Designation: C1862 − 17

Standard Test Method for the Nominal Joint Strength of End-Plug Joints in Advanced Ceramic Tubes at Ambient and Elevated Temperatures[1]

This standard is issued under the fixed designation C1862; 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 the push-out force, nominal joint strength, and nominal burst pressure of bonded ceramic end-plugs in advanced ceramic cylindrical tubes (monolithic and composite) at ambient and elevated temperatures (see 4.2). The test method is broad in scope and end-plugs may have a variety of different configurations, joint types, and geometries. It is expected that the most common type of joints tested are adhesively bonded end-plugs that use organic adhesives, metals, glass sealants, and ceramic adhesives (sintered powders, sol-gel, polymer-derived ceramics) as the bonding material between the end-plug and the tube. This test method describes the test capabilities and limitations, the test apparatus, test specimen geometries and preparation methods, test procedures (modes, rates, mounting, alignment, testing methods, data collection, and fracture analysis), calculation methods, and reporting procedures.

1.2 In this end-plug push-out (EPPO) test method, test specimens are prepared by bonding a fitted ceramic plug into one end of a ceramic tube. The test specimen tube is secured into a gripping fixture and test apparatus, and an axial compressive force is applied to the interior face of the plug to push it out of the tube. (See 4.2.) The axial force required to fracture (or permanently deform) the joined test specimen is measured and used to calculate a nominal joint strength and a nominal burst pressure. Tests are performed at ambient or elevated temperatures, or both, based on the temperature capabilities of the test furnace and the test apparatus.

1.3 This test method is applicable to end-plug test specimens with a wide range of configurations and sizes. The test method does not define a standardized test specimen geometry, because the purpose of the test is to determine the nominal joint strength and nominal burst pressure of an application-specific plug-tube design. The test specimen should be similar in size and configuration with the intended application and product design.

1.4 Calculations in this test method include a nominal joint strength which is specific to the adhesives, adherends, configuration, size, and geometry of the test specimen. The nominal joint strength has value as a comparative test for different adhesives and plug configurations in the intended application geometry. When using nominal joint strength for comparison purposes, only values obtained using identical geometries should be compared due to potential differences in induced stress states (shear versus tensile versus mixed mode). The joint strength calculated in this test may differ widely from the true shear or tensile strength (or both) of the adhesive due to mixed-mode stress states and stress concentration effects. (True adhesive shear and tensile strengths are material properties independent of the joint geometry.)

1.5 In this test, a longitudinal failure stress is being calculated and reported. This longitudinal failure stress acts as an engineering corollary to the burst pressure value measured from a hydrostatic pressure test, which is a more difficult and complex test procedure. Thus this longitudinal failure stress is recorded as a nominal burst pressure. As a general rule, the absolute magnitude of the nominal burst pressure measured in this EPPO test is different than the absolute magnitude of a burst pressure from a hydrostatic burst pressure test, because the EPPO test does not induce the hoop stresses commonly observed in a hydrostatic pressure test.

1.6 The use of this test method at elevated temperatures is limited by the temperature capabilities of the loading fixtures, the gripping method (adhesive, mechanical clamping, etc.), and the furnace temperature limitations.

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

1.8 *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.*

1.9 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the*

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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
C1322 Practice for Fractography and Characterization of Fracture Origins in Advanced Ceramics
C1469 Test Method for Shear Strength of Joints of Advanced Ceramics at Ambient Temperature
D907 Terminology of Adhesives
D3878 Terminology for Composite Materials
D4896 Guide for Use of Adhesive-Bonded Single Lap-Joint Specimen Test Results
E4 Practices for Force Verification of Testing Machines
E6 Terminology Relating to Methods of Mechanical Testing
E105 Practice for Probability Sampling of Materials
E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process
E220 Test Method for Calibration of Thermocouples By Comparison Techniques
E230/E230M Specification for Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples
E251 Test Methods for Performance Characteristics of Metallic Bonded Resistance Strain Gages
E337 Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)
E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application
IEEE/ASTM SI 10 American National Standard for Metric Practice

3. Terminology

3.1 *Definitions:*

3.1.1 The definitions of terms relating to strength 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. The definitions of terms relating to adhesives in Terminology D907 apply to the terms used in this test method. Pertinent definitions as listed in Practice E1012, Terminology C1145, Terminology D3878, Terminology D907, and Terminology E6 are shown in the following with the appropriate source given in parentheses. Key terms are given below.

