Designation: C1469 – 10 (Reapproved 2015)

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.

[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.

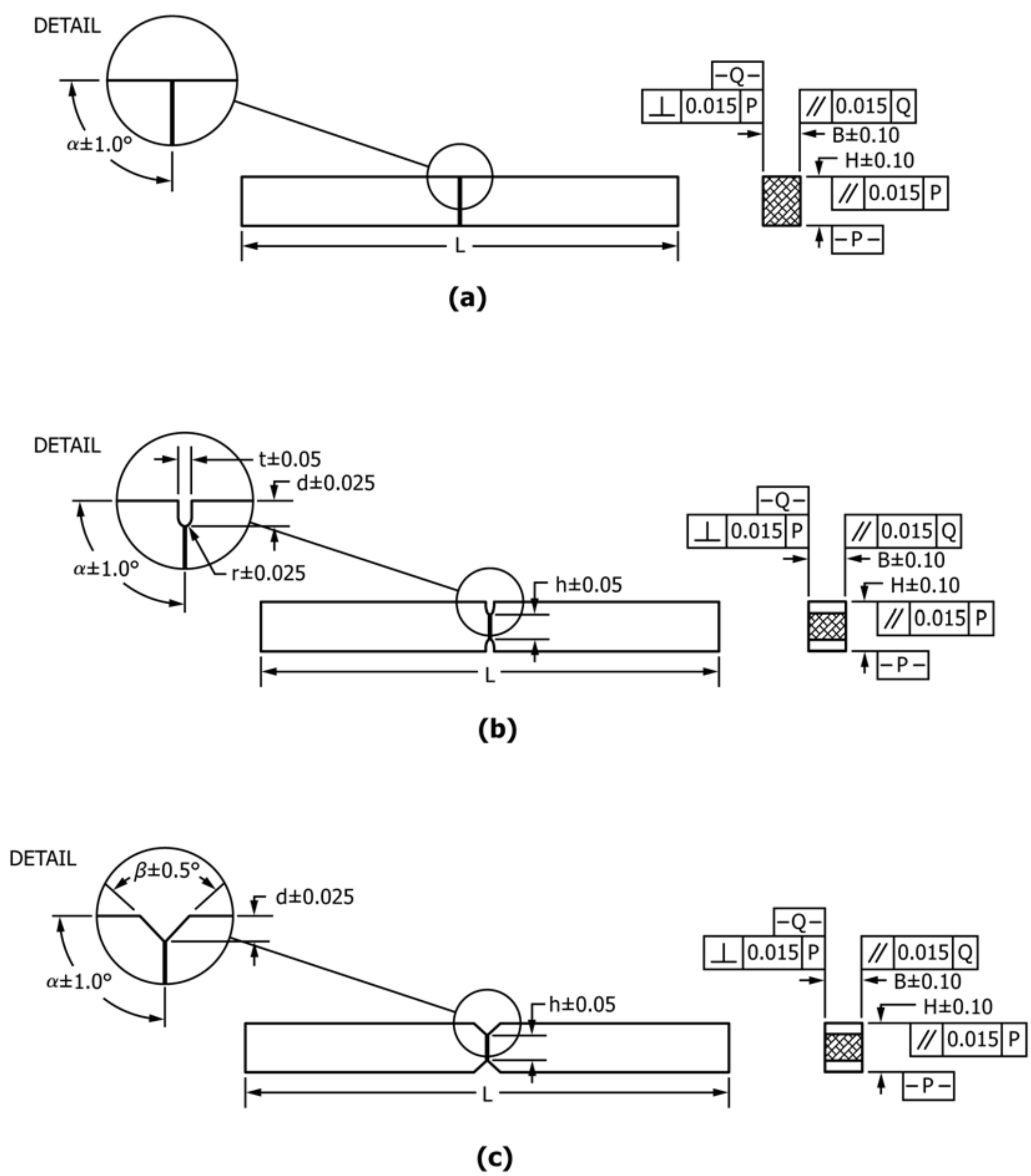
3.1.4 *ceramic matrix composite, n*—material consisting of two or more materials (insoluble in one another), in which the major, continuous component (matrix component) is a ceramic while the secondary component(s) may be ceramic, glass-ceramic, glass, metal, or organic in nature. These components are 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

