



Designation: ~~D5449/D5449M—16~~ D5449/D5449M – 22

## Standard Test Method for Transverse Compressive Properties of Hoop Wound Polymer Matrix Composite Cylinders<sup>1</sup>

This standard is issued under the fixed designation D5449/D5449M; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the U.S. Department of Defense.*

### 1. Scope

1.1 This test method determines the transverse compressive properties of wound polymer matrix composites reinforced by high-modulus continuous fibers. It describes testing of hoop wound (90°) cylinders in axial compression for determination of transverse compressive properties.

1.2 The technical content of this ~~standard-test method~~ has been stable since 1993 without significant objection from its stakeholders. As there is limited technical support for the maintenance of this ~~standard-test method~~, changes since that date have been limited to items required to retain consistency with other ASTM D30 Committee standards, including editorial changes and incorporation of updated guidance on specimen preconditioning and environmental testing. The ~~standard-test method~~, therefore, should not be considered to include any significant changes in approach and practice since 1993. Future maintenance of the ~~standard-test method~~ will only be in response to specific requests and performed only as technical support allows.

1.3 Units—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system ~~must~~ shall be used independently of the other. ~~Combining other, and values from the two systems may result in nonconformance with the standard; shall not be combined.~~

1.3.1 Within the text, the inch-pound units are shown in brackets.

1.4 *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~~ safety, health, and ~~health~~ environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

### 2. Referenced Documents

#### 2.1 ASTM Standards:<sup>2</sup>

**D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement**

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.04 on Lamina and Laminate Test Methods.

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<sup>2</sup> 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.



D883 Terminology Relating to Plastics  
 D2584 Test Method for Ignition Loss of Cured Reinforced Resins  
 D2734 Test Methods for Void Content of Reinforced Plastics  
 D3171 Test Methods for Constituent Content of Composite Materials  
 D3878 Terminology for Composite Materials  
 D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials  
 D5448/D5448M Test Method for Inplane Shear Properties of Hoop Wound Polymer Matrix Composite Cylinders  
 D5450/D5450M Test Method for Transverse Tensile Properties of Hoop Wound Polymer Matrix Composite Cylinders  
 E4 Practices for Force Calibration and Verification of Testing Machines  
 E6 Terminology Relating to Methods of Mechanical Testing  
 E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves  
 E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process  
 E132 Test Method for Poisson's Ratio at Room Temperature  
 E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods  
 E251 Test Methods for Performance Characteristics of Metallic Bonded Resistance Strain Gages  
 E456 Terminology Relating to Quality and Statistics  
 E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method  
 E1237 Guide for Installing Bonded Resistance Strain Gages

### 3. Terminology

3.1 *Definitions*—Terminology D3878 defines terms relating to high-modulus fibers and their composites. Terminology D883 defines terms relating to plastics. Terminology E6 defines terms relating to mechanical testing. Terminology E456 and Practice E177 defines terms relating to statistics. In the event of a conflict between terms, Terminology D3878 shall have precedence over other standards.

NOTE 1—If the term represents a physical quantity, its analytical dimensions are stated immediately following the term (or letter symbol) in fundamental dimension form, using the following ASTM standard symbology for fundamental dimensions, shown within square brackets:  $[M]$  for mass,  $[L]$  for length,  $[T]$  for time,  $[\theta]$  for thermodynamic temperature, and  $[nd]$  for non-dimensional quantities. Use of these symbols is restricted to analytical dimensions when used with square brackets, as the symbols may have other definitions when used without the brackets.

#### 3.2 *Definitions of Terms Specific to This Standard:*<sup>3</sup>

3.2.1 *winding*—~~an entire part completed by one winding operation and then cured.~~

3.2.1 *hoop wound, n*—a winding of a cylindrical component in which the filaments are circumferentially oriented.

3.2.2 *specimen*—~~specimen, n~~—a single part cut from a winding. ~~Each~~winding; ~~each~~ winding may yield several specimens.

3.2.3 *transverse compressive modulus,  $E_{22}$  [ $ML^{-1}T^{-2}$ ], n*—the compressive elastic modulus of a unidirectional material in the direction perpendicular to the reinforcing fibers.

