Designation: D 5961/D 5961M – 96

Standard Test Method for Bearing Response of Polymer Matrix Composite Laminates[1]

This standard is issued under the fixed designation D 5961/D 5961M; 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 test method determines the bearing response of polymer matrix composite laminates by either double shear (Procedure A) or single shear (Procedure B) tensile loading of a coupon. Standard specimen configurations using fixed values of test parameters are described for each procedure. However, when fully documented in the test report, a number of test parameters may be optionally varied. The material form is limited to high-modulus continuous-fiber or discontinuous-fiber reinforced composites for which the elastic properties are balanced and symmetric with respect to the test direction.

1.2 This test method is consistent with the recommendations of MIL-HDBK-17, which describes the desirable attributes of a bearing response test method.

1.3 *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.*

1.4 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 nonconformance with the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

D 792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement[2]
D 883 Terminology Relating to Plastics[2]
D 953 Test Method for Bearing Strength of Plastics[2]
D 2584 Test Method for Ignition Loss of Cured Reinforced Resins[3]
D 2734 Test Methods for Void Content of Reinforced Plastics[3]
D 3171 Test Method for Fiber Content of Resin-Matrix Composites by Matrix Digestion[4]
D 3878 Terminology of High-Modulus Reinforcing Fibers and Their Composites[4]
D 5229/D 5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials[4]
D 5687/D 5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation[4]
E 4 Practices for Force Verification of Testing Machines[5]
E 6 Terminology Relating to Methods of Mechanical Testing[5]
E 83 Practice for Verification and Classification of Extensometers[5]
E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process[6]
E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[6]
E 238 Test Method for Pin-Type Bearing Test of Metallic Materials[5]
E 456 Terminology Relating to Quality and Statistics[6]
E 1309 Guide for the Identification of Composite Materials in Computerized Material Property Databases[4]
E 1434 Guide for Development of Standard Data Records for Computerization of Mechanical Test Data for High-Modulus Fiber-Reinforced Composite Materials[4]
E 1471 Guide for the Identification of Fibers, Fillers, and Core Materials in Computerized Material Property Databases[4]

2.2 *Other Document:*

MIL-HDBK-17, *Polymer Matrix Composites*, Vol 1, Section 7[7]

3. Terminology

3.1 *Definitions*—Terminology D 3878 defines terms relating to high-modulus fibers and their composites. 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

[1] This test method is under the jurisdiction of ASTM Committee D-30 on High Modulus Fibers and Their Composites and is the direct responsibility of Subcommittee D30.05 on Structural Test Methods.

Current edition approved May 10, 1996. Published July 1996.

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

[3] *Annual Book of ASTM Standards*, Vol 08.02.

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

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

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

[7] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

shall have precedence over the other documents.

3.2 *Definitions of Terms Specific to This Standard*:

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 nondimensional 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.

3.2.1 *bearing area*, $[L^2]$, *n*—the area of that portion of a bearing coupon used to normalize applied loading into an effective bearing stress; equal to the diameter of the loaded hole multiplied by the thickness of the coupon.

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

3.2.3 *bearing strain*, ϵ^{br} [*nd*], *n*—the normalized hole deformation in a bearing coupon, equal to the deformation of the bearing hole in the direction of the bearing load, divided by the diameter of the hole.

3.2.4 *bearing strength*, F_x^{br} $[ML^{-1}T^{-2}]$, *n*—the value of bearing stress occurring at a significant event on the bearing stress/bearing strain curve.

3.2.4.1 *Discussