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 multidirectional polymer matrix composite laminates reinforced by high-modulus fibers. The composite material forms are limited to continuous-fiber or discontinuous-fiber (tape or fabric, or both) reinforced composites in which the laminate is balanced and symmetric with respect to the test direction. The range of acceptable test laminates and thicknesses are described in 8.2.1.

1.2 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.

1.3 *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 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 Methods for Constituent Content of Composite Materials[4]
D 3878 Terminology for Composite Materials[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 Fiber-Reinforced Polymer-Matrix Composite Materials in Databases[4]
E 1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases[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 *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.

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[1] This test method 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.
[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.

3.2.2 *principal material coordinate system*, *n*—a coordinate system with axes that are normal to the planes of symmetry inherent to a material.

3.2.2.1 *Discussion*—Common usage, at least for Cartesian axes (123, *xyz*, and so forth), generally assigns the coordinate system axes to the normal directions of planes of symmetry in order that the highest property value in a normal direction (for elastic properties, the axis of greatest stiffness) would be 1 or *x*, and the lowest (if applicable) would be 3 or *z*. Anisotropic materials do not have a principal material coordinate system due to the total lack of symmetry, while, for isotropic materials, any coordinate system is a principal material coordinate system. In laminated composites the principal material coordinate system has meaning only with respect to an individual orthotropic lamina. The related term for laminated composites is "reference coordinate system."

3.2.3 *reference coordinate system*, *n*—a coordinate system for laminated composites used to define ply orientations. One of the reference coordinate system axes (normally the Cartesian *x*-axis) is designated the reference axis, assigned a position, and the ply principal axis of each ply in the laminate is referenced relative to the reference axis to define the ply orientation for that ply.

3.2.4 *specially orthotropic*, *adj*—a description of an orthotropic material as viewed in its principal material coordinate system. In laminated composites, a specially orthotropic laminate is a balanced and symmetric laminate of the $[0_i/90_j]_{ns}$ family as viewed from the reference coordinate system, such that the membrane-bending coupling terms of the laminate constitutive relation are zero.

3.3 *Symbols:*

3.3.1 *A*—cross-sectional area of a specimen.

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*—specimen thickness.

3.3.5 *n*—number of specimens per sample population.

3.3.6 *N*—number of plies in laminate under test.

3.3.7 F_x^{OHTu}—ultimate open hole (notched) tensile strength in the test direction.

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

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

3.3.10 *w*—specimen width.

3.3.11 x_i—test result for an individual specimen 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. Edge-mounted extensometer displacement transducers are optional. Ultimate strength is calculated based on the gross cross-sectional area, disregarding the presence of the hole. While the 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.

4.2 The only acceptable failure mode for ultimate open-hole tensile strength is one which passes through the hole in the test specimen.

5. Significance and Use

5.1 This test method is designed to produce notched tensile strength data for structural design allowables, 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 (OHT).

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 caused by 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 specimen 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 from 1.5 to 3.0 unless the experiment is investigating the influence of this ratio.

6.3 *Material Orthotropy*—The degree of laminate orthotropy strongly affects the failure mode and measured OHT strength. Valid OHT strength results should only be reported when appropriate failure modes are observed, in accordance with 11.4.

6.4 *Thickness Scaling*—Thick composite structures do not necessarily fail at the same strengths as thin structures with the same laminate orientation (that is, strength does not always scale linearly with thickness). Thus, data gathered using this test method may not translate directly into equivalent thick-structure properties.

6.5 *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. 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 specimen 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 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. 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. Fabric laminates containing satin-type weaves shall have symmetric warp surfaces, unless otherwise noted in the report.

NOTE 2—Typically a $[45_i/-45_i/0_j/90_k]_{ms}$ tape or $[45_i/0_j]_{ms}$ 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.