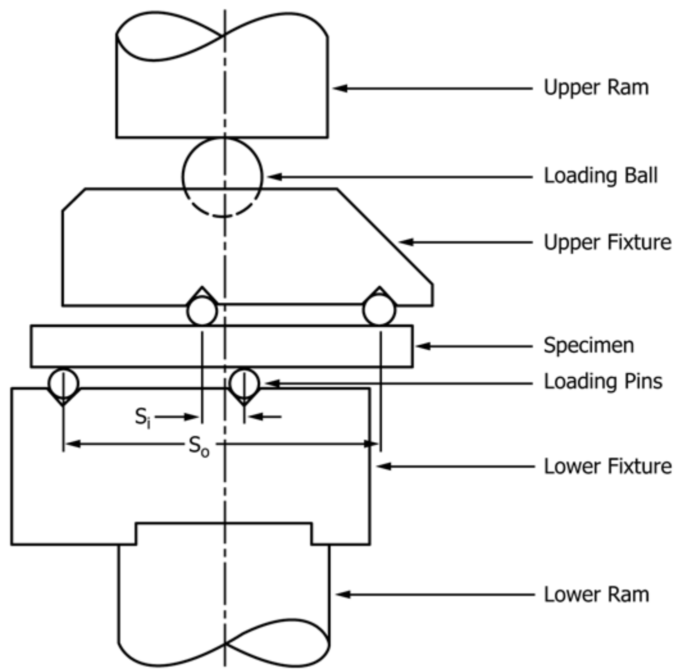


FIG. 2 Schematic of Test Fixture

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 ± $S_i/2$ 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.

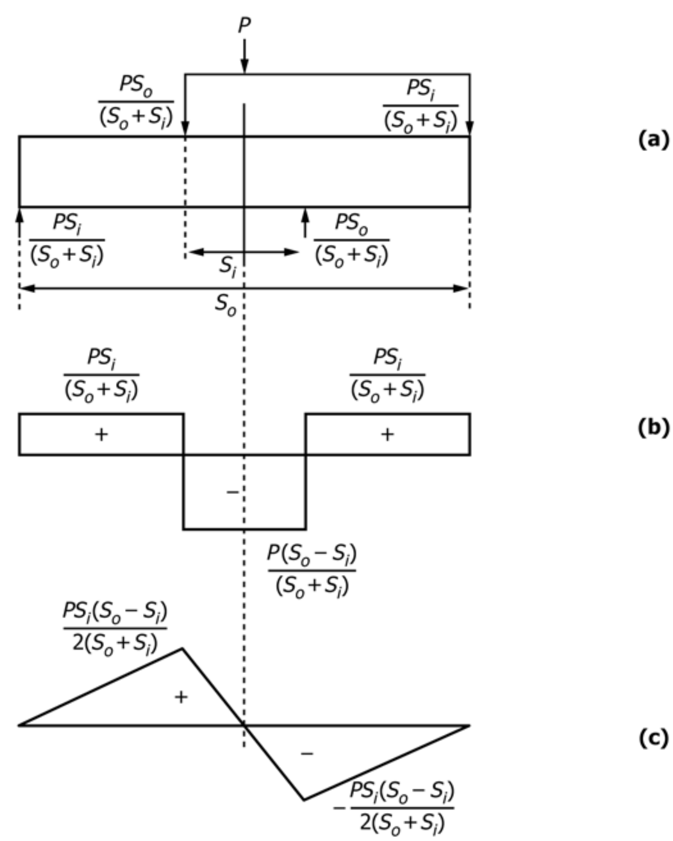


FIG. 3 Idealized a) Force, b) Shear, and c) Moment Diagrams for Asymmetric Four-point Flexure, Where S_o and S_i Are the Outer and Inner Reaction Span Distances, Respectively, and P is the Applied Force

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 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

