Designation: D3479/D3479M – 19 (Reapproved 2023)

Standard Test Method for Tension-Tension Fatigue of Polymer Matrix Composite Materials[1]

This standard is issued under the fixed designation D3479/D3479M; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This test method determines the fatigue behavior of polymer matrix composite materials subjected to tensile cyclic loading. The composite material forms are limited to continuous-fiber or discontinuous-fiber reinforced composites for which the elastic properties are specially orthotropic with respect to the test direction. This test method is limited to unnotched test specimens subjected to constant amplitude uniaxial in-plane loading where the loading is defined in terms of a test control parameter.

1.2 This test method presents two procedures where each defines a different test control parameter.

1.2.1 *Procedure A*—A system in which the test control parameter is the load (stress) and the machine is controlled so that the test specimen is subjected to repetitive constant amplitude load cycles. In this procedure, the test control parameter may be described using either engineering stress or applied load as a constant amplitude fatigue variable.

1.2.2 *Procedure B*—A system in which the test control parameter is the strain in the loading direction and the machine is controlled so that the test specimen is subjected to repetitive constant amplitude strain cycles. In this procedure, the test control parameter may be described using engineering strain in the loading direction as a constant amplitude fatigue variable.

1.3 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
D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
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
E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application

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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 D30.04 on Lamina and Laminate Test Methods.

Current edition approved Sept. 1, 2023. Published September 2023. Originally approved in 1976. Last previous edition approved in 2019 as D3479/D3479M – 19. DOI: 10.1520/D3479_D3479M-19R23.

[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.

E1823 Terminology Relating to Fatigue and Fracture Testing

3. Terminology

3.1 *Definitions*—Terminology D3878 defines terms relating to high-modulus fibers and their composites. Terminology E1823 defines terms relating to fatigue. Terminology D883 defines terms relating to plastics. Terminology E6 defines terms relating to mechanical testing. 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.

3.2 *Definitions of Terms Specific to This Standard:* The following definitions shall have precedence over Terminology D3878 and over other standards.

3.2.1 *constant amplitude loading, n—in fatigue*, a loading in which all of the peak values of the test control parameter are equal and all of the valley values of the test control parameter are equal.

3.2.2 *fatigue loading transition, n—in the beginning of fatigue loading*, the number of cycles before the test control parameter reaches the desired peak and valley values.

3.2.3 *frequency, f* $[T^{-1}]$, *n—in fatigue loading*, the number of load (stress) or strain cycles completed in 1 s (Hz).

3.2.4 *load (stress) ratio, R [nd], n—in fatigue loading*, the ratio of the minimum applied load (stress) to the maximum applied load (stress).

3.2.5 *peak, n—in fatigue loading*, the occurrence where the first derivative of the test control parameter versus time changes from positive to negative sign; the point of maximum load (stress) or strain in constant amplitude loading.

3.2.6 *replicate (repeat) tests, n*—nominally identical tests on different test specimens conducted at the same nominal value of the independent variable.

3.2.7 *residual stiffness,* $[FL^{-2}]$, *n*—the value of modulus of a specimen under quasi-static loading conditions after the specimen is subjected to fatigue loading.

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

3.2.9 *spectrum loading, n—in fatigue*, a loading in which the peak values of the test control parameter are not equal or the valley values of the test control parameter are not equal (also known as variable amplitude loading or irregular loading.)

3.2.10 *strain ratio,* R_ε *[nd], n—in fatigue loading*, the ratio of the minimum applied strain to the maximum applied strain.

3.2.11 *test control parameter, n*—the variable in constant amplitude loading whose maximum and minimum values remain the same during cyclic loading, in other words, load (stress) or strain.

3.2.12 *valley, n—in fatigue loading*, the occurrence where the first derivative of the test control parameter versus time changes from negative to positive; the point of minimum load (stress) or strain in constant amplitude loading.

