Standard Test Method for Ultimate Strength of Advanced Ceramics with Diametrally Compressed C-Ring Specimens at Ambient Temperature[1]

1. Scope*

1.1 This test method covers the determination of ultimate strength under monotonic loading of advanced ceramics in tubular form at ambient temperatures. The ultimate strength as used in this test method refers to the strength obtained under monotonic compressive loading of C-ring specimens such as shown in Fig. 1 where monotonic refers to a continuous nonstop test rate with no reversals from test initiation to final fracture. This method permits a range of sizes and shapes since test specimens may be prepared from a variety of tubular structures. The method may be used with microminiature test specimens.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.2.1 Values expressed in this test method are in accordance with the International System of Units (SI) and IEEE/ASTM SI 10.

1.3 *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.*

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
C1368 Test Method for Determination of Slow Crack Growth Parameters of Advanced Ceramics by Constant Stress-Rate Flexural Testing at Ambient Temperature
C1683 Practice for Size Scaling of Tensile Strengths Using Weibull Statistics for Advanced Ceramics
E4 Practices for Force Verification of Testing Machines
E6 Terminology Relating to Methods of Mechanical Testing
E337 Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)
IEEE/ASTM SI 10 American National Standard for Use of the International System of Units (SI): The Modern Metric System

3. Terminology

3.1 *Definitions:*

3.1.1 *advanced ceramic*—an engineered, high-performance, predominately nonmetallic, inorganic, ceramic material having specific functional qualities. **(C1145)**

3.1.2 *breaking load*—the load at which fracture occurs. **(E6)**

3.1.3 *C-ring*—circular test specimen geometry with the mid-section (slot) removed to allow bending displacement (compression or tension). **(E6)**

3.1.4 *flexural strength*—a measure of the ultimate strength of a specified beam in bending.

3.1.5 *modulus of elasticity*—the ratio of stress to corresponding strain below the proportional limit. **(E6)**

3.1.6 *slow crack growth*—subcritical crack growth (extension) which may result from, but is not restricted to, such mechanisms as environmentally assisted stress corrosion or diffusive crack growth.

4. Significance and Use

4.1 This test method may be used for material development, material comparison, quality assurance, and characterization. Extreme care should be exercised when generating design data.

4.2 For a C-ring under diametral compression, the maximum tensile stress occurs at the outer surface. Hence, the C-ring specimen loaded in compression will predominately

[1] This test method is under the jurisdiction of ASTM Committee C28 on Advanced Ceramics and is the direct responsibility of Subcommittee C28.04 on Applications.

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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.**