3.1.2 *adherend, n*—a body held to another body by an adhesive. **(D907)**

3.1.3 *adhesion failure, n*—rupture of an adhesive bond in which the separation appears visually to be at the adhesive/adherend interface. **(D907)**

3.1.4 *adhesive, n*—a substance capable of holding materials together by surface attachment. **(D907)**

3.1.4.1 *Discussion*—'Adhesive' is a general term and includes among others cement, glue, mucilage, and paste. All of these terms are loosely used interchangeably. Various descriptive adjectives are applied to the term 'adhesive' to indicate certain characteristics as follows: (*1*) physical form, that is, liquid adhesive, tape adhesive, etc.; (*2*) chemical type, that is, silicate adhesive, resin adhesive, etc.; (*3*) materials bonded, that is, paper adhesive, metal-plastic adhesive, can label adhesive, etc.; (*4*) condition of use, that is, hot setting adhesive, room temperature setting adhesive, etc.

3.1.5 *advanced ceramic, n*—a highly engineered, high performance, predominately nonmetallic, inorganic, ceramic material having specific functional attributes. **(C1145)**

3.1.6 *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. **(C1145)**

3.1.7 *cohesive failure, n*—rupture of a bonded assembly in which the separation appears visually to be in the adhesive or the adherend. **(D907)**

3.1.8 *elastic stress limit, [FL^{-2}], n*—the greatest stress which a material is capable of sustaining without any permanent strain remaining upon complete release of the stress, in units of MPa. **(E6)**

3.1.9 *joining, n*—controlled formation of chemical or mechanical bond, or both, between similar or dissimilar materials. **(C1469)**

3.1.10 *shear stress, [FL^{-2}], n*—the stress component tangential to the plane on which the forces act. **(E6)**

3.1.11 *true shear strength, [FL^{-2}], n*—the maximum uniform shear stress which a material is capable of sustaining in the absence of all normal stresses. **(D4896)**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *collet(s), n*—a sleeve placed on a shaft or tube and tightened so as to grip the shaft or tube.

3.2.1.1 *Discussion*—Collets may come in a variety of forms. A common example is a split conical collet which features a cone-shaped segmented sleeve that is tightened with a tapered collar.

3.2.2 *failure, n*—an arbitrary point beyond which a material or system ceases to be functional for its intended use.

3.2.2.1 *Discussion*—Failure strength is commonly defined by the force parameter (force, moment, torque, stress, etc.) applied to a test specimen that produces brittle fracture and loss of load-carrying capability or permanent deformation beyond a specified limit such as the elastic stress limit. Due to the

[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.

ceramic nature of the ceramic components being tested, failure will typically be catastrophic.

3.2.3 *nominal burst pressure, P_{NB} [FL^{-2}], n*—a burst pressure value calculated from the push-out force at failure and the face area of the end-plug in units of MPa.

3.2.4 *nominal joint strength, S_{NJ} [FL^{-2}], n*—the calculated strength at failure in units of MPa, calculated from the push-out force and the calculated adhesive bond area of the defined test specimen.

3.2.5 *push-out force, F_{PO} [F], n*—in a push-out test with a specific test specimen geometry and size, the force level at which failure occurs in units of N.

3.2.5.1 *Discussion*—Push-out force is defined at failure, however reductions in force during testing due to microcracking or other means that do not meet failure criteria may be tracked and reported.