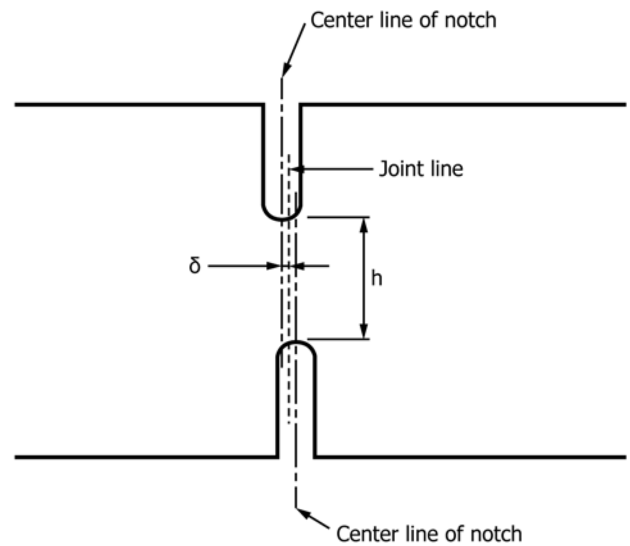
6.1 Fractures that initiate outside of the joint region may be due to factors, such as localized stress concentrations, extraneous stresses introduced by improper force transfer. Such fractures will constitute invalid tests.

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 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.



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

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).

7.4 *Combination Square*—Used to draw perpendicular lines to specimen axis at the locations of inner loading points. The tolerance must be within 0.5°.

7.5 *Test Fixture*—The test fixture consists of top and bottom sections, reaction-pins, and a force transfer ball, as shown schematically in Fig. 2. The bottom section is placed on a stationary base, for example, a compression platen. The test specimen is positioned between the top and bottom sections of the fixture. The force is transmitted from the test machine to the fixture by the force transfer ball; however, a pin also can be used in place of the force transfer ball. Table 1 contains symbols, nomenclature, and recommended dimensions for the test fixture (Fig. 2), where the tolerances for S_o and S_i after alignment is ±0.2 mm (see 10.4 for details). The tolerances for the diameter of the force transfer ball and reaction-pin are ±0.1 mm and ±0.01 mm, respectively.

NOTE 2—The reaction-pin diameter in this standard is 3 mm, unlike that in Test Method C1161 where it is a 4.5 mm. Unpublished finite element analyses have indicated that the smaller pin diameter better approximates the "point loading", thus the stress profile at the joint in Fig. 3.

NOTE 3—It should be indicated that when there are restrictions for pins to rotate freely, as in Fig. 2, the resulting friction may become a factor in the measurements, as indicated in Test Method C1161. So far, however, no systematic study has been conducted in the current test method regarding this issue.

7.5.1 Test fixtures, including the pins and ball, and loading rams shall be stiff and elastic under loading. These pieces may be made of a ceramic with an elastic modulus between 200 and 400 GPa and a flexural strength no less than 275 MPa, as specified in Test Method C1211. Dense high purity silicon carbide and alumina are the typical candidate materials. Alternatively, the above components may be made of hardened steel which has a hardness no less than HRC 40 or which has a yield strength no less than 1240 MPa, as specified in Test Method C1161, C1211.

8. Precautionary Statement

8.1 During the conduct of this test method, the possibility of flying fragments of broken test material may be high. The brittle nature of advanced ceramics and the release of strain energy contribute to the potential release of uncontrolled fragments upon fracture. Means for containment and retention of these fragments for later fractographic reconstruction and analysis is highly recommended.

9. Test Specimen

9.1 *Test Specimen Geometry*—Depending on the flexural strength of the joint, any one of the three test specimen geometries is suitable for this test method (see 4.1 and Fig. 1a, Fig. 1b, Fig. 1c). The opposing notches on the notched test specimens shall be made symmetrically at the centerline of the joint (Fig. 1b and Fig. 1c). Moreover, the depth of each of the notches shall be one fourth of the overall height of the test specimen (H/4). While the drawings in Fig. 1 show the tolerances for the test specimens, Table 2 shows symbols, nomenclature and recommended dimensions for the test specimen. If necessary, the test specimen dimensions, that is, length, height, width and notch depth, if applicable) can be adjusted to meet special requirements. Report any deviation from the recommended values of Table 2.

9.2 *Test Specimen Preparation*—Any machining procedure may be used that is deemed satisfactory for a class of materials so long as it induces no unwanted surface/subsurface damage or residual stresses. The grinding of uniform test specimen in Fig. 1a shall be along the longitudinal axis of the test specimen, according to standard procedures described in Test Method C1161, C1211.

