Designation: C1468 – 19a

Standard Test Method for Transthickness Tensile Strength of Continuous Fiber-Reinforced Advanced Ceramics at Ambient Temperature[1]

This standard is issued under the fixed designation C1468; 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 transthickness tensile strength (S_U^T) under monotonic uniaxial tensile loading of continuous fiber-reinforced ceramics (CFCC) at ambient temperature. This test method addresses, but is not restricted to, various suggested test specimen geometries, test fixtures, data collection, and reporting procedures. In general, round or square test specimens are tensile tested in the direction normal to the thickness by bonding appropriate hardware to the samples and performing the test. For a Cartesian coordinate system, the x-axis and the y-axis are in the plane of the test specimen. The transthickness direction is normal to the plane and is labeled the z-axis for this test method. For CFCCs, the plane of the test specimen normally contains the larger of the three dimensions and is parallel to the fiber layers for unidirectional, bidirectional, and woven composites. Note that transthickness tensile strength as used in this test method refers to the tensile strength obtained under monotonic uniaxial tensile loading, where "monotonic" refers to a continuous nonstop test rate with no reversals from test initiation to final fracture.

1.2 This test method is intended primarily for use with all advanced ceramic matrix composites with continuous fiber reinforcement: unidirectional (1D), bidirectional (2D), woven, and tridirectional (3D). In addition, this test method also may be used with glass (amorphous) matrix composites with 1D, 2D, and 3D continuous fiber reinforcement. This test method does not directly address discontinuous fiber-reinforced, whisker-reinforced, or particulate-reinforced ceramics, although the test methods detailed here may be equally applicable to these composites. It should be noted that 3D architectures with a high volume fraction of fibers in the "z" direction may be difficult to test successfully.

1.3 Values are in accordance with the International System of Units (SI) and 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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* Additional recommendations are provided in 6.7 and Section 7.

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C1145 Terminology of Advanced Ceramics

C1239 Practice for Reporting Uniaxial Strength Data and Estimating Weibull Distribution Parameters for 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

C1468 Test Method for Transthickness Tensile Strength of Continuous Fiber-Reinforced Advanced Ceramics at Ambient Temperature

D3878 Terminology for Composite Materials

E4 Practices for Force Verification of Testing Machines

E6 Terminology Relating to Methods of Mechanical Testing

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E337 Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

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[1] This test method 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.

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

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 Metric Practice

3. Terminology

3.1 *Definitions:*

3.1.1 The definitions of terms relating to tensile testing appearing in Terminology E6 apply to the terms used in this test method. The definitions of terms relating to advanced ceramics appearing in Terminology C1145 apply to the terms used in this test method. The definitions of terms relating to fiber-reinforced composites appearing in Terminology D3878 apply to the terms used in this test method. Pertinent definitions as listed in Practice E1012 and Terminologies C1145, D3878, and E6 are shown in the following with the appropriate source given in brackets. Terms used in conjunction with this test method are defined as follows:

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

3.1.3 *bending strain* $[LL^{-1}]$, *n*—the difference between the strain at the surface and the axial strain. **[E1012]**

3.1.4 *breaking force [F], n*—the force at which fracture occurs, P_{max}, is the breaking force in units of N. **[E6]**

3.1.5 *ceramic matrix composite (CMC), 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. **[C1145]**

3.1.6 *continuous fiber-reinforced ceramic matrix composite (CFCC), n*—a ceramic matrix composite in which the reinforcing phase consists of continuous filaments, fibers, yarn, or knitted or woven fabrics. **[C1145]**

3.1.7 *gage length [L], n*—the original length $[L_{GL}]$ of that portion of the test specimen over which strain or change of length is determined. **[E6]**

3.1.8 *modulus of elasticity* $[FL^{-2}]$, *n*—the ratio of stress to corresponding strain below the proportional limit. **[E6]**

3.1.9 *percent bending, n*—the bending strain times 100 divided by the axial strain. **[E1012]**

3.1.10 *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. **[E6]**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *fixturing, n*—fixturing is referred to as the device(s) bonded to the test specimen. It is this device(s) that is actually gripped or pinned to the load train. The fixturing transmits the applied force to the test specimen.