4. Summary of Test Method

4.1 This test method is used to determine the push-out force, the nominal joint strength, and the nominal burst pressure of bonded ceramic end-plugs, typically using adhesives, in advanced ceramic cylindrical tubes (monolithics and composites) at ambient and elevated temperatures. Test specimens are prepared by bonding a fitted ceramic plug into one end of a ceramic tube. The test specimen tube is secured into a loading fixture and an axial compressive force is applied to the interior face of the end-plug until failure occurs. The axial force required to fracture (or yield) the test specimen joint is measured and used to calculate a nominal joint strength and a nominal burst pressure. Tests are done at ambient temperatures and at elevated temperatures, based on test furnace and test fixture temperature capabilities.

4.2 Typical end-joint test specimens and a typical test system are shown schematically in Figs. 1 and 2, respectively. Selection of the test specimen geometry and size depends on the functional design of the application-specific tube and the size limitations of the available test material.

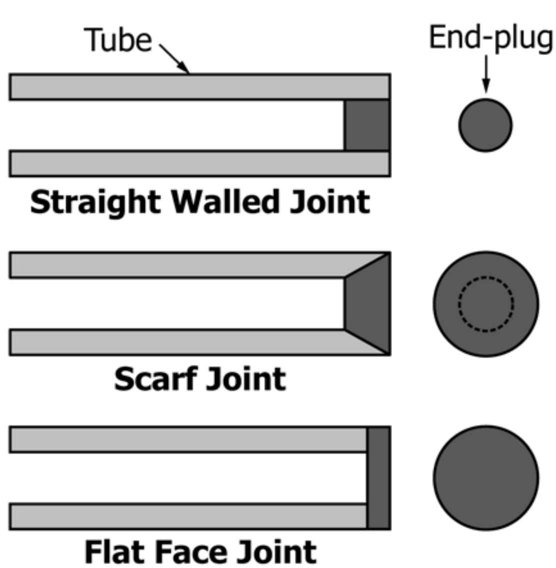

FIG. 1 Ceramic Test Specimens with Different End-Plug Configurations

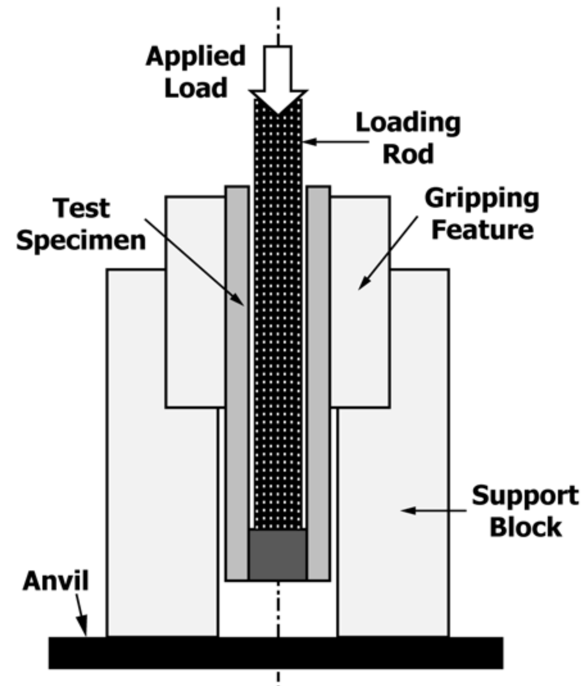

FIG. 2 Example EPPO Test Method Schematic

4.3 The force application arrangement of this test method is direct axial compression on the end face of the plug, where the predominant forces (shear, tensile, and mixed mode) occur in the circumferential adhesive bond section between the plug and the tube.

5. Significance and Use

5.1 Advanced ceramics are candidate materials for high-temperature structural applications requiring high strength along with wear and corrosion resistance. In particular, ceramic tubes are being considered and evaluated as hermetically tight fuel containment tubes for nuclear reactors. These ceramic tubes require end-plugs for containment and structural integrity. The end-plugs are commonly bonded with high-temperature adhesives into the tubes. The strength and durability of the test specimen joint are critical engineering factors, and the joint strength has to be determined across the full range of operating temperatures and conditions. The test method has to determine the breaking force, the nominal joint strength, the nominal burst pressure, and the failure mode for a given tube/plug/adhesive configuration.

