Designation: D 5449/D 5449M – 93

# Standard Test Method for Transverse Compressive Properties of Hoop Wound Polymer Matrix Composite Cylinders[1]

This standard is issued under the fixed designation D 5449/D 5449M; 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 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 values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3 *This standard does not purport to address all of the safety problems, 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.*

## 2. Referenced Documents

2.1 *ASTM Standards:*

D 792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement[2]

D 883 Terminology Relating to Plastics[2]

D 2584 Test Method for Ignition Loss of Cured Reinforced Resins[3]

D 2734 Test Methods for Void Content of Reinforced Plastics[3]

D 3171 Test Methods for Fiber Content of Resin-Matrix Composites by Matrix Digestion[4]

D 3878 Terminology Relating to High-Modulus Reinforcing Fibers and Their Composites[4]

D 5229/D 5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials[4]

D 5448/D 5448M Test Method for Inplane Shear Properties of Hoop Wound Polymer Matrix Composite Cylinders[4]

D 5450/D 5450M Test Method for Transverse Tensile Properties of Hoop Wound Polymer Matrix Composite Cylinders[4]

E 4 Practices for Force Verification of Testing Machines[5]

E 6 Terminology Relating to Methods of Mechanical Testing[5]

E 111 Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus[5]

E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process[6]

E 132 Test Method for Poisson's Ratio at Room Temperature[5]

E 177 Practice for Use of Terms Precision and Bias in ASTM Test Methods[6]

E 251 Test Methods for Performance Characteristics of Bonded Resistance Strain Gages[5]

E 456 Terminology Relating to Quality and Statistics[6]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[6]

E 1237 Practice for Installing Bonded Resistance Strain Gages[5]



## 3. Terminology

3.1 *Definitions*—Terminology D 3878 defines terms relating to high-modulus fibers and their composites. Terminology D 883 defines terms relating to plastics. Terminology E 6 defines terms relating to mechanical testing. Terminology E 456 and Practice E 177 defines terms relating to statistics. In the event of a conflict between terms, Terminology D 3878 shall have precedence over other standards.

3.2 *Definitions of Terms Specific to This Standard:* [7]

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

3.2.2 *hoop wound, n*—a winding of a cylindrical component where the filaments are circumferentially oriented.

3.2.3 *specimen*—a single part cut from a winding. Each

[1] This test method is under the jurisdiction of ASTM Committee D-30 on High Modulus Fibers and Their Composites and is the direct responsibility of Subcommittee D30.04 on Lamina and Laminate Test Methods.

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[2] *Annual Book of ASTM Standards*, Vol 08.01.

[3] *Annual Book of ASTM Standards*, Vol 08.02.

[4] *Annual Book of ASTM Standards*, Vol 15.03.

[5] *Annual Book of ASTM Standards*, Vol 03.01.

[6] *Annual Book of ASTM Standards*, Vol 14.02.

[7] 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, [θ] 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.

winding may yield several specimens.

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

3.2.5 *transverse compressive strength*, $\sigma_{22}^{uc}$, $[MT^{-2}L^{-1}]$, *n*—the strength of a unidirectional material when a compressive load is applied in the direction perpendicular to the reinforcing fibers.

3.2.6 *transverse compressive strain at failure*, $\epsilon_{22}^{uc}[nd]$, *n*—the value of strain, perpendicular to the reinforcing fibers in a unidirectional material, at failure when a compressive load is applied in the direction perpendicular to the reinforcing fibers.

## 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 load. The transverse compressive strength can be determined from the maximum load carried prior to failure. If the coupon strain is monitored with strain gages 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 which 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 which 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 coupon 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 due to 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 12.2.

## 7. Apparatus

7.1 *Micrometers*, suitable ball type for reading to within 0.025 ± 0.010 mm [0.001 ± 0.0004 in.] of the specimen inner and outer diameters. Flat anvil-type micrometer or calipers of similar resolution may be used for the overall specimen length and the gage length (the free length between the fixtures).