3.2.4 *transverse compressive ~~strength,  $\sigma_{22}^{uc}$  [ $MLnd^{-1}T^{-2}$ ], n~~*—~~the strength of a unidirectional material~~ value of strain, perpendicular to the reinforcing fibers in a unidirectional material, at failure when a compressive force is applied in the direction perpendicular to the reinforcing fibers.

3.2.5 *transverse compressive ~~strain at failure,  $\epsilon_{22}^{uc}$  [ $ndML^{-1}T^{-2}$ ], n~~*—~~the value of strain, perpendicular to the reinforcing fibers in a unidirectional material, at failure~~ strength of a unidirectional material when a compressive force is applied in the direction perpendicular to the reinforcing fibers.

3.2.6 *winding, n*—an entire part completed by one winding operation and then cured.

<sup>3</sup> If the term represents a physical quantity, its analytical dimensions are stated immediately following the term (or letter symbol) in fundamental dimension form, using the following ASTM standard symbology for fundamental dimensions, shown within square brackets:  $[M]$  for mass,  $[L]$  for length,  $[T]$  for time,  $[\theta]$  for thermodynamic temperature, and  $[nd]$  for nondimensional quantities. Use of these symbols is restricted to analytical dimensions when used with square brackets, as the symbols may have other definitions when used without the brackets.

## 4. Summary of Test Method

4.1 A thin-walled hoop wound cylinder nominally 100 mm [4 in.] in diameter and 140 mm [5½ in.] in length is bonded into two end fixtures. The specimen fixture assembly is mounted in the testing machine and monotonically loaded in compression while recording force. The transverse compressive strength can be determined from the maximum force carried before failure. If the cylinder strain is monitored with strain gauges then the stress-strain response, the compressive strain at failure, transverse compression modulus of elasticity, and Poisson's ratio can be derived.

## 5. Significance and Use

5.1 This test method is designed to produce transverse compressive property data for material specifications, research and development, quality assurance, and structural design and analysis. Factors that influence the transverse compressive response and should therefore be reported are: material, method of material preparation, specimen preparation, specimen conditioning, environment of testing, specimen alignment and gripping, speed of testing, void content, and fiber volume fraction. Properties in the test direction that may be obtained from this test method are:

5.1.1 Transverse compressive strength,  $\sigma_{22}^{uc}$ ,

5.1.2 Transverse compressive strain at failure,  $\epsilon_{22}^{uc}$ ,

5.1.3 Transverse compressive modulus of elasticity,  $E_{22}$ , and

5.1.4 Poisson's ratio,  $\gamma_{21}$ .

## 6. Interference

6.1 *Material and Specimen Preparation*—Poor material fabrication practices, lack of control of fiber alignment, and damage induced by improper specimen machining are known causes of high material data scatter in composites.

6.2 *Bonding Specimens to Test Fixtures*—A high percentage of failures in or near the bond between the test specimen and the test fixture, especially when combined with high material data scatter, is an indicator of specimen bonding problems. Specimen to fixture bonding is discussed in 11.5.

6.3 *System Alignment*—Excessive bending may cause premature failure, as well as highly inaccurate modulus of elasticity determination. Every effort should be made to eliminate excess bending from the test system. Bending may occur as a result of misaligned grips, misaligned specimens in the test fixtures, or from departures of the specimens from tolerance requirements. The alignment should always be checked as discussed in 13.2.

## 7. Apparatus

7.1 *Micrometers and Calipers*—A micrometer with a 4 to 7 mm [0.16 to 0.28 in.] nominal diameter ball-interface or a flat anvil interface shall be used to measure the specimen wall thickness, inner diameter, and outer diameter. A ball interface is recommended for these measurements when at least one surface is irregular (e.g., for example, a coarse peel ply surface, which is neither smooth nor flat). A micrometer or caliper with a flat anvil interface shall be used for measuring the overall specimen length, the gauge length (the free length between the fixtures), and other machined surface dimensions. The use of alternative measurement devices is permitted if specified (or agreed to) by the test requestor and reported by the testing laboratory. The accuracy of the instruments shall be suitable for reading to within  $\pm 1\%$  of the sample dimensions. For typical specimen geometries, an instrument with an accuracy of  $\pm 0.0025$  mm [ $\pm 0.0001$  in.] is adequate for wall thickness measurements, while an instrument with an accuracy of  $\pm 0.025$  mm [ $\pm 0.001$  in.] is adequate for measurement of the inner diameter, outer diameter, overall specimen length, gauge length, and other machined surface dimensions.