5.2 The EPPO test provides information on the strength and the deformation of test specimen joints under applied shear, tensile, and mixed-mode stresses (with different plug geometries) at various temperatures and after environmental conditioning.

5.3 The end-plug test specimen geometry is a direct analog of the functional plug-tube application and is the most direct way of testing the tubular joint for the purposes of development, evaluation, and comparative studies involving adhesives and bonded products, including manufacturing quality control. This test method is a more realistic test for the intended geometry than the current shear test of ceramic joints (Test Method C1469), which uses an asymmetric four-point shear test on a flat adhesive face joint.

5.4 The EPPO test method may be used for joining method development and selection, adhesive comparison and screening, and quality assurance. This test method is not recommended for adhesive property determination, design data generation, material model verification/validation, or combinations thereof.

6. Interferences

6.1 The EPPO test in its basic form is a variation of the common single-lap joint shear test geometry, based on the rotation of a single-plane lap joint to form a cylindrical lap joint. So the complexities of the single-lap joint (as described in Guide D4896) are carried over to the EPPO test.

6.2 As described in Guide D4896, many factors (geometric, adhesive properties, adherend properties, force levels) affect the stress levels in the adhesive bond section and the failure strength values in a given experimental adhesive bond lap-type test. All of these factors interact to determine the actual stress levels at different points in the test specimen joint section. For full engineering analysis of the joint system and the test results, all of these factors should be carefully controlled and measured during testing.

6.2.1 The strain and stress conditions in the bond section may vary spatially, based on variations in the bond morphology and properties and the stress-strain interaction with the adherends. Critical factors are adhesive bond length and thickness, adhesive shear and tensile moduli and Poisson's ratio, adherend thickness, adherend shear and tensile moduli and Poisson's ratio, and interface surface conditions.

6.2.2 Depending on the type of adhesive and the process conditions, the adhesive bond may contain residual stresses and critical flaws that may affect the experimental strength. This is a particular concern with many of the high-temperature adhesives commonly used to bond advanced ceramics. In many cases, the residual stresses and critical flaw populations increase with larger bond section sizes and bond thicknesses.

6.3 Misalignment in the load system produces bending stresses in the joint that give erroneous test results. Bending stresses develop as a result of misaligned end-plugs in the tube specimens, out-of-tolerance test specimens (straightness and concentricity), out-of-tolerance test specimens and misfit of end-plugs, misalignment of the test specimen in the grip fixture, and misalignment load train components.

6.4 A common variable in adhesives is the different modes of joint failure: elastic-brittle versus ductile-plastic that occur for different types of adhesives and at different temperatures for a given adhesive. For each adhesive system and test condition, the failure criteria have to be appropriately defined to determine the point at which the adhesive functionally fails under stress.

6.5 The gripping mechanism shall be sufficiently strong at the test conditions so that the test specimen is securely held in the grip section and failure occurs in the end-plug section, not in the grip section of the test specimen. Grip failure is more likely at elevated temperatures, because of degradation of the grip adhesive at elevated temperatures and because of differential thermal expansion stresses between the grip fixture and the test specimen.

6.6 The adhesive properties may change with temperature and with time, either under test specimen conditioning or in aggressive test environments. In particular, ceramic and glass adhesives often fail by slow crack growth under moisture or elevated temperature conditions (or both), which may produce a different flaw population and microstructure, a change in failure mechanisms, or a combination thereof.

6.7 At elevated testing temperatures, differential thermal stresses caused by different thermal expansion coefficients between the end-plug, the adhesive, and the adherend often introduce additional stresses that may produce premature adhesive failure.

7. Apparatus

7.1 *Testing Machine*—Test specimens shall be tested in compressive loading with any suitable testing machine provided that uniform rates of direct loading are maintained. The force-measuring system shall be free of initial lag at the loading rates used, and shall be equipped with a means for retaining readout of the maximum force as well as a force-time or force-displacement record. Machines used for axial compression testing shall conform with and have an accuracy in accordance with Practices E4.

