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Designation: C1360 – 10

StandardPractice for Constant-Amplitude, Axial, Tension-Tension Cyclic Fatigue of Continuous Fiber-Reinforced Advanced Ceramics at Ambient Temperatures[1]

This standard is issued under the fixed designation C1360; 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 behavior and performance of continuous fiber-reinforced advanced ceramic composites (CFCCs) at ambient temperatures. This practice builds on experience and existing standards in tensile testing CFCCs at ambient temperatures and addresses various suggested test specimen geometries, specimen fabrication methods, testing modes (force, 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 nonuniform or multiaxial stress states).

1.2 This practice applies primarily to advanced ceramic matrix composites with continuous fiber reinforcement: unidirectional (1-D), bi-directional (2-D), and tri-directional (3-D) or other multi-directional reinforcements. In addition, this practice may also be used with glass (amorphous) matrix composites with 1-D, 2-D, 3-D, and other multi-directional continuous fiber reinforcements. This practice does not directly address discontinuous fiber-reinforced, whisker-reinforced or particulate-reinforced ceramics, although the methods detailed here may be equally applicable to these composites.

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

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:*[2]

C1145 Terminology of Advanced Ceramics
C1275 Test Method for Monotonic Tensile Behavior of Continuous Fiber-Reinforced Advanced Ceramics with Solid Rectangular Cross-Section Test Specimens at Ambient Temperature
D3479/D3479M Test Method for Tension-Tension Fatigue of Polymer Matrix Composite Materials
D3878 Terminology for Composite Materials
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
E337 Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)
E467 Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System
E468 Practice for Presentation of Constant Amplitude Fatigue Test Results for Metallic Materials
E739 Practice for Statistical Analysis of Linear or Linearized Stress-Life (***S-N***) and Strain-Life (ε-***N***) Fatigue Data
E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application
E1150 Definitions of Terms Relating to Fatigue (Withdrawn 1996)[3]
E1823 Terminology Relating to Fatigue and Fracture Testing
IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI) (The Modern Metric System)

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 C28.07 on Ceramic Matrix Composites.

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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.

*A Summary of Changes section appears at the end of this standard

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3.1.1 Definitions of terms relating to advanced ceramics, fiber-reinforced composites, tensile testing, and cyclic fatigue as they appear in Terminology C1145, Terminology D3878, Terminology E6, and Terminology E1823, respectively, apply to the terms used in this practice. Selected terms with definitions non specific to this practice follow in 3.2 with the appropriate source given in parenthesis. Terms specific to this practice are defined in 3.3.

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 C1145.)

3.2.2 *axial strain [LL^{-1}], n*—the average longitudinal strains measured at the surface on opposite sides of the longitudinal axis of symmetry of the test specimen by two strain-sensing devices located at the mid length of the reduced section. (See Practice E1012.)

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 test specimen. (See Practice E1012.)

3.2.4 *ceramic matrix composite, n*—a material consisting of two or more materials (insoluble in one another), in which the major, continuous component (matrix component) is a ceramic, while the secondary component(s) (reinforcing component) may be ceramic, glass-ceramic, glass, metal or organic in nature. These components are combined on a macroscale to form a useful engineering material possessing certain properties or behavior not possessed by the individual constituents. (See Test Method C1275.)

3.2.5 *continuous fiber-reinforced ceramic matrix composite (CFCC), n*—a ceramic matrix composite in which the reinforcing phase consists of a continuous fiber, continuous yarn, or a woven fabric. (See Terminology C1145.)

3.2.6 *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 Terminology E1823.)

3.2.7 *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 Terminology E1823.) See Fig. 1 for nomenclature relevant to cyclic fatigue testing.

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

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

3.2.8 *cyclic fatigue life, N_f*—the number of loading cycles of a specified character that a given test specimen sustains before failure of a specified nature occurs. (See Terminology E1823.)

3.2.9 *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, Nf 10^6 – 10^7). (See Terminology E1823.)

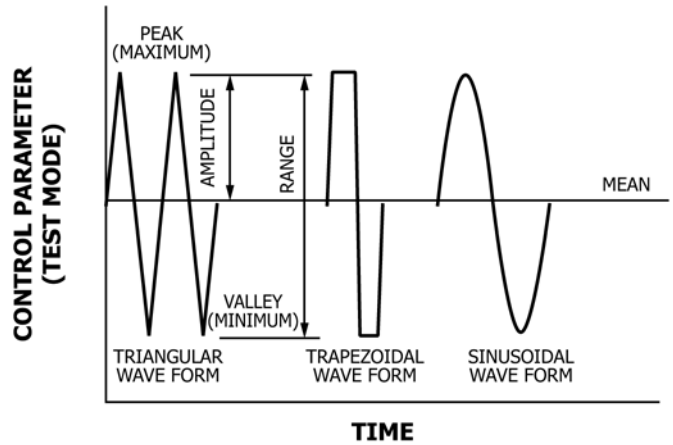

FIG. 1 Cyclic Fatigue Nomenclature and Wave Forms

3.2.9.1 *Discussion*—Certain materials and environments preclude the attainment of a cyclic fatigue limit. Values tabulated as "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.