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 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 D 5448/D 5448M and D 5450/D 5450M.

7.3 *Testing Machine*, comprised of the following:

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

7.3.2 *Movable Member*.

7.3.3 *Steel Platens*, two, flat, one of which connects to the load-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.



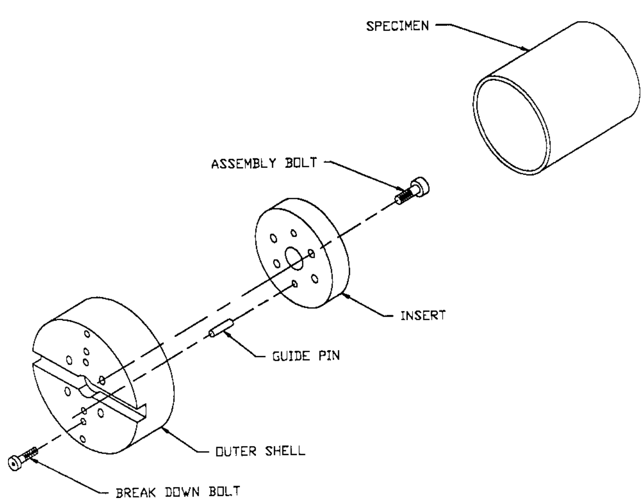


**FIG. 1 Assembly Drawing for the Compression Fixture and Specimen**

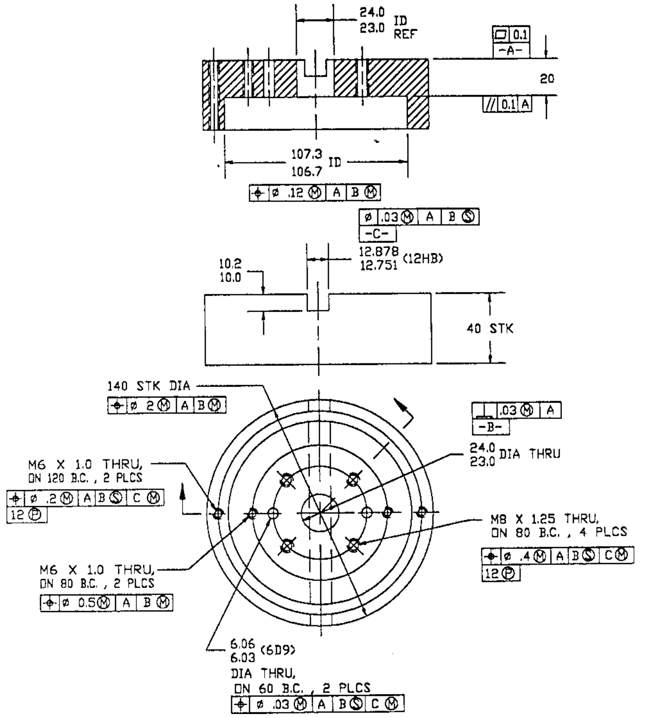


FIG. 2 The Outer Shell of the Compression Fixture in Metric Units

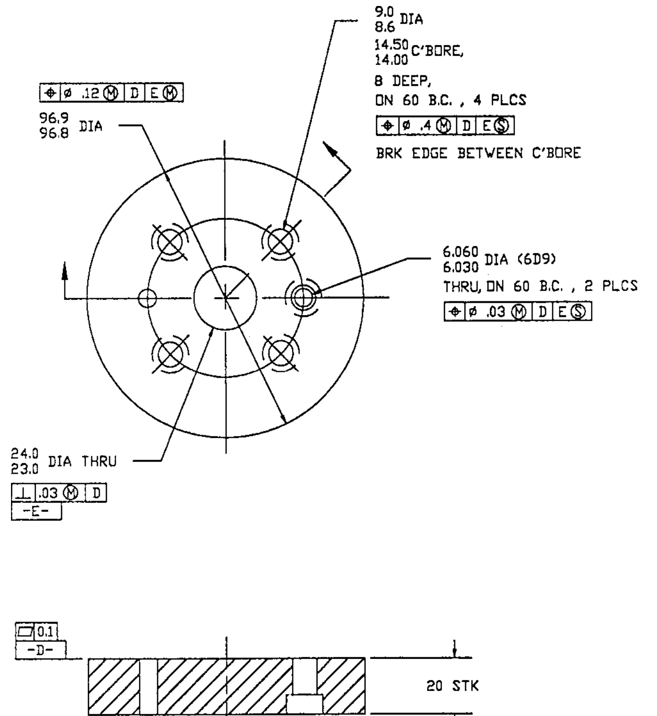