9.2.1 Conduct any grinding or cutting with ample supply of appropriate filtered coolant to keep the workpiece and grinding wheel constantly flooded and particles flushed. Grind in at least two stages, ranging from coarse to fine rate of material removal.

9.2.2 Remove stock at a rate on the order of 0.03 mm/pass if using diamond tools that have between 320 and 600 grit. Remove equal stock from each face, where applicable.

9.2.3 Other types of material removal processes may be used if they meet the requirements for dimensional tolerances, surface characteristics, and residual stresses.

9.3 *Handling Precaution*—Exercise care in the storing and handling of finished test specimens to avoid the introduction of severe flaws. In addition, direct attention to pre-test storage of test specimens in controlled environments or desiccators to avoid unquantifiable environmental degradation of test specimens prior to testing.

9.4 *Number of Valid Tests*—Conduct a minimum of ten valid tests per test condition, unless statistically significant results can be obtained from fewer valid tests, such as in the case of a designed experiment. For statistically significant data, the procedures outlined in Practice E122 shall be consulted.

9.5 *Valid Tests*—A valid individual test is one that meets all the following requirements: all the testing requirements of this test method, and fracture occurs in the joint region unless those

TABLE 1 Recommended Dimensions for Test Fixture

Dimension	Description	Nominal Value	Tolerance
S_i	Inner span	4.0 mm	±0.2 mm
S_o	Outer span	30.0 mm	±0.2 mm
	Force transfer ball diameter	7.5 mm	±0.1 mm
	Reaction-pin diameter	3.00 mm	±0.01 mm

TABLE 2 Recommended Dimensions for Test Specimens

Dimension	Description	Nominal Value	Tolerance
L	Test specimen length	36.0 mm	±0.5
H	Test specimen height	4.0 mm	±0.1
B	Test specimen width	3.0 mm	±0.1
h	Distance between notches	2.00 mm	±0.05
α	Angle between test specimen axis and joint line	90 °	±1°
β	Notch angle (V-notch)	90 °	±1°
	Notch root radius (V-notch)	None	—
d	Depth of notch	1.000 mm	±0.025
t	Notch width (straight notch)	0.50 mm	±0.05
r	Notch root radius (straight notch)	0.250 mm	±0.025

tests fracturing outside the joint region are interpreted tests for the purpose of censored test analyses.

10. Procedure

10.1 *Test Specimen Dimensions*—Determine the thickness and width of the gage section of each test specimen to within 0.01 mm. Avoid damaging the critical gage section area by performing these measurements either optically, for example, an optical comparator or mechanically using a flat, anvil-type micrometer. In either case the resolution of the instrument shall be as specified in 7.3. Exercise extreme caution to prevent damaging the test specimen gage section. Record and report the measured dimensions and locations of the measurements for use in the calculation of the shear stress. Use the average of multiple (three or more) measurements in the stress calculations.

10.1.1 Additionally, make post-fracture measurements of the joint region dimensions using instruments described in 10.1. Measure and record only the dimensions at the plane of fracture for the purpose of calculating the shear strength. In case the fracture process severely fragments the joint region thus making post-fracture measurements of dimensions difficult, use the procedures detailed in 10.1.

10.2 *Test Modes and Rates*—Test modes may involve force or displacement (that is, stroke) control. In all cases report both test mode and test rate.

10.2.1 Displacement-controlled tests are employed in cumulative damage or yielding deformation processes to prevent a runaway condition (that is rapid uncontrolled deformation and fracture), characteristic of force or stress controlled tests.

10.2.2 *Displacement Rate*—Use a constant cross-head displacement rate of 0.005 mm/s unless otherwise found acceptable as determined under conditions of 10.2.1.

10.2.3 *Force Rate*—Use a constant force rate equivalent to a displacement rate of 0.005 mm/s unless otherwise found acceptable.

