



Designation: D 6742/D 6742M – 02

Standard Practice for Filled-Hole Tension and Compression Testing of Polymer Matrix Composite Laminates¹

This standard is issued under the fixed designation D 6742/D 6742M; 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 reappraisal. A superscript epsilon (ε) indicates an editorial change since the last revision or reappraisal.

1. Scope

1.1 This practice provides instructions for modifying open-hole tension and compression test methods to determine filled-hole tensile and compressive strengths. The composite material forms are limited to continuous-fiber reinforced polymer matrix composites in which the laminate is both symmetric and balanced with respect to the test direction. The range of acceptable test laminates and thicknesses are described in 8.2.1.

1.2 This practice supplements Test Methods D 5766/D 5766M (for tension testing) and D 6484/D 6484M (for compression testing) with provisions for testing specimens that contain a close-tolerance fastener or pin installed in the hole. Several important test specimen parameters (for example, fastener selection, fastener installation method, and fastener hole tolerance) are not mandated by this practice; however, repeatable results require that these parameters be specified and reported.

1.3 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.

1.4 *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 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 Displacement²
- D 883 Terminology Relating to Plastics²

¹ This practice is under the jurisdiction of ASTM Committee D30 on Composite Materials, and is the direct responsibility of Subcommittee D30.05 on Structural Test Methods.

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

- D 3171 Test Methods for Constituent Content of Composite Materials³
- D 3878 Terminology for Composite Materials³
- D 5229/D 5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials³
- D 5766/D 5766M Test Method for Open-Hole Tensile Strength of Polymer Matrix Composite Laminates³
- D 6484/D 6484M Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates³
- D 6507 Practice for the Fiber Reinforcement Orientation Codes for Composite Materials³
- E 6 Terminology Relating to Methods of Mechanical Testing⁴
- E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods⁵
- E 456 Terminology Relating to Quality and Statistics⁵
- E 1309 Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases³
- E 1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases³

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 define terms relating to statistics. In the event of a conflict between terms, Terminology D 3878 shall have precedence over the other standards.

3.2 *Definitions of Terms Specific to This Standard:*

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 International 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.

³ *Annual Book of ASTM Standards*, Vol 15.03.

⁴ *Annual Book of ASTM Standards*, Vol 03.01.

⁵ *Annual Book of ASTM Standards*, Vol 14.02.

3.2.1 *nominal value, n*—a value, existing in name only, assigned to a measurable property for the purpose of convenient designation. Tolerances may be applied to a nominal value to define an acceptable range for the property.

3.2.2 *countersink flushness, n*—depth or protrusion of countersunk fastener head relative to the laminate surface after installation. A positive value indicates protrusion of the fastener head above the laminate surface; a negative value indicates depth below the surface.

3.2.3 *countersink depth, n*—depth of countersinking required to properly install a countersunk fastener, such that countersink flushness is nominally zero. Countersink depth is nominally equivalent to the height of the fastener head.

3.3 Symbols:

3.3.1 A = cross-sectional area of a specimen.

3.3.2 d = fastener diameter.

3.3.3 D = specimen hole diameter.

3.3.4 d_{csk} = countersink depth.

3.3.5 d_{μ} = countersink flushness.

3.3.6 f = distance, perpendicular to loading axis, from hole edge to closest side of specimen.

3.3.7 F_x^{fhu} = ultimate filled-hole compressive strength in the test direction.

3.3.8 F_x^{fhu} = ultimate filled-hole tensile strength in the test direction.

3.3.9 g = distance, parallel to loading axis, from hole edge to end of specimen.

3.3.10 h = specimen thickness.

3.3.11 P^{max} = maximum load prior to failure.

3.3.12 w = specimen width.

4. Summary of Practice

4.1 *Filled-Hole Tensile Strength*—In accordance with Test Method D 5766/D 5766M, but with a close-tolerance fastener or pin installed in the hole, perform a uniaxial tension test of a balanced, symmetric laminate with a centrally located hole.

4.2 *Filled-Hole Compressive Strength*—In accordance with Test Method D 6484/D 6484M, but with a close-tolerance fastener or pin installed in the hole, perform a uniaxial compression test of a balanced, symmetric laminate with a centrally located hole.

NOTE 2—For both test methods, ultimate strength is calculated based on the gross cross-sectional area, disregarding the presence of the filled hole. While the filled hole causes a stress concentration and reduced net section, it is common aerospace practice to develop notched design allowable strengths based on gross section stress to account for various stress concentrations (fastener holes, free edges, flaws, damage, and so forth) not explicitly modeled in the stress analysis.