7.1.1 *Cross-Head Displacement Measurement*—The cross-head displacement should be measured as a record of the force-time response of the test specimen. Cross-head displacement of the test machine shall not be used to define displacement or strain in the end-plug test section.

7.1.2 *Force-Measurement Devices*—The measurement devices used in determining the force shall be accurate within ±1 % at any force within the selected load range of the testing machine as defined in Practices E4. Force calibration shall be performed in compression for universal machines.

7.2 *Test Apparatus Fixture:*

7.2.1 *General*—The test apparatus shall be designed, fabricated, and assembled so that the compressive force is applied to the test specimen axially, uniformly, and with negligible friction. The test apparatus shall apply an axial compressive force to the interior face of the end-plug without inducing excessive bending stresses or transverse shear stresses in the test specimen. Force application should be accomplished with a universal testing machine with appropriate gripping and loading fixtures. A typical test apparatus consists of a base plate, a support block, a gripping fixture, and a loading rod. A schematic of a test apparatus is shown in Fig. 2.

NOTE 1—It is not the intent of this test method to require specific loading and alignment fixtures for testing. Different test apparatus configurations can be designed and used for testing. The primary requirement is that the test fixture (as designed and fabricated) securely grips the test specimen and that the force is applied axially and uniformly. An example of an axial test apparatus for small ceramic tube specimens (10-mm diameter and 50 to 70 mm long) is described in Appendix X1.

7.2.2 The test apparatus shall be built with adequate materials and sized large enough to contain the test specimen and to support the applied forces without deformation or damage to the apparatus at the test temperatures. Flat bearing surfaces on the base plate, the support block, and the grip fixture shall have flat and parallel surfaces to within 0.002 m/m.

NOTE 2—At ambient temperatures, the fixture materials are commonly high-strength, high-hardness steels. At elevated temperatures (>500 °C), high-nickel alloys or high-strength ceramics (aluminum oxide, silicon carbide) are necessary for strength, hardness, and stability at the test temperature. Selected materials need to be compatible with materials being tested to avoid chemical interactions at high temperatures.

7.2.3 *Gripping Fixture*—A gripping fixture is necessary to secure the test specimen in the test apparatus without slipping or breakage while force is applied. The gripping fixture also aligns the test specimen in the load train. Gripping fixtures for tube specimens are grouped into two classes: mechanical grip fixtures (mechanical clamps, collets, and collars) and adhesive bonding into grips. The gripping mechanism should be designed to apply as uniform a pressure as possible across the test specimen in order to reduce induced stresses in the test specimen. Additional information on gripping methods can be found in Appendix X2.

NOTE 3—The brittle nature of advanced ceramics requires a uniform force application between the grip fixture and the gripped section of the test specimen. Line or point contacts and nonuniform forces can produce stress concentrations and Hertzian stresses, leading to crack initiation and fracture of the test specimen in the gripped section. The selection of a gripping method depends on the strength, rigidity, and brittleness of the ceramic tubes. Mechanical grips are an option if they secure the test specimen without slipping or breakage in the grips at the test conditions. If the tubes are small, thin-walled, brittle, and rigid, adhesive gripping methods are typically more successful than mechanical gripping.

7.2.4 *Loading Rod*—The loading rod shall be straight, rigid, and strong enough to apply force directly to the plug face without bending, deformation, or damage. The loading rod shall be long enough to reach the bottom of the test specimen with direct contact to the upper loading anvil. Adequate precautions shall be taken to avoid/minimize friction between the loading rod and the interior of the test specimen tube. The loading rod diameter should be 90 % of the inside diameter of the tube.

7.2.5 *Support Block*—The purpose of the support block is to align and hold the gripping fixture in place. Alignment features in the support block may use conical or spherical seats to maintain axial and lateral alignment of the gripping fixture.

7.2.6 *Alignment*—The test apparatus shall be designed and constructed to keep extraneous bending stresses and strains around the circumference of the test specimen at less than ±10 % difference from the mean stress around the circumference.