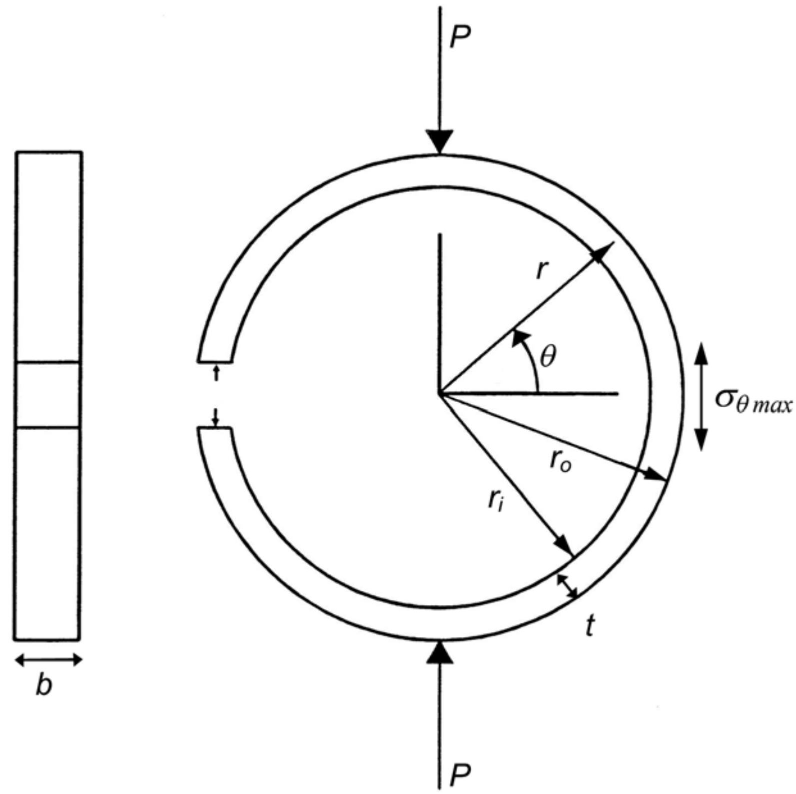

FIG. 1 C-Ring Test Geometry with Defining Geometry and Reference Angle (θ) for the Point of Fracture Initiation on the Circumference

evaluate the strength distribution and flaw population(s) on the external surface of a tubular component. Accordingly, the condition of the inner surface may be of lesser consequence in specimen preparation and testing.

NOTE 1—A C-ring in tension or an O-ring in compression may be used to evaluate the internal surface.

4.2.1 The flexure stress is computed based on simple curved-beam theory (**1**, **2**, **3**, **4**, **5**).[3] It is assumed that the material is isotropic and homogeneous, the moduli of elasticity are identical in compression or tension, and the material is linearly elastic. These homogeneity and isotropy assumptions preclude the use of this standard for continuous fiber reinforced composites. Average grain size(s) should be no greater than one fiftieth (1⁄50) of the C-ring thickness. The simple curved-beam theory stress solution is in good agreement (typically better than 1%) with a theory of elasticity solution as discussed in (3) for the geometries chosen for this standard. The simple beam theory stress equations are relatively simple. They are relatively easy to integrate for Weibull effective volume or effective area computations as shown in Appendix X1.

4.2.2 The simple curved beam and theory of elasticity stress solutions both are two-dimensional plane stress solutions. They do not account for stresses in the axial (parallel to b) direction, or variations in the circumferential (hoop, σ_θ) stresses through the width (b) of the test piece. The variations in the circumferential stresses increase with increases in width (b) and ring thickness (t). The variations can be substantial (> 10 %) for test specimens with large b. The circumferential stresses peak at the outer edges. Therefore, the width (b) and thickness (t) of the specimens permitted in this test method are limited so that axial stresses are negligible (see Ref. 5) and the variations of the circumferential stresses from the nominal simple curved beam theory stress calculations are typically less than 4 %. See Ref. (3) and (4) for more information on the variation of the circumferential stresses as a function of ring thickness (t) and ring width (b).

4.2.3 The test piece outer rim corners are vulnerable to edge damage, another reason to minimize the differences in the circumferential stresses across the ring outer surface.

4.2.4 Other geometry C–ring test specimens may be tested, but comprehensive finite element analyses shall be performed to obtain accurate stress distributions. If strengths are to be scaled (converted) to strengths of other sizes or geometries, then Weibull effective volumes or areas shall be computed using the results of the finite element analyses.

4.3 Because advanced ceramics exhibiting brittle behavior generally fracture catastrophically from a single dominant flaw for a particular tensile stress field, the surface area and volume of material subjected to tensile stresses is a significant factor in determining the ultimate strength. Moreover, because of the statistical distribution of the flaw population(s) in advanced ceramics exhibiting brittle behavior, a sufficient number of specimens at each testing condition is required for statistical analysis and design. This test method provides guidelines for the number of specimens that should be tested for these purposes (see 8.4).

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

4.4 Because of a multitude of factors related to materials processing and component fabrication, the results of C-ring tests from a particular material or selected portions of a part, or both, may not necessarily represent the strength and deformation properties of the full-size end product or its in-service behavior.

4.5 The ultimate strength of a ceramic material may be influenced by slow crack growth or stress corrosion, or both, and is therefore, sensitive to the testing mode, testing rate, or environmental influences, or a combination thereof. Testing at sufficiently rapid rates as outlined in this test method may minimize the consequences of subcritical (slow) crack growth or stress corrosion.

