Designation: D6873/D6873M – 23

Standard Practice for Bearing Fatigue Response of Polymer Matrix Composite Laminates[1]

This standard is issued under the fixed designation D6873/D6873M; 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 bearing test methods to determine the fatigue behavior of composite materials subjected to cyclic bearing forces. 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 Method D5961/D5961M with provisions for testing specimens under cyclic loading. Several important test specimen parameters (for example, fastener selection, fastener installation method, and 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
D5961/D5961M Test Method for Bearing Response 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
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

3. Terminology

3.1 *Definitions*—Terminology D3878 defines terms relating to high-modulus fibers and their composites. Terminology

[1] This practice is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.05 on Structural Test Methods.

Current edition approved Sept. 1, 2023. Published September 2023. Originally approved in 2003. Last previous edition approved in 2019 as D6873/D6873M – 19. DOI: 10.1520/D6873_D6873M-23.

[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.

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:*

d = fastener or pin diameter
D = specimen hole diameter
D_i = measured hole diameter prior to fatigue loading
D_N = measured hole diameter after N fatigue cycles
h = specimen thickness
k = calculation factor used in bearing equations to distinguish single-fastener tests from double-fastener tests
K_i = joint stiffness prior to fatigue loading
K_N = joint stiffness after N fatigue cycles
N = number of constant amplitude cycles
P = force carried by specimen
P^{max} = greater of the absolute values of the peak and valley values of force
P^{min} = lesser of the absolute values of the peak and valley values of force
δ = crosshead or extensometer translation
δ_i = fastener translation prior to fatigue loading
δ_N = fastener translation after N fatigue cycles
δ_{Nc} = crosshead or extensometer displacement at zero force after quasi-static compressive loading
δ_{Nt} = crosshead or extensometer displacement at zero force after quasi-static tensile loading
ΔD_N = hole elongation after N fatigue cycles
ΔK_N = percent reduction in joint stiffness after N fatigue cycles
ΔP = change in force over joint stiffness range under quasi-static loading
$\Delta\delta$ = change in crosshead or extensometer displacement over joint stiffness range under quasi-static loading
σ^{alt} = alternating bearing stress during fatigue loading
σ^{brm} = maximum cyclic bearing stress magnitude, given by the greater of the absolute values of σ^{max} and σ^{min}
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 hole elongation and joint stiffness, given by the greater of the absolute values of σ^{max} and $0.5 \times \sigma^{min}$
σ^{mean} = mean bearing 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 hole elongation and joint stiffness, given by the greater of the absolute values of σ^{min} and $0.5 \times \sigma^{max}$

4. Summary of Practice

4.1 In accordance with Test Method D5961/D5961M, but under constant amplitude fatigue loading, perform a uniaxial test of a bearing specimen. 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 D5961/D5961M. The micrometer or gauge used shall be capable of determining the hole and fastener diameters to ±8 µm [±0.0003 in.].

7.2 *Testing Machine*—In addition to the requirements described in Test Method D5961/D5961M, 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 sinusoidal 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 *Grips*—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 hole elongation, a support fixture shall be used to stabilize the specimen. The support fixture shall be in accordance with that described in Test Method D5961/D5961M

Procedure B for single shear specimens, and with that described in Test Method D5961/D5961M Procedure D for double shear specimens.

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 Method D5961/D5961M, 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 Method D5961/D5961M with the following restrictions:

8.2.2.1 *Tensile Loadings Only*—Procedure A (double shear), Procedure B (single shear, two-piece specimen), and Procedure C (single shear, one-piece specimen) configurations may be utilized. For Procedure B, both the single fastener joint and the double fastener joint geometries may be utilized. If the support fixture is used, the length of each specimen half and doubler must be adjusted to accommodate loading with the fixture. Direct measurement of hole diameter(s) is required to determine hole elongation.