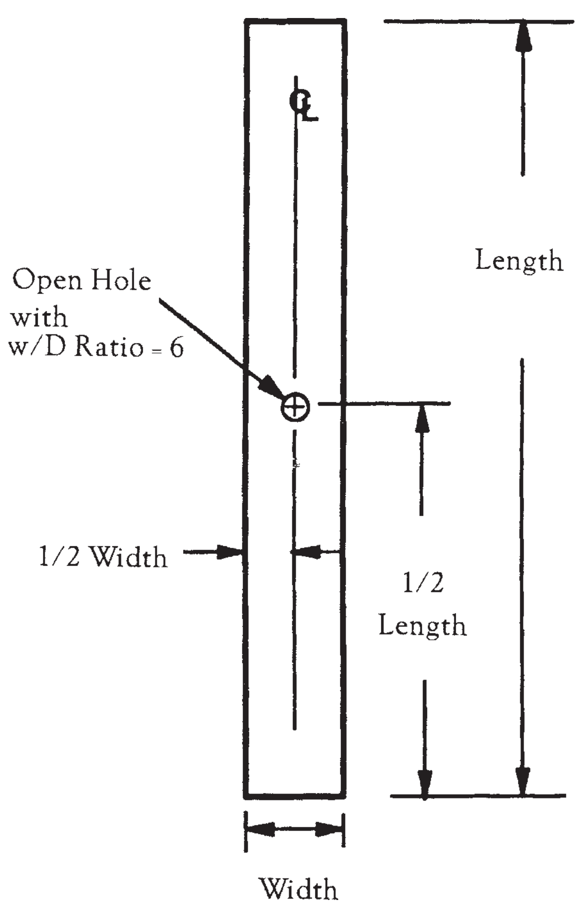

FIG. 1 Schematic of Open Hole Tension Test Specimen

8.2.2 *Dimensions*—The width of the specimen is 36 ± 1 mm [1.50 ± 0.05 in.] and the length range is 200 to 300 mm [8.0 to 12.0 in.]. The notch consists of a centrally located hole, 6 ± 0.06 mm [0.250 ± 0.003 in.] in diameter, centered by length to within 0.12 mm [0.005 in.] and by width to within 0.05 mm [0.002 in.]. 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*—Special care shall be taken to ensure that creation of the specimen hole does not delaminate or otherwise damage the material surrounding the hole. Holes should be drilled undersized and reamed to final dimensions. Record and report the specimen hole preparation methods. 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, specimen type and geometry, and conditioning travelers (if required).

11.1.2 The tensile properties and data reporting format desired.

NOTE 3—Determine specific material property, accuracy, and data reporting requirements prior to test for proper selection of instrumentation and data recording equipment. Estimate the specimen 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, extensometry requirements and related calculations.

11.1.5 If performed, the sampling method, specimen 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 Condition the specimens as required. Store the specimens in the conditioned environment until test time, if the test environment is different than the conditioning environment.

11.2.4 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 specimen, in accordance with the Procedure section of Test Method D 3039/D 3039M. If strain response local to the hole is to be determined, attach either one or two extensometers to the specimen edge(s) ensuring the hole is located within the extensometer gage section.

11.4 *Failure Modes*—Failures that do not occur at the 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 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. Fig. 2 illustrates these three acceptable failure modes. 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 re-examine the means of load introduction into the material. Factors considered should include the grip pressure, grip alignment, and specimen thickness taper.

13. Calculation

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

$$F_x^{OHTu} = P^{max}/A \tag{1}$$

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

13.2 *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 specimen across hole, mm [in.], and
D = diameter of hole, mm [in.].

13.3 *Diameter to Thickness Ratio*—Calculate the actual diameter to thickness ratio, as shown in Eq 3. Report both the nominal ratio calculated using nominal values and the actual ratio calculated with measured dimensions.

$$D/h \text{ ratio} = \frac{D}{h} \tag{3}$$

where:

D = diameter of hole, mm [in.], and
h = specimen thickness near hole, mm [in.].

