Designation: D7291/D7291M – 22

Standard Test Method for Through-Thickness "Flatwise" Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material[1]

This standard is issued under the fixed designation D7291/D7291M; 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 through-thickness "flatwise" tensile strength and elastic modulus of fiber reinforced polymer matrix composite materials. A tensile force is applied normal to the plane of the composite laminate using adhesively bonded thick metal end-tabs. The composite material forms are limited to continuous fiber (unidirectional reinforcement or two-dimensional fabric) or discontinuous fiber (nonwoven or chopped) reinforced composites.

1.2 The through-thickness strength results using this test method will in general not be comparable to Test Method D6415 since this method subjects a relatively large volume of material to an almost uniform stress field while Test Method D6415 subjects a small volume of material to a non-uniform stress field.

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 shall be used independently of the other, and values from the two systems shall not be combined.

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

1.4 This standard may involve hazardous materials, operations, and equipment.

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

1.6 *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:*[2]

D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
D883 Terminology Relating to Plastics
D2584 Test Method for Ignition Loss of Cured Reinforced Resins
D2651 Guide for Preparation of Metal Surfaces for Adhesive Bonding
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
D5687/D5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation
D6415 Test Method for Measuring the Curved Beam Strength of a Fiber-Reinforced Polymer-Matrix Composite
E4 Practices for Force Calibration and 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
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

[1] This test method is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.06 on Interlaminar Properties.

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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.

E456 Terminology Relating to Quality and Statistics
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application

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 define terms relating to statistics. In the event of a conflict between terms, Terminology D3878 shall have precedence over the other terminology 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, [*Θ*] 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:*

3.2.1 *flatwise tensile ultimate strength, F^{tu} [$M L^{-1} T^{-2}$], n*—the ultimate strength of the composite material in the out-of-plane (through-thickness) direction.

3.2.2 *through-thickness tensile modulus, E^{chord} [$M L^{-1} T^{-2}$], n*—the chord modulus of elasticity of the composite material in the out-of-plane (through-thickness) direction.

3.3 *Symbols:*

3.3.1 *A*—cross-sectional area of specimen in the through-thickness direction,

3.3.2 *CV*—coefficient of variation statistic of a sample population for a given property (in percent),

3.3.3 E^{chord}— through-thickness tensile modulus.

3.3.4 F^{tu}— flatwise tensile ultimate strength.

3.3.5 *n*—number of specimens.

3.3.6 P_{max}—maximum force carried by test specimen before failure.

3.3.7 S_{n-1}—standard deviation statistic of a sample population for a given property.

3.3.8 x_i—measured or derived property for an individual specimen from the sample population.

3.3.9 $\bar{x}$—sample mean (average).

3.3.10 ε—indicated through-thickness tensile strain from strain transducer.

3.3.11 σ—through-thickness tensile stress.

4. Summary of Test Method

4.1 A composite specimen in the shape of either a straight-sided cylindrical disk or a reduced gage section cylindrical "spool" is adhesively bonded to cylindrical metal end tabs. The bonded assembly is loaded under "flatwise" tension loading by a force applied normal to the plane of the composite laminate until failure of the laminate occurs (Fig. 1). The test is considered valid only when failure occurs entirely within the composite laminate. The test is considered invalid if failure of the bond-line, or partial failure of the bond-line and the surface layer of the composite, occurs. The failure mode of this test is not controlled; therefore, the actual failure may be intralaminar or interlaminar in nature.

4.2 If force-strain data are required, the specimen may be instrumented with strain gages provided certain specimen thickness requirements are satisfied (see 8.2).

5. Significance and Use

5.1 This test method is designed to produce through-thickness failure data for structural design and analysis, quality assurance, and research and development. Factors that influence the through-thickness tensile strength, and should therefore be reported, include the following: material and fabric reinforcement, methods of material and fabric preparation, methods of processing and specimen fabrication, specimen stacking sequence, specimen conditioning, environment of

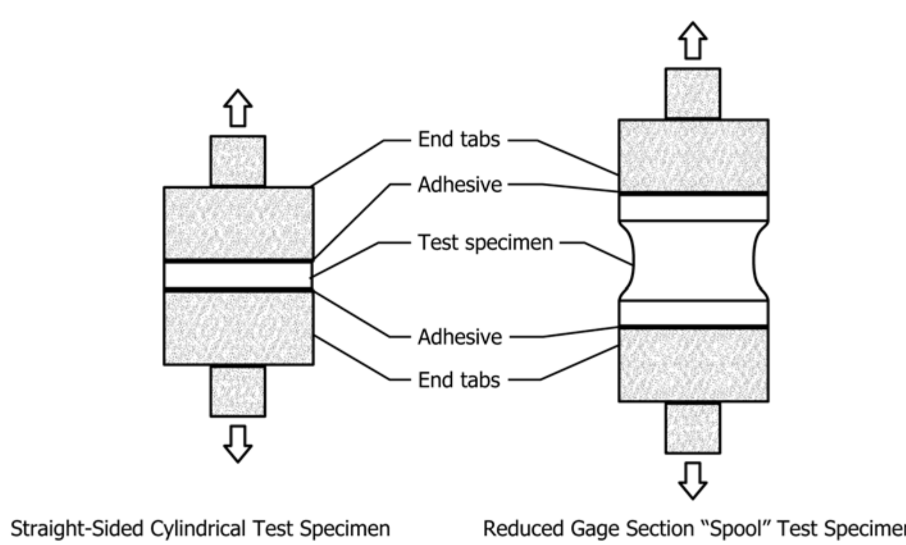

FIG. 1 Flatwise Tension Specimen and End Tab Assembly

testing, specimen alignment, speed of testing, time at temperature, void content, and volume reinforcement content.