8.2.2.2 *Compressive Loadings Applied*—Both the Procedure B (single shear) and Procedure D (double shear) configurations and corresponding support fixtures may be utilized. For Procedure B, both the single fastener joint and the double fastener joint geometries may be utilized; the length of each specimen half and doubler must be adjusted to accommodate loading with the support fixture. Hole elongation may be determined through either direct measurement or quasi-static loadings; joint stiffness may also be determined.

8.2.3 *Adhesive*—For specimens with bonded doublers, the adhesive should have sufficient durability as to withstand fatigue loading for the duration of the test.

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

8.3 *Specimen Preparation*—Specimens shall be prepared in accordance with Test Method D5961/D5961M. 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 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 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 hole elongation (and joint stiffness if applicable) is to be measured, method of measuring hole elongation, fastener and debris removal requirements, quasi-static peak and valley forces for hole elongation and joint stiffness measurement (if applicable), hole elongation level or percent joint stiffness reduction at which fatigue loading shall cease, and run-out cycles. Historically, bearing fatigue testing has ceased after the hole elongation level has reached 10 % to 25 % of the initial hole diameter, or after joint stiffness has been reduced by 10 % to 25 % from the initial stiffness.

11.1.3 All other parameters documented in Test Method D5961/D5961M.

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, assembly, and fastener torquing in accordance with Test Method D5961/D5961M.

11.3 *Test Procedure:*

11.3.1 *Supported Specimen Installation*—If the specimen is to be tested with support fixture, install the test specimen into the support fixture as described in Test Method D5961/D5961M.

11.3.2 *Temperature Monitoring*—Attach temperature recording device in a manner not to influence the dynamic response of the specimen. It is recommended to attach the device to a fastener, as fatigue loading will typically cause a greater increase in fastener temperature than in laminate temperature. The device may be attached to the fastener using adhesive, tape, or a spring clip; when utilizing a spring clip, use insulating material to isolate the temperature recording device from the spring clip. 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 composite. For some material systems a change in 10 °C [18 °F] has demonstrated measurable degradation of material properties.

NOTE 3—When testing a conditioned specimen at elevated temperature with no fluid exposure control, the percentage moisture loss of the specimen prior to test completion may be estimated by placing a conditioned traveler coupon of known weight within the test chamber at the same time the specimen is placed in the chamber. Upon completion of the test, the traveler coupon is removed from the chamber, weighed, and the percentage weight loss calculated and reported. It should be noted that specimen moisture loss may differ from the traveler moisture loss due to cyclic loading-induced heating of the specimen.

11.3.3 *Specimen Insertion*—In accordance with Test Method D5961/D5961M, insert the specimen and support fixture (as applicable) into the test machine.

NOTE 4—Monitor the specimen for the occurrence of slippage or crushing as a result of the grips or fixture. Should either slippage or crushing occur and lead to premature specimen failure, this data should not be reported as valid.

11.3.4 *Extensometer Installation*—Attach extensometer(s) to the edges of the specimen in accordance with Test Method D5961/D5961M.

NOTE 5—It is recommended that joint stiffness changes be monitored using an extensometer. Crosshead deflection data may be used if it is first demonstrated that percent joint stiffness reduction measurements are consistent with those obtained from extensometer data.

11.3.5 *Quasi-Static Loading*—If force versus deformation data is being used to determine hole elongation and joint stiffness, perform an initial quasi-static loading cycle.

11.3.5.1 *Quasi-Static Forces*—The quasi-static tension and compression forces shall be those corresponding to σ^{maxq} and σ^{minq} as defined in 3.3.

11.3.5.2 *Loading*—From zero force, apply tensile force to the specimen quasi-statically up to the force (stress) corresponding to σ^{maxq}, then return to zero force. Apply compressive force to the specimen up to the force (stress) corresponding to σ^{minq}, then return to zero force. Force (stress) versus crosshead deflection and extensometer deflection shall be recorded during the quasi-static force cycle. A hysteresis curve, similar to those shown in Fig. 1, should be observed after graphically plotting the force (stress) versus deflection data. The quasi-static loading should be conducted under force control with a low loading rate (such that a typical hysteresis cycle takes approximately 20 s to 30 s to complete). A minimum sampling rate of 2 to 3 data recordings per second, and a target minimum of 50 data points per hysteresis cycle, are recommended.