FIG. 4 The Insert of the Compression Fixture in Metric Units



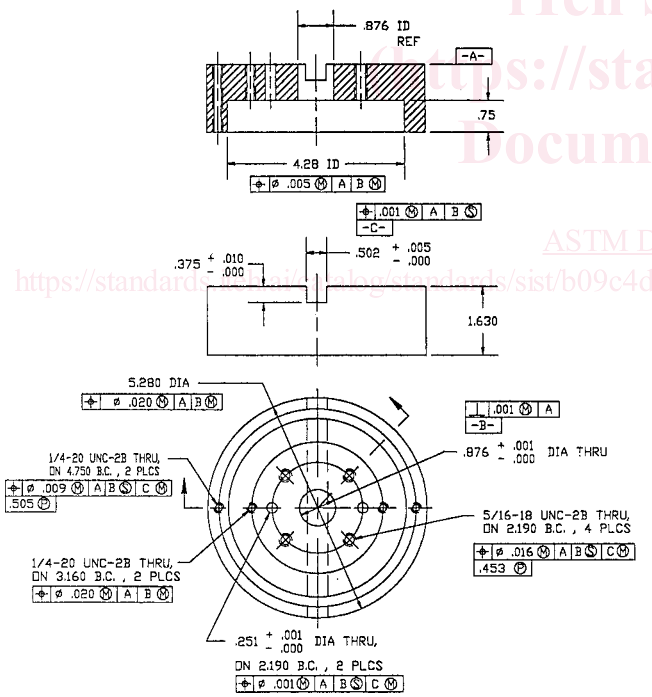


FIG. 3 The Outer Shell of the Compression Fixture in English Units

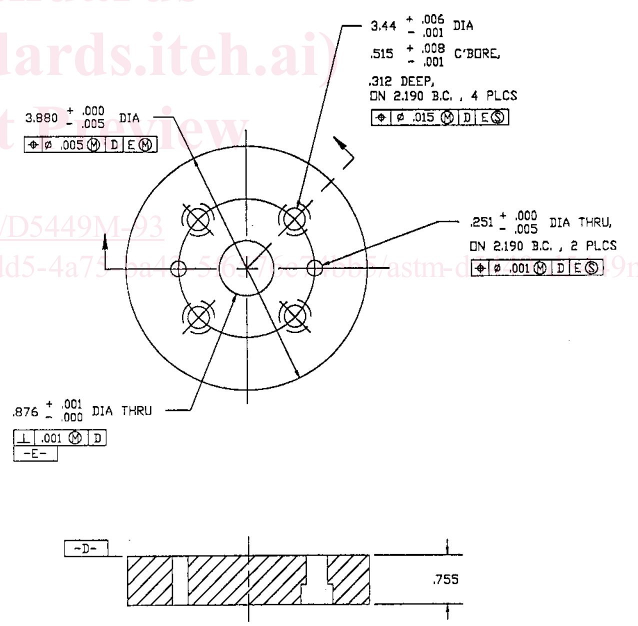


FIG. 5 The Insert of the Compression Fixture in English Units

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 *Load Indicator*—A suitable load-indicating mechanism capable of showing the total compressive load carried by the test specimen. This mechanism shall be essentially free of inertia-lag at the specified rate of testing and shall indicate the load within an accuracy of ±1 % of the actual value, or better. The accuracy of the testing machine shall be verified in accordance with Practice E 4.