4.6 The flexural behavior and strength of an advanced monolithic ceramic are dependent on the material's inherent resistance to fracture, the presence of flaws, or damage accumulation processes, or a combination thereof. Analysis of fracture surfaces and fractography, though beyond the scope of this test method, is highly recommended (further guidance may be obtained from Practice C1322 and Ref (**6**)).

5. Interferences

5.1 Test environment (vacuum, inert gas, ambient air, etc.) including moisture content (that is, relative humidity) may have an influence on the measured ultimate 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 inert strength (strength potential) of a material shall therefore 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 in uncontrolled ambient air for the purpose of evaluating maximum inert strength (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 C-ring specimens are useful for the determination of ultimate strength of tubular components in the as-received/as-used condition without surface preparations that may distort the strength controlling flaw population(s). Nonetheless, machining damage introduced during specimen preparation can be either a random interfering factor in the determination of the maximum inert strength (strength potential), or an inherent part of the strength characteristics being measured. Universal or standardized methods of surface/sample preparation do not exist. Hence, final machining steps may or may not negate machining damage introduced during the initial machining. Thus, specimen fabrication history may play an important role in the measured strength distributions and shall be reported.

5.3 Very small C-ring test specimens made by micro fabrication methods may also be tested. These typically are tested in the as-fabricated state and do not require any machining preparation. Chamfers or edge bevels may not be necessary. Dimensional nonuniformities (e.g., through-thickness tapers or fabrication template artifacts) may alter the stress state and create experimental errors.

6. Apparatus

6.1 *Loading*—Specimens shall be loaded in any suitable testing machine provided that uniform rates of direct loading can be maintained. The system used to monitor the loading shall be free from any initial lags and will have the capacity to record the maximum load applied to the C-ring specimen during the test. Testing machine accuracy shall be within 1.0 % in accordance with Practices E4.

6.1.1 This test method permits the use of either fixed loading rams or, when necessary (see 9.3), a self-adjusting fixture. A self-adjusting fixture may include a universal joint or spherically seated platen used in conjunction with the upper loading ram. Such an articulating fixture may be necessary to ensure even line loading from front to back across the top of a C-ring test specimen. Articulation from side to side is not required since a flat loading platen contacts the C-ring at its top on its centerline. When fixed loading rams are used, they shall be aligned so that the platen surfaces which come into contact with the specimens are parallel to within 0.015 mm over the width of the test piece. Alignment of the testing system must be verified at a minimum at the beginning and at the end of a test series. An additional verification of alignment is recommended, although not required, at the middle of the test series.

NOTE 2—A test series is interpreted to mean a discrete group of tests on individual specimens conducted within a discrete period of time on a particular material configuration, test specimen geometry, test conditions, or other uniquely definable qualifier. For example, a test series may be composed of one material comprising ten specimens of one geometry tested at a fixed rate in strain control to final fracture in ambient air).

6.1.2 Materials such as foil or thin rubber sheet shall be used between the loading rams and the specimen for ambient temperature tests to reduce the effects of friction and to redistribute the load. Aluminum oxide (alumina) felt or other high-temperature "cloth" with a high-temperature capability may also be used at ambient or elevated temperature. The use of a material with a high-temperature capability is recommended to ensure consistency with elevated temperature tests (if planned), provided the high-temperature "cloth" is chemically compatible with the specimen at all testing temperatures.

6.2 The fixture used during the tests shall be stiffer than the specimen to ensure that a majority of the crosshead travel (at least 80 %) is imposed on the C-ring specimen.

6.3 *Data Acquisition*—At the minimum, an autographic record of applied load shall be obtained. Either analog chart recorders or digital data acquisition systems can be used for this purpose. Ideally, an analog chart recorder or plotter shall be used in conjunction with a digital data acquisition system to provide an immediate record of the test as a supplement to the digital record. Recording devices shall be accurate to 0.1 % of full scale and shall have a minimum data acquisition rate of 10 Hz with a response of 50 Hz deemed more than sufficient.

7. Hazards

7.1 During the conduct of this test, the possibility of flying fragments of broken test material may be high. Means for containment and retention of these fragments for safety, later fractographic reconstruction, and analysis is highly recommended. It is advisable to buffer the fragments so that they do