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*

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

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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.

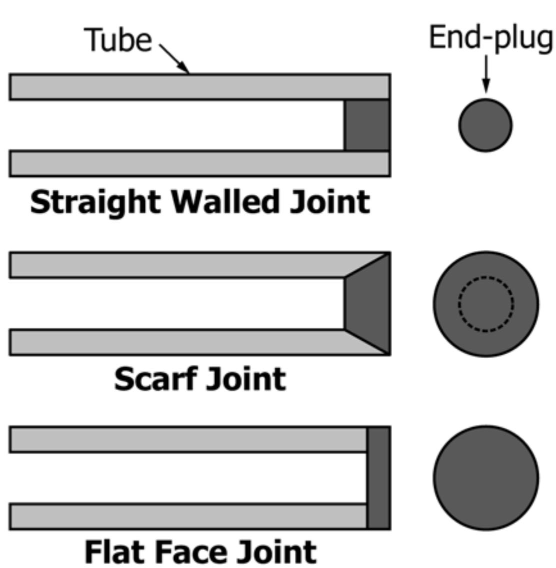

FIG. 1 Ceramic Test Specimens with Different End-Plug Configurations

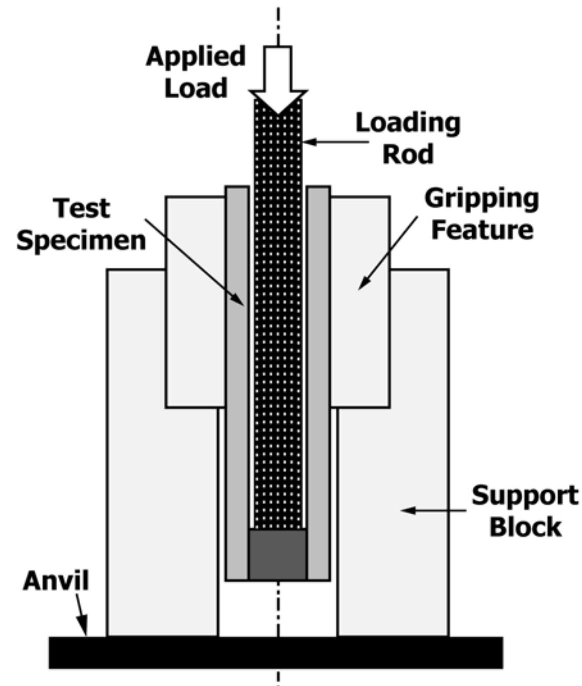

FIG. 2 Example EPPO Test Method Schematic

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