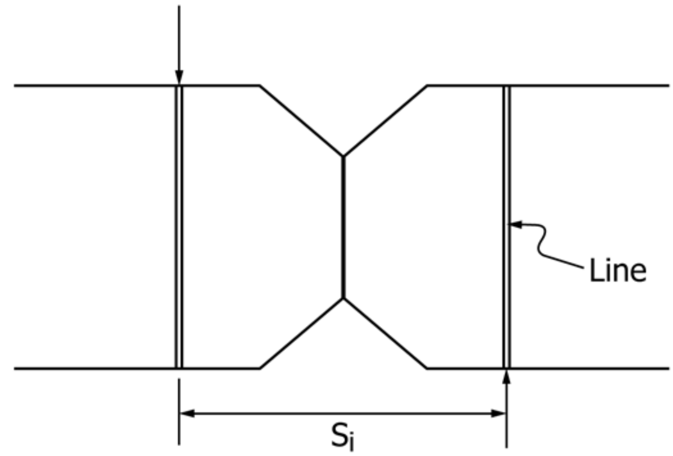
10.3 *Preparations for Testing*—Set the test mode and test rate on the test machine. Ready the autograph data acquisition systems for data logging.

10.4 *Conducting the Test:*

10.4.1 Using a sharpened pencil (or a razor), a combination square and a digital micrometer, draw two parallel lines on the test specimen, which are at the distance of $S_i/2 \pm 0.2$ mm from the centerline of the joint along the longitudinal axis of the test specimen, as can be seen in a V-notched specimen in Fig. 5. (These lines are to be used as guides to better position the inner loading points on the test specimen.) In addition, make markings on the test specimen surface to indicate the orientation of test specimen with respect to test fixture.

NOTE 4—These markings are critical especially for brittle materials with shallow notches, which often fracture in an unstable manner making reconstruction of the test specimen for post-fracture evaluation difficult.

10.4.2 Prepare to mount the test specimen in the test fixture by first placing the bottom section of the fixture with two reaction-pins on a flat base, for example, a compression platen. Ensure that bottom section of the fixture is positioned properly with respect to the axial force line of the test machine; furthermore, position the test specimen on the reaction-pins in the center of fixture. Place the top section of the fixture, which has two reaction-pins and the force transfer ball, on the test specimen and ensure that the test specimen is centered side-to-side and front-to-back within the fixture. Align the diametral center of the inner reaction-pin on the bottom section of the fixture with the corresponding perpendicular line on the test specimen. To improve the accuracy of test results, perform this alignment by a travelling microscope of a type used in the fracture mechanics tests. Similarly, align the center of the inner reaction-pin on the top fixture with the corresponding perpendicular line on the test specimen. Laboratory experiments showed that following this practice the accuracy of S_o and S_i support spans is ±0.2 mm. As a result, the line-of-action of the force (Fig. 2) acts through the center line of the joint within 0.2 mm. The modifications in test fixture may be allowed such as, using a fixed top fixture instead of the one shown in Fig. 2. In such cases, however, it is important to insure that the reaction-pins of the top fixture make a simultaneous contact with the top surface of the test specimens and that the alignment of inner pins with respect to the joint is not compromised. Note that the nonarticulating fixtures could lead to serious experimental errors unless both the test specimen and the top and bottom fixtures are nearly perfectly parallel.



NOTE 1—The arrows indicate the inner loading points.

FIG. 5 Schematics of Lines Drawn at the Sites of the Inner Loading Points in V-Notched Specimen

NOTE 5—The accuracy of distance between the lines made on the test specimen and placement of test specimen in the fixture are very important; therefore, the preparation to test should be done carefully to minimize the bending moment at the joint, as shown by the bending moment diagram in Fig. 3c.

10.4.3 Bring the test fixture close to the actuator or cross head of the test machine to prepare for testing. Apply a pretest force (<20 N) and recheck the alignment before commencing the actual testing.

10.4.4 Begin data acquisition. Initiate the action of the test machine.

10.4.5 After fracture of the test specimen, disable the action of the test machine and the data collection of the data acquisition system. Measure and note the breaking force with an accuracy of ±1 % of the force range.

10.4.6 Carefully remove and reconstruct the test specimen to determine whether the test was valid, that is, fracture occurred in the joint. The marks made in 10.4.1 can be used to facilitate reassembly. Measure the height and depth of the fracture cross-section within 0.01 mm. Avoid damaging the fracture surfaces by preventing them from contacting each other or other objects.

