of load over time. A load ratio of $R=0$ (minimum equal to zero) constitutes the maximum amplitude (amplitude equal to one half the maximum) for tension-tension cyclic fatigue. A load ratio of $R=0.1$ is often chosen for tension-tension cyclic fatigue so as to impose maximum amplitudes while minimizing the possibility of a “slack” (loose and non-tensioned) load train. The choice of R or A is dictated by the final use of the test result.

5.4 Surface preparation of test specimens can introduce

⁷ The boldface numbers in parentheses refer to the list of references at the end of this standard.