7.2 *Compression Fixture*—The compression fixture consists of a steel outer shell and insert. An assembly drawing for these components and the test fixture is shown in Fig. 1.

7.2.1 *Outer Shell*—The outer shell (SI units Fig. 2, English units Fig. 3) is circular with a concentric circular hollow in one face, a groove along the diameter of the other face, and a center hole through the thickness. Along the diameter perpendicular to the groove, three pairs of small eccentric holes are placed at three radial distances. The two outer pairs of holes are threaded. Four

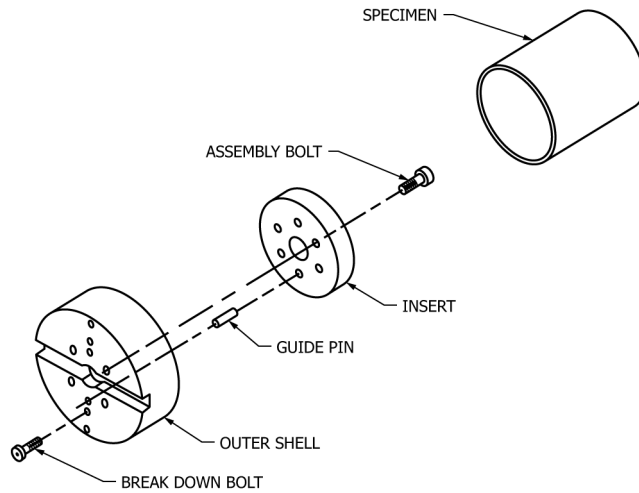


FIG. 1 Assembly Drawing for the Compression Fixture and Specimen

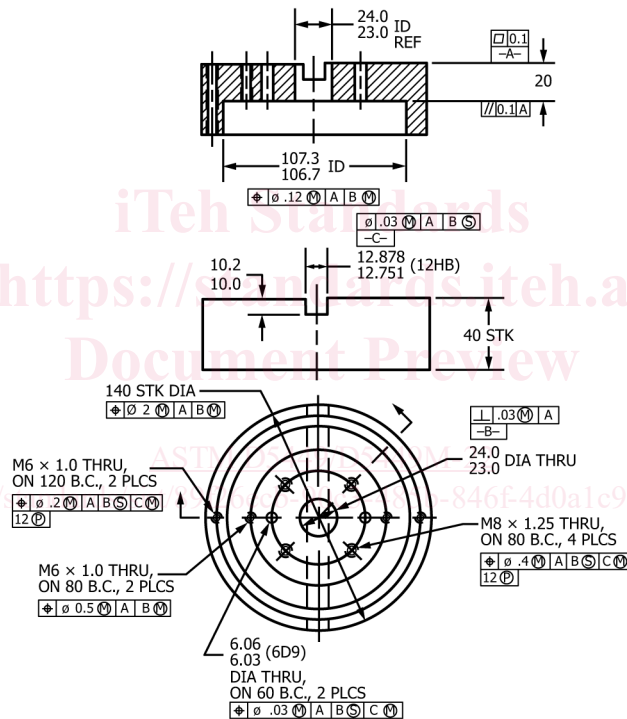


FIG. 2 The Outer Shell of the Compression Fixture in Metric Units

additional threaded holes are placed at the same radial distance as the innermost pair of holes at 90° intervals starting 45° from the diameter that passes through the center groove.

7.2.2 *Insert*—The fixture insert is circular with a center hole through the thickness (SI units Fig. 4, English units Fig. 5). Two sets of holes are placed along a concentric centerline. These holes align with the innermost set of holes in the outer shell. The set of four holes at 90° intervals are counterbored. The insert is fastened inside the hollow of the outer shell to form the concentric groove used to put the specimen in the fixture (Fig. 1).

7.2.3 The outer shell and insert for the compression fixture are the same outer shell and insert used for the fixtures in standard test methods D5448/D5448M and D5450/D5450M.