3.2.13 *wave form, n*—the shape of the peak-to-peak variation of the test control parameter as a function of time.

3.3 *Symbols:*

3.3.1 S_{max} *(or* ε_{max}*)*—the value of stress (or strain) corresponding to the peak value of the test control parameter in a constant amplitude loading.

3.3.2 S_{min} *(or* ε_{min}*)*—the value of stress (or strain) corresponding to the valley value of the test control parameter in a constant amplitude loading.

3.3.3 S_{mn} *(or* ε_{mn}*)*—the mean value of stress (or strain) as given by $S_{\mathrm{mn}} = (S_{\mathrm{max}} + S_{\mathrm{min}})/2$ or $\varepsilon_{\mathrm{mn}} = (\varepsilon_{\mathrm{max}} + \varepsilon_{\mathrm{min}})/2$.

3.3.4 S_a *(or* ε_a*)*—the difference between the mean value of stress (or strain) and the maximum and minimum stress (or strain) as given by $S_{\mathrm{a}} = (S_{\mathrm{max}} - S_{\mathrm{min}})/2$ or $\varepsilon_{\mathrm{a}} = (\varepsilon_{\mathrm{max}} - \varepsilon_{\mathrm{min}})/2$.

3.3.5 N_f—the scalar value of fatigue life or number of constant amplitude cycles to failure.

3.3.6 α—Weibull fatigue life scale parameter.

3.3.7 β—Weibull fatigue life shape parameter.

4. Summary of Test Method

4.1 The tensile specimen described in Test Method D3039/D3039M is mounted in the grips of the testing machine and is tested as follows:

4.1.1 *Procedure A*—The specimen is cycled between minimum and maximum in-plane axial load (stress) at a specified frequency. The number of load cycles at which failure occurs (or at which a predetermined change in specimen stiffness is observed) can be determined for a specimen subjected to a specific load (stress) ratio and maximum stress. For some purposes it is useful to obtain the in-plane stiffness at selected cycle intervals from static axial stress-strain curves using modulus determination procedures found in Test Method D3039/D3039M.

4.1.2 *Procedure B*—The specimen is cycled between minimum and maximum in-plane axial strain at a specified frequency. The number of strain cycles at which specimen failure occurs (or at which a predetermined change in specimen stiffness is observed) can be determined at a given strain ratio and maximum strain. For some purposes it is useful to obtain the in-plane stiffness at selected cycle intervals from static axial stress-strain curves using modulus determination procedures found in Test Method D3039/D3039M or continuously from dynamic axial stress-strain data using similar procedures as found in Test Method D3039/D3039M.

5. Significance and Use

5.1 This test method is designed to yield tensile fatigue data for material specifications, research and development, quality assurance, and structural design and analysis. The primary test result is the fatigue life of the test specimen under a specific loading and environmental condition. Replicate tests may be used to obtain a distribution of fatigue life for specific material types, laminate stacking sequences, environments, and loading conditions. Guidance in statistical analysis of fatigue life data, such as determination of linearized stress life (S-N) or strain-life (ε-N) curves, can be found in Practice E739.

5.2 This test method can be utilized in the study of fatigue damage in a polymer matrix composite such as the occurrence of microscopic cracks, fiber fractures, or delaminations.[3] The specimen's residual strength or stiffness, or both, may change due to these damage mechanisms. The loss in stiffness may be quantified by discontinuing cyclic loading at selected cycle intervals to obtain the quasi-static axial stress-strain curve using modulus determination procedures found in Test Method D3039/D3039M. The loss in strength associated with fatigue damage may be determined by discontinuing cyclic loading to obtain the static strength using Test Method D3039/D3039M.

NOTE 1—This test method may be used as a guide to conduct tension-tension variable amplitude loading. This information can be useful in the understanding of fatigue behavior of composite structures under spectrum loading conditions, but is not covered in this test method.