NOTE 6—In some instances, the applied tensile and compressive forces may not be high enough to overcome friction at the fastener hole. When this occurs, hole elongation will be relatively small, and it is recommended to measure hole elongation directly (if possible) in addition to taking force versus deformation data.

11.3.5.3 *Extensometer Removal*—Remove extensometer(s) from the specimen prior to fatigue loading.

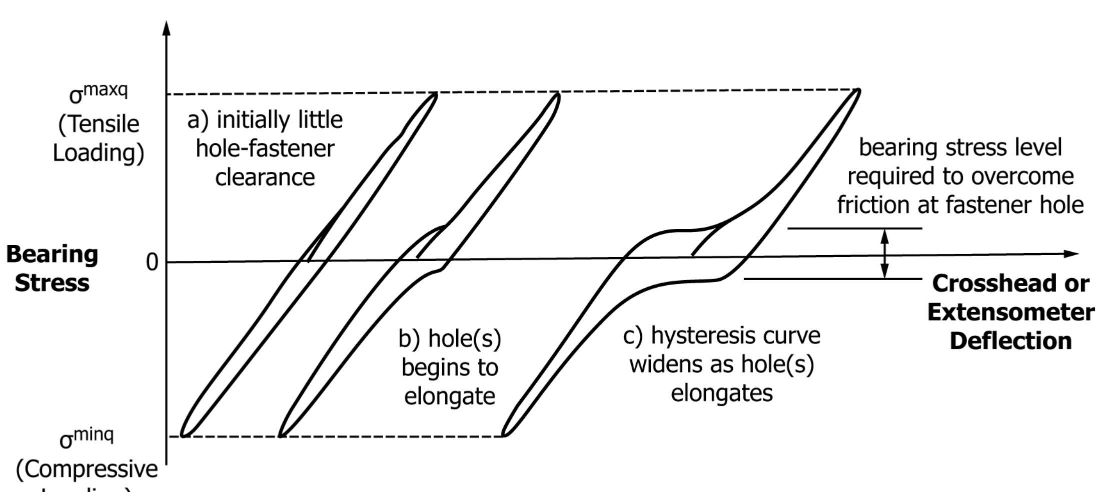

FIG. 1 Typical Bearing Stress versus Deflection Plots Depicting Shape of Hysteresis Curve

11.3.6 *Fatigue Loading:*

11.3.6.1 *Method A (Amplitude Loading)*—This approach of transitioning force to the specimen consists of quasi-statically increasing the force until reaching the desired mean force (stress), in other words the set point, and slowly increasing the force (stress) amplitude, in other words the span, until the desired peak and valley values are obtained. In this approach, a fatigue loading transition occurs before the desired peak and valley values are reached. The number of loading cycles corresponding to this transition shall be reported.

11.3.6.2 *Method B (Direct Loading)*—This approach of transitioning force to the specimen consists of quasi-statically increasing the force to either the maximum or minimum force (stress) followed by immediate cycling between maximum and minimum force using a haversine wave form (for which the valley values will not decrease below the minimum force). This approach eliminates the fatigue loading transition associated with amplitude loading and is only possible with modern signal generators and controllers.

11.3.6.3 *Monitoring Force*—Following the fatigue force transition, the peak and valley force values should be monitored periodically. If required, the settings of the force controller should be adjusted to achieve the desired loading. It is common for the peak and valley force 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.

11.4 *Hole Elongation and Joint Stiffness Measurement:*

11.4.1 *Halt Fatigue Loading*—After a prescribed number of fatigue cycles have been conducted, halt the fatigue loading and return the specimen to zero force. Remove the specimen (and fixture if appropriate) from the test machine.

