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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.

[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.

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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.

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