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*—Load versus strain data shall be determined by means of bonded resistance strain gages. Each strain gage shall be 6.3 mm [0.25 in.] in length. The

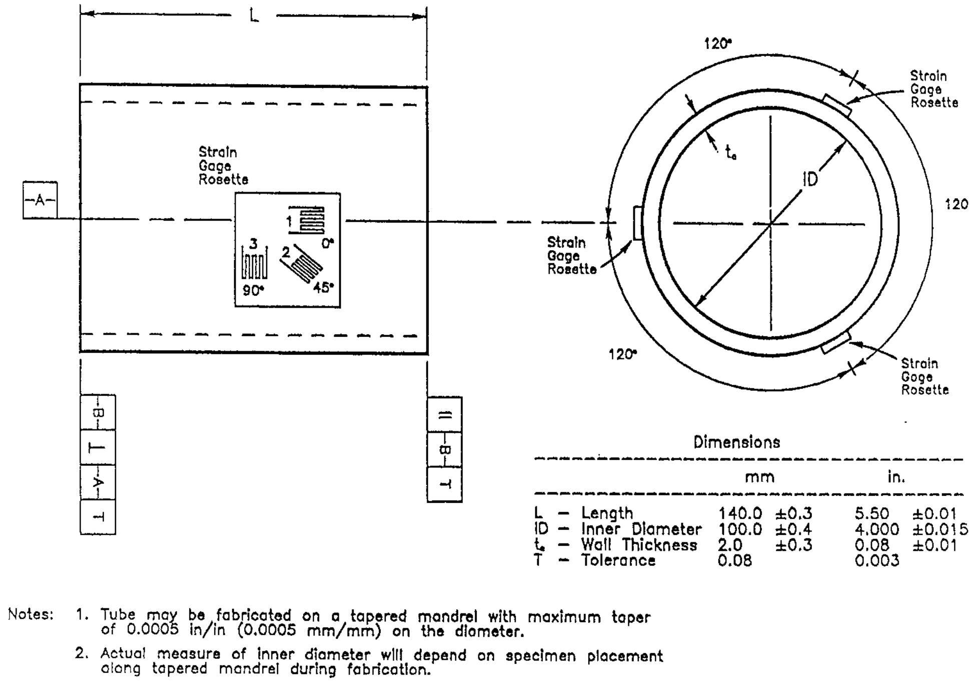


**FIG. 6 Test Specimen Shown with Strain Gage Configuration**

specimen shall be instrumented to measure strain in both the axial and circumferential direction to determine Poisson's Ratio. Strain gage rosettes (0°/45°/90°) shall be used to correct for gage misalignment. Gage calibration certification shall comply with Test Method E 251. Some guidelines on the use of strain gages on composites are presented as follows. A general reference on the subject is Tuttle and Brinson.[8]

7.4.1 *Surface Preparation*—The surface preparation of fiber-reinforced composites discussed in Practice E 1237 can penetrate the matrix material and cause damage to the reinforcing fibers, resulting in improper coupon failures. Reinforcing fibers should not be exposed or damaged during the surface preparation process. The strain gage 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-gage installation surface preparation of fiber-reinforced composite materials.

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

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 non-ambient temperature environments.

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

7.5 *Conditioning Chamber*—When conditioning materials at non-laboratory environments, a temperature/vapor-level controlled environment conditioning chamber is required which shall be capable of maintaining the required temperature to within ±3°C [±5°F] and the required relative vapor level to within ±3 %. 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 gage section of the test specimen at the required test environment during the mechanical test.

## 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 E 122 should be consulted. The method of sampling shall be reported.

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.]. This will provide a 102-mm [4.0-in.] gage length. The inner diameter of all specimens shall be 100 ± 4 mm [4.000 ± 0.015 in.]. Specimens may be fabricated on a tapered mandrel



[8] Tuttle, M. E., and Brinson, H. F., "Resistance Foil Strain Gage 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.