6. Interferences

6.1 *Material and Specimen Preparation*—Poor material fabrication practices, lack of control of fiber alignment, and damage induced by improper coupon machining are known causes of a large degree scatter in composite fatigue data.

6.2 *System Alignment*—Excessive bending will cause premature failure. Every effort should be made to eliminate excess bending from the test system. Bending may occur due to misaligned grips, or from specimens themselves if improperly installed in the grips, or from out-of-tolerance due to poor specimen preparation. If there is any doubt as to the alignment inherent in a given test machine then the alignment should be checked as discussed in 7.2.6.

6.3 *Tab Failure*—Premature failure of the specimen in the tab region is common in tension-tension fatigue testing as a result of stress concentrations in the vicinity of tab region. A set of preliminary fatigue tests are recommended to find the combination of tab material, tab length, and adhesive that minimizes tab failures. Using an optical microscope to view the edge of the specimen, it can be determined if similar states of damage occur in the tab region and the gauge region.

6.4 *Load History*—Variations in testing frequency, and stress (or strain) ratio from test to test will result in variations in fatigue life data. Every effort should be made to evaluate the fatigue performance of composite laminates using the same testing frequencies and load (or stress) ratios.

6.5 *Test Laminate Lay-up and Specimen Configuration*—Results are affected by the test laminate lay-up and fiber orientation(s) as well as the specimen configuration. The test specimen requirements in 8.1 reference Test Method D3039/D3039M, which provides recommendations for specimen width, thickness, length, use of tabs, and tab geometry based upon the test laminate fiber orientation. Specimens containing multi-directional fiber orientations may exhibit delamination initiation under fatigue loading due to free edge effects. Specimens of 0° unidirectional fiber orientation may demonstrate very flat S-N or ε-N behavior, and may require modifications to the Test Method D3039/D3039M geometry to promote fatigue failures in the gauge section of the specimen.

7. Apparatus

7.1 *Micrometers*—As described in Test Method D3039/D3039M.

7.2 *Testing Machine*—The testing machine shall be in conformance with Practices E4 and E467, and shall satisfy the following requirements:

7.2.1 *Testing Machine Heads*—The testing machine shall have both an essentially stationary head and a movable head.

7.2.2 *Drive Mechanism and Controller*—The testing machine shall be capable of imparting to the movable head a controlled velocity with respect to the stationary head. The velocity of the movable head shall be capable of being regulated under cyclic load (stress) or strain conditions. The drive mechanism and controller shall be in compliance with Practice E467 and 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.

7.2.3 *Load Indicator*—As described in Test Method D3039/D3039M. The load indicator shall be in compliance with Practice E4. The fatigue rating of the load indicator shall exceed the loads at which testing will take place. Additionally this test method recommends compliance with Practice E467 for the development of a system dynamic conversion for the verification of specimen loads to within 1 % of true loads.

7.2.4 *Strain Indicator*—It is recommended that an extensometer be used for strain determination for strain control in Procedure B, or to obtain strain data for Procedure A. For specimens to be tested per Procedure A and to be checked for initial stiffness only, a bonded strain gauge (or gauges) may be used for static strain measurements. This test method follows extensometer requirements as found in Test Method D3039/D3039M. Verification of data acquisition and extensometer accuracy shall be completed in accordance with Practice E83. However, a static verification is insufficient for dynamic loading, and it is recommended as a minimum to conduct a dynamic verification using Appendix X3 of Practice E83. Practice E83 discusses dynamic calibration of the extensometer by comparing extensometer strain to those from strain gauges during cyclic loading. Practice E83 discusses the assessment of the vibrational sensitivity of the extensometer using a single moving anvil.

NOTE 2—The user is also cautioned that the effect of temperature variation on strain reading by extensometers may result in erroneous fatigue data as is discussed in Practice E83.

7.2.5 *Grips*—As described in Test Method D3039/D3039M. The grips shall also have sufficient fatigue rating for loads at which testing will take place.

