Designation: C1341 – 13 (Reapproved 2023)

Standard Test Method for Flexural Properties of Continuous Fiber-Reinforced Advanced Ceramic Composites[1]

This standard is issued under the fixed designation C1341; 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 flexural properties of continuous fiber-reinforced ceramic composites in the form of rectangular bars formed directly or cut from sheets, plates, or molded shapes. Three test geometries are described as follows:

1.1.1 *Test Geometry I*—A three-point loading system utilizing center point force application on a simply supported beam.

1.1.2 *Test Geometry IIA*—A four-point loading system utilizing two force application points equally spaced from their adjacent support points, with a distance between force application points of one-half of the support span.

1.1.3 *Test Geometry IIB*—A four-point loading system utilizing two force application points equally spaced from their adjacent support points, with a distance between force application points of one-third of the support span.

1.2 This test method applies primarily to all advanced ceramic matrix composites with continuous fiber reinforcement: unidirectional (1D), bidirectional (2D), tridirectional (3D), and other continuous fiber architectures. In addition, this test method may also be used with glass (amorphous) matrix composites with continuous fiber reinforcement. However, flexural strength cannot be determined for those materials that do not break or fail by tension or compression in the outer fibers. This test method does not directly address discontinuous fiber-reinforced, whisker-reinforced, or particulate-reinforced ceramics. Those types of ceramic matrix composites are better tested in flexure using Test Methods C1161 and C1211.

1.3 Tests can be performed at ambient temperatures or at elevated temperatures. At elevated temperatures, a suitable furnace is necessary for heating and holding the test specimens at the desired testing temperatures.

1.4 This test method includes the following:

1.5 The values stated in SI units are to be regarded as the standard in accordance with IEEE/ASTM SI 10.

1.6 *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.*

1.7 *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

C1211 Test Method for Flexural Strength of Advanced Ceramics at Elevated Temperatures

[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 May 1, 2023. Published June 2023. Originally approved in 1996. Last previous edition approved in 2018 as C1341 – 13 (2018). DOI: 10.1520/C1341-13R23.

[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.

C1239 Practice for Reporting Uniaxial Strength Data and Estimating Weibull Distribution Parameters for Advanced Ceramics
C1292 Test Method for Shear Strength of Continuous Fiber-Reinforced Advanced Ceramics at Ambient Temperatures
D790 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
D2344/D2344M Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates
D3878 Terminology for Composite Materials
D6856/D6856M Guide for Testing Fabric-Reinforced "Textile" Composite Materials
E4 Practices for Force Calibration and Verification of Testing Machines
E6 Terminology Relating to Methods of Mechanical Testing
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
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)
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
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 The definitions of terms relating to flexure testing appearing in Terminology E6 apply to the terms used in this test method. The definitions of terms relating to advanced ceramics appearing in Terminology C1145 apply to the terms used in this test method. The definitions of terms relating to fiber-reinforced composites appearing in Terminology D3878 apply to the terms used in this test method. Pertinent definitions as listed in Test Method C1161, Test Methods D790, Terminology C1145, Terminology D3878, and Terminology E6 are shown in the following, with the appropriate source given in brackets. Additional terms used in conjunction with this test method are also defined in the following.

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

3.1.3 *breaking force [F], n*—the force at which fracture occurs. (In this test method, fracture consists of breakage of the test bar into two or more pieces or a loss of at least 20 % of the maximum force carrying capacity.) **E6**

3.1.4 *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.

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

3.1.6 *flexural strength [FL^{-2}], n*—measure of the ultimate strength of a specified beam in bending. **C1161**

3.1.7 *four-point-⅓-point flexure, n*—a configuration of flexural strength testing where a test specimen is symmetrically loaded at two locations that are situated one-third of the overall span away from the outer two support bearings.

3.1.8 *four-point-¼-point flexure, n*—a configuration of flexural strength testing where a test specimen is symmetrically loaded at two locations that are situated one-quarter of the overall span away from the outer two support bearings. **C1161**

3.1.9 *fracture strength [FL^{-2}], n*—the calculated flexural stress at the breaking force.

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

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

3.1.11.1 *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 force application, the scale to which the stress-strain diagram is plotted, and other factors. When determination of proportional limit is required, the procedure and sensitivity of the test equipment shall be specified. **E6**

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

3.1.13 *span-to-depth ratio [nd], n*—for a particular test specimen geometry and flexure test configuration, the ratio (L/d) of the outer support span length (L) of the flexure test specimen to the thickness/depth (d) of test specimen (as used and described in Test Methods D790).

3.1.14 *three-point flexure, n*—a configuration of flexural strength testing where a test specimen is loaded at a location midway between two support bearings. **C1161**

4. Summary of Test Method

4.1 A bar of rectangular cross section is tested in flexure as a beam as in one of the following three geometries:

4.1.1 *Test Geometry I*—The bar rests on two supports and force is applied by means of a loading roller midway between the supports (see Fig. 1).

