Designation: D 3479/D 3479M – 96 (Reapproved 2002)$^{\epsilon 1}$

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

This standard is issued under the fixed designation D 3479/D 3479M; 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 Department of Defense.

ϵ[1] NOTE—Sections 2.1 and 3.1 were revised editorially in October 2002.

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. 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 non-conformance with this standard.

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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 883 Terminology Relating to Plastics[2]

D 3039/D 3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials[3]

D 3878 Terminology for Composite Materials[3]

D 5229/D 5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials[3]

E 4 Practices for Force Verification of Testing Machines[4]

E 6 Terminology Relating to Methods of Mechanical Testing[4]

E 83 Practice for Verification and Classification of Extensometers[4]

E 122 Practice for Calculating Sample Size to Estimate, With a Specified Tolerable Error, the Average for a Characteristic of a Lot or Process[5]

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[5]

E 456 Terminology for Relating to Quality and Statistics[5]

E 467 Practice for Verification of Constant Amplitude Dynamic Loads on Displacements in an Axial Load Fatigue Testing System[4]

E 739 Practice for Statistical Analysis of Linear or Linearized Stress-Life (S-N) and Strain-Life (ϵ-N) Fatigue Data[4]

E 1012 Practice for Verification of Specimen Alignment Under Tensile Loading[4]

E 1049 Practices for Cycle Counting in Fatigue Analysis[4]

E 1823 Terminology Relating to Fatigue and Fracture Testing[4]

3. Terminology

3.1 *Definitions*—Terminology D 3878 defines terms relating

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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 June 10, 1996. Published August 1996. Originally published as D 3479 – 76. Last previous edition D 3479 – 76.

[2] *Annual Book of ASTM Standards*, Vol 08.01.

[3] *Annual Book of ASTM Standards*, Vol 15.03.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

[5] *Annual Book of ASTM Standards*, Vol 14.02.

to high-modulus fibers and their composites. Terminology E 1823 defines terms relating to fatigue. 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:* The following definitions shall have precedence over Terminology D 3878 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 illustrated in Fig. 1 and given by $S_{\mathrm{mn}} = (S_{\mathrm{max}} + S_{\mathrm{min}})/2$ or $\epsilon_{\mathrm{mn}} = (\epsilon_{\mathrm{max}} + \epsilon_{\mathrm{min}})/2$.

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 illustrated in Figure 1 and given by $S_{\mathrm{a}} = (S_{\mathrm{max}} - S_{\mathrm{min}})/2$ or $\epsilon_{\mathrm{a}} = (\epsilon_{\mathrm{max}} - \epsilon_{\mathrm{min}})/2$.

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 D 3039/D 3039M 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 D 3039/D 3039M.

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 D 3039/D 3039M or continuously from dynamic axial stress-strain data using similar procedures as found in Test Method D 3039/D 3039M.

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 E 739.

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.[6] The specimen's residual strength or stiffness, or both, may change

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

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 D 3039/D 3039M. The loss in strength associated with fatigue damage may be determined by discontinuing cyclic loading to obtain the static strength using Test Method D 3039/D 3039M.

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 gage 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.

7. Apparatus

7.1 *Micrometers*—As described in Test Method D 3039/ D 3039M.

7.2 *Testing Machine*—The testing machine shall be in conformance with Practices E 4 and E 467, 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 E 467 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 D 3039/D 3039M. The load indicator shall be in compliance with Practice E 4. 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 E 467 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 gage (or gages) may be used for static strain measurements. This test method follows extensometer requirements as found in Test Method D 3039/ D 3039M. Verification of data acquisition and extensometer accuracy shall be completed in accordance with Practice E 83. 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 E 83. Practice E 83 discusses dynamic calibration of the extensometer by comparing extensometer strain to those from strain gages during cyclic loading. Practice E 83 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 E 83.

7.2.5 *Grips*—As described in Test Method D 3039/ D 3039M. 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 E 1012 describes alignment guidelines for the determination of out of plane loading during static tensile testing. In addition to Practice E 1012, the system shall be aligned using static tension procedures outlined in Test Method D 3039/D 3039M.

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 D 3039/D 3039M 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.[7,8,9]

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 E 122 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 E 739.

