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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method for Ultimate Strength of Advanced Ceramics with Diametrally Compressed C-Ring Specimens at Ambient Temperature[1]

This standard is issued under the fixed designation C 1323; 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 ultimate strength under monotonic loading of advanced ceramics in tubular form at ambient temperatures. Note that ultimate strength as used in this test method refers to the strength obtained under monotonic compressive loading of C-ring specimens where monotonic refers to a continuous nonstop test rate with no reversals from test initiation to final fracture.

1.2 Values expressed in this test method are in accordance with the International System of Units (SI) and Practice E 380.

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:*

C 1145 Terminology on Advanced Ceramics[2]

C 1161 Test Method for Flexural Strength of Advanced Ceramics at Ambient Temperature[2]

C 1239 Practice for Reporting Uniaxial Strength Data and Estimating Weibull Distribution Parameters for Advanced Ceramics[2]

E 4 Practices for Force Verification of Testing Machines[3]

E 6 Terminology Relating to Methods of Mechanical Testing[3]

E 337 Test Method for Measured Humidity with Psychrometer (Measurement of Wet- and Dry-Bulb Temperatures)[4]

E 380 Practice for Use of International System of Units (SI) (the Modernized Metric System)[5]

2.2 *Military Standards:*[6]

MIL-HDBK-790 Fractography and Characterization of Fracture Origins in Advanced Structural Ceramics

MIL-STD-1942(A) Flexural Strength of High Performance Ceramics at Ambient Temperature

3. Terminology

3.1 *Definitions:*

3.1.1 *advanced ceramic*—an engineered, high-performance, predominately nonmetallic, inorganic, ceramic material having specific functional qualities. **(C 1145)**

3.1.2 *breaking load*—the load at which fracture occurs. **(E 6)**

3.1.3 *C-ring*—circular test specimen geometry with the mid-section (slot) removed to allow bending displacement (compression or tension). **(E 6)**

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. **(E 6)**

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 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.

4.3 The flexure stress is computed based on simple curved-beam theory **(1)**[7] with assumptions that the material is isotropic and homogeneous, the moduli of elasticity are identical in compression or tension, and the material is linearly elastic; all homogeneity and isotropy assumptions preclude the use of this

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[1] This test method is under the jurisdiction of ASTM Committee C-28 on Advanced Ceramics and is the direct responsibility of Subcommittee C28.01 on Properties and Performance.

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[2] *Annual Book of ASTM Standards*, Vol 15.01.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] *Annual Book of ASTM Standards*, Vol 11.03.

[5] *Annual Book of ASTM Standards*, Vol 14.01.

[6] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

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

standard for continuous fiber reinforced composites. Average grain size(s) shall be no greater than one fiftieth (1⁄50) of the C-ring thickness.

4.4 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).

4.5 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.

4.6 The ultimate strength of a ceramic material may be influenced by slow crack growth or 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.

4.7 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 MIL HDBK-790 and Ref **(2)**).

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) of pristine material (that is, increase frequency of surface or edge initiated fractures compared to volume initiated fractures), or an inherent part of the strength characteristics being measured. Universal or standardized methods of surface/sample preparation do not exist. Hence, it shall be understood that 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.

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 E 4.

6.1.1 This test method permits the use of either fixed loading rams or, when necessary (see 9.3), a self-adjusting fixture such as a universal joint or spherically seated platen may be used in conjunction with the upper loading ram. 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. 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 composed of Material A comprising ten specimens of Geometry B 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. 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.

8. Specimen

8.1 *General*—The C-ring geometry is designed to evaluate the ultimate strength of advanced monolithic materials in tubular form in as-received or as-machined form. When possible, the specimen shall reflect the actual size of the component to minimize size scaling effects and to increase the likelihood that the specimen will have the same microstructure and flaw population(s) as the component. Hence, standard specimen dimensions or overall sizes can not be recommended without compromising the original purpose of the test method. Instead, specimens shall be prepared from the stock used for the actual component when possible.