13.4 *Percent Bending*—If two edge-mounted extensometers are used, edgewise percent bending may be calculated in accordance with Test Method D 3039/D 3039M.

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

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

$$s_{n-1} = \sqrt{(\sum_{i=1}^{n} x_i^2 - n\bar{x}^2)/(n-1)} \tag{5}$$

$$CV = 100 \times s_{n-1}/\bar{x} \tag{6}$$

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.

14. Report

14.1 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.

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):

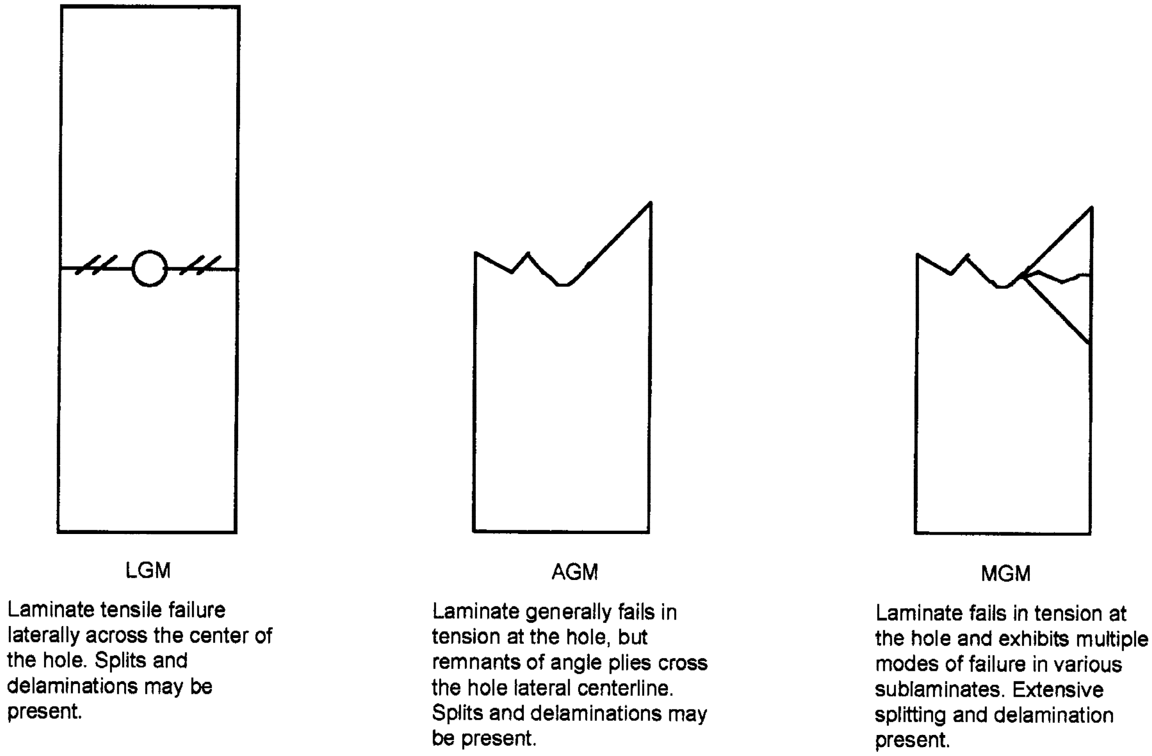

FIG. 2 Acceptable Open Hole Tensile Failure Modes

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

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

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

14.2.4 Nominal diameter to thickness ratio and actual diameter to thickness ratio for each specimen.

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

14.2.6 Extensometer type, stress-strain curves, tabulated stress versus strain data, or percent bending versus load or head displacement, or combination thereof, for each specimen so evaluated.

14.2.7 Failure mode and location of failure for each specimen.

15. Precision and Bias

15.1 *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.

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.

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.

15.2 *Precision*:

15.2.1 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.

15.2.2 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.

15.2.3 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.

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

16. Keywords

16.1 composite materials; open hole tensile strength; tension testing