7.2.6 *System Alignment*—Poor system alignment can be a significant contributor to premature fatigue failure and fatigue life data scatter. Practice E1012 describes alignment guidelines for the determination of out of plane loading during static tensile testing. In addition to Practice E1012, the system shall

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[3] Reifsnider, K. L., "Damage and Damage Mechanics," *Composite Materials Series: Fatigue of Composites*, Vol 4, 1991, pp. 11–75.

be aligned using static tension procedures outlined in Test Method D3039/D3039M.

7.3 *Thermocouple and Temperature Recording Devices*—Capable of reading specimen temperature to ±0.5 °C [±1.0 °F].

8. Sampling and Test Specimens

8.1 *Specimen*—The test specimen geometry, dimensions, preparation, and tabbing are as described in Test Method D3039/D3039M with the following additions:

8.1.1 *Specimen Preparation*—Special care should be taken in specimen preparation to ensure that specimen edges are sufficiently free of flaws. Such flaws may lead to premature failure due to edge delamination. It is recommended that all specimen edges be polished to a final finish such that fibers within a single ply may be observed clearly with a common optical microscope.

8.1.2 *Stacking Sequence*—The stacking sequence should be evaluated for free edge effects to minimize the likelihood of delamination initiation, unless that is a factor to be studied in the test.[4,5,6]

8.1.3 *Adhesive*—For specimens with end tabs, the tabbing adhesive should have sufficient durability as to withstand fatigue loading for the duration of the test.

8.2 *Number of Tests*—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.

8.2.1 *Sample Size for S-N or ε-N Curve*—The recommended minimum number of specimens in the development of S-N or ε-N data is described in Table 1. A minimum of three different load or strain levels are recommended in development of S-N or ε-N data. For additional procedures consult Practice E739.

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.

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

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

10. Conditioning

10.1 The recommended pre-test condition is effective moisture equilibrium at a specific 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 3—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 *Common Procedure*—The following procedures are common to both Procedure A and Procedure B.

11.1.1 *Cross-section Determination*—Following final specimen machining, but before conditioning and testing, measure the specimen width and the specimen thickness at three places in the gauge section to the accuracy of 7.1. Report the averages of the thickness, h, and width, w, and use the average values to calculate the specimen area as $A = w \times h$. Report area in units of mm^2 [$in.^2$].

NOTE 4—The test requester may request that additional measurements be performed after the machined specimens have gone through any conditioning or environmental exposure.

11.1.2 Condition the specimens as required. If the test environment is different than the conditioning environment, specimens shall be stored in the conditioned environment until test time.

11.1.3 *Static Testing*—Test five control specimens quasi-statically at the specified environment in accordance with Test Method D3039/D3039M. Calculate the mean tensile strength and the mean axial strain at failure.

11.1.4 *Load Levels*—Select the maximum and minimum test control parameter, S_{min} and S_{max} or ε_{min} and ε_{max}, for constant amplitude fatigue loading and report as a percentage of the mean tensile strength or the mean axial strain at failure. Calculate and report the load (stress) ratio or strain ratio for the constant amplitude fatigue loading.

11.1.5 *Frequency and Wave Form of Testing*—Select and report the frequency and wave form of the fatigue loading. For the purpose of development of an S-N or ε-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.

11.1.6 *Temperature Monitoring*—Attach temperature recording device in a manner not to influence the dynamic

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[4] Pagano, N. J., and Pipes, R. B., "The Influence of Stacking Sequence on Laminate Strength," *Journal of Composite Materials*, Vol 5, 1971, pp. 5–57.

[5] Whitney, J. M., "Free Edge Effects in the Characterization of Composite Materials," Analysis of Test Methods for High Modulus Fibers and Composites, ASTM STP 521, American Society Testing Materials, 1973, pp. 167–180.

[6] Pipes, R. B., et al, "Influence of Free Edge Upon the Strength of Angle-Ply Laminates," ibid., pp. 218–228.