Designation: D 5766/D 5766M – 95

Standard Test Method for Open Hole Tensile Strength of Polymer Matrix Composite Laminates[1]

This standard is issued under the fixed designation D 5766/D 5766M; 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 open hole tensile strength of polymer matrix composite laminates reinforced by high-modulus fibers. The composite material forms are limited to continuous-fiber or discontinuous-fiber reinforced composites in which the laminate is balanced and symmetric with respect to the test direction. The standard test laminate is of the [45/0/−45/90]*ns* stacking sequence family, where the sublaminate repeat index *n* is adjusted to yield a laminate thickness within the range discussed in 8.2.1. Other laminates may be tested provided the laminate configuration is reported with the results, however, the test method is unsatisfactory for unidirectional tape laminates containing only one ply orientation.

1.2 *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.*

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.

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 3039/D 3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials[4]

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

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

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

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

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 1309 Guide for Identification of Composite Materials in Computerized Material Property Databases[4]

E 1434 Guide for Development of Standard Data Records for Computerization of Mechanical Test Data for High-Modulus Fiber-Reinforced Composite Materials[4]

E 1471 Guide for Identification of Fibers, Fillers and Core Materials in Computerized Material Property Databases[4]

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 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.

3.2.1 *balanced laminate, n*—laminate in which all laminae at angles other than 0 degrees or 90 degrees occur only in ± pairs, though each ply of a pair is not required to be located adjacent to the other.

3.2.2 *nominal value, n*—a value, existing in name only,

[1] This test method is under the jurisdiction of ASTM Committee D-30 on High Modulus Fibers and Their Compositesand is the direct responsibility of Subcommittee D30.05on Structural 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.

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.

3.2.3 *ply orientation*, θ, *n*—the angle between a reference direction and the ply principal axis. The angle is expressed in degrees, is never greater than 90°, and is shown as a positive quantity when taken from the reference direction to the ply principal axis, following the right-hand-rule.

3.2.3.1 *Discussion*—The reference direction is usually related to a primary load-carrying direction.

3.2.4 *ply principal axis*, *n*—the coordinate axis in the plane of a lamina that is used as the reference direction for that lamina.

3.2.4.1 *Discussion*—The ply principal axis will, in general, be different for each ply of a laminate. The direction of this axis relative to some reference axis is defined by the ply orientation. The convention is to align the ply principal axis with a material feature that is the direction of maximum stiffness (such as the fiber direction for unidirectional tape or the warp direction for fabric reinforced material). Conventions for other laminated material forms have not yet been established.

3.2.5 *symmetric laminate, n*—is one in which the orientation, form, and material (and warp surface, for satin-type fabrics) for the plies located on one side of the midplane is the mirror image of the stacking sequence on the other side of the midplane.

3.2.6 *warp surface, n*—the side of a woven fabric, in a satin-type weave pattern, which is dominated by the warp yarns.

3.3 *Symbols:*

3.3.1 A—cross-sectional area of a coupon.

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

3.3.3 D—hole diameter.

3.3.4 h—coupon thickness.

3.3.5 n—number of coupons per sample population.

3.3.6 N—number of plies in laminate under test.

3.3.7 F_x^{OHTu}—ultimate tensile strength in the test direction.

3.3.8 P^{max}—maximum load carried by test coupon prior to failure.

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

3.3.10 w—coupon width.

3.3.11 x_i—test result for an individual coupon from the sample population for a given property.

3.3.12 $\bar{x}$—mean or average (estimate of mean) of a sample population for a given property.

3.3.13 σ—normal stress.

4. Summary of Test Method

4.1 A uniaxial tension test of a balanced, symmetric laminate is performed in accordance with Test Method D 3039/D 3039M, although with a centrally located hole and without strain or displacement transducers. Ultimate strength is calculated based on the gross cross-sectional area, disregarding the presence of the hole.

5. Significance and Use

5.1 This test method is designed to produce notched tensile strength data for material specifications, research and development, and quality assurance. Factors that influence the notched tensile strength and should 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), specimen conditioning, environment of testing, specimen alignment and gripping, speed of testing, void content, and volume percent reinforcement. Properties that may be derived from this test method include the following:

5.1.1 Open hole (notched) tensile strength.

6. Interferences

6.1 *Hole Preparation*—Due to the dominating presence of the notch, and the lack of need to measure the material response, results from this test method are relatively insensitive to parameters that would be of concern in an unnotched tensile property test. However, since the notch dominates the strength, consistent preparation of the hole, without damage to the laminate, is important to meaningful results. Damage due to hole preparation will affect strength results. Some types of damage, such as delaminations, can blunt the stress concentration because of the hole, increasing the load-carrying capacity of the coupon and the calculated strength.