7.3 *Testing Machine*, comprised of the following:

7.3.1 *Fixed Member*—A fixed or essentially stationary member.

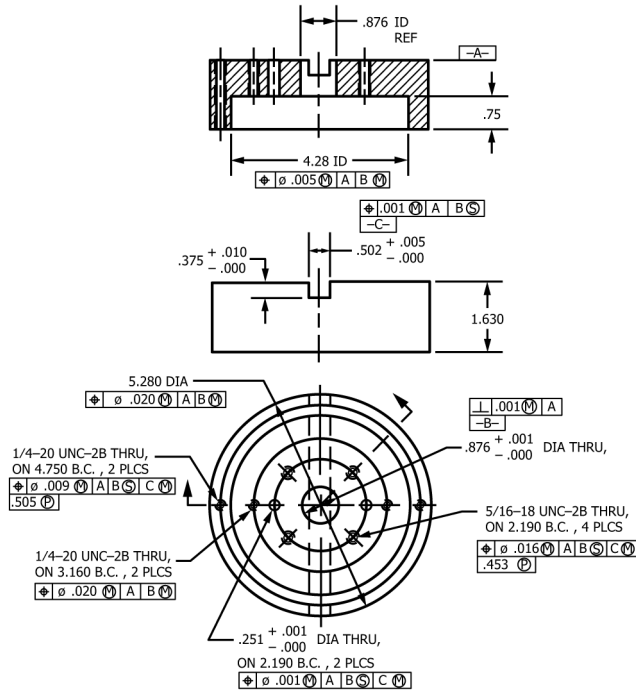


FIG. 3 The Outer Shell of the Compression Fixture in English Units

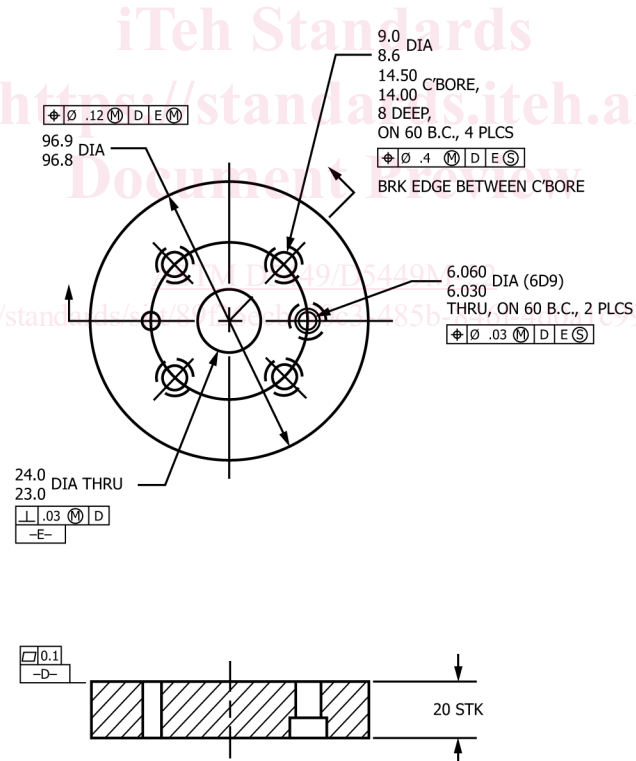


FIG. 4 The Insert of the Compression Fixture in Metric Units

7.3.2 Movable Member.

7.3.3 Steel Platens, two, flat, one of which connects to the force-sensing device and the other at the opposite end of the assembled test fixture. At least one (preferably both) of these platens is coupled to the test machine with a swivel joint, that is, a hemispherical ball on the machine that fits into a hemispherical recess on one or both of the platens.

