INTERNATIONAL

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Standard Test Method for Shear Strength of Joints of Advanced Ceramics at Ambient Temperature[1]

This standard is issued under the fixed designation C1469; 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 shear strength of joints in advanced ceramics at ambient temperature. Test specimen geometries, test specimen fabrication methods, testing modes (that is, force or displacement control), testing rates (that is, force or displacement rate), data collection, and reporting procedures are addressed.

1.2 This test method is used to measure shear strength of ceramic joints in test specimens extracted from larger joined pieces by machining. Test specimens fabricated in this way are not expected to warp due to the relaxation of residual stresses but are expected to be much straighter and more uniform dimensionally than butt-jointed test specimens prepared by joining two halves, which are not recommended. In addition, this test method is intended for joints, which have either low or intermediate strengths with respect to the substrate material to be joined. Joints with high strengths should not be tested by this test method because of the high probability of invalid tests resulting from fractures initiating at the reaction points rather than in the joint. Determination of the shear strength of joints using this test method is appropriate particularly for advanced ceramic matrix composite materials but also may be useful for monolithic advanced ceramic materials.

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

1.4 *This test method does not purport to address the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are noted in 8.1 and 8.2.

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
- C1275 Test Method for Monotonic Tensile Behavior of Continuous Fiber-Reinforced Advanced Ceramics with Solid Rectangular Cross-Section Test Specimens at Ambient Temperature
- C1341 Test Method for Flexural Properties of Continuous Fiber-Reinforced Advanced Ceramic Composites
- D3878 Terminology for Composite Materials
- D5379/D5379M Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method
- E4 Practices for Force 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
- 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 The definitions of terms relating to shear strength testing appearing in Terminology E6, to advanced ceramics appearing in Terminologies C1145 and D3878 apply to the terms used in this test method. Additional terms used in conjunction with this test method are defined as follows.

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[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.

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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.

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*—force at which fracture occurs.

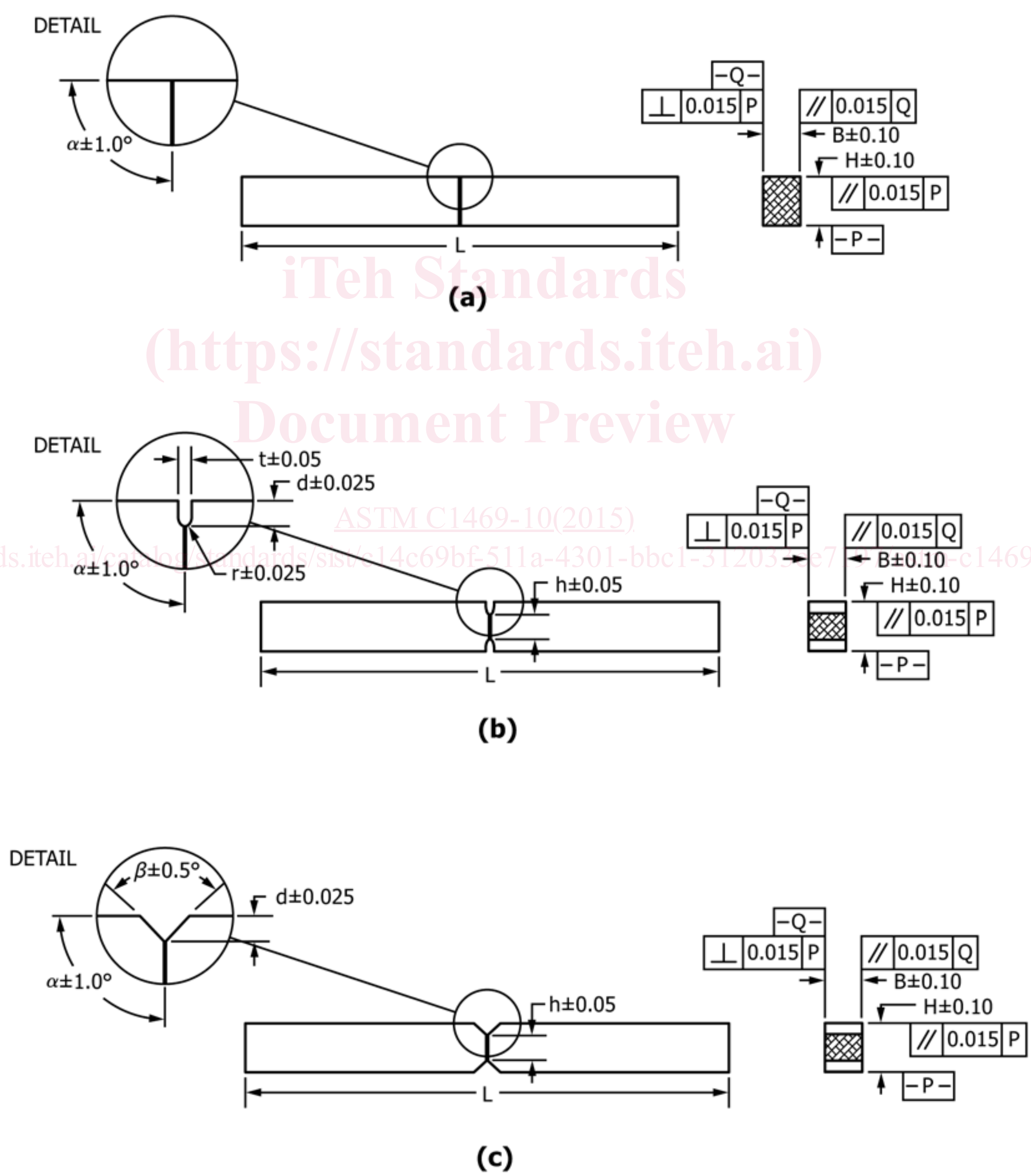
3.1.4 *ceramic matrix composite, n*—material consisting of two or more materials (insoluble in one another), in which the major, continuous component (matrix component) is a ceramic while the secondary component(s) may be ceramic, glass-ceramic, glass, metal, or organic in nature. These components are combined on macroscale to form a useful engineering material possessing certain properties or behavior not possessed by the individual constituents. **C1275**

