Designation: D6873/D6873M – 19

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
E4 Practices for Force 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 Practice 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 D883 defines terms relating to plastics. Terminology E6 defines terms relating to mechanical testing. Terminology E1823 defines terms relating to fatigue. Terminology E456 and

[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.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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:*

3.2.1 *bearing force, P [MLT^{-2}], n*—the total force carried by a bearing coupon.

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

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

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

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

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

3.2.7 *nominal value, n*—a value, existing in name only, assigned to a measurable property for the purpose of convenient designation. Tolerances may be applied to a nominal value to define an acceptable range for the property.

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

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

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

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

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

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

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. Cycle the specimen between minimum and maximum axial forces (stresses) at a specified frequency. At selected cyclic intervals, determine the hole elongation either through direct measurement or from a force (stress) versus deformation curve obtained by quasi-statically loading the specimen through one tension-compression cycle. If hole elongation is determined from a force (stress) versus deformation curve, also determine the percent joint stiffness reduction using the force versus deformation data. Determine the number of force cycles at which failure occurs, or at which a predetermined hole elongation or percent joint stiffness reduction is achieved, for a specimen subjected to a specific force (stress) ratio and bearing stress magnitude.

5. Significance and Use

5.1 This practice provides supplemental instructions for using Test Method D5961/D5961M to obtain bearing fatigue data for material specifications, research and development, material design allowables, and quality assurance. The primary property that results 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 data, such as determination of linearized stress life (S-N) curves, can be found in Practice E739.

5.2 This practice can be utilized in the study of fatigue damage in a polymer matrix composite bearing specimen. The loss in strength associated with fatigue damage may be determined by discontinuing cyclic loading to obtain the static strength using Test Method D5961/D5961M.

NOTE 2—This practice may be used as a guide to conduct spectrum 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 standard.

5.3 Factors that influence bearing fatigue response and shall therefore be reported include the following: material, methods of material fabrication, accuracy of lay-up, laminate stacking sequence and overall thickness, specimen geometry, specimen preparation (especially of the hole), fastener-hole clearance, fastener type, fastener geometry, fastener installation method, fastener torque (if appropriate), countersink depth (if appropriate), specimen conditioning, environment of testing, time at temperature, type of mating material, number of fasteners, type of support fixture, specimen alignment and gripping, test frequency, force (stress) ratio, bearing stress magnitude, void content, and volume percent reinforcement. Properties that result include the following:

5.3.1 Hole elongation versus fatigue life curves for selected bearing stress values.

5.3.2 Percent joint stiffness reduction versus fatigue life curves for selected bearing stress values.

5.3.3 Bearing stress versus hole elongation curves at selected cyclic intervals.

5.3.4 Bearing stress versus percent joint stiffness reduction curves at selected cyclic intervals.

5.3.5 Bearing stress versus fatigue life curves for selected hole elongation values.

5.3.6 Bearing stress versus fatigue life curves for selected percent joint stiffness reduction values.

6. Interferences

6.1 *Force (Stress) Ratio*—Results are affected by the force (stress) ratio under which the tests are conducted. Specimens loaded under tension-tension or compression-compression force (stress) ratios develop hole elongation damage on one side of the fastener hole, whereas specimens loaded under tension-compression force (stress) ratios can develop damage on both sides of the fastener hole. Experience has demonstrated that reversed (tension-compression) force ratios are critical for bearing fatigue-induced hole elongation, with fully reversed tension-compression ($R = -1$) being the most critical force ratio (**1-3**).[3]

6.2 *Loading Frequency*—Results are affected by the loading frequency at which the test is conducted. High cyclic rates may induce heating due to friction within the joint, and may cause variations in specimen temperature and properties of the composite. Varying the cyclic frequency during the test is generally not recommended, as the response may be sensitive to the frequency utilized and the resultant thermal history.

6.3 *Fastener Torque/Pre-load*—Results are affected by the installed fastener pre-load (clamping pressure). Laminates can exhibit significant differences in hole elongation behavior and failure mode due to changes in fastener pre-load under both tensile and compressive loading. Experience has demonstrated that low fastener torque/clamp-up is generally critical for bearing fatigue-induced hole elongation (**1**, **2**, **4**). It should be noted that in some instances, low torque testing of single shear specimens has proven unsuccessful due to loosening of the fastener nut/collar during fatigue loading caused by deformation of the pin/bolt.

6.4 *Debris Buildup and Removal*—Results are affected by the buildup of fiber-matrix debris resulting from damage associated with hole elongation, and whether such debris is removed during the test. The presence of debris may mask the actual degree of hole elongation, and can increase both the friction force transfer and temperature within the specimen under fatigue loading. Experience has demonstrated that non-reversed force ratios (especially compression-compression force ratios) exhibit greater debris buildup than reversed force ratios. Fastener and debris removal can facilitate a more accurate measurement of hole elongation (**1**, **2**, **4**). In general, removing fastener(s) and cleaning the specimen hole(s) prior to measurement is recommended to ensure conservatism of hole elongation data to account for the potential removal of debris over time (due to fluid exposure, for example). However, fastener and debris removal during the test may result in an unrepresentative measurement of hole elongation growth behavior; thus, fastener and debris removal requirements shall be specified by the test requestor. Fasteners such as blind bolts and lockbolts are not practical to remove during fatigue testing; use of such fasteners may preclude cleaning of the specimen hole(s).

6.5 *Environment*—Results are affected by the environmental conditions under which the tests are conducted. Laminates tested in various environments can exhibit significant differences in hole elongation behavior, joint stiffness response, and failure mode. Experience has demonstrated that elevated temperature, humid environments are generally critical for

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