NOTE 4—Misalignment bending stresses can develop with nonuniform test specimens (variations in tube diameter, concentricity, and straightness; non-parallel end-plug faces; see 10.2) and from misalignments in the load train.

7.2.6.1 A compliant layer such as copper or graphite sheet may be used between the face/tip of the loading rod and the interior face of the end-plug to reduce or eliminate stress concentrations and misalignments.

7.2.6.2 The loading rod may use hemispherical or rounded features/fixtures or other alignment aides at the top and bottom to maintain axial alignment of the applied force. The flat face of the hemispherical load plate should sit on the end-plug to avoid point contact stresses on the end-plug (see Fig. 3). This alignment correction may not require a compliant layer.

7.3 *Strain Gauges*—Strain gages are not used in this test method to measure adhesive strain in the end-plug bond section during testing. Strain gages on the test specimen tube may be used to assess bending stresses and strains produced by misalignment (12.3.5). If used, strain gages shall be selected and used per Test Methods E251.

7.4 *Data Acquisition*—Applied force and cross-head displacement as a function of time shall be recorded. Use either digital data acquisition systems or analog chart recorders for this purpose, although a digital record is recommended for ease of later data analysis. Recording devices shall be accurate to 1.0 % of full scale. A minimum data acquisition rate of 10 Hz shall be used, and the acquisition rate shall be fast enough to capture the maximum force within 1 %.

7.5 *Dimension-Measuring Devices*—Micrometers, calipers, and optical microscopy used for measuring linear dimensions shall be accurate and precise to at least one-half the smallest unit to which the individual dimension is required to be measured. For testing small diameter (<20 mm) test specimens, the measuring devices should have an accuracy of 0.01 mm.

7.6 *Elevated Temperature Testing:*

7.6.1 *General*—This test method is applicable to elevated temperature testing with the use of suitable furnace equipment and temperature control and measurement. The test temperature shall be selected based on the functional temperature requirements of the ceramic application. The furnace may have

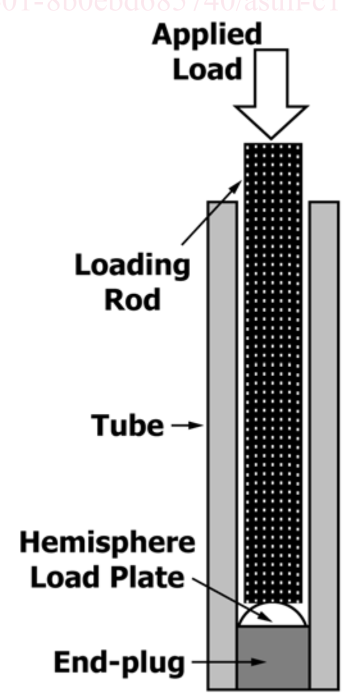

FIG. 3 Loading Rod Schematic Using a Hemispherical Load Plate

an air, inert, or vacuum environment, as required. If an inert or vacuum chamber is used, and it is necessary to direct the force through a bellows, fittings, or seal, it shall be verified that losses or errors in force measurement do not exceed 1 % of the expected failure forces.

7.6.2 *Furnace Configuration*—The furnace system shall be constructed and have a temperature-control system to maintain a constant temperature in the end-plug test section during each testing period. The variation in temperature with time during the test shall be no greater than ±5 °C or ±1 % of the test temperature, whichever is larger. The furnace system shall be configured so that spatial thermal differences along the length of the end-plug test section of the test specimen are no greater than ±5 °C or ±1 % of the test temperature (whichever is larger).

NOTE 5—Furnace systems can be configured in a variety of ways to accommodate test specimens, including traditional box furnace designs or small resistance heating elements in close proximity to the end-plug section. Heating can be done with any suitable heating method (indirect electrical resistance heating elements, direct induction, indirect induction through a susceptor, radiant lamp, or direct resistance in the test specimen) that maintains proper temperature conditions.

