Designation: C1773 – 21

Standard Test Method for Monotonic Axial Tensile Behavior of Continuous Fiber-Reinforced Advanced Ceramic Tubular Test Specimens at Ambient Temperature[1]

This standard is issued under the fixed designation C1773; 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 determines the axial tensile strength and stress-strain response of continuous fiber-reinforced advanced ceramic composite tubes at ambient temperature under monotonic loading. This test method is specific to tube geometries, because fiber architecture and specimen geometry factors are often distinctly different in composite tubes, as compared to flat plates.

1.2 In the test method a composite tube/cylinder with a defined gage section and a known wall thickness is fitted/bonded into a loading fixture. The test specimen/fixture assembly is mounted in the testing machine and monotonically loaded in uniaxial tension at ambient temperature while recording the tensile force and the strain in the gage section. The axial tensile strength and the fracture strength are determined from the maximum applied force and the fracture force. The strains, the proportional limit stress, and the tensile modulus of elasticity are determined from the stress-strain data.

1.3 This test method applies primarily to advanced ceramic matrix composite tubes with continuous fiber reinforcement: unidirectional (1D, filament wound and tape lay-up), bidirectional (2D, fabric/tape lay-up and weave), and tridirectional (3D, braid and weave). These types of ceramic matrix composites are composed of a wide range of ceramic fibers (oxide, graphite, carbide, nitride, and other compositions) in a wide range of crystalline and amorphous ceramic matrix compositions (oxide, carbide, nitride, carbon, graphite, and other compositions).

1.4 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.

1.5 The test method describes a range of test specimen tube geometries based on past tensile testing of ceramic composite tubes. These geometries are applicable to tubes with outer diameters of 10 to 150 mm and wall thicknesses of 1 to 25 mm, where the ratio of the outer diameter-to-wall thickness (d_O/t) is typically between 5 and 30.

1.5.1 This test method is specific to ambient temperature testing. Elevated temperature testing requires high-temperature furnaces and heating devices with temperature control and measurement systems and temperature-capable grips and loading fixtures, which are not addressed in this test method.

1.6 The test method addresses test equipment, gripping methods, testing modes, allowable bending stresses, interferences, tubular test specimen geometries, test specimen preparation, test procedures, data collection, calculation, reporting requirements, and precision/bias in the following sections.

1.7 *Units*—The values stated in SI units are to be regarded as standard.

1.8 *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.* Specific precautionary statements are given in Section 8.

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

1.9 *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

C1273 Test Method for Tensile Strength of Monolithic Advanced Ceramics at Ambient Temperatures

C1557 Test Method for Tensile Strength and Young's Modulus of Fibers

D3878 Terminology for Composite Materials

D5450 Test Method for Transverse Tensile Properties of Hoop Wound Polymer Matrix Composite Cylinders

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

E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

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

E251 Test Methods for Performance Characteristics of Metallic Bonded Resistance Strain Gages

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

E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application

3. Terminology

3.1 *Definitions:*

3.1.1 Pertinent definitions, as listed in Terminology C1145, Practice E1012, Terminology D3878, and Terminology E6, are shown in the following with the appropriate source in bold type. Additional terms used in conjunction with this test method are defined in the following:

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

3.1.3 *axial strain, n*—the average of the 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. **E1012**

3.1.4 *bending strain, 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. **E1012**

3.1.5 *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. **C1145**

3.1.6 *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. **C1145**

3.1.7 *fracture (breaking) force, $P_{fracture}$, n*—the force at which the test specimen ruptures, breaking into two or more pieces.

3.1.8 *fracture strength, S_f, n*—the tensile stress at which the test specimen ruptures, breaking into two or more pieces or where the applied force drops off significantly. Typically, a 10 % force drop off is considered significant.

3.1.9 *gage length, l_O, n*—the original length of that portion of the test specimen over which strain or change of length is determined. **E6**

3.1.10 *matrix cracking stress, n*—the applied tensile stress at which the matrix in the composite cracks into a series of roughly parallel blocks normal to the tensile stress.

3.1.10.1 *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 which 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 (elastic limit).

3.1.11 *modulus of elasticity, E, n*—the ratio of stress to corresponding strains below the proportional limit. **E6**

3.1.12 *modulus of resilience, U_r, n*—strain energy per unit volume required to elastically stress the material from zero to the proportional limit indicating the ability of the material to absorb energy when deformed elastically and return it when unloaded.

3.1.13 *modulus of toughness, U_r, n*—strain energy per unit volume required to stress the material from zero to final fracture indicating the ability of the material to absorb energy beyond the elastic range (that is, damage tolerance of the material).

