ASTM INTERNATIONAL

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Standard Practice for
Open-Hole Fatigue Response of Polymer Matrix Composite Laminates[1]

This standard is issued under the fixed designation D7615/D7615M; 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 static open-hole tensile and compressive strength test methods to determine the fatigue behavior of composite materials subjected to cyclic tensile or compressive forces, or both. 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.

1.2 This practice supplements Test Methods D5766/D5766M and D6484/D6484M with provisions for testing specimens under cyclic loading. Several important test specimen parameters, for example fatigue force (stress) ratio, are not mandated by this practice; however, repeatable results require that these parameters be specified and reported.

1.3 This practice is limited to test specimens subjected to constant amplitude uniaxial loading, where the machine is controlled so that the test specimen is subjected to repetitive constant amplitude force (stress) cycles. Either engineering stress or applied force may be used as a constant amplitude fatigue variable. The repetitive loadings may be tensile, compressive, or reversed, depending upon the test specimen and procedure utilized.

1.4 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.

1.4.1 Within the text the inch-pound units are shown in brackets.

1.5 *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.*

1.6 *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

D3878 Terminology for Composite Materials

D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials

D5766/D5766M Test Method for Open-Hole Tensile Strength of Polymer Matrix Composite Laminates

D6484/D6484M Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates

D8509 Guide for Test Method Selection and Test Specimen Design for Bolted Joint Related Properties

E4 Practices for Force Calibration and Verification of Testing Machines

E6 Terminology Relating to Methods of Mechanical Testing

E83 Practice for Verification and Classification of Extensometer Systems

E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E456 Terminology Relating to Quality and Statistics

E467 Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System

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

E1823 Terminology Relating to Fatigue and Fracture Testing

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3. Terminology

3.1 *Definitions*—Terminology D3878 defines terms relating to high-modulus fibers and their composites. Terminology D883 defines terms relating to plastics. Terminology E6 defines terms relating to mechanical testing. Terminology E1823 defines terms relating to fatigue. Terminology E456 and Practice E177 define terms relating to statistics. In the event of a conflict between terms, Terminology D3878 shall have precedence over the other standards.

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*—Refer to Guide D8509.

3.3 *Symbols:*

A = Cross-sectional area of a specimen
D = specimen hole diameter
h = specimen thickness
K = specimen chord stiffness, P/δ
K_i = specimen chord stiffness prior to fatigue cycles
K_N = specimen chord stiffness after N fatigue cycles
N = number of constant amplitude cycles
Δ_N = change in chord stiffness after N fatigue cycles
P = force carried by specimen
P^{maxq} = peak force under quasi-static loading for measurement of stiffness
P^{minq} = valley force under quasi-static loading for measurement of stiffness
w = specimen width
δ = crosshead or extensometer translation
σ^{alt} = alternating open hole stress during fatigue loading
σ^{max} = value of stress corresponding to the peak value of force (stress) under constant amplitude loading
σ^{maxq} = value of stress corresponding to the peak value of force (stress) under quasi-static loading for measurement of stiffness, given by the greater of the absolute values of σ^{max} and $0.5 \times \sigma^{min}$
σ^{mean} = mean normal stress during fatigue loading
σ^{min} = value of stress corresponding to the valley value of force (stress) under constant amplitude loading
σ^{minq} = value of stress corresponding to the valley value of force (stress) under quasi-static loading for measurement of stiffness, given by the greater of the absolute values of σ^{min} and $0.5 \times \sigma^{max}$
σ^{ohm} = maximum cyclic open hole stress magnitude, given by the greater of the absolute values of σ^{max} and σ^{min}

4. Summary of Practice

4.1 In accordance with Test Methods D5766/D5766M or D6484/D6484M, but under constant amplitude fatigue loading, perform a uniaxial test of an open-hole specimen. Cycle the specimen between minimum and maximum axial forces (stresses) at a specified frequency. At selected cyclic intervals, determine the specimen stiffness from a force versus deforma-

tion curve obtained by quasi-statically loading the specimen through one tension, compression, or tension-compression cycle as applicable. Determine the number of force cycles at which failure occurs (or at which a predetermined change in specimen stiffness is observed) for a specimen subjected to a specific force (stress) ratio and stress magnitude. Refer to Guide D8509 for additional test details.

5. Significance and Use

5.1 Refer to Guide D8509.

6. Interferences

6.1 Refer to Guide D8509.

7. Apparatus

7.1 *General Apparatus*—General apparatus shall be in accordance with Test Method D5766/D5766M Configuration A for tension-tension fatigue loading, and in accordance with Test Method D6484/D6484M Procedure A for tension-compression and compression-compression fatigue loading. The micrometer or gauge used shall be capable of determining the hole diameter to ±0.025 mm [±0.001 in.].

7.2 *Testing Machine*—In addition to the requirements described in Test Methods D5766/D5766M or D6484/D6484M, the testing machine shall be in conformance with Practice E467 and shall satisfy the following requirements:

7.2.1 *Drive Mechanism and Controller*—The velocity of the movable head shall be capable of being regulated under cyclic force (stress) conditions. The drive mechanism and controller shall be capable of imparting a continuous loading wave form to the specimen. It is important to minimize drift of the fatigue loading away from the maximum and minimum values. Achieving such accuracy is critical in the development of reliable fatigue life data since small errors in loading may result in significant errors in fatigue life. It is recommended that the test controller be equipped with a Test Amplitude controller, capable of monitoring the fatigue forces at least once every three cycles.

7.2.2 *Force Indicator*—The force indicator shall be in compliance with Practices E4. The fatigue rating of the force indicator shall exceed the forces at which testing will take place. Additionally, this practice recommends compliance with Practice E467 for the development of a system dynamic conversion for the verification of specimen forces to within 1 % of true forces.