7.6.3 *Temperature Measurement*—The temperature-measurement device for the test specimen shall have a resolution of 2 °C or better. If temperature is measured with a thermocouple, the test specimen temperature shall be monitored with the thermocouple tip located no more than 1 mm from the end-joint section of the test specimen. Either a fully sheathed or exposed bead junction may be used. If a sheathed tip is used, it shall be verified that negligible error is associated with the sheath.

7.6.3.1 A separate thermocouple may be used to control the furnace chamber if necessary, but the test specimen temperature shall be the reported temperature of the test.

7.6.3.2 The thermocouple(s) shall be calibrated and used in accordance with Test Method E220 and Specification E230/E230M.

7.6.3.3 The temperature measurement shall be accurate to within ±5 °C. The accuracy shall include the error inherent to the thermocouple as well as any errors in the measuring instruments.

7.6.4 *System Equilibrium*—The time for the system to reach thermal equilibrium at test temperature shall be determined for the test temperature to be used. This shall be performed for both hot-furnace loading or cold-furnace loading, to support test specimen heat-up per 12.4.2.

7.6.5 *Temperature Data Acquisition*—At a minimum for elevated temperature tests, record temperature as single measurements at the initiation and completion of the actual test. However, temperature may also be recorded continuously, similar to force and strain except the record begins at the start of the heating of the furnace (including ramp-up to test temperature).

8. Calibration and Standardization

8.1 Calibration of equipment (force measurement, strain measurement, thermocouples, etc.) shall be provided by the supplier against standards traced to a national measurement institute, such as the National Institute of Standards and Technology (NIST). Recalibration shall be performed with traceable standards on all equipment on a yearly interval or whenever accuracy is in doubt.

8.2 *Reference Materials*—There are currently no standard reference materials for this type of test.

9. Hazards

9.1 *Precaution*—During the conduct of this test method, the possibility of flying fragments of broken test material is quite 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 safety as well as later fractographic reconstruction and analysis is highly recommended. Caution should be used during collection of fragments as they may be sharp.

9.2 *Precaution*—Elevated temperature testing often produces the possibility of fire, burns, and electrical shorts. Furnaces shall be properly designed, assembled, and operated to minimize those hazards.

9.3 *Precaution*—Exposed fibers at the edges of fiber-reinforced composite test specimens present a hazard due to the sharpness and brittleness of the ceramic fiber. Inform all persons required to handle these materials of such conditions and the proper handling techniques.

10. Test Specimens, Preparation, and Sampling

10.1 *Test Specimen Geometry*—While EPPO test specimens are defined as a joined tube and end-plug, a variety of test specimen geometry is acceptable if it meets the gripping, fracture location, bending limits, and temperature profile requirements of this test method. A minimum length between the bottom of the grips and the inner surface of the end-plug shall be 25 mm to ensure that fracture is not influenced by grip-induced stresses on the test specimen.

NOTE 6—The exact geometry is dependent on the purpose of the test and the design configuration and geometry of the end-use component. Generally, the dimensions (length, diameter, wall thickness, end-plug geometry, etc.) of the end-plug test specimen will reflect the size and dimensions of the end-use component, although it might not be possible to test exceedingly large tube-joints due to limits of test equipment. If it is desired to evaluate the effects of geometry and the adhesive processing, then the size of the test specimen and resulting bond geometry will be selected to accurately assess the test variables. In addition, grip methods will influence the final length and design of the test specimen geometry. These different test objectives will produce a wide range of test specimen diameters and length and preclude the use of a single, standardized test specimen geometry. An example of a test specimen geometry and test apparatus developed in 2015 for silicon carbide composite tubes for the nuclear industry is shown in Appendix X1.

10.1.1 A major factor in the design of the test specimen is the configurational fit between the end-plug and the tube. Critical factors are the bond geometry (for example, straight-wall plug, scarf-joint plug, flat-face plug; see Fig. 1), the bond length and area, and the adhesive bond thickness between the tube inside diameter (ID) and the plug outside diameter (OD). The test specimen bond geometry may match the bond configuration of the end-use component.