5. Significance and Use

5.1 This practice provides supplemental instructions that allow Test Methods D 5766/D 5766M (for tension testing) and D 6484/D 6484M (for compression testing) to determine filled-hole tensile and compressive strength data for material specifications, research and development, material design allowables, and quality assurance. Factors that influence filled-hole tensile and compressive strengths and shall therefore be reported include the following: material, methods of material fabrication, accuracy of lay-up, laminate stacking sequence and

overall thickness, specimen geometry, specimen preparation (especially of the hole), fastener-hole clearance, fastener type, fastener geometry, fastener installation method, fastener torque (if appropriate), countersink depth (if appropriate), specimen conditioning, environment of testing, specimen alignment and gripping, speed of testing, void content, and volume percent reinforcement. Properties that result include the following:

5.1.1 Filled-hole tensile (FHT) strength, F_x^{fht} .

5.1.2 Filled-hole compressive (FHC) strength, F_x^{fhu} .

6. Interferences

6.1 *Fastener-Hole Clearance*—Compression test results, in particular, are affected by the clearance arising from the difference between hole and fastener diameters. A 25- μm [0.001-in.] change in clearance can change the observed failure mode and affect strength results by as much as 25 % (1).⁶ For this reason, both the hole and fastener diameters must be accurately measured and recorded. A typical aerospace tolerance on fastener-hole clearance is +75/−0 μm [+0.003/−0.000 in.] for structural fastener holes. Filled-hole specimen behavior is also affected by clearance under tensile loading, but to a lesser degree than under compressive loads (2-3). Damage caused by insufficient clearance during fastener installation will affect strength results. Countersink flushness (depth or protrusion of the fastener head in a countersunk hole) will affect strength results, and must be accurately measured and recorded.

6.2 *Fastener Torque/Preload*—Results are affected by the installed fastener preload (clamping pressure). Laminates can exhibit significant differences in both failure load and failure mode because of changes in fastener preload under both tensile and compressive loading. The critical preload condition (either high or low clamping pressure) can vary depending upon the type of loading, the material system, laminate stacking sequence, and test environment (3-5). Compared to open-hole tensile (OHT) strengths, filled-hole tensile (FHT) strengths can be either higher or lower than corresponding OHT values, depending on the material system, stacking sequence, test environment, and amount of fastener torque (6). Notched tensile strengths can be high torque critical for some layups and low torque (or open hole) critical for others, depending upon the characteristics of the material system (resin brittleness, fiber strain to failure, and so forth), the test environment, and the modes of failure that arise. Filled-hole compressive (FHC) strengths are almost always higher than the corresponding open-hole compressive (OHC) strengths, although high versus low clamp-up criticality can vary depending upon the material system, stacking sequence, and test environment (5).

6.3 *Fastener Type/Hole Preparation*—Results are affected by the geometry and type of fastener used (for example, lockbolt, blind bolt) and the fastener installation procedures. Results are also affected by the hole preparation procedures.

6.4 *Environment*—Results are affected by the environmental conditions under which the tests are conducted. Laminates

⁶ Boldface numbers in parentheses refer to the list of references at the end of this practice.

tested in various environments can exhibit significant differences in both failure load and failure mode. Experience has demonstrated that cold temperature environments are generally critical for filled-hole tensile strength, while elevated temperature, humid environments are generally critical for filled-hole compressive strength. However, critical environments must be assessed independently for each material system, stacking sequence, and torque condition tested.

6.5 Specimen Geometry—In addition to the geometrical interferences documented in Test Methods D 5766/D 5766M and D 6484/D 6484M, results may be affected by the ratio of countersunk (flush) head depth to thickness; the preferred ratio is the range of 0.0 to 0.7 unless the experiment is investigating the influence of this ratio. Results may also be affected by the ratio of specimen width to fastener diameter, which may vary from the preferred ratio of 6 depending upon the particular fastener and hole diameters used. Results may also be affected if the hole is not centered by length or width.

6.6 Material Orthotropy—The degree of laminate orthotropy strongly affects the failure mode and measured FHT and FHC strengths. Valid FHT and FHC strength results should only be reported when appropriate failure modes are observed, according to 11.5.