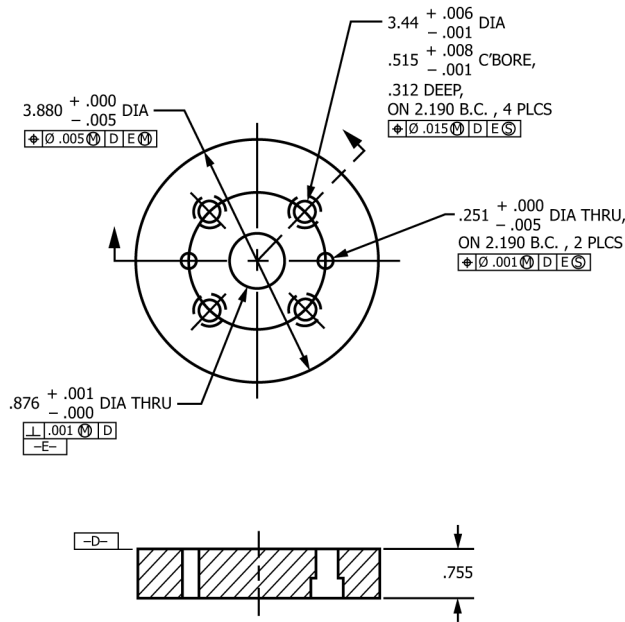


FIG. 5 The Insert of the Compression Fixture in English Units

7.3.4 *Drive Mechanism*, for imparting to the movable member a uniform controlled velocity with respect to the fixed member, this velocity to be regulated as specified in 11.6.

7.3.5 *Force Indicator*—A suitable force-indicating mechanism capable of showing the total compressive force carried by the test specimen. This mechanism shall be essentially free of inertia-lag at the specified rate of testing and shall indicate the force within an accuracy of  $\pm 1\%$  of the actual value, or better. The accuracy of the testing machine shall be verified in accordance with Practice E4.

7.3.6 *Construction Materials*—The fixed member, movable member, platens, drive mechanism, and fixtures shall be constructed of such materials and in such proportions that the total longitudinal deformation of the system contributed by these parts is minimized.

7.4 *Strain-Indicating Device*—Force versus strain data shall be determined by means of bonded resistance strain gauges. Each strain gauge shall be 6.3 mm [0.25 in.] in length. The specimen shall be instrumented to measure strain in both the axial and circumferential direction to determine Poisson's ratio. Strain gauge rosettes ( $0^\circ/45^\circ/90^\circ$ ) shall be used to correct for gauge misalignment. Gauge calibration certification shall comply with Test Method E251. Some guidelines on the use of strain gauges on composites are presented as follows. A general reference on the subject is Tuttle and Brinson.<sup>4</sup>

7.4.1 *Surface Preparation*—The surface preparation of fiber-reinforced composites discussed in Guide E1237 can penetrate the matrix material and cause damage to the reinforcing fibers, resulting in improper specimen failures. Reinforcing fibers should not be exposed or damaged during the surface preparation process. The strain gauge manufacturer should be consulted regarding surface preparation guidelines and recommended bonding agents for composites, pending the development of a set of standard practices for strain gauge installation surface preparation of fiber-reinforced composite materials.

7.4.2 *Gauge Resistance*—Consideration should be given to the selection of gauges having larger resistance to reduce heating effects on low-conductivity materials. Resistances of 350  $\Omega$  or higher are preferred. Additional considerations should be given to the use of the minimum possible gauge excitation voltage consistent with the desired accuracy (1 to 2 V is recommended) to reduce further the power consumed by the gauge. Heating of the specimen by the gauge may affect the performance of the material directly, or it may affect the indicated strain as a result of a difference between the gauge temperature compensation factor and the coefficient of thermal expansion of the specimen material.

<sup>4</sup> Tuttle, M. E., and Brinson, H. F., "Resistance Foil Strain Gauge Technology as Applied to Composite Materials," *Experimental Mechanics*, Vol 24, No. 1, March 1984, pp. 54–64; errata noted in Vol 26, No. 2, January 1986, pp. 153–154.

7.4.3 *Temperature Considerations*—Consideration of some form of temperature compensation is recommended, even when testing at standard laboratory atmosphere. Temperature compensation is required when testing in nonambient temperature environments.

7.4.4 *Transverse Sensitivity*—Consideration should be given to the transverse sensitivity of the selected strain gauge. The strain gauge manufacturer should be consulted for recommendations on transverse sensitivity corrections and effects on composites. This is particularly important for a transversely mounted gauge used to determine Poisson’s ratio.