3.2.2 *transthickness, n*—the direction parallel to the thickness, that is, out-of-plane dimension, as identified in 1.1, and also typically normal to the plies for 1D, 2D laminate, and woven cloth. For 3D laminates, this direction is typically taken to be normal to the thickness and associated with the "*z*" direction.

4. Significance and Use

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

4.2 Continuous fiber-reinforced ceramic matrix composites generally are characterized by glass or fine grain-sized (<50 µm) ceramic matrices and ceramic fiber reinforcements. CFCCs are candidate materials for high-temperature structural applications requiring high degrees of corrosion and oxidation resistance, wear and erosion resistance, and inherent damage tolerance, that is, toughness. In addition, continuous fiber-reinforced glass (amorphous) matrix composites are candidate materials for similar but possibly less demanding applications. Although shear test methods are used to evaluate shear interlaminar strength (τ_{ZX}, τ_{ZY}) in advanced ceramics, there is significant difficulty in test specimen machining and testing. Improperly prepared notches can produce nonuniform stress distribution in the shear test specimens and can lead to ambiguity of interpretation of strength results. In addition, these shear test specimens also rarely produce a gage section that is in a state of pure shear. Uniaxially forced transthickness tensile strength tests measure the tensile interlaminar strength (S_U^T), avoid the complications listed above, and provide information on mechanical behavior and strength for a uniformly stressed material. The ultimate strength value measured is not a direct measure of the matrix strength, but a combination of the strength of the matrix and the level of bonding between the fiber, fiber/matrix interphase, and the matrix.

4.3 CFCCs tested in a transthickness tensile test (TTT) may fail from a single dominant flaw or from a cumulative damage process; therefore, the volume of material subjected to a uniform tensile stress for a single uniaxially forced TTT may be a significant factor in determining the ultimate strength of CFCCs. The probabilistic nature of the strength distributions of the brittle matrices of CFCCs requires a sufficient number of test specimens at each testing condition for statistical analysis and design, with guidelines for test specimen size and sufficient numbers provided in this test method. Studies to determine the exact influence of test specimen volume on strength distributions for CFCCs have not been completed. It should be noted that strengths obtained using other recommended test specimens with different volumes and areas may vary due to these volume differences.

4.4 The results of TTTs of test specimens fabricated to standardized dimensions from a particular material, or selected portions of a part, or both, may not totally represent the strength and deformation properties of the entire full-size end product or its in-service behavior in different environments.

4.5 For quality control purposes, results derived from standardized TTT 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.

4.6 The strength of CFCCs is dependent on their inherent resistance to fracture, the presence of flaws, damage accumulation processes, or a combination thereof. Analysis of fracture surfaces and fractography, though beyond the scope of this test method, is highly 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 strength. In particular, the behavior of materials susceptible to slow crack growth fracture will be strongly influenced by test environment and testing rate. Testing to evaluate the maximum strength potential of a material should be conducted in inert environments or at sufficiently rapid testing rates, or both, so as to minimize slow crack growth effects. Conversely, testing can be conducted in environments and testing modes and rates representative of service conditions to evaluate material performance under use conditions. When testing is conducted in uncontrolled ambient air with the intent of evaluating maximum strength potential, relative humidity and temperature must be monitored and reported. Testing at humidity levels >65 % RH is not recommended and any deviations from this recommendation must be reported.

5.2 Surface and edge preparation of test specimens can introduce fabrication flaws which may have pronounced effects on the measured transthickness strength (**1**).[3] Machining damage introduced during test specimen preparation can be either a random interfering factor in the determination of strength of pristine material, that is, increased frequency of surface-initiated fractures compared to volume-initiated fractures, or an inherent part of the strength characteristics. Universal or standardized test methods of surface and edge preparation do not exist. It should be understood that final machining steps may, or may not, negate machining damage introduced during the initial machining; thus, test specimen fabrication history may play an important role in the measured strength distributions and should be reported. In addition, the nature of fabrication used for certain composites, for example, chemical vapor infiltration or hot pressing, may require the testing of test specimens in the as-processed condition.