6.7 Other—Additional sources of potential data scatter are documented in Test Method D 5766/D 5766M for tension tests and in Test Method D 6484/D 6484 for compression tests.

7. Apparatus

7.1 General Apparatus—General apparatus shall be in accordance with Test Methods D 5766/D 5766M (for tension tests) and D 6484/D 6484M (for compression tests), although with a fastener or pin installed in the specimen hole. The micrometer or gage used shall be capable of determining the hole and fastener diameters to $\pm 8 \mu\text{m}$ [± 0.0003 in.].

7.2 Fastener—The fastener or pin type shall be specified as an initial test parameter and reported. The nominal fastener diameter shall be 6 mm [0.25 in.], unless a range of diameters is being investigated. Some fastener types (for example blind bolts) may not be available in this diameter; for these, it is recommended to use a fastener for which the diameter is as close as possible to 6 mm [0.25 in.]. The installation torque (if applicable) shall be specified as an initial test parameter and reported. This value may be a measured torque or a specification torque for fasteners with lock-setting features. If washers are used, the washer type, number of washers, and washer location(s) shall be specified as initial test parameters and reported. Reuse of fasteners is not recommended because of potential differences in through-thickness clamp-up for a given torque level, caused by wear of the threads.

7.3 Torque Wrench—If using a torqued fastener, the torque wrench used to tighten the fastener shall be capable of determining the applied torque to within $\pm 10\%$ of the desired value.

8. Sampling and Test Specimens

8.1 Sampling—For tension tests, sampling shall be in accordance with Test Method D 5766/D 5766M. For compression tests, sampling shall be in accordance with Test Method D 6484/D 6484M.

8.2 Geometry:

8.2.1 Stacking Sequence—The standard tape and fabric laminates shall have multidirectional fiber orientations (fibers shall be oriented in a minimum of two directions) and balanced and symmetric stacking sequences. For tension specimens, nominal thickness shall be 2.5 mm [0.10 in.], with a permissible range of 2 to 4 mm [0.080 to 0.160 in.], inclusive. For compression specimens, nominal thickness shall be 4 mm [0.160 in.], with a permissible range of 3 to 5 mm [0.125 to 0.200 in.], inclusive. Fabric laminates containing satin-type weaves shall have symmetric warp surfaces, unless otherwise specified and noted in the report.

NOTE 3—Typically, a $[45_i/-45_j/0_k]_{ns}$ tape or $[45_i/0_j]_{ns}$ fabric laminate should be selected such that a minimum of 5% of the fibers lay in each of the four principal orientations. This laminate design has been found to yield the highest likelihood of acceptable failure modes. Consult Practice D 6507 for information on fiber orientation codes.

8.2.2 Specimen Configuration—For tension tests, the test specimen configuration shall be in accordance with Test Method D 5766/D 5766M. For compression tests, the test specimen configuration shall be in accordance with Test Method D 6484/D 6484M. The nominal hole diameter may vary from that specified in Test Methods D 5766/D 5766M and D 6484/D 6484M depending upon the type of fastener used.

8.3 Specimen Preparation—For tension tests, specimens shall be prepared in accordance with Test Method D 5766/D 5766M. For compression tests, specimens shall be prepared in accordance with Test Method D 6484/D 6484M. Use appropriate hole preparation procedures specified by the test requestor.

9. Calibration

9.1 The accuracy of all measuring equipment shall have certified calibrations that are current at the time of use of the equipment.

10. Conditioning

10.1 *Standard Conditioning Procedure*—Unless a different environment is specified as part of the experiment, the test specimens shall be conditioned in accordance with Procedure C of Test Method D 5229/D 5229M, and stored and tested at standard laboratory atmosphere ($23 \pm 3^\circ\text{C}$ [$73 \pm 5^\circ\text{F}$] and $50 \pm 10\%$ relative humidity).

11. Procedure

11.1 Parameters to Be Specified Before Test:

11.1.1 The specimen sampling method, specimen type and geometry, fastener type and material, countersink angle and depth (if appropriate), fastener torque (if appropriate), use of washers (if appropriate), cleaning process, and conditioning travelers (if required).

11.1.2 All other parameters documented in Test Method D 5766/D 5766M for tension tests and Test Method D 6484/D 6484M for compression tests.

11.2 General Instructions:

11.2.1 Any deviations from these procedures, whether intentional or inadvertent, shall be reported.

11.2.2 If specific gravity, density, reinforcement volume, or void volume are to be reported, then obtain these samples from