7.5 *Conditioning Chamber*—When conditioning materials at nonlaboratory/non-laboratory environments, a temperature/vapor-level controlled environment conditioning chamber is required which that shall be capable of maintaining the required temperature to within  $\pm 3^{\circ}\text{C}$  [ $\pm 5^{\circ}\text{F}$ ]  $\pm 3^{\circ}\text{C}$  [ $\pm 5^{\circ}\text{F}$ ] and the required relative vapor humidity level to within  $\pm 3\%$   $\pm 3\%$  RH. Chamber conditions shall be monitored either on an automated continuous basis or on a manual basis at regular intervals.

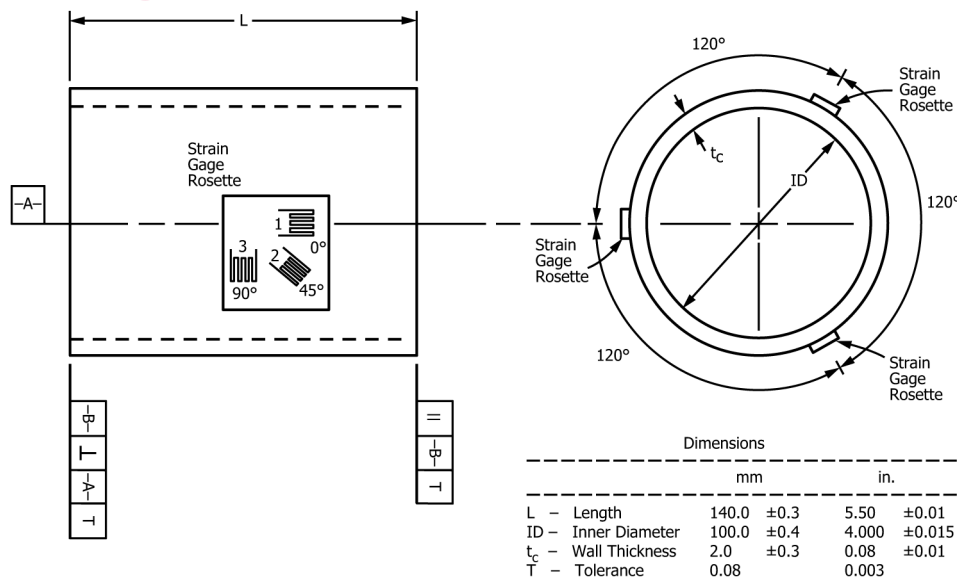
7.6 *Environmental Test Chamber*—An environmental test chamber is required for testing environments other than ambient testing laboratory conditions. This chamber shall be capable of maintaining the gauge section of the test specimen at the required test environment during the mechanical test. The test temperature shall be maintained within  $\pm 3^{\circ}\text{C}$  [ $\pm 5^{\circ}\text{F}$ ] of the required temperature, and the relative humidity level shall be maintained to within  $\pm 3\%$  RH of the required humidity level.

## 8. Sampling and Test Specimens

8.1 *Sampling*—At least five specimens per test condition should be tested unless valid results can be gained through the use of fewer specimens, such as in the case of a designed experiment. For statistically significant data, the procedures outlined in Practice E122 should be consulted. The method of sampling shall be reported.

NOTE 2—If specimens are to undergo environmental conditioning to equilibrium, and are of such type or geometry that the weight change of the material cannot be properly measured by weighing the specimen itself, then another traveler of the same nominal thickness and appropriate size shall be used to determine when equilibrium has been reached for the specimens being conditioned.

8.2 *Geometry*—The test specimen shall be as shown in Fig. 6. The length of all specimens shall be 140 mm [5.5 in.]–140 mm [5.5 in.]. This will provide a 102 mm [4.0 in.] gauge length. The inner diameter of all specimens shall be  $100 \pm 4$  mm [4.000  $\pm$  0.015 in.]–0.015 in.]. Specimens may be fabricated on a tapered mandrel yielding a maximum taper over the specimen length of 0.0005 mm/mm/mm [in./in.] on the diameter. The specimens shall have a nominal wall



- Notes: 1. Tube may be fabricated on a tapered mandrel with maximum taper of 0.0005 in/in (0.0005 mm/mm) on the diameter.  
 2. Actual measure of inner diameter will depend on specimen placement along tapered mandrel during fabrication.

FIG. 6 Test Specimen Shown with Strain Gauge Configuration