3.1.13.1 *Discussion*—The modulus of toughness can also be referred to as the cumulative damage energy and as such is regarded as an indication of the ability of the material to sustain damage rather than as a material property. Fracture mechanics methods for the characterization of CFCCs have not been developed. The determination of the modulus of toughness as

[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.

provided in this test method for the characterization of the cumulative damage process in CFCCs may become obsolete when fracture mechanics methods for CFCCs become available.

3.1.14 *proportional limit stress, σ_o, n*—the greatest stress that a material is capable of sustaining without any deviation from proportionality of stress to strain (Hooke's law). **E6**

3.1.14.1 *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 stress is required, the procedure and sensitivity of the test equipment should be specified.

3.1.15 *percent bending, n*—the bending strain times 100 divided by the axial strain. **E1012**

3.1.16 *slow crack growth, 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. **C1145**

3.1.17 *stress corrosion, n*—environmentally induced degradation that results in the formation and growth of cracks and/or damage in glasses and many ceramics when subjected to the combined action of a corroding agent and stress. **C1145**

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

3.1.18 *tensile strength, S_u, 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**

3.1.19 *tow, n*—in fibrous composites, a continuous, ordered assembly of essentially parallel, collimated filaments, normally without twist and of continuous filaments. **D3878**

3.1.20 *uniaxial tension, n*—the application of tensile force coaxially with the long dimension of the test specimen.

4. Summary of Test Method

4.1 This test method involves the testing of a ceramic composite tube/cylinder with a known wall thickness in monotonic uniaxial tension at ambient temperature. The prepared test specimen with a defined gage section is fitted/bonded into a loading fixture and the test specimen/fixture assembly is mounted in the testing machine. The test specimen is loaded in axial tension while recording the applied force and resulting strain. The axial tensile strength S_u and the fracture strength S_f are determined from the maximum applied force and the fracture force. The axial strains, the proportional limit stress, and the tensile modulus of elasticity are determined from the stress-strain response data.

4.2 Tensile strength as used in this test method refers to the tensile strength obtained under monotonic uniaxial loading. In uniaxial loading, the force is applied coaxially with the long dimension of the tube test specimen. Monotonic refers to a continuous nonstop test rate with no reversals from test initiation to final fracture.

4.3 This test method is applicable to a range of test cylinder specimen geometries and sizes, which are described and considered in Section 9. A single fixed test specimen geometry cannot be defined because there is a wide range of composite cylinder configurations in use and development. The different described test specimen geometries are typically applicable to tubes with outer diameters of 10 to 150 mm and wall thicknesses of 1 to 25 mm, where the ratio of the outer diameter-to-wall thickness (d_O /t) is between 5 and 30.

5. Significance and Use

5.1 This test method provides information on the uniaxial tensile properties and tensile stress-strain response of a ceramic composite tube—tensile strength and strain, fracture strength and strain, proportional limit stress and strain, tensile elastic modulus, etc. The information may be used for material development, material comparison, quality assurance, characterization, and design data generation.

5.2 Continuous fiber-reinforced ceramic composites (CFCCs) are composed of continuous ceramic-fiber directional (1D, 2D, and 3D) reinforcements in a fine-grain-sized (<50 µm) ceramic matrix with controlled porosity. Often these composites have an engineered thin (0.1 to 10 µm) interface coating on the fibers to produce crack deflection and fiber pull-out. These ceramic composites offer high-temperature stability, inherent damage tolerance, and high degrees of wear and corrosion resistance. As such, these ceramic composites are particularly suited for aerospace and high-temperature structural applications (**1, 2**).[3]

5.3 CFCC components have a distinctive and synergistic combination of material properties, interface coatings, porosity control, composite architecture (1D, 2D, and 3D), and geometric shape that are generally inseparable. Prediction of the mechanical performance of CFCC tubes (particularly with braid and 3D weave architectures) cannot be made by applying measured properties from flat CFCC plates to the design of tubes. Direct uniaxial tensile strength tests of CFCC tubes are needed to provide reliable information on the mechanical behavior and strength of tube geometries.

5.4 CFCCs generally experience "graceful" fracture from a cumulative damage process, unlike monolithic advanced ceramics which fracture catastrophically from a single dominant flaw. The tensile behavior and strength of a CFCC are dependent on its inherent resistance to fracture, the presence of flaws, and any damage accumulation processes. These factors are affected by the composite material composition and variability in material and testing—components, reinforcement architecture and volume fraction, porosity content, matrix morphology, interface morphology, methods of material fabrication, test specimen preparation and conditioning, and surface condition.

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