6. Interferences

6.1 *Material and Specimen Preparation*—Poor material fabrication practices, lack of control of fiber alignment, voids, and damage induced by improper specimen machining are known causes of high material data scatter in composites in general. In addition, surface finish of the cylindrical machined surface and lack of control of parallelism of laminate surfaces can lead to erroneous through-thickness strength results. Laminate stacking sequences that are not balanced and symmetric could lead to adhesive bondline failures.

6.2 *Material with Coarse Structure*—This test method assumes that the material is relatively homogeneous with respect to the size of the test section. Certain fabric and braided composites with large repeating unit cell sizes (>12 mm [0.5 in.]) should not be tested with this specimen size. It may be possible to scale-up the specimen size and fixtures to accommodate such materials, but this is beyond the scope of this test method.

6.3 *Load Eccentricity*—Bending of the specimen during loading can occur, affecting strength results. Bending may occur due to poor specimen preparation, non-parallel laminate surfaces, improper bonding of the specimen to the end tabs, or machine/load train misalignment.

6.4 *Void Content*—The through-thickness tensile strength measured using this method is extremely sensitive to reinforcement volume and void content. Consequently, the test results may reflect manufacturing quality as much as material properties.

7. Apparatus

7.1 *Micrometers and Calipers*—A micrometer with a 4 to 8 mm [0.16 to 0.32 in.] nominal diameter ball-interface or a flat anvil interface shall be used to measure the specimen thickness. A ball interface is recommended for thickness measurements when at least one surface is irregular (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 length, width, 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 instrument(s) shall be suitable for reading to within 1 % of the specimen dimensions. For typical specimen geometries, an instrument with an accuracy of ±0.0025 mm [±0.0001 in.] is adequate for thickness measurements, while an instrument with an accuracy of ±0.025 mm [±0.001 in.] is adequate for measurement of length, width, other machined surface dimensions.

7.2 *Fixtures*—The apparatus consists of three different fixtures.

7.2.1 The loading fixtures are used to load the specimen and end tab assembly. They can be either self-aligning or fixed grip and shall not apply eccentric loads.

7.2.2 The end tabs are bonded to the specimen (Figs. 2 and 3). The end tabs are attached to the loading fixture during the test. The threads on the end tabs provide a means to attach the specimen and end tab assembly to the loading fixture. They also provide a means to attach constant diameter bushings for the purpose of aligning the specimen and end tab assembly in the bonding fixture. The end tab thickness shall be a minimum

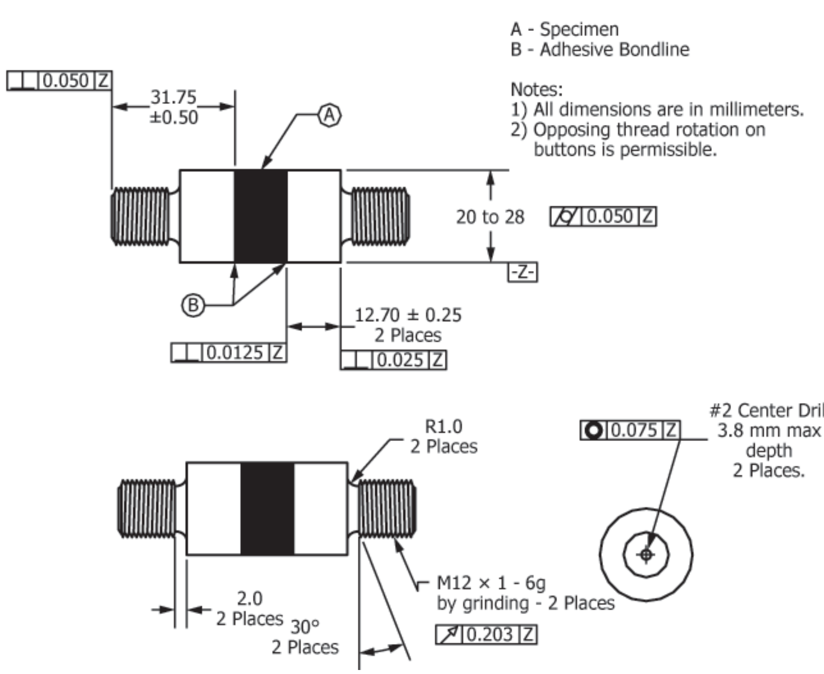

FIG. 2 Drawing of End Tabs and Cylindrical Specimen Assembly (SI units)