Designation: D 6742/D 6742M – 0~~1~~2

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

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 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 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:*

[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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D 792 Test Methods for Density and Specific Gravity (Relative Density) and Density of Plastics by Displacement[2]
D 883 Terminology Relating to Plastics[2]
D 3171 Test Methods for Constituent Content of Composite Materials[3]
D 3878 Terminology for Composite Materials[3]
D 5229/D 5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials[3]
D 5766/D 5766M Test Method for Open-Hole Tensile Strength of Polymer Matrix Composite Laminates[3]
D 6484/D 6484M Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates[3]
D 6507 Practice for the Fiber Reinforcement Orientation Codes for Composite Materials[3]
E 6 Terminology Relating to Methods of Mechanical Testing[4]
E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[5]
E 456 Terminology Relating to Quality and Statistics[5]
E 1309 Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases[3]
E 1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases[3]

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.

3.2.1 *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_{fl}= countersink flushness.

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

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

3.3.8 F_x^{fhtu}= 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.

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

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^{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)**.[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 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 ~~evaluated~~ 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 ~~coupon~~ 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

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

[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 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 $[45_i/-45_i/0_j/90_k]_{ns}$ 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 D 6507 for information on fiber orientation codes.

8.2.2 *Specimen Configuration*—For tension tests, the test ~~coupon~~ specimen configuration shall be in accordance with Test Method D 5766/D 5766M. For compression tests, the test ~~coupon~~ 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 ± 3°C [73 ± 5°F] and 50 ± 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 the same panels being tested. Specific gravity and density may be evaluated by means of Test Method D 792. Volume percent of the constituents may be evaluated by one of the matrix digestion procedures of Test Method D 3171, or, for certain reinforcement materials such as glass and ceramics, by the matrix burn-off technique of Test Method D 3171.

11.2.3 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.

11.2.4 Following final specimen preparation and any conditioning, but before testing, the specimen width, w, and the specimen thickness, h, in the vicinity of the hole shall be measured. 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].

11.2.5 *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.

11.2.6 *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.

11.3 *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.

11.4 *Test Procedure*:

11.4.1 *Tension Test Method*—The tension test of the laminate specimen shall be performed in accordance with Test Method D 5766/D 5766M.

11.4.2 *Compression Test Method*—The compression test of the laminate specimen shall be performed in accordance with Test Method D 6484/D 6484M.

11.5 *Failure Modes*—Failures that do not occur at or near the fastener hole are not acceptable failure modes and the data shall be noted as invalid. The failure is often heavily influenced by delamination and the failure mode may exhibit much delamination. Three-place failure mode descriptors, summarized in Table 1, shall be used. This notation uses the first place to describe failure type, the second to describe failure area, and the last to describe failure location. Fig. 1 illustrates acceptable failure modes for tension tests. Fig. 2 and Fig. 3 illustrate acceptable failure modes for compression tests. The mode of failure may be found to vary on different sides of the hole.

12. Validation

12.1 Values for ultimate properties shall not be calculated for any specimen that breaks at some obvious flaw, unless such flaw constitutes a variable being studied. Retests shall be performed for any specimen on which values are not calculated.

12.2 A significant fraction of failures in a sample population occurring away from the center hole shall be cause to reexamine the means of load introduction into the material. Factors considered should include the fixture alignment, grip pressure, grip alignment, separation of fixture halves, specimen thickness taper, and uneven machining of specimen ends.

13. Calculation

13.1 *Ultimate Strength*:

13.1.1 *Tension Test Method*—The ultimate filled hole tensile strength shall be calculated using Eq 1, and the results reported to three significant figures. Both the nominal strength calculated using nominal values and the actual strength calculated with measured dimensions shall be reported.

$$F_x^{fhtu} = P^{max}/A \quad (1)$$

where:

F_x^{fhtu} = ultimate filled hole tensile strength, MPa [psi];
P^{max} = maximum load before failure, N [lbf]; and
A = gross cross-sectional area (disregarding hole) = $h \times w$, mm^2 [in^2].

NOTE 4—The hole diameter is ignored in the tensile strength calculations; the gross cross-sectional area is used.

13.1.2 *Compression Test Method*—The ultimate filled hole compressive strength shall be calculated using Eq 2, and the results reported to three significant figures. Both the nominal strength calculated using nominal values and the actual strength calculated with measured dimensions shall be reported.

$$F_x^{fhcu} = P^{max}/A \quad (2)$$

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

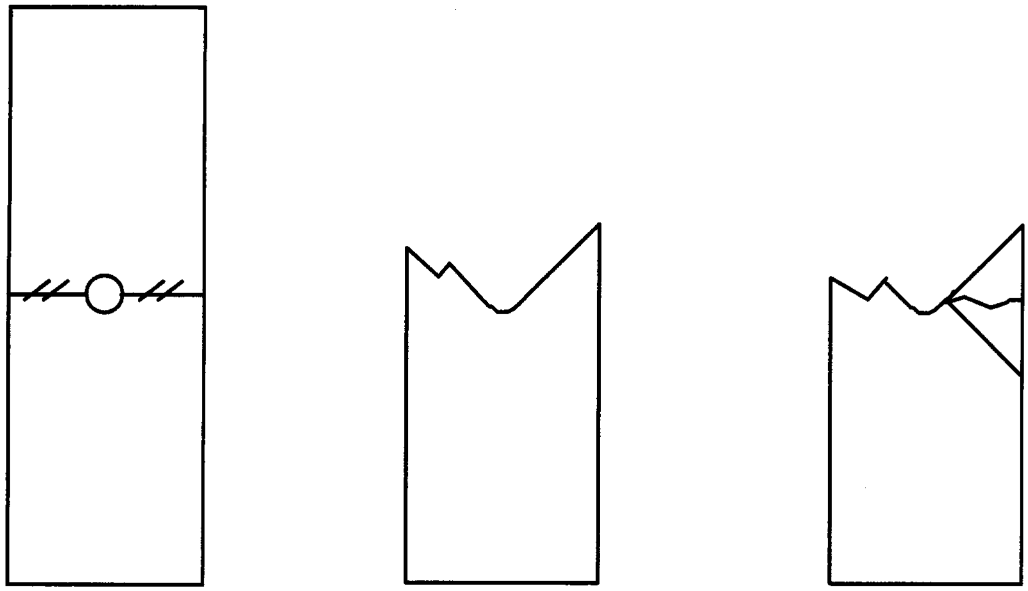


FIG. 1 Acceptable Filled-Hole Tensile Failure Modes

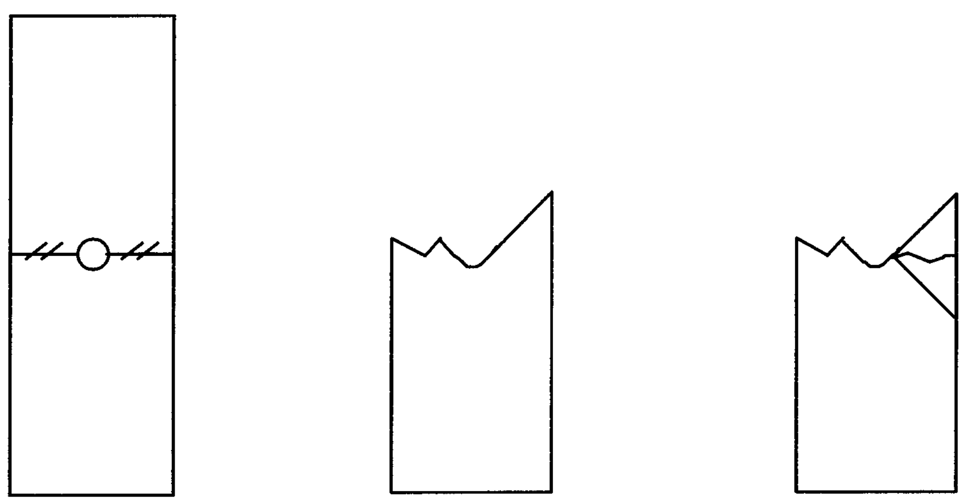
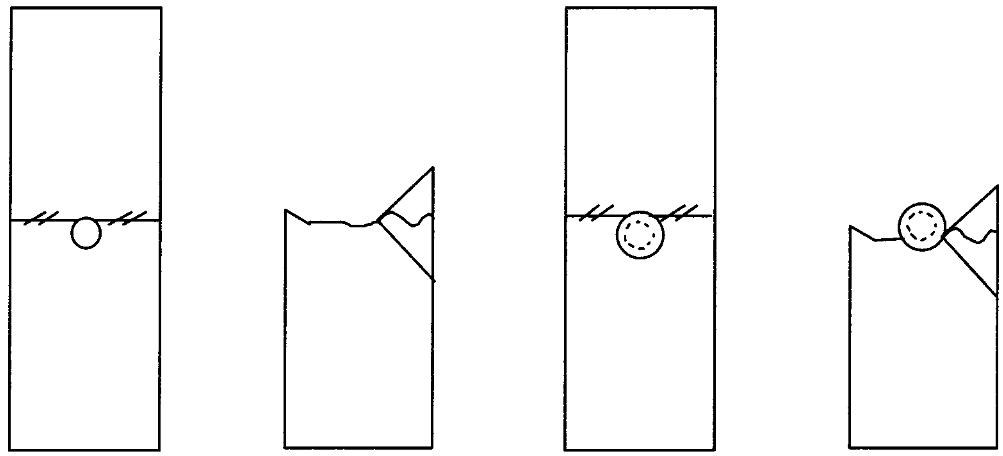


FIG. 2 Acceptable Filled-Hole Compressive Failure Modes Near Center of Hole

where:

F_x^{fhcu} = ultimate filled hole compressive strength, MPa [psi];
P^{max} = maximum load before failure, N [lbf]; and
A = gross cross-sectional area (disregarding hole) = $h \times w$, mm^2 [in^2].



LGO — Laminate compressive failure laterally across the specimen at the fastener hole, but offset from the center of the hole (bearing or surface failure local to hole, followed by 0-degree ply dominated kinking/buckling). Splits and delaminations may be present.

MGO — Laminate fails in compression offset from the center of the hole and exhibits multiple modes of failure in various sublaminates. Extensive splitting and delamination present.

LGF — Laminate compressive failure laterally across the specimen offset from the hole, at the fastener, nut or washer edge (surface failure, followed by 0-degree ply dominated kinking/buckling). Splits and delaminations may be present.

MGF — Laminate fails in compression at the fastener, nut or washer edge and exhibits multiple modes of failure in various sublaminates. Extensive splitting and delamination present.

FIG. 3 Acceptable Filled-Hole Compressive Failure Modes Offset From Center of Hole

NOTE 5—The hole diameter is ignored in the compressive strength calculations; the gross cross-sectional area is used.

13.2 *Width-to-Diameter Ratio*—Calculate the width-to-diameter ratio of the laminate specimen in accordance with Test Methods D 5766/D 5766M (for tension tests) and D 6484/D 6484M (for tension tests). Both the nominal ratio calculated using nominal values and the actual ratio calculated with measured dimensions shall be reported.

13.3 *Diameter-to-Thickness Ratio*—Calculate the diameter-to-thickness ratio of the laminate specimen in accordance with Test Method D 6484/D 6484M. Both the nominal ratio calculated using nominal values and the actual ratio calculated with measured dimensions shall be reported.

13.4 *Countersink-Depth-to-Thickness Ratio*—If a countersunk (flush) fastener is installed in the hole, calculate the countersink-depth-to-thickness ratio as shown in Eq 3. Both the nominal ratio calculated using nominal values and the actual ratio calculated with measured dimensions shall be reported.

$$d_{csk}/h \text{ ratio} = \frac{d_{csk}}{h} \quad (3)$$

where:

d_{csk} = fastener countersink depth, mm [in.] and

h = specimen thickness near hole, mm [in.].

13.5 *Percent Bending*—If two edge-mounted extensometers are used in compression testing, edgewise percent bending shall be calculated in accordance with Test Method D 6484/D 6484M.

13.6 *Statistics*—For each series of tests, the average value, standard deviation, and coefficient of variation (in percent) for each property determined (for both nominal and actual properties if applicable) shall be calculated. Use the methods documented in Test Methods D 5766/D 5766M (for tension tests) and D 6484/D 6484M (for compression tests).

14. Report

14.1 The report shall include all appropriate parameters in accordance with Test Method D 5766/D 5766M for tension tests and Test Method D 6484/D 6484M for compression tests, making use of Guides E 1309 and E 1434.

14.2 In addition, the report shall include the following information, or references pointing to other documentation containing this information, to the maximum extent applicable (reporting of items beyond the control of a given testing laboratory, such as might occur with material details or panel fabrication parameters, shall be the responsibility of the requestor):

14.2.1 The revision level or date of issue of this practice.

14.2.2 Any variations to these test methods, anomalies noticed during testing, or equipment problems occurring during testing.

14.2.3 Location of fastener head (bag side or tool side, if appropriate), washer type and material (if appropriate), number of washers (if appropriate), washer location (if appropriate), cleaning process, and lubricant (if appropriate).

14.2.4 Measured hole and fastener diameters.

14.2.5 Hole preparation and fastener installation specifications, including torque if appropriate (results will be specific to the type of fastener used and the method of installation).

14.2.6 If a countersunk (flush) head fastener is installed in the hole, countersink angle, measured countersink depth, countersink flushness, nominal countersink-depth-to-thickness ratio, and actual countersink-depth-to-thickness ratio for each specimen.

15. Precision and Bias

15.1 *Precision*—The data required for the development of a precision statement is not available for these methods.

15.2 *Bias*—Bias cannot be determined for these methods as no acceptable reference standards exist.

16. Keywords

16.1 bolted joints; composite materials; compression testing; fastener; filled-hole compressive strength; filled-hole tensile strength; tension testing

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