3.2.10 *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 Terminology E1823).

3.2.11 *gage length, [L], n*—the original length of that portion of the test specimen over which strain or change of length is determined. (See Terminology E6.)

3.2.12 *force ratio, n*—in cyclic fatigue loading, the algebraic ratio of the two loading parameters of a cycle; the most widely used ratios (See Terminology E1150, E1823):

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

and

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

3.2.13 *matrix-cracking stress [FL^{-2}], n*—The applied tensile stress at which the matrix cracks into a series of roughly parallel blocks normal to the tensile stress. (See Test Method C1275.)

3.2.13.1 *Discussion*—In some cases, the matrix-cracking stress may be indicated on the stress-strain curve by deviation from linearity (proportional limit) or incremental drops in the stress with increasing strain. In other cases, especially with materials that do not possess a linear portion of the stress-strain curve, the matrix cracking stress may be indicated as the first stress at which a permanent offset strain is detected in the unloading stress-strain curve (elastic limit).

3.2.14 *modulus of elasticity [FL^{-2}], n*—The ratio of stress to corresponding strain below the proportional limit. (See Terminology E6.)

3.2.15 *proportional limit stress [FL^{-2}], n*—the greatest stress that a material is capable of sustaining without any deviation from proportionality of stress to strain (Hooke's law). (See Terminology E6.)

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3.2.15.1 *Discussion*—Many experiments have shown that values observed for the proportional limit vary greatly with the sensitivity and accuracy of the testing equipment, eccentricity of loading, the scale to which the stress-strain diagram is plotted, and other factors. When determination of proportional limit is required, specify the procedure and sensitivity of the test equipment.

3.2.16 *percent bending, n*—the bending strain times 100 divided by the axial strain. (See Practice E1012.)

3.2.17 *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 Terminology E1150 and Practice E468.)

3.2.18 *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 (See Test Method C1275).

3.2.19 *tensile strength* $[FL^{-2}]$, *n*—the maximum tensile stress which a material is capable of sustaining. Tensile strength is calculated from the maximum force during a tension test carried to rupture and the original cross-sectional area of the test specimen. (See Terminology E6.)

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *fracture strength* $[FL^{-2}]$, *n*—the tensile stress that the material sustains at the instant of fracture. Fracture strength is calculated from the force at fracture during a tension test carried to rupture and the original cross-sectional area of the test specimen.

3.3.1.1 *Discussion*—In some cases, the fracture strength may be identical to the tensile strength if the force at fracture is the maximum for the test.

3.3.2 *maximum stress,* $S_{min}[FL^{-2}]$, *n*—the maximum applied stress during cyclic fatigue.

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

$$S_m = \frac{S_{max} + S_{min}}{2} \tag{1}$$

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

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

$$S_a = \frac{S_{max} - S_{min}}{2} = S_{max} - S_m = S_m - S_{min} \tag{2}$$

3.3.6 *stress range,* ΔS *or* $S_r[FL^{-2}]$, *n*—the difference between the maximum stress and the minimum stress such that

$$\Delta S = S_r = S_{max} - S_{min} \tag{3}$$

3.3.7 *time to cyclic fatigue 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 Continuous fiber-reinforced ceramic matrix composites are generally characterized by crystalline matrices and ceramic fiber reinforcements. These materials are candidate materials for structural applications requiring high degrees of wear and corrosion resistance, and high-temperature inherent damage tolerance (that is, toughness). In addition, continuous fiber-reinforced glass matrix composites are candidate materials for similar but possibly less-demanding applications. Although flexural test methods are commonly used to evaluate the mechanical behavior of monolithic advanced ceramics, the non-uniform stress distribution in a flexural test specimen in addition to dissimilar mechanical behavior in tension and compression for CFCCs leads to ambiguity of interpretation of test results obtained in flexure for CFCCs. Uniaxially-loaded tensile tests provide information on mechanical behavior for a uniformly stressed material.

4.3 The cyclic fatigue behavior of CFCCs can have appreciable non-linear effects (for example, sliding of fibers within the matrix) which may be related to the heat transfer of the specimen to the surroundings. Changes in test temperature, frequency, and heat removal can affect test results. It may be desirable to measure the effects of these variables to more closely simulate end-use conditions for some specific application.

4.4 Cyclic fatigue by its nature is a probabilistic phenomenon as discussed in STP 91A (Ref (**1**)) and STP 588 (Ref (**2**)).[4] In addition, the strengths of the brittle matrices and fibers of CFCCs are probabilistic in nature. Therefore, a sufficient number of test specimens at each testing condition is required for statistical analysis and design, with guidelines for sufficient numbers provided in STP 91A (Ref (**1**)), STP 588 (Ref (**2**)), and Practice E739. Studies to determine the influence of test specimen volume or surface area on cyclic fatigue strength distributions for CFCCs have not been completed. The many different tensile test 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 of material in the gage section of the test specimens.

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

4.6 Cumulative damage due to cyclic fatigue may be influenced by testing mode, testing rate (related to frequency), differences between maximum and minimum force(*R* or A),

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

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