8.1.1 *Specimen Size*—To maintain plane stress conditions **(3,4)** in the specimen while avoiding undue influence from the edges (edge effects), the width of the sample shall be at least one, but no greater than four times the thickness:

$$1 \leq \frac{b}{r_o - r_i} \leq 4 \quad (1)$$

where the dimensional terms b, r_o, and r_i are defined in Fig. 1.

NOTE 3—Experimental or finite-element studies, or both, are recommended to verify the magnitude, distribution, and uniaxiality of the stresses in the actual C-ring used for testing.

8.1.2 The slot height (L) in the C-ring specimen (Fig. 1) shall be at least equal to the width of the specimen to ensure that the slot is significantly greater than the maximum displacement at failure. When thin tubular specimens are studied, a larger slot not to exceed one fourth of the outer circumference may be required.

8.1.3 The parallelism tolerance for the two machined sides of the C-ring specimen is 0.015 mm.

8.2 *Specimen Preparation*—Depending on the intended application of the ultimate strength data, use one of the following three specimen preparation procedures:

8.2.1 *As-Fabricated*—The external and internal surface of the C-ring specimen shall simulate the surface conditions and processing route of an application where no machining is used. No additional machining specifications for these surfaces are relevant. Each side section shall be machined from the tubular stock and lap finished with 15 µm media to remove any large machining defects. All edges shall then be either chamfered at 45° to a distance of 0.15 ± 0.05 mm or rounded to a radius of

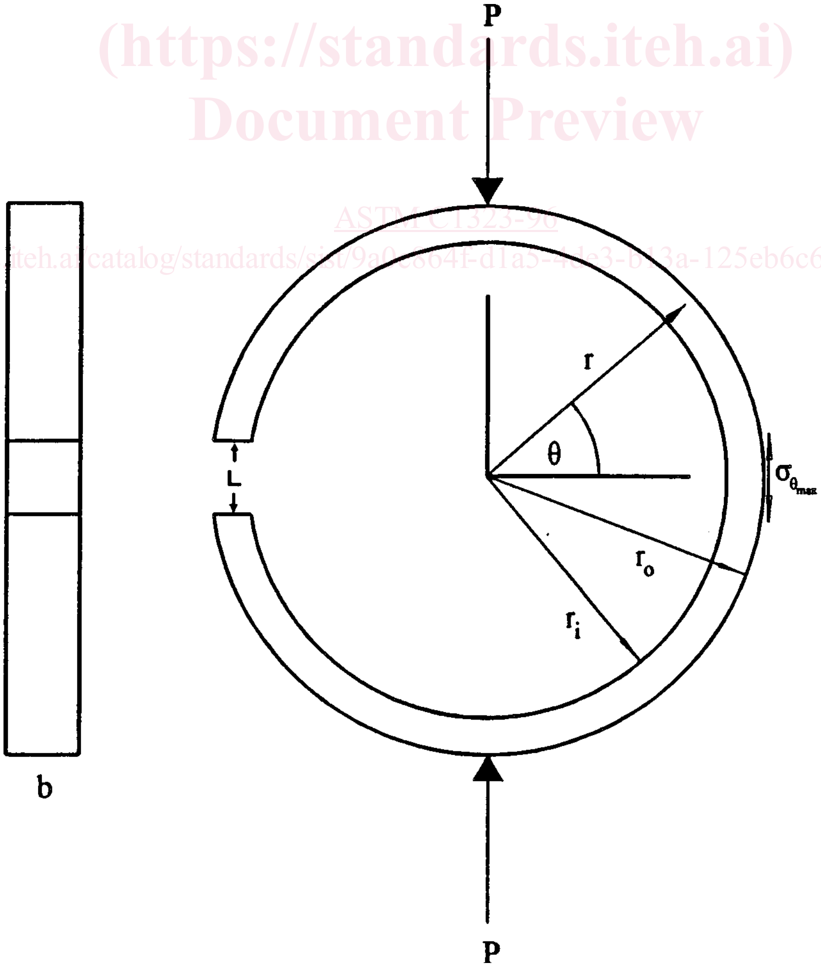

FIG. 1 C-Ring Test Geometry with Defining Geometry and Reference Angle (θ) for the Point of Fracture Initiation on the Circumference