4.1.2 *Test Geometry IIA*—The bar rests on two supports and force is applied at two points (by means of two inner rollers), each an equal distance from the adjacent outer support point. The inner support points are situated one-quarter of the overall span away from the outer two support bearings. The distance

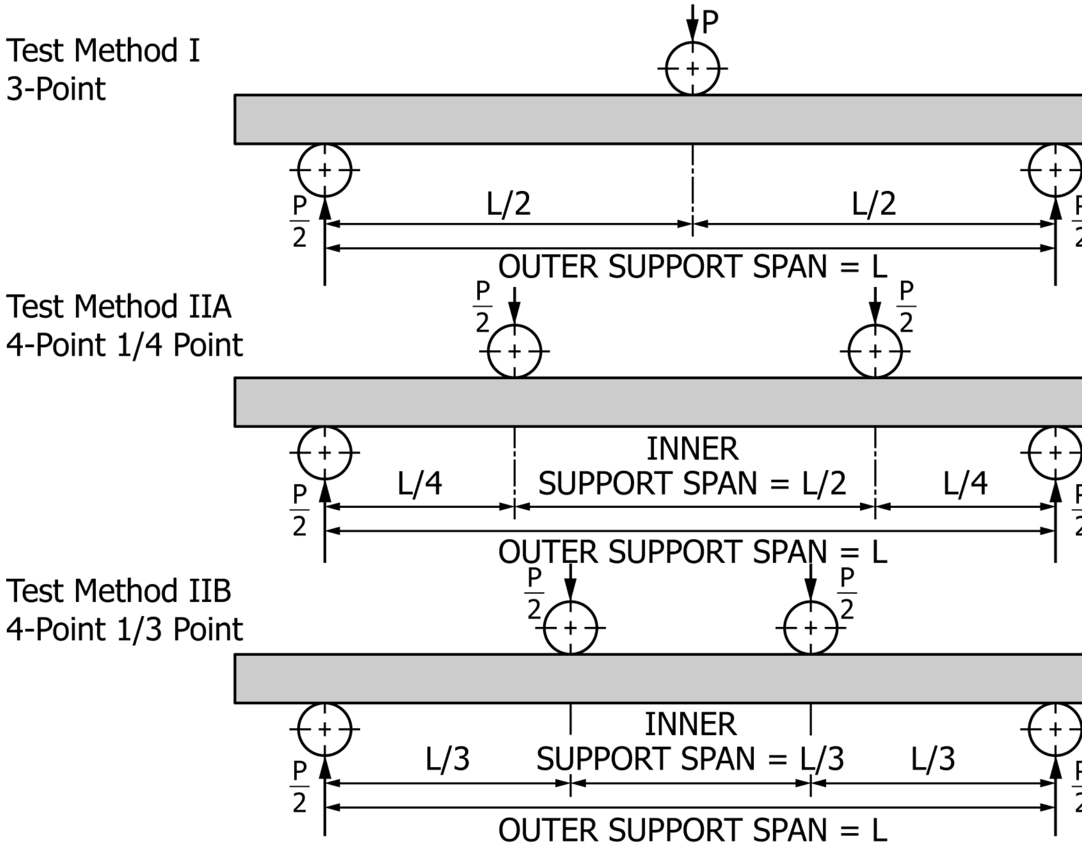

FIG. 1 Flexure Test Geometries and Force Diagram

between the inner rollers (that is, the load span) is one-half of the support span (see Fig. 1).

4.1.3 *Test Geometry IIB*—The bar rests on two supports and force is applied at two points (by means of two loading rollers), situated one-third of the overall span away from the outer two support bearings. The distance between the inner rollers (that is, the inner support span) is one-third of the outer support span (see Fig. 1).

4.2 The test specimen is deflected until rupture occurs in the outer fibers or until there is a 20 % decrease from the peak force.

4.3 The flexural properties of the test specimen (flexural strength and strain, fracture strength and strain, modulus of elasticity, and stress-strain curves) are calculated from the force and deflection using elastic beam equations.

5. Significance and Use

5.1 This test method is used for material development, quality control, and material flexural specifications. Although flexural test methods are commonly used to determine design strengths of monolithic advanced ceramics, the use of flexure test data for determining tensile or compressive properties of CFCC materials is strongly discouraged. The nonuniform stress distributions in the flexure test specimen, the dissimilar mechanical behavior in tension and compression for CFCCs, low shear strengths of CFCCs, and anisotropy in fiber architecture all lead to ambiguity in using flexure results for CFCC material design data (**1-4**).[3] Rather, uniaxial-forced tensile and compressive tests are recommended for developing CFCC material design data based on a uniformly stressed test condition.

5.2 In this test method, the flexure stress is computed from elastic beam theory with the simplifying assumptions that the material is homogeneous and linearly elastic. This is valid for composites where the principal fiber direction is coincident/transverse with the axis of the beam. These assumptions are necessary to calculate a flexural strength value, but limit the application to comparative type testing such as used for material development, quality control, and flexure specifications. Such comparative testing requires consistent and standardized test conditions, that is, test specimen geometry/thickness, strain rates, and atmospheric/test conditions.

5.3 Unlike monolithic advanced ceramics which fracture catastrophically from a single dominant flaw, CFCCs generally experience "graceful" fracture from a cumulative damage process. Therefore, the volume of material subjected to a uniform flexural stress may not be as significant a factor in determining the flexural strength of CFCCs. However, the need to test a statistically significant number of flexure test specimens is not eliminated. Because of the probabilistic nature of the strength of the brittle matrices and of the ceramic fiber in

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