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Standard Guide for Test Method Selection and Test Specimen Design for Bolted Joint Related Properties[1]

This standard is issued under the fixed designation D8509/D8509M; 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 guide covers the test method selection and associated test specimen design to produce test data to be used for typical bolted joint analyses. These test methods are limited to use with multi-directional polymer matrix composite laminates reinforced by high-modulus fibers. This standard is intended to be used by persons requesting these test types.

1.2 Test requestors designing these specimens need to be familiar with the referenced Test Method and Practice standards, CMH-17 Volume 3 Chapter 11, and the stress analysis methods that will use the resulting design data.

1.3 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

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, and 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]

D883 Terminology Relating to Plastics
D3039/D3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials
D3878 Terminology for Composite Materials
D4762 Guide for Testing Polymer Matrix Composite Materials
D5687/D5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation
D5766/D5766M Test Method for Open-Hole Tensile Strength of Polymer Matrix Composite Laminates
D5961/D5961M Test Method for Bearing Response of Polymer Matrix Composite Laminates
D6484/D6484M Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates
D6641/D6641M Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture
D6742/D6742M Practice for Filled-Hole Tension and Compression Testing of Polymer Matrix Composite Laminates
D6873/D6873M Practice for Bearing Fatigue Response of Polymer Matrix Composite Laminates
D7248/D7248M Test Method for High Bearing - Low Bypass Interaction Response of Polymer Matrix Composite Laminates Using 2-Fastener Specimens
D7332/D7332M Test Method for Measuring the Fastener Pull-Through Resistance of a Fiber-Reinforced Polymer Matrix Composite
D7615/D7615M Practice for Open-Hole Fatigue Response of Polymer Matrix Composite Laminates
D8066/D8066M Practice Unnotched Compression Testing of Polymer Matrix Composite Laminates
D8387/D8387M Test Method for High Bypass – Low Bearing Interaction Response of Polymer Matrix Composite Laminates

[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] 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.

E739 Guide for Statistical Analysis of Linear or Linearized Stress-Life (***S-N***) and Strain-Life (ε-***N***) Fatigue Data

2.2 *Other Documents:*

CMH-17 Composite Materials Handbook-17, Polymer Matrix Composites, Volume 3, Chapter 11

3. Terminology

3.1 *Definitions:*

3.1.1 Terminology D3878 defines terms relating to high-modulus fibers and their composites. Terminology D883 defines terms relating to plastics. In the event of a conflict between terms, Terminology D3878 shall have precedence.

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 *Definitions of Terms Specific to This Standard:*

Geometry Terms:

3.2.1 *bearing area, $[L^2]$, n*—the area of that portion of a bearing specimen used to normalize applied loading into an effective bearing stress; equal to the diameter of the loaded hole multiplied by the thickness of the specimen.

3.2.2 *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.

3.2.3 *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.

3.2.4 *diameter-to-thickness ratio, D/h [nd], n*—the ratio of the hole diameter to the specimen thickness.

3.2.4.1 *Discussion*—The diameter-to-thickness ratio may be either a nominal value determined from nominal dimensions or an actual value determined from measured dimensions.

3.2.5 *edge distance ratio, edge/D [nd], n*—the ratio of the distance between the center of the hole and the specimen edge to the hole diameter. The edge distance is measured perpendicular to the primary bypass loading or normal to the applied bearing load direction. The edge/D ratio is typically one-half of the w/D ratio.

3.2.5.1 *Discussion*—The edge distance ratio may be either a nominal value determined from nominal dimensions or an actual value determined from measured dimensions. Two distance ratios are typically considered during the design of composite parts: edge distance ratio and end distance ratio. Design requirements for these ratios may be different.

3.2.6 *end distance ratio, e/D [nd], n*—the ratio of the distance between the center of the hole and the specimen end to the hole diameter. The end distance is measured parallel to the primary bypass loading direction or the applied bearing load direction.

3.2.6.1 *Discussion*—The end distance ratio is often imprecisely referred as "edge distance ratio". The end distance ratio may be either a nominal value determined from nominal dimensions or an actual value determined from measured dimensions.

3.2.7 *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.

3.2.8 *width-to-diameter ratio, w/D [nd], n*—the ratio of the specimen width to the hole diameter.

3.2.8.1 *Discussion*—The width-to-diameter ratio may be either a nominal value determined from nominal dimensions or an actual value determined from measured dimensions.

Bearing Terms:

3.2.9 *bearing chord stiffness, E^{br} $[ML^{-1}T^{-2}]$, n*—the chord stiffness between two specific bearing stress or bearing strain points in the linear portion of the bearing stress/bearing strain curve.

3.2.10 *bearing force, P $[MLT^2]$, n*—the total force carried by a bearing specimen.

3.2.11 *bearing strain, ε^{br} [nd], n*—the normalized hole deformation in a bearing specimen, equal to the deformation of the bearing hole in the direction of the bearing force, divided by the diameter of the hole.

3.2.12 *bearing strength, F_x^{br} $[ML^{-1}T^{-2}]$, n*—the value of bearing stress occurring at a significant event (maximum force, significant force drop, or defined bearing strain level) on the bearing stress/bearing strain curve.

3.2.12.1 *Discussion*—Two types of bearing strengths are commonly identified, and noted by an additional superscript: offset strength and ultimate strength.

3.2.13 *bearing stress, F^{br} $[ML^{-1}T^{-2}]$, n*—the bearing force divided by the bearing area.

3.2.14 *offset bearing strength, F_x^{bro} $[ML^{-1}T^{-2}]$, n*—the value of bearing stress, in the direction specified by the subscript, at the point where a bearing chord stiffness line, offset along the bearing strain axis by a specified bearing strain value, intersects the bearing stress/bearing strain curve.