3.1.5 *joining, n*—controlled formation of chemical, or mechanical bond, or both, between similar or dissimilar materials.

3.1.6 *shear strength [F/L^2], n*—maximum shear stress that a material is capable of sustaining. Shear strength is calculated from breaking force in shear and shear area.

4. Summary of Test Method

4.1 This test method describes an asymmetrical four-point flexure test method to determine shear strengths of advanced ceramic joints. Test specimens and test setup are shown schematically in Fig. 1 and Fig. 2, respectively. Selection of the test specimen geometry depends on the bond strength of the joint, which may be determined by preparing longer test specimens of the same cross-section and using a standard four-point flexural strength test, for example, Test Method C1161 for monolithic advanced ceramic base material and Test Method C1341 for composite advanced ceramic base material.



NOTE 1—The width of the joint, which varies between 0.05 and 0.20 mm, based on the joining method used, is smaller than that of the notch in b). All dimensions are given in mm.

FIG. 1 Schematics of Test Specimen Geometries: a) Uniform, b) Straight-Notched and c) V-Notched

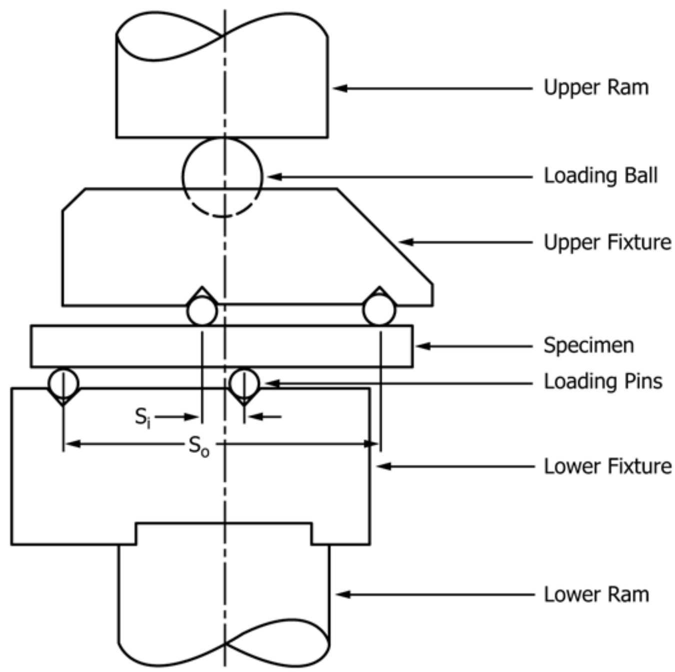


FIG. 2 Schematic of Test Fixture

If the joint flexural strength is low (that is, <25 % of the flexural strength of the base material), the recommended test specimen geometry for shear strength testing of the joint is the uniform test specimen shown in Fig. 1a. If the joint flexural strength is moderate (that is, 25 to 50 % of the flexural strength of the base material), the recommended test specimen geometry for shear strength testing of the joint is the straight- or V-notched test specimen shown in Fig. 1b and Fig. 1c, respectively. If the joint flexural strength is high (>50 % of the flexural strength of the base material) this test method should not be used to measure shear strength of advanced ceramic joints because very high contact stresses at the reaction points will provide a high probability of invalid tests (that is, fractures not at the joint).