11.4.2 *Fastener Torque Measurement and Removal*—If debris removal is specified by the test requestor and the fastener(s) is to be reused, mark the direction of loading on the fastener head(s). Determine the torque level(s) of the fastener(s) prior to removal by first tightening the nut (holding the pin/bolt fixed) until resistance is overcome and the nut begins to rotate. Increase the torque level an additional 0.25 N-m (2 in.-lb) and record the measured value. Subtract 0.25 N-m (2 in.-lb) from the measured value, and record this value as the torque level prior to removal. Torque measurement by loosening the nut is not recommended, as static friction under the nut contributes to the loosening torque level and is highly variable, especially after fatigue loading. If debris removal is specified by the test requestor, remove the fastener(s) from the specimen.

11.4.3 *Debris Removal*—If debris removal is specified by the test requestor, clean the specimen hole(s), removing powdery debris in accordance with the specified hole preparation procedures.

NOTE 7—In general, cleaning the specimen hole(s) prior to measurement is recommended to ensure conservatism of hole elongation data.

11.4.4 *Hole Measurement*—If direct measurement is being used to determine hole elongation, measure the diameter of the hole(s) in the direction of the bearing force using micrometer or gauge.

11.4.5 *Fastener Re-Installation*—If the fastener(s) and debris were removed, clean the specimen hole(s) and surrounding clamping area as was done prior to loading. Clean the fastener/pin shank(s). If a replacement fastener(s) is to be used, measure the fastener/pin diameter(s) at the bearing surface location. In accordance with Test Method D5961/D5961M, install the fastener(s), and torque to the lesser of the initial installation torque or the torque level prior to removal as determined in 11.4.2. If the fastener(s) is being reused, ensure the marks on the head(s) are aligned with the loading direction. Record the technique of fastener re-installation (reuse or replacement).

11.4.6 *Specimen Re-Insertion*—Re-insert the specimen (and fixture, if appropriate) into the test machine as in 11.3.3. Re-attach extensometer(s) as in 11.3.4 if appropriate.

11.4.7 *Quasi-Static Loading*—If force versus deformation data is being used to determine hole elongation and joint stiffness, perform a quasi-static loading cycle as in 11.3.5.

11.4.8 *Re-Initiate Fatigue Loading*—Commence applying fatigue forces again, as in 11.3.6.

11.5 *Failure*—Record the number of loading cycles at which specimen fracture occurred, at which the designated hole elongation or percent joint stiffness reduction was achieved, or at run-out. Depending upon the purpose for which the test is being conducted a specific loss in dynamic stiffness rather than fracture or hole elongation may constitute failure.

11.5.1 *Failure Mode*—Record the mode and location of failure of the specimen in accordance with Test Method D5961/D5961M.

12. Validation

12.1 Fatigue properties shall not be calculated for any specimen that breaks at some obvious flaw, unless such flaw constitutes a variable being studied. Retests shall be performed for any specimen on which values are not calculated.

12.2 A significant fraction of failures in a sample population occurring away from the fastener hole(s) shall be cause to re-examine the means of force introduction into the material. Factors considered should include the specimen alignment, fixture alignment (if appropriate), grip pressure, grip alignment, separation of fixture halves, specimen thickness taper, and uneven machining of specimen ends.

12.3 Initial fatigue cycles will often demonstrate a high friction force level, which will typically decrease to a steady-state level. If specimens are tested without debris removal, debris accumulation may increase the friction force level near the end of life. As this condition may provide an indication of reduced hole elongation, it is recommended that hole elongation data obtained after the friction force increases above the steady state level be considered invalid.

13. Calculations

13.1 *Geometric Calculations*—Calculate the specimen width to diameter ratio, the edge distance ratio, the diameter to thickness ratio, and the countersink depth to thickness ratio (if appropriate) in accordance with Test Method D5961/D5961M. Both the nominal ratio calculated using nominal values and the actual ratio calculated with measured dimensions shall be reported.