6.2 *Geometry*—Results are affected by the ratio of specimen width to hole diameter; this ratio should be maintained at 6, unless the experiment is investigating the influence of this ratio. Results may also be affected by the ratio of hole diameter to thickness; the preferred ratio is the range of 1.5–3.0 unless the experiment is investigating the influence of this ratio.

6.3 *Other*—Additional sources of potential data scatter in testing of composite materials are described in Test Method D 3039/D 3039M.

7. Apparatus

7.1 Apparatus shall be in accordance with Test Method D 3039/D 3039M. However, the procedure herein does not measure material response, so strain or deflection measurement related discussions in Test Method D 3039/D 3039M do not apply. Additionally, a micrometer or gage capable of determining the hole diameter to ±0.025 mm [±0.001 in.] is required.

8. Sampling and Test Specimens

8.1 *Sampling*—Sampling shall be in accordance with Test Method D 3039/D 3039M.

8.2 *Geometry*—The coupon geometry shall be in accordance with Test Method D 3039/D 3039M, as modified by the following, and illustrated by the schematic of Fig. 1. Any variation of the stacking sequence, specimen width or length, or hole diameter from that specified shall be clearly noted in the report.

8.2.1 *Stacking Sequence*—The normal laminate shall have a balanced and symmetric stacking sequence of [45/0/−45/90]*ns*, where *n* is selected to keep the laminate thickness as close as possible to 2.5 mm [0.10 in.], with a permissible range of 2–4 mm [0.080–0.160 in.], inclusive. Laminates containing satin-type weaves shall have symmetric warp surfaces, unless otherwise noted in the report.

8.2.2 *Dimensions*—The width of the specimen is 36 ± 1

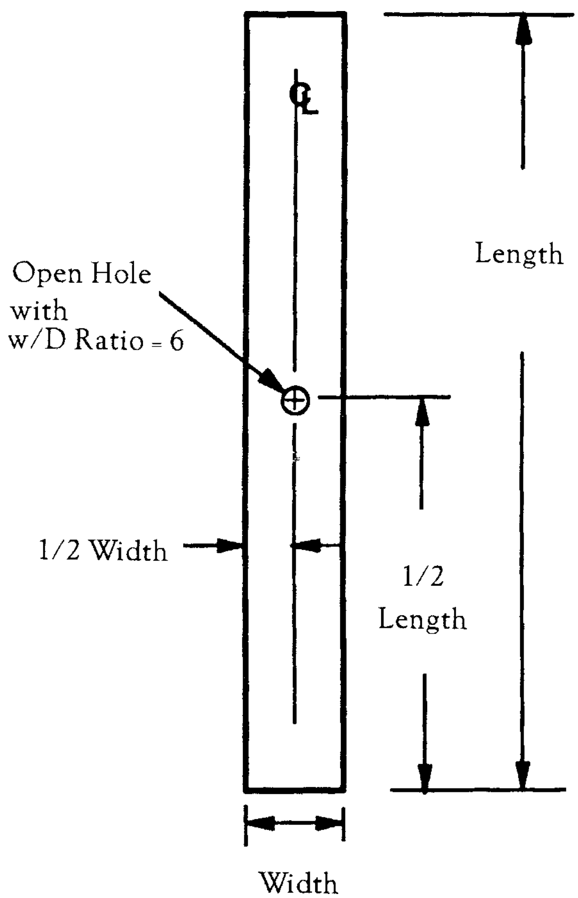


FIG. 1 Schematic of Open Hole Tension Test Coupon

mm [1.50 ± 0.05 in.] and the length range is 200–300 mm [8.0–12.0 in.]. The notch consists of a centrally located hole, 6± 0.06 mm [0.250 ± 0.003 in.] diameter, placed within 0.1 mm [0.005 in.] of the axial centerline of the coupon. While tabs may be used, they are not required and generally not needed, since the open hole acts as sufficient stress riser to force failure in the notched region.

8.3 *Specimen Preparation*—Care must be taken in preparation of the hole so as not to delaminate the material. The most common successful hole preparation technique begins by drilling an undersized hole, with backup plates on both surfaces and coolant; and finishes by reaming to the final desired hole diameter. The finished hole shall be clean and smooth with sharp unbeveled edges, but not polished. The specimen shall not have any delamination damage. Other specimen preparation techniques and requirements are noted in Test Method D 3039/D 3039M.

9. Calibration

9.1 Calibration shall be in accordance with Test Method D 3039/D 3039M.

10. Conditioning

10.1 Conditioning shall be in accordance with Test Method D 3039/D 3039M.

11. Procedure

11.1 *Parameters To Be Specified Prior to Test*:

11.1.1 The tension specimen sampling method, coupon type and geometry, and conditioning travelers (if required).

11.1.2 The tensile properties and data reporting format desired.

NOTE 2—Determine specific material property, accuracy, and data reporting requirements prior to test for proper selection of instrumentation and data recording equipment. Estimate the coupon strength to aid in transducer selection, calibration of equipment, and determination of equipment settings.

11.1.3 The environmental conditioning test parameters.

11.1.4 If performed, the sampling method, coupon geometry, and test parameters used to determine density and reinforcement volume.

11.2 *General Instructions*:

11.2.1 Report any deviations from this test method, whether intentional or inadvertent.

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 tension tested. Specific gravity and density may be evaluated by means of Test Methods 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 2584. The void content equations of Test Methods D 2734 are applicable to both Test Method D 2584 and the matrix digestion procedures.

11.2.3 Following any conditioning, but before the tensile testing, measure and report the specimen hole diameter to the nearest 0.025 mm [0.001 in.]. Inspect the hole and areas adjacent to the hole for delaminations. Report the location and size of any delaminations found. Perform other measurements in accordance with Test Method D 3039/D 3039M.

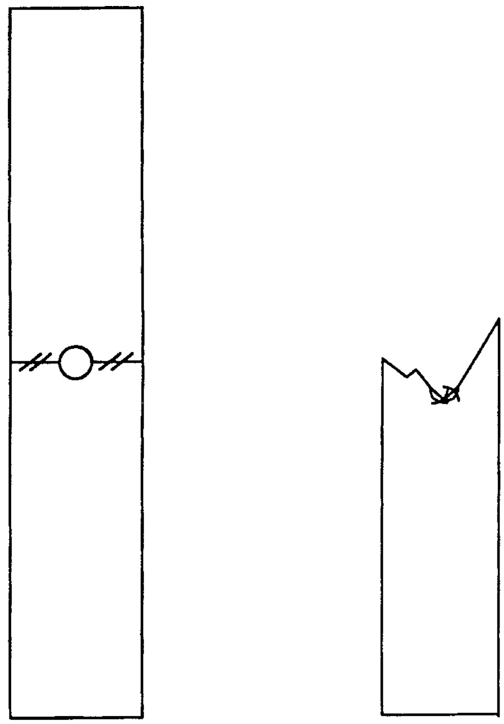
11.3 *Tensile Testing*—Perform other measurements, and the tension test of the laminate coupon, in accordance with the Procedure section of Test Method D 3039/D 3039M.

11.4 *Failure Modes*—The failure is often heavily influenced by delamination and the failure mode may exhibit much delamination. Failures that do not occur at the hole are not acceptable failure modes and the data shall be noted as invalid. Fig. 2 illustrates the two acceptable failure modes. Three-place failure mode descriptors for these modes, following those given in Test Method D 3039/D 3039M and 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. Failure mode codes for valid tests for this test method are limited to ___ GM, where the second and third place holders are limited to Gage Middle. The first place holder would normally be either L for Lateral, A for Angled, or M for Multi-mode.

12. Calculation

12.1 *Ultimate Strength*—Calculate the ultimate open hole tensile strength using Eq 1 and report the results to three significant figures.

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



LGM

Laminate tensile failure laterally across the center of the hole.

AGM

Laminate generally fails in tension at the hole, but remnants of angle plies cross the hole lateral centerline.

FIG. 2 Acceptable Open Hole Tensile Failure Modes

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	<1W from grip/tab	W	Left	L
Lateral	L	Gage	G	Right	R
Multi-mode	M(xyz)	Multiple areas	M	Middle	M
long. Splitting	S	Various	V	Various	V
eXplosive	X	Unknown	U	Unknown	U
Other	O				

where:

F_x^{OHTu} = ultimate open hole tensile strength, MPa [psi],
P^{max} = maximum load prior to failure, N [lbf], and
A = gross cross-sectional area (disregarding hole) from Test Method D 3039/D 3039M, mm^2 [in.^{2}].

NOTE 3—The hole diameter is ignored in the strength calculation; the gross cross-sectional area is used.

12.2 *Width to Diameter Ratio*—Calculate the actual width to diameter ratio, as shown in Eq 2. Report both the nominal ratio calculated using nominal values and the actual ratio calculated with measured dimensions.

$$w/D \text{ ratio} = \frac{w}{D} \tag{2}$$

where:

w = width of coupon across hole, mm [in.], and
D = diameter of hole, mm [in.].

12.3 *Statistics*—For each series of tests calculate the average value, standard deviation, and coefficient of variation (in percent) for each property determined:

$$\bar{x} = (\sum_{i=1}^{n} x_i)/n \tag{3}$$

$$s_{n-1} \sqrt{(\sum_{i=1}^{n} x_i^2 - n\bar{x}^2)/(n-1)} \tag{4}$$

$$CV = 100 \times s_{n-1}/\bar{x} \tag{5}$$

where:

$\bar{x}$ = sample mean (average),
$s_n{-1}$ = sample standard deviation,
CV = sample coefficient of variation, in percent,
n = number of specimens, and
x_i = measured or derived property.

13. Report

13.1 The report shall include all appropriate parameters in accordance with Test Method D 3039/D 3039M, making use of Guides E 1309, E 1471, and E 1434.

13.2 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):

13.2.1 The revision level or date of issue of this test method.

13.2.2 Any variations to this test method, anomalies noticed during testing, or equipment problems occurring during testing.

13.2.3 Nominal width to diameter ratio, and actual width to diameter ratio for each specimen.

13.2.4 Nominal diameter to thickness ratio and actual width to diameter ratio for each specimen.

13.2.5 Individual ultimate open hole tensile strengths and average value, standard deviation, and coefficient of variation (in percent) for the population.

13.2.6 Failure mode and location of failure for each specimen.

14. Precision and Bias

14.1 *Round-Robin Results*—A round robin for precision data was conducted on this test method in 1989. Nine laboratories participated in the evaluation of three material systems from three different material suppliers, using quasi-isotropic laminates. Each laboratory tested at ambient laboratory conditions a randomly distributed sample of 5 specimens of each material type, prepared by the material supplier, using a loading rate of 0.05 in./min. All specimens were untabbed, and gripping methods among the laboratories varied. The conduct of the round-robin deviated from this test method in two respects: thickness was measured via a double-ball micrometer, and material moisture content was not controlled. The average results for each laboratory are listed in Table 2.

14.2 *Precision*:

TABLE 2 1989 Round-Robin Data

Lab	F_x^{OHTu}, MPa [ksi]					
	Material A[A]		Material B[B]		Material C[C]	
	Average	CV	Average	CV	Average	CV
1	279 [40.5]	2.72	422 [61.2]	1.12	477 [69.2]	1.31
2	283 [41.1]	7.98	400 [58.0]	2.60	475 [68.9]	1.90
3	276 [40.0]	6.98	412 [59.8]	1.92	465 [67.5]	1.07
4	272 [39.4]	4.47	422 [61.2]	1.72	472 [68.4]	3.00
5	283 [41.0]	5.51	414 [60.0]	1.52	473 [68.6]	3.41
6	283 [41.0]	3.15	419 [60.8]	2.12	485 [70.4]	3.61
7	280 [40.6]	5.64	416 [60.4]	4.30	470 [68.1]	5.39
8	273 [39.6]	7.04	414 [60.0]	3.55	482 [69.9]	2.22
9	265 [38.5]	2.75	419 [60.7]	3.31	480 [69.6]	6.70
Average	277 [40.2]	5.05	415 [60.2]	2.46	476 [69.0]	3.18
CV	5.31		2.86		3.53	

[A] Carbon/brittle epoxy fabric at [45/0/−45/90]*s* using 34 Msi modulus carbon fiber.
[B] Carbon/toughened epoxy tape at [45/0/−45/90]2*s* using 42 Msi modulus carbon fiber.
[C] Carbon/thermoplastic tape at [45/0/−45/90]2*s* using 42 Msi modulus carbon fiber.

14.2.1 The precision is defined as a 95 % confidence interval, which can be expressed two ways. Practice E 691 suggests that for this degree of confidence the maximum difference between an individual observation and the average should be within 2.0 standard deviations, while the maximum difference between any two observations should be within 2.8 standard deviations. For brevity, only the magnitude of the latter is reported; the former can be derived from the latter. Two types of precision can also be defined: within-laboratory (the repeatability) or between-laboratory (the reproducibility); both of which are reported.

14.2.2 The within-laboratory conditions were essentially single-operator, one-day, same-apparatus conditions, during which time neither the apparatus nor environment was likely to change appreciably.

14.2.3 The results, summarized in Table 3 indicate that this test method is relatively insensitive to minor variations in testing practices, but is sensitive to material type.

14.3 *Bias*—Bias cannot be determined for this test method as no acceptable reference standard exists.

15. Keywords

15.1 composite materials; open hole tensile strength; tension testing

TABLE 3 1989 Round-Robin Statistics

Material System	Between Observation 95 % Confidence Interval	
	Within Laboratory Repeatability[A] $2.8 \times S_r$	Between Laboratories Reproducibility[A] $2.8 \times S_R$
A	15.1	15.1
B	7.44	8.09
C	10.2	10.2

[A] Normalized to mean, in percent.