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 *Standard Conditioning Procedure*—Condition in accordance with Procedure C of Test Method D 5229/D 5229M; store and test at standard laboratory atmosphere (23 ± 3°C [73 ± 5°F] and 50 ± 10 % relative humidity) unless a different environment is specified as part of the experiment.

10.2 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, it is desirable to monitor the test system with an environmental chamber so that unintended changes in 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.

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

[8] 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.

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

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

11.1.1 *Cross-section Determination*—Following final specimen machining, but before testing, measure the specimen area as $A = w \times h$ at three places in the gage section and report the area as the average of these three measurements to the accuracy of 7.1. Record average area in units of mm^2 [$in.^2$].

11.1.2 *Static Testing*—Test five control specimens quasi-statically at the specified environment in accordance with D 3039/D 3039M. Calculate the mean tensile strength and the mean axial strain at failure.

11.1.3 *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.

11.1.4 *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.

11.1.5 *Temperature Monitoring*—Attach temperature recording device in a manner not to influence the dynamic response of the specimen. The temperature of the specimen shall be monitored, and the frequency should be kept low enough to avoid significant temperature variations, unless that is a factor to be studied in the test. Caution is recommended when selecting loading frequencies; high cyclic rates may cause variations in specimen temperature and properties of the matrix material. For some material systems a change in 10°C [18°F], has demonstrated measurable degradation of material properties.

11.1.6 *Specimen Insertion*—Place the specimen in the grips of the testing machine, taking care to align the long axis of the gripped section with the test direction. Tighten the grips, recording the pressure used on the pressure controllable grips and the grip/specimen contact area.

NOTE 3—Monitor the specimen for the occurrence of slippage or crushing as a result of the grips. Should either slippage or crushing occur and lead to premature specimen failure, this data should not be reported as valid.

11.1.7 *Failure*—Record the number of loading cycles at which specimen fracture or other designated degrees of failure occurred. A polymer matrix composite may appear to be structurally intact even though significant fatigue damage may be present. Depending on the purpose for which the test is being conducted a specific loss in dynamic stiffness rather than final fracture may constitute failure.

NOTE 4—For unidirectional laminates where the loading and fiber direction slightly differ, it is recommended to fatigue laminates until final failure. However, fatigue lives greater than 10^7 loading cycles are common for such specimens. Rather than remove specimens at some upper limit on the number of load cycles (such as 10^7 cycles), it is useful to record the number of cycles corresponding to a specific specimen condition. Possible conditions include when a specimen has completely delaminated forming two sublaminates or when a laminate has split completely in the transverse direction.

11.2 *Procedure A*—These procedures apply for the case in which the test control parameter is the applied load (stress). This procedure utilizes two approaches to transitioning from zero load to the desired fatigue loading:

11.2.1 *Amplitude Loading*—This approach of transitioning load to the specimen consists of quasi-statically increasing the load until reaching the desired mean load (stress), in other words, the set point, and slowly increasing the load (stress) amplitude, in other words, the span, until the desired peak and valley values are obtained. In this approach a fatigue loading transition occurs between the no load condition and when the loading reaches the desired peak and valley values. The number of loading cycles corresponding to this transition shall be reported.

11.2.2 *Direct Loading*—This approach of transitioning load to the specimen consists of quasi-statically increasing the load to the minimum load (stress) followed by immediate cycling between maximum and minimum load using a haversine wave form. This approach eliminates the fatigue loading transition associated with amplitude loading and is only possible with modern signal generators and controllers.

11.2.3 *Strain Measurement*—If strain is to be monitored, attach a suitable strain monitoring device as specified and record method of attachment.

11.2.4 *Monitoring Load*—Following the fatigue loading transition, the peak and valley load values should be monitored periodically. If required, the settings of load controller should be adjusted to achieve the desired loading. It is common for the peak and valley load values to drift during fatigue loading due to changes in compliance of the specimen. Report instances in which the loading was not within 2 % of the desired peak and valley values.

11.3 *Procedure B*—These procedures apply for the case in which the test control parameter is the axial strain. This procedure utilizes the same load transition approaches as discussed in Procedure A except that constant amplitude loading is defined by the maximum strain, minimum strain, mean strain, and strain amplitude.

11.3.1 *Strain Measurement*—Attach an extensometer to the specimen and configure its output signal such that the testing system may measure and adjust axial strain applied to the specimen. Record the method of attachment.

NOTE 5—The user is cautioned that slight movement of the extensometer due to slipping, vibration, or other such means may result in sudden specimen failure.

