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.

Designation: C1366 – 19

Standard Test Method for Tensile Strength of Monolithic Advanced Ceramics at Elevated Temperatures[1]

This standard is issued under the fixed designation C1366; 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 tensile strength under uniaxial loading of monolithic advanced ceramics at elevated 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. Tensile strength as used in this test method refers to the tensile strength obtained under uniaxial loading.

1.2 This test method applies primarily to advanced ceramics which macroscopically exhibit isotropic, homogeneous, continuous behavior. While this test method applies primarily to monolithic advanced ceramics, certain whisker- or particle-reinforced composite ceramics as well as certain discontinuous fiber-reinforced composite ceramics may also meet these macroscopic behavior assumptions. Generally, continuous fiber ceramic composites (CFCCs) do not macroscopically exhibit isotropic, homogeneous, continuous behavior and application of this test method 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 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.* Refer to Section 7 for specific precautions.

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

C1161 Test Method for Flexural Strength of Advanced Ceramics at Ambient Temperature

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

C1322 Practice for Fractography and Characterization of Fracture Origins in Advanced Ceramics

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

E4 Practices for Force Verification of Testing Machines

E6 Terminology Relating to Methods of Mechanical Testing

E21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials

E83 Practice for Verification and Classification of Extensometer Systems

E220 Test Method for Calibration of Thermocouples By Comparison Techniques

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

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 Definitions of terms relating to tensile testing and advanced ceramics as they appear in Terminology E6 and Terminology C1145, respectively, apply to the terms used in

[1] This test method is under the jurisdiction of ASTM Committee C28 on Advanced Ceramics and is the direct responsibility of Subcommittee C28.01 on Mechanical Properties and Performance.

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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.

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this test method. Pertinent definitions are shown in the following with the appropriate source given in parentheses. 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, predominately non-metallic, inorganic, ceramic material having specific functional attributes. (See Terminology C1145.)

3.1.3 *axial strain [LL^{-1}], n*—the 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. (See Practice E1012.)

3.1.4 *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 E1012.)

3.1.5 *breaking load [F], n*—the load at which fracture occurs. (See Terminology E6.)

3.1.6 *fractography, n*—the means and methods for characterizing a fractured specimen or component. (See Terminology C1145.)

3.1.7 *fracture origin, n*—the source from which brittle fracture commences. (See Terminology C1145).

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

3.1.9 *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.

3.1.10 *tensile strength, S_u [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 E6.)

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 High-strength, monolithic advanced ceramic materials are generally characterized by small grain sizes (<50 μm) and bulk densities near the theoretical density. These materials are candidates for load-bearing structural applications requiring high degrees of wear and corrosion resistance and elevated-temperature strength. Although flexural test methods are commonly used to evaluate strength of advanced ceramics, the nonuniform stress distribution of the flexure specimen limits the volume of material subjected to the maximum applied stress at fracture. Uniaxially loaded tensile strength tests provide information on strength-limiting flaws from a greater volume of uniformly stressed material.

4.3 Because of the probabilistic strength distributions of brittle materials such as advanced ceramics, a sufficient number of test specimens at each testing condition is required for statistical analysis and eventual design with guidelines for sufficient numbers provided in this test method. Size-scaling effects as discussed in Practice C1239 will affect the strength values. Therefore, strengths obtained using different recommended tensile test specimen geometries with different volumes or surface areas of material in the gage sections will be different due to these size differences. Resulting strength values can, in principle, be scaled to an effective volume or effective surface area of unity as discussed in Practice C1239.

4.4 Tensile tests provide information on the strength and deformation of materials under uniaxial stresses. Uniform stress states are required to effectively evaluate any nonlinear stress-strain behavior which may develop as the result of testing mode, testing rate, processing or alloying effects, environmental influences, or elevated temperatures. These effects may be consequences of stress corrosion or sub-critical (slow) crack growth which can be minimized by testing at appropriately rapid rates as outlined in this test method.

4.5 The results of tensile tests of 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.

4.6 For quality control purposes, results derived from standardized tensile test specimens can be considered to be indicative of the response of the material from which they were taken for particular primary processing conditions and post-processing heat treatments.

4.7 The tensile strength of a ceramic material is dependent on both its inherent resistance to fracture and the presence of flaws. Analysis of fracture surfaces and fractography as described in Practice C1322 and MIL-HDBK-790, though beyond the scope of this test method, are recommended for all purposes, especially for design data.

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 tensile strength. In particular, the behavior of materials susceptible to slow crack growth fracture will be strongly influenced by test environment, testing rate, and elevated temperatures. Testing to evaluate the maximum strength potential of a material should be conducted in inert environments or at sufficiently rapid testing rates, or both, 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, monitor and report relative humidity and ambient temperature. Testing at humidity levels >65 % relative humidity (RH) is not recommended.

5.2 Surface preparation of test specimens can introduce fabrication flaws that may have pronounced effects on tensile strength. 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

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volume-initiated fractures), or an inherent part of the strength characteristics. Surface preparation can also lead to the introduction of residual stresses. Universal or standardized test methods of surface preparation do not exist. Final machining steps may or may not negate machining damage introduced during the early coarse or intermediate machining. Thus, report test specimen fabrication history since it may play an important role in the measured strength distributions.

