~~Designation:C1358–05~~ Designation: C1358 – 11

Standard Test Method for Monotonic Compressive Strength Testing of Continuous Fiber-Reinforced Advanced Ceramics with Solid Rectangular Cross-Section Test Specimens at Ambient Temperatures[1]

This standard is issued under the fixed designation C1358; 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 compressive strength including stress-strain behavior under monotonic uniaxial loading of continuous fiber-reinforced advanced ceramics at ambient temperatures. This test method addresses, but is not restricted to, various suggested test specimen geometries as listed in the appendix. In addition, test specimen fabrication methods, testing modes (force, displacement, or strain control), testing rates (force rate, stress rate, displacement rate, or strain rate), allowable bending, and data collection and reporting procedures are addressed. Compressive strength as used in this test method refers to the compressive strength obtained under monotonic uniaxial loading where monotonic refers to a continuous nonstop test rate with no reversals from test initiation to final fracture.

1.2 This test method applies primarily to advanced ceramic matrix composites with continuous fiber reinforcement: uni-directional (1–D), bi-directional (2–D), and tri-directional (3–D) or other multi-directional reinforcements. In addition, this test method may also be used with glass (amorphous) matrix composites with 1–D, 2–D, 3–D, and other multi-directional continuous fiber reinforcements. 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.

1.3 The values stated in SI units are to be regarded as the standard and are in accordance with SI 10-02 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

D695 Test Method for Compressive Properties of Rigid Plastics

D3379 Test Method for Tensile Strength and Young's Modulus for High-Modulus Single-Filament Materials

D3410/D3410M Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading

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)

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

SI 10-02 IEEE/ASTM SI 10 American National Standard for Use of the International System of Units (SI): The Modern Metric System

[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.

~~Current edition approved June 1, 2005. Published July 2005. Originally approved in 1996. Last previous edition approved in 2000 as C1358–96 (2000), DOI: 10.1520/C1358-05.~~

Current edition approved July 15, 2011. Published August 2011. Originally approved in 1996. Last previous edition approved in 2005 as C1358 – 05. DOI: 10.1520/C1358-11

[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. Terminology

3.1 *Definitions:*

3.1.1 The definitions of terms relating to compressive testing, advanced ceramics, and fiber-reinforced composites, appearing in Terminology E6, Test Method D695, Practice E1012, Terminology C1145, Test Method D3410/D3410M, and Terminology D3878 apply to the terms used in this test method. Pertinent definitions are shown as follows with the appropriate source given in parentheses. Additional terms used in conjunction with this test method are defined in 3.2.

3.2 *Definitions of Terms Specific to This Standard:*

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

3.2.2 *axial strain [LL^{-1}]*, *n*—average longitudinal 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. **E1012**

3.2.3 *bending strain [LL^{-1}]*, *n*—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. **E1012**

3.2.4 *breaking force [F]*, *n*—force at which fracture occurs. **E6**

3.2.5 *ceramic matrix composite*, *n*—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.

3.2.6 *compressive strength [FL^{-2}]*, *n*—maximum compressive stress which a material is capable of sustaining. Compressive strength is calculated from the maximum force during a compression test carried to rupture and the original cross-sectional area of the specimen. **E6**

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

3.2.8 *gage length [L]*, *n*—original length of that portion of the specimen over which strain or change of length is determined. **E6**

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

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

3.2.10.1 *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. **E6**

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

3.2.12 *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. **C1145**

4. Significance and Use

4.1 This test method 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 (CFCCs) are generally characterized by fine-grain sized (<50 µm) matrices and ceramic fiber reinforcements. In addition, continuous fiber-reinforced glass (amorphous) matrix composites can also be classified as CFCCs. Uniaxial-loaded compressive strength tests provide information on mechanical behavior and strength for a uniformly stressed CFCC.

4.3 Generally, ceramic and ceramic matrix composites have greater resistance to compressive forces than tensile forces. Ideally, ceramics should be compressively stressed in use, although engineering applications may frequently introduce tensile stresses in the component. Nonetheless, compressive behavior is an important aspect of mechanical properties and performance. The compressive strength of ceramic and ceramic composites may not be deterministic Therefore, test a sufficient number of test specimens to gain an insight into strength distributions.

4.4 Compression tests provide information on the strength and deformation of materials under uniaxial compressive stresses. Uniform stress states are required to effectively evaluate any nonlinear stress-strain behavior that may develop as the result of cumulative damage processes (for example, matrix cracking, matrix/fiber debonding, fiber fracture, delamination, etc.) that may be influenced by testing mode, testing rate, effects of processing or combination of constituent materials, or environmental influences. Some of these effects may be consequences of stress corrosion or sub-critical (slow) crack growth which can be minimized by testing at sufficiently rapid rates as outlined in this test method.

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

4.6 For quality control purposes, results derived from standardized compressive 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.

4.7 The compressive behavior and strength of a CFCC are dependent on, and directly related to, the material. Analysis of fracture surfaces and fractography, though beyond the scope of this test method, 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 compressive strength. In particular, the behavior of materials susceptible to slow crack growth will be strongly influenced by test environment, testing rate, and test temperature. Conduct tests to evaluate the maximum strength potential of a material in inert environment or at sufficiently rapid testing rates, or both, to minimize slow crack growth effects. Conversely, conduct tests in environments or at test modes, or both, and rates representative of service conditions to evaluate material performance under use conditions. Monitor and report relative humidity and ambient temperature when testing is conducted in uncontrolled ambient air with the intent of evaluating maximum strength potential. Testing at humidity levels >65 % relative humidity (RH) is not recommended.

5.2 Surface preparation of test specimens, although normally not considered a major concern in CFCCs, can introduce fabrication flaws that may have pronounced effects on compressive mechanical properties and behavior (for example, shape and level of the resulting stress-strain curve, compressive strength and strain, proportional limit stress and strain, etc.) Machining damage introduced during test specimen preparation can be either a random interfering factor in the determination of ultimate 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 to be measured. Surface preparation can also lead to the introduction of residual stresses. Universal or standardized test methods of surface preparation do not exist. 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 (that is, it may not be possible to machine the test specimen faces without compromising the in-plane fiber architecture). Final machining steps may, or may not, negate machining damage introduced during the initial machining. Thus, report test specimen fabrication history since it may play an important role in the measured strength distributions.

5.3 Bending in uniaxial compressive tests can introduce eccentricity leading to geometric instability of the test specimen and buckling failure before true compressive strength is attained. In addition, if deformations or strains are measured at surfaces where maximum or minimum stresses occur, bending may introduce over or under measurement of strains depending on the location of the strain-measuring device on the test specimen. Bending can be introduced from, among other sources, initial load train misalignment, misaligned test specimens as installed in the grips, warped test specimens, or load train misalignment introduced during testing due to low lateral machine/grip stiffness.

5.4 Fractures that initiate outside the uniformly stressed gage section of a test specimen may be due to factors such as stress concentrations or geometrical transitions, extraneous stresses introduced by gripping, or strength-limiting features in the microstructure of the test specimen. Such non-gage section fractures will normally constitute invalid tests. In addition, for frictional face-loaded geometrics, gripping pressure is a key variable in the initiation of fracture. Insufficient pressure can shear the outer plies in laminated CFCCs; while too much pressure can cause local crushing of the CFCC and may initiate fracture in the vicinity of the grips.

5.5 Lateral supports are sometimes used in compression tests to reduce the tendency of test specimen buckling. However, such lateral supports may introduce sufficient frictional stress so as to artificially increase the force required to produce compressive failure. In addition, the lateral supports and attendant frictional stresses may invalidate the assumption of uniaxial stress state. When lateral supports are used, the frictional effect should be quantified to ensure that its contribution is small, and the means for doing so reported along with the quantity of the frictional effect.

6. Apparatus

6.1 *Testing Machines*— Machines used for compressive testing shall conform to Practices E4. The forces used in determining compressive strength shall be accurate within ±1 % at any force within the selected ~~load~~force range of the testing machine as defined in Practices E4. A schematic showing pertinent features of one possible compressive testing apparatus is shown in Fig. 1.

6.2 *Gripping Devices*:

6.2.1 *General*—Various types of gripping devices may be used to transmit the measured force applied by the testing machine to the test specimens. The brittle nature of the matrices of CFCCs requires a uniform interface between the grip components and the gripped section of the test specimen. Line or point contacts and nonuniform pressure can produce Hertzian-type stresses leading to crack initiation and fracture of the test specimen in the gripped section.

6.2.1.1 The primary recommended gripping system for compressive testing CFCCs employs active grip interfaces that require a continuous application of a mechanical, hydraulic, or pneumatic force to transmit the force applied by the test machine to the test specimen. These types of grip interfaces (that is, frictional face-loaded grips) cause a force to be applied normal to the surface of the gripped section of the test specimen. Transmission of the uniaxial force applied by the test machine is then accomplished by friction between the test specimen and the grip faces. Thus, important aspects of active grip interfaces are uniform contact between the gripped section of the test specimen and the grip faces and constant coefficient of friction over the grip/specimen interface.