NOTE 6—Results from test specimens fracturing outside the joint region cannot be used in the direct calculation of a mean joint shear strength. Such results are considered anomalous and can be used only as censored tests. To complete a required statistical sample for purposes of mean joint shear strength, one replacement test specimen should be tested for each test specimen which fractures outside the joint region.

10.4.7 Determine the ambient temperature and relative humidity in accordance with Test Method E337.

10.4.8 Visual examination and light microscopy are recommended to determine the mode and type of fracture, as well as, the location of fracture initiation.

11. Calculation

11.1 *Joint Shear Strength*—Calculate the shear strength in units of MPa as follows:

$$\tau_J = Shear\ Strength = \frac{P_{max}\,(S_o - S_i)}{A\,(S_o + S_i)} \quad (1)$$

where:

P_{max} = the breaking force in units of N,
S_o and S_i = the outer and inner spans, respectively, and
A = the shear area in units of mm^2.

11.1.1 Shear area for uniform test specimen (see Fig. 1a). Calculate the shear area in units of mm^2 as follows:

$$A = HB \quad (2)$$

where:

H = the test specimen height, and
B = the test specimen width (both in units of mm).

11.1.2 Shear area for notched test specimens (see Fig. 1b and Fig. 1c). Calculate the shear area in units of mm^2 as follows:

$$A = hB \quad (3)$$

where:

h = the distance between the notches, and
B = the test specimen width (both in units of mm) (see Fig. 1b and Fig. 1c).

11.2 *Statistics*—For each series of tests calculate the mean, standard deviation, and coefficient of variation (in %) for each property determined as follows:

$$[\text{Mean}] \quad \bar{x} = \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right) \quad (4)$$

$$[\text{Standard Deviation}] \quad S_{n-1} = \sqrt{\frac{\left(\sum_{i=1}^{n} X_i^2 - n\,\bar{X}^2\right)}{(n-1)}} \quad (5)$$

$$[\text{Percent Coefficient of Variation}] \quad CV = \frac{100\,S_{n-1}}{\bar{x}} \quad (6)$$

where:

n = the number of valid tests, and
x_i = the measured property.

12. Report

12.1 *Test Set*—Include the following information in the report for the test set. Report any significant deviations from the procedures and requirements of this test method.

12.1.1 Date and location of testing.

12.1.2 Indicate the type of test specimen geometry. Include a drawing or sketch of the test fixture.

12.1.3 Include a drawing or sketch of the type and configuration of the test machine. If a commercial test machine is used, the manufacturer and model number of the test machine will suffice.

12.1.4 Include all relevant data such as vintage and identification data, with emphasis on the date of manufacture of the material. For commercial materials, the commercial designation must be reported.

12.1.5 Description of the method of test specimen preparation including all stages of machining.

12.1.6 Heat treatments, coatings, or pretest exposures, if any applied either to the as-processed material or to the as-fabricated test specimen.

12.1.7 Test environment including relative humidity (Test Method E337), ambient temperature, and atmosphere, for example, ambient air, dry nitrogen, silicone oil, etc.).

12.1.8 Test mode (force or displacement control) and actual test rate (force rate or displacement rate).

12.1.9 Include the total number of test specimens (n_T) with special emphasis on the number of valid tests (n) that fractured in the joint region. This information will reveal the success rate of the particular test specimen geometry and test apparatus.

12.1.10 Report shear strength of each test specimen.

12.1.11 Mean, standard deviation, and coefficient of variation for the measured shear strength for each test series.

12.1.12 Failure mode and the location of fracture with respect to the joint.

13. Precision and Bias

13.1 Because of the nature of these materials and lack of a wide data base, no definitive statement can be made at this time concerning precision and bias of this test method; however, the agreement of shear strength results from comparative tests between this test method and Iosipescu shear test method (Test Method D5379/D5379M) using 6061-aluminum alloy test specimens indicates that the current test method could produce reasonable data.[5]

14. Keywords

14.1 asymmetrical four-point test; ceramic joint; ceramics; shear force; shear strength

[5] Ö. Ünal, D.J. Barnard, I.E. Anderson, "A Shear Test Method to Measure Shear Strength of Metallic Materials and Solder Joints Using Small Specimens," *Scripta Metall.*, 40, 271 (1999).