4.2 The testing arrangement of this test method is asymmetrical flexure, as illustrated by the force, shear and moment diagrams in Fig. 3a, Fig. 3b, and Fig. 3c, respectively. Note that the greatest shear exists over a region of $\pm$ $S_i/2$ around the centerline of the joint (see Fig. 3b). In addition, while the moment is zero at the centerline of the joint, the maximum moments occur at the inner reaction points (see Fig. 3c). The points of maximum moments are where the greatest probability of fracture of the base material may occur if the joint flexural strength, and therefore, joint shear strength is too high.

5. Significance and Use

5.1 Advanced ceramics are candidate materials for structural applications requiring high degrees of wear and corrosion resistance, often at elevated temperatures.

5.2 Joints are produced to enhance the performance and applicability of materials. While the joints between similar materials are generally made for manufacturing complex parts and repairing components, those involving dissimilar materials usually are produced to exploit the unique properties of each

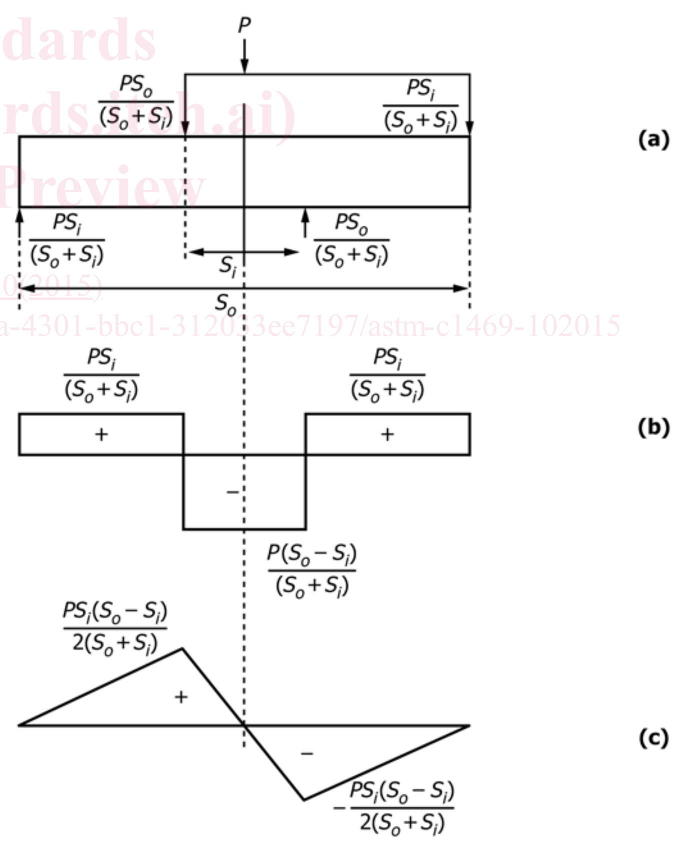


FIG. 3 Idealized a) Force, b) Shear, and c) Moment Diagrams for Asymmetric Four-point Flexure, Where S_o and S_i Are the Outer and Inner Reaction Span Distances, Respectively, and P is the Applied Force

constituent in the new component. Depending on the joining process, the joint region may be the weakest part of the component. Since under mixed-mode and shear loading, the load transfer across the joint requires reasonable shear strength, it is important that the quality and integrity of joint under in-plane shear forces be quantified. Shear strength data are also needed to monitor the development of new and improved joining techniques.

5.3 Shear tests provide information on the strength and deformation of materials under shear stresses.

5.4 This test method may be used for material development, material comparison, quality assurance, characterization, and design data generation.

5.5 For quality control purposes, results derived from standardized shear 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.