11.3.2 *Monitoring Strain*—Following the fatigue loading transition, the peak and valley strain values shall be monitored periodically and adjusted to achieve the desired loading. Report instances in which the strain was not within 2 % of the desired peak and valley values.

12. Calculation

12.1 *Fatigue Life Distribution*:

12.1.1 *Log-Normal Distribution*—The use of a log-normal distribution is presented in Practice E 739 for the representation of constant amplitude fatigue life data.

12.1.2 *Weibull Distribution*—The two parameter Weibull distribution is commonly used to represent constant amplitude fatigue life data. A two parameter Weibull distribution density function for fatigue life may be expressed as

$$f(N) = \frac{\beta}{\alpha}\left(\frac{N}{\alpha}\right)^{\beta-1} \exp\left[-\left(\frac{N}{\alpha}\right)^{\beta}\right] \quad (1)$$

The Weibull distribution cumulative function for fatigue life may be given by

$$\mathrm{F(N)} = 1 - \exp\left[-\left(\frac{N}{\alpha}\right)^{\beta}\right] \quad (2)$$

One method of determining the Weibull scale and shape parameters, α and β, is the maximum likelihood technique.[10]

12.2 *S-N curve*, *ϵ-N curve*—As described in Practice E 739.

13. Report

13.1 The report shall include the following:

13.1.1 The revision level or date of issue of this test method and any variations to this test method, anomalies noticed during testing, or equipment problems occurring during testing.

13.1.2 The date(s) and location(s) of the test and the names of the test operator(s).

13.1.3 Identification of the material tested including: material specification, material type, material designation, and form or weave.

13.1.4 Description of the fabrication including: cure cycle and consolidation method.

13.1.5 Average ply thickness of the material.

13.1.6 Results of any non-destructive evaluation tests.

13.1.7 Method of preparing the test specimen including: specimen labeling scheme and method; specimen geometry; sampling method; coupon cutting method; identification of tab geometry; tab material; and tab adhesive used.

13.1.8 Description of test equipment including: test machine; grips; jaws; grip pressure; alignment results; data acquisition sampling rate and equipment type; calibration dates and methods for all measurement and test equipment.

13.1.9 Description of specimens including: number of specimens tested; dimensions of each specimen; stacking sequence of the laminate; and the mean specimen thickness.

13.1.10 Description of environmental conditions including: relative humidity and temperature of the testing laboratory and, if used, of the test machine environmental chamber.

13.1.11 Description of the loading including: test control parameter; frequency; wave form; average number of fatigue loading transition cycles; and instances in which the loading was not within 2 % of the desired peak and valley values.

13.1.12 Whether Procedure A or Procedure B was used and the type and method of attachment of load or strain control and data acquisition equipment used.

13.1.13 Number of cycles to failure, peak test control parameter, valley test control parameter, load or strain ratio, specimen condition during testing leading to failure (such as edge delamination), and mode of failure for each specimen.

13.1.14 If a failure criterion other than fracture of the specimen is used (that is loss in stiffness or residual strength, excessive creep, matrix crazing delamination, and so forth) it should be noted.

13.1.15 Tensile strength of control specimens for Procedure

[10] Talreja, R., "Estimation of Weibull Parameters for Composite Material Strength and Fatigue Life Data," Fatigue of Fibrous Composite Materials, ASTM STP 723, American Society for Testing Materials, 1981, pp. 291–311.

A or strain to failure for Procedure B; average value, standard deviation, and coefficient of variation.

13.2 Reporting of following items are recommended:

13.2.1 Identification of the material tested including: manufacturer; manufacturer's lot or batch number; source (if not from manufacturer); date of certification; expiration of certification; filament diameter; tow or yarn filament count and twist; sizing; fiber areal weight; matrix type; prepreg matrix content; and prepreg volatiles content.

13.2.2 Description of the fabrication steps used to prepare the laminate including: fabrication start date; fabrication end date; process specification; and description of the equipment used.

13.2.3 Description of laminate physical properties: density; volume percent reinforcement; and void content. Also report test methods, specimen sampling method, and test parameters, and test results.

14. Precision and Bias

14.1 *Precision*—The data required for the development of a precision statement is not available for this test method.

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

15. Keywords

15.1 composite materials; fatigue; polymer matrix composites; properties