5.3 Bending in uniaxial TTTs can cause or promote nonuniform stress distributions with maximum stresses occurring at the test specimen edge, leading to nonrepresentative fractures. Similarly, fracture from edge flaws may be accentuated or suppressed by the presence of the nonuniform stresses caused by bending.

NOTE 1—Finite element calculations were performed for the square cross section test specimen for the forcing conditions and test specimen thickness investigated in Reference (**1**). Stress levels along the four corner edges were found to be lower than the interior, except for the corners at the bond lines where the stress was slightly higher than the interior. Stress levels along the sides and interior of the test specimen were found to be uniform.

6. Apparatus

6.1 *Testing Machines*—Machines used for TTT shall conform to the requirements of Practices E4. The forces used in determining tensile strength shall be accurate within ±1 % at any force within the selected force range of the testing machine as defined in Practices E4. A schematic showing pertinent features of the TTT apparatus for two possible forcing configurations is shown in Figs. 1 and 2.

6.1.1 Values for transthickness tensile strength can range a great deal for different types of CFCC. Therefore, it is helpful to know an expected strength value in order to properly select a force range. Approximate transthickness tensile strength values (**1**) for several CFCCs are as follows: porous oxide/oxide composites range from 2 to 10 MPa; hot-pressed, fully dense SiC/MAS-5 glass-ceramic composites range from 14 to 27 MPa; Polymer Infiltrated and Pyrolyzed (PIP) SiC/SiNC range from 15 to 32 MPa; and hot-pressed SCS-6/Si_3N_4 ranges from 30 to 43 MPa.

6.1.2 For any testing apparatus, the load train will need to be aligned for angularity and concentricity. Alignment of the testing system will need to be measured and is detailed in A1.1 of Test Method C1275.

6.2 *Gripping Devices:*

6.2.1 *General*—Various types of gripping devices may be used to transmit the force applied by the testing machine to the test fixtures and into the test specimens. The brittle nature of the matrices of CFCCs requires accurate alignment. Bending moments can produce stresses leading to premature crack initiation and fracture of the test specimen. Gripping devices can be classified generally as those employing active and those employing passive grip interfaces as discussed in the following

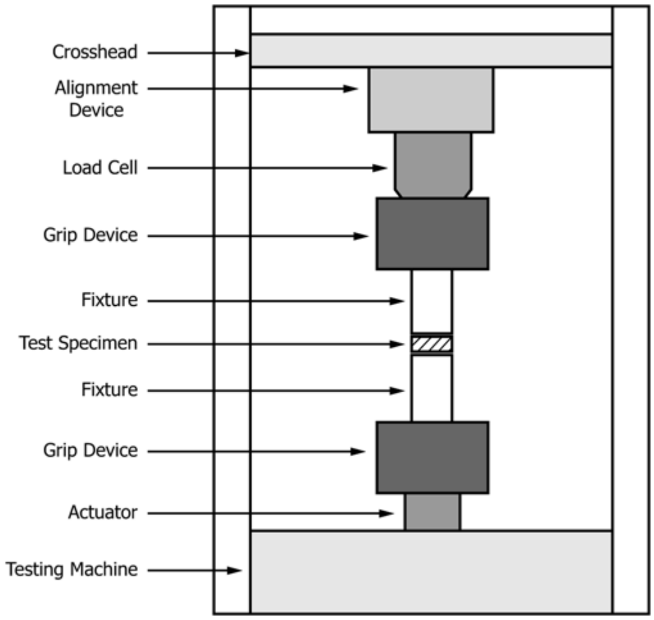

FIG. 1 Schematic Diagram of One Possible Apparatus for Conducting a Uniaxial Transthickness Tensile Test

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[3] The boldface numbers in parentheses refers to the list of references at the end of this standard.