7.2.3 *Extensometers*—The extensometer gauge length shall be 25 mm [1.0 in.]. Extensometers shall satisfy, at a minimum, Practice E83, Class B-1 requirements for the strain range of interest, and shall be calibrated over that range in accordance with Practice E83. The extensometers shall be essentially free of intertia lag at the specified speed of testing.

7.2.4 *Grips*—As described in Test Method D5766/D5766M for tension-tension fatigue loading or Test Method D6484/D6484M Procedure A for tension-compression and compression-compression fatigue loading, where use of hydraulic grips is recommended for fatigue loading. The grips shall have sufficient fatigue rating for forces at which testing will take place.

7.3 *Support Fixture*—If compressive forces are applied, either during fatigue loading or during quasi-static loading to determine residual strength or monitor specimen stiffness, a support fixture shall be used to stabilize the specimen. The support fixture shall be in accordance with that described in Test Method D6484/D6484M.

7.4 *Thermocouple and Temperature Recording Devices,* capable of reading specimen temperature to ±0.5 °C [±1.0 °F].

8. Sampling and Test Specimens

8.1 *Sampling*—For statistically significant data, the procedures outlined in Practice E122 should be consulted. From the number of tests selected a statistically significant distribution of data should be obtained for a given material, stacking sequence, environment, and loading condition.

8.1.1 *Sample Size for S-N Curve*—The recommended minimum number of specimens in the development of S-N data is described in Table 1. A minimum of three different force (stress) levels is recommended in development of S-N data. For additional procedures consult Practice E739.

8.2 *Geometry*—In addition to the requirements described in Test Methods D5766/D5766M and D6484/D6484M, the specimen geometry shall satisfy the following requirements:

8.2.1 *Stacking Sequence*—The stacking sequence should be evaluated for free edge effects to minimize the likelihood of edge delamination initiation.

8.2.2 *Specimen Configuration*—The test specimen configuration shall be in accordance with Test Methods D5766/D5766M Configuration A for tension-tension loading or D6484/D6484M for tension-compression and compression-compression loading.

8.3 *Specimen Preparation*—Specimens shall be prepared in accordance with Test Method D5766/D5766M or Test Method D6484/D6484M. Special care should be taken to ensure that specimen edges are sufficiently free of obvious flaws as determined by visual inspection. Such flaws may lead to premature failure due to edge delamination.

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 The recommended pre-test condition is effective moisture equilibrium at a specified relative humidity as established by Test Method D5229/D5229M; however, if the test requestor

does not explicitly specify a pre-test conditioning environment, no conditioning is required and the test specimens may be tested as prepared.

10.2 The pre-test specimen conditioning process, to include specified environmental exposure levels and resulting moisture content, shall be reported with the test data.

NOTE 2—The term moisture, as used in Test Method D5229/D5229M, includes not only the vapor of a liquid and its condensate, but the liquid itself in large quantities, as for immersion.

10.3 If no explicit conditioning process is performed, the specimen conditioning process shall be reported as "unconditioned" and the moisture content as "unknown."

10.4 Maintaining testing environment is critical to obtaining consistent fatigue data since testing for long periods of time (days or weeks) is not uncommon. For unattended tests, the test environment shall be monitored so that unintended changes in the test environment result in suspension of the test. Report the testing environment for the duration of the test.

11. Procedure

11.1 *Parameters to Be Specified Prior to Test:*

11.1.1 The specimen sampling method, specimen type and geometry, minimum and maximum test forces (stresses) σ^{min} and σ^{max} for each test, force (stress) ratio for each test, test frequency and wave form of the fatigue loading. For the purpose of development of an S-N curve, all specimens shall be tested at the same frequency and wave form unless that is a factor to be studied in the test.

11.1.2 Fatigue cycle counts at which stiffness is to be measured, method of measuring stiffness, quasi-static peak and valley forces for stiffness measurement (if applicable), stiffness level at which fatigue loading shall cease, and run-out cycles.

NOTE 3—Fatigue damage accumulation curves are "S" shaped requiring more data points at earlier cycles and again closer to failure (the latter requires some estimate of N at failure) to capture the damage accumulation behavior. For example, during a 2 million cycle test, stiffness may be checked at the following intervals: N = 1, 2, 5, 10, 20, 50, 100, 200, 500, 1000, 2000, 5000, 10 000, 20 000, 50 000, and every 100 000 cycles thereafter. The final interval is typically constant and should be one order of magnitude less than the anticipated N at failure.

11.1.3 All other parameters documented in Test Methods D5766/D5766M or D6484/D6484M.

11.2 *General Instructions:*

11.2.1 Any deviations from these procedures, whether intentional or inadvertent, shall be reported.

11.2.2 Perform general instructions for conditioning, measurement, cleaning, and assembly in accordance with Test Methods D5766/D5766M or D6484/D6484M.

11.3 *Test Procedure:*

11.3.1 *Supported Specimen Installation*—If the specimen is to be tested in tension-compression or compression-compression fatigue loading, a support fixture in accordance with that described in Test Method D6484/D6484M shall be used to stabilize the specimen. Install the test specimen into the support fixture as described in Test Method D6484/D6484M.

11.3.2 *Temperature Monitoring*—Attach temperature recording device in a manner not to influence the dynamic response of the specimen. The device may be attached to the

TABLE 1 Number of Specimens Required for Each S-N Curve

Type of Test	Minimum Number of Test Specimens
Preliminary and exploratory	6
Research and development testing	12
Design allowables data	24
Reliability data	24