3.2.14.1 *Discussion*—Unless otherwise specified, an offset bearing strain of 2 % is to be used in this test method.

3.2.15 *ultimate bearing strength, F_x^{bru} $[ML^{-1}T^{-2}]$, n*—the value of bearing stress, in the direction specified by the subscript, at the maximum force capability of a bearing specimen.

Bypass Terms:

3.2.16 *gross bypass stress, f^{gr_byp} $[ML^{-1}T^{-2}]$, n*—the gross bypass stress for tensile loadings is calculated from the total force bypassing the fastener hole.

3.2.17 *net bypass stress, f^{net_byp} $[ML^{-1}T^{-2}]$, n*—the net bypass stress for tensile loading is calculated from the force bypassing the fastener hole minus the force reacted in bearing at the fastener.

3.2.17.1 *Discussion*—For compressive loadings the gross and net bypass stresses are equal and are calculated using the force that bypasses the fastener hole (since for the compressive loading case the bearing stress reaction is on the same side of the fastener as the applied force, the force reacted in bearing does not bypass the fastener hole). Several alternate definitions for gross and net bypass stress have been used historically in the aerospace industry. Comparison of data from tests conforming to this standard with historical data may need to account for differences in the bypass definitions.

3.2.18 *ultimate gross bypass strength,* $F_x^{gr\_byp}$ $[ML^{-1}T^{-2}]$, *n*—the value of gross bypass stress, in the direction specified by the subscript, at the maximum force capability of the specimen.

3.2.19 *ultimate net bypass strength,* $F_x^{net\_byp}$ $[ML^{-1}T^{-2}]$—the value of net bypass stress, in the direction specified by the subscript, at the maximum force capability of the specimen.

Fatigue Terms:

3.2.20 *constant amplitude loading, n*—a loading in which all of the peak values of force (stress) are equal and all of the valley values of force (stress) are equal.

3.2.21 *fatigue loading transition, n*—in the beginning of fatigue loading, the number of cycles before the force (stress) reaches the desired peak and valley values.

3.2.22 *force (stress) ratio, R [nd], n*—the ratio of the minimum applied force (stress) to the maximum applied force (stress).

3.2.23 *frequency, f* $[T^{-1}]$, *n*—the number of force (stress) cycles completed in 1 s (Hz).

3.2.24 *hole elongation, ΔD [L], n*—the permanent change in hole diameter in a bearing coupon caused by damage formation, equal to the difference between the hole diameter in the direction of the bearing force after a prescribed loading and the hole diameter prior to loading.

3.2.25 *peak, n*—the occurrence where the first derivative of the force (stress) versus time changes from positive to negative sign; the point of maximum force (stress) in constant amplitude loading.

3.2.26 *residual strength,* $[MLT^{-2}]$, *n*—the value of force (stress) required to cause failure of a specimen under quasi-static loading conditions after the specimen is subjected to fatigue loading.

3.2.27 *run-out, n*—an upper limit on the number of force cycles to be applied.

3.2.28 *spectrum loading, n*—a loading in which the peak values of force (stress) are not equal or the valley values of force (stress) are not equal (also known as variable amplitude loading or irregular loading).

3.2.29 *valley, n*—the occurrence where the first derivative of the force (stress) versus time changes from negative to positive sign; the point of minimum force (stress) in constant amplitude loading.

3.2.30 *wave form, n*—the shape of the peak-to-peak variation of the force (stress) as a function of time.

4. Summary of Guide

4.1 This guide provides information for selecting and designing test specimens to determine the laminate strength properties related to bolted joint analyses, including tension and compression laminate strength for open and filled hole configurations, laminate bearing strength, and laminate bearing/bypass interaction strength. It also covers open hole and bearing fatigue specimens. This guide compiles and updates information for test requestors that was previously located in the referenced Test Method and Practice standards.

4.2 Users of this guide should also review Guide D4762, as well as the referenced test method standards.

4.3 Users of this guide should be familiar with the stress analysis methods that will use the resulting design data. The following references discuss these methods and associated test data for composite structures:

4.3.1 CMH-17, Volume 1 Chapter 2 (**1**)[3],

4.3.2 CMH-17, Volume 1 Chapter 7 (**1**),

4.3.3 CMH-17, Volume 3 Chapter 11 (**1**),

4.3.4 Esp, Chapter 11 (**2**), and

4.3.5 ASM Handbook (**3**).

5. Test Method Selection and Usage

5.1 This section describes the test methods covered by this guide, and how the data is typically used for analysis in the aerospace industry.

5.2 *Open Hole Tests:*

5.2.1 Open hole tension (Test Method D5766/D5766M) and open hole compression (Test Method D6484/D6484M) tests on multi-directional composite laminates are often conducted for material characterization (see CMH-17 Vol. 1, Chapter 2), material specifications and quality assurance, design allowables covering manufacturing defects and accidental damage (see CMH-17 Vol. 3, Chapter 12), and design allowables for bolted joints bearing/bypass interaction analysis (see CMH-17 Vol. 3, Chapter 11). These tests involve a uniaxially loaded test of a balanced, symmetric laminate with a centrally located hole.

5.2.2 Ultimate strength for open hole tests 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.

5.2.3 Open hole strengths are affected by the environmental conditions under which the tests are conducted. Laminates tested in various environments can exhibit significant differences in failure force. Experience has demonstrated that cold temperature environments are generally critical for open-hole tensile strength, while humidity pre-conditioned, elevated temperature environments are generally critical for open-hole

[3] The boldface numbers in parentheses refer to a list of references at the end of this standard.