Designation: D6742/D6742M – 17

Standard Practice for
Filled-Hole Tension and Compression Testing of Polymer Matrix Composite Laminates[1]

This standard is issued under the fixed designation D6742/D6742M; 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 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 D5766/D5766M (for tension testing) and D6484/D6484M (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. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

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, 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:*[2]

D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
D883 Terminology Relating to 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
D5766/D5766M Test Method for Open-Hole Tensile Strength of Polymer Matrix Composite Laminates
D6484/D6484M Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates
D6507 Practice for Fiber Reinforcement Orientation Codes for Composite Materials
E6 Terminology Relating to Methods of Mechanical Testing
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E456 Terminology Relating to Quality and Statistics

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 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

[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.

Current edition approved Oct. 15, 2017. Published October 2017. Originally approved in 2001. Last previous edition approved in 2012 as D6742/D6742M – 12. DOI: 10.1520/D6742_D6742M-17.

[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.

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.

3.2.1 *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:*

A = cross-sectional area of a specimen

d = fastener diameter

D = specimen hole diameter

d_{csk} = countersink depth

d_{fl} = countersink flushness

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

F_x^{fhcu} = ultimate filled-hole compressive strength in the test direction

F_x^{fhtu} = ultimate filled-hole tensile strength in the test direction

g_1 = distance, parallel to loading axis, from hole edge to end of specimen

h = specimen thickness

P^{max} = maximum force carried by test specimen prior to failure

w = specimen width

4. Summary of Practice

4.1 *Filled-Hole Tensile Strength*—In accordance with Test Method D5766/D5766M, 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 D6484/D6484M, 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 D5766/D5766M (for tension testing) and D6484/D6484M (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 (including hole diameter, diameter-to-thickness ratio, and width-to-diameter ratio), 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, time at temperature, void content, and volume percent reinforcement. Properties that result include the following:

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

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

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**).[3] 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 forces(**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 force 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

[3] Boldface numbers in parentheses refer to the list of references at the end of this practice.

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 tested in various environments can exhibit significant differences in both failure force 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 D5766/D5766M and D6484/D6484M, 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 11.6.

6.7 *Other*—Additional sources of potential data scatter are documented in Test Method D5766/D5766M for tension tests and in Test Method D6484/D6484M for compression tests.

7. Apparatus

7.1 *General Apparatus*—General apparatus shall be in accordance with Test Methods D5766/D5766M (for tension tests) and D6484/D6484M (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 ±8 µm [±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 ±10 % of the desired value.

8. Sampling and Test Specimens

8.1 *Sampling*—For tension tests, sampling shall be in accordance with Test Method D5766/D5766M. For compression tests, sampling shall be in accordance with Test Method D6484/D6484M.

8.2 *Geometry:*

8.2.1 *Stacking Sequence*—The standard 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 $[45_i/–45_i/0_j/90_k]_{ns}$ 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 D6507 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 D5766/D5766M. For compression tests, the test specimen configuration shall be in accordance with Test Method D6484/D6484M. The nominal hole diameter may vary from that specified in Test Methods D5766/D5766M and D6484/D6484M depending upon the type of fastener used.

8.3 *Specimen Preparation*—For tension tests, specimens shall be prepared in accordance with Test Method D5766/D5766M. For compression tests, specimens shall be prepared in accordance with Test Method D6484/D6484M. Use appropriate hole preparation procedures specified by the test requestor.

8.4 If specific gravity, density, reinforcement volume, or void volume are to be reported, then obtain these samples from the same panels being tested. Specific gravity and density may be evaluated by means of Test Method D792. Volume percent of the constituents may be evaluated by one of the matrix digestion procedures of Test Method D3171, or, for certain reinforcement materials such as glass and ceramics, by the matrix burn-off technique of Test Method D3171.

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 The recommended pre-test condition is effective moisture equilibrium at a specific relative humidity as established by Test Method D5229/D5229M; however, if the test requestor does not explicitly specify a pre-test conditioning environment, no conditioning is required and the test specimens may be tested as prepared.

10.2 The pre-test specimen conditioning process, to include specified environmental exposure levels and resulting moisture content, shall be reported with the test data.

NOTE 4—The term moisture, as used in Test Method D5229/D5229M, includes not only the vapor of a liquid and its condensate, but the liquid itself in large quantities, as for immersion.

10.3 If no explicit conditioning process is performed the specimen conditioning process shall be reported as "unconditioned" and the moisture content as "unknown."

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 D5766/D5766M for tension tests and Test Method D6484/D6484M 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 Following final specimen preparation, but before conditioning and testing, measure the specimen width, and the specimen thickness, at three places in the gage section in the vicinity of the hole. Report the averages of the thickness, h, and width, w, and use the average values as measured dimensions in subsequent calculations for ultimate strength and geometric ratios. The hole diameter, D, the fastener diameter, d, the countersink depth d_{csk} (if appropriate), the countersink flushness, d_{fl} (if appropriate), distance from hole edge to closest specimen side, f, and distance from hole edge to specimen end, g, shall also be measured. The accuracy of all measurements shall be within 1 % of the dimension, unless otherwise specified in this practice. Dimensions shall be recorded to three significant figures in units of millimetres [inches].

NOTE 5—The test requester may request that additional measurements be performed after the machined specimens have gone through any conditioning or environmental exposure.

11.2.3 *Cleaning*—The specimen hole, surrounding clamping area, and fastener shank shall be cleaned. If the fastener threads are required to be lubricated, the lubricant shall be applied to the nut threads instead of the fastener threads. Extreme care shall be taken not to accidentally transfer any of the lubricant to the fastener shank, the specimen hole, or to the clamping area during assembly and torquing. The cleaning method and lubricant used (if any) shall be recorded and reported.

11.2.4 *Specimen Assembly*—Assemble test specimen with fastener or pin (and washers if used), in accordance with the fastener installation procedures specified by the test requestor.

11.2.5 *Fastener Torquing*—If using a torqued fastener, the fastener shall be tightened to the required value using a calibrated torque wrench. The actual torque value shall be recorded and reported.

11.3 Condition the specimens as required. Specimens shall be stored in the conditioned environment until test time, if the test environment is different than the conditioning environment.

NOTE 6—The test requester may request that the hole be cleaned and the fastener installed after the specimens have gone through any conditioning or environmental exposure. Conditioning the specimen with the fastener installed is representative of the in-service environmental exposure of structural parts, but the additional weight may complicate the determination of the composite equilibrium moisture content. In such circumstances, the use of conditioning traveler specimens without fasteners is recommended for weight measurement.

11.4 *Test Procedure:*

NOTE 7—When testing a conditioned specimen at elevated temperature with no fluid exposure control, the percentage moisture loss of the specimen prior to test completion may be estimated by placing a conditioned traveler coupon of known weight within the test chamber at the same time the specimen is placed in the chamber. Upon completion of the test, the traveler coupon is removed from the chamber, weighed, and the percentage weight calculated and reported.

11.4.1 *Tension Test Method*—The tension test of the laminate specimen shall be performed in accordance with Test Method D5766/D5766M.

11.4.2 *Compression Test Method*—The compression test of the laminate specimen shall be performed in accordance with Test Method D6484/D6484M.

11.5 *Data Recording*—Record force versus crosshead displacement (and force versus strain, if extensometers are utilized) continuously, or at frequent regular intervals; for this test

TABLE 1 Three-Place Failure Mode Codes

First Character		Second Character		Third Character	
Failure Type	Code	Failure Area	Code	Failure Location	Code
Angled	A	inside grip/tab	I	bottom	B
Edge delamination	D	at grip/tab	A	top	T
Grip/tab	G	<1 *w* from grip/tab	W	left	L
Lateral	L	gage	G	right	R
Multimode	M(xyz)	multiple areas	M	middle, center of hole	M
Long, splitting	S	various	V	offset from center of hole	O
Explosive	X	unknown	U	offset of fastener edge	F
Other	O			various	V
				unknown	U