6. Interferences

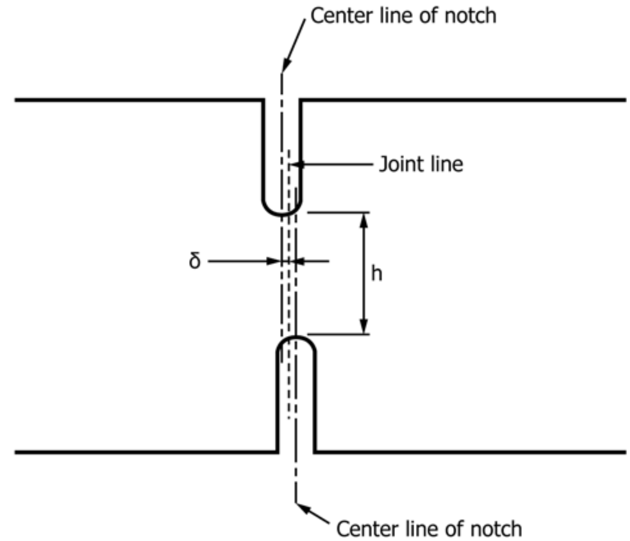
6.1 Fractures that initiate outside of the joint region may be due to factors, such as localized stress concentrations, extraneous stresses introduced by improper force transfer. Such fractures will constitute invalid tests.

6.2 Since the joint width is typically small, that is, 0.05 to 0.20 mm, the proper machining of the notches at the joint region is very critical (see Fig. 1). Improper machining of the notches can lead to undesired fracture at the reaction points. Furthermore, nonsymmetrical machining of the nothces can be decisive as to how the fracture occurs between the notches.

NOTE 1—Finite element stress analysis of nonsymmetrical nothces showed that when there is a misalignment between the notches and the mid-plane of the joint, spurious normal (σ_x) tensile stresses are generated at the notches which tend to "tear" the joint and would artificially affect (reduce) the magnitude of shear strength measured from the joint. The magnitude of these tensile stresses could be significant depending on the material system being investigated. Based on this analysis, it is recommended that the ratio of misalignment between the notch root and mid-plane of the joint, δ, and the distance between the notches, *h*, should be kept to less than 0.0125. (See Fig. 4.)

6.3 In this test method, the shear force required to cause fracture in the joint region depends on the span lengths of S_o and S_i in the fixture[3] (see Fig. 3). These lengths and the strength of the joint relative to that of the base material determine whether fracture takes place at the joint region or at the reaction points. Depending on this relative strength, it may be necessary to conduct preliminary tests to establish the appropriate S_o and S_i distances for the fixture to be used.[4]

6.4 The accuracy of insertion and alignment of the test specimen with respect to the fixture is critical; therefore, preparations for testing should be done carefully to minimize



NOTE 1—It is recommended that δ/h ratio in both notch types is less than 0.0125.

FIG. 4 Schematic of Misalignment, δ, between the Joint Line and Notch Root Shown for Straight—Notched Specimen

the bending moment at the joint, which strongly depends on the inner and outer reaction spans, as seen in Fig. 3c. See details in 10.4.

6.5 Test environment (vacuum, inert gas, ambient air, etc.) including moisture content, for example, relative humidity, may have an influence on the measured shear strength. Conversely, testing can be conducted in environments and testing modes and rates representative of service conditions to evaluate material performance under those conditions. When testing is conducted in uncontrolled ambient air with the objective of evaluating maximum 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 shall be reported.

7. Apparatus

7.1 *Testing Machines*—The testing machine shall be in conformance with Practices E4. The forces used in determining shear strength shall be accurate within ±1 % at any force within the selected force range of the testing machine as defined in Practices E4.

7.2 *Data Acquisition*—At a minimum, autographic records of applied force and cross-head displacement versus time shall be obtained. Either analog chart recorders or digital data acquisition systems may be used for this purpose although a digital record is recommended for ease of later data analysis. Ideally, an analog chart recorder or plotter should be used in conjunction with the 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 ±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.

7.3 *Dimension-Measuring Devices*—Micrometers and other devices used for measuring linear dimensions must be accurate and precise to at least 0.01 mm.

[3] J.M. Slepetz, T.F. Zagaeski, and R.F. Novello, "In-Plane Shear Test for Composite Materials," AMMRC-TR-78-30, Army Materials and Mechanics Research Center, Watertown, MA, July 1978.

[4] Ö. Ünal, I.E. Anderson, and S.I. Maghsoodi, "A Test Method to Measure Shear Strength of Ceramic Joints at High Temperatures," *J. Am. Ceram. Soc.*, 80, 1281 (1997).