5.3 Bending in uniaxial tensile tests can cause or promote nonuniform stress distributions with maximum stresses occurring at the test specimen surface, leading to nonrepresentative fractures originating at surfaces or near geometrical transitions. Bending may be introduced from several sources including misaligned load trains, eccentric or misshaped test specimens, and nonuniformly heated test specimens or grips. In addition, if strains or deformations are measured at surfaces where maximum or minimum stresses occur, bending may introduce over or under measurement of strains. Similarly, fracture from surface flaws may be accentuated or muted by the presence of the nonuniform stresses caused by bending.

6. Apparatus

6.1 *Testing Machines*—Machines used for tensile testing 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 a possible tensile testing apparatus is shown in Fig. 1.

6.2 *Gripping Devices:*

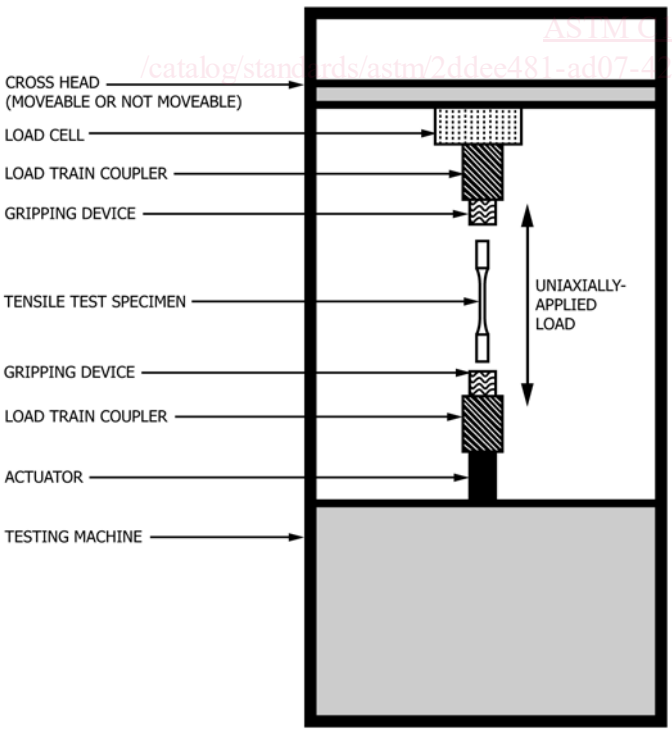

FIG. 1 Schematic Diagram of One Possible Apparatus for Conducting a Uniaxially Loaded Tensile Test

6.2.1 *General*—Various types of gripping devices may be used to transmit the measured load applied by the testing machine to the test specimen. The brittle nature of advanced ceramics 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 stress leading to crack initiation and fracture of the test specimen in the gripped section. Gripping devices can be classed generally as those employing active and those employing passive grip interfaces as discussed in the following sections. Uncooled grips located inside the heated zone are termed "hot grips" and generally produce almost no thermal gradient in the test specimen but at the relative expense of grip materials of at least the same temperature capability as the test material and increased degradation of the grips due to exposure to the elevated-temperature oxidizing environment. Grips located outside the heated zone surrounding the test specimen may or may not employ cooling. Uncooled grips located outside the heated zone are termed "warm grips" and generally induce a mild thermal gradient in the test specimen but at the relative expense of elevated-temperature alloys in the grips and increased degradation of the grips due to exposure to the elevated-temperature oxidizing environment. Cooled grips located outside the heated zone are termed "cold grips" and generally induce a steep thermal gradient in the test specimen at a greater relative expense because of grip cooling equipment and allowances, although with the advantage of consistent alignment and little degradation from exposure to elevated temperatures.

NOTE 1—The expense of the cooling system for cold grips is balanced against maintaining alignment which remains consistent from test to test (stable grip temperature) and decreased degradation of the grips due to exposure to the elevated-temperature oxidizing environment. When grip cooling is employed, means should be provided to control the cooling medium to maximum fluctuations of 5 K (less than 1 K preferred) about a set point temperature (**1**)[3] over the course of the test to minimize thermally induced strain changes in the test specimen. In addition, opposing grip temperatures should be maintained at uniform and consistent temperatures within ±5 K (less than ±1 K preferred) (**1**) so as to avoid introducing unequal thermal gradients and subsequent nonuniaxial stresses in the test specimen. Generally, the need for control of grip temperature fluctuations or differences may be indicated if test specimen gage section temperatures cannot be maintained within the limits required in 9.3.2.

6.2.1.1 *Active Grip Interfaces*—Active grip interfaces require a continuous application of a mechanical, hydraulic, or pneumatic force to transmit the load applied by the test machine to the test specimen. Generally, these types of grip interfaces 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/test specimen interface.

(*a*) For cylindrical test specimens, a one-piece split-collet arrangement acts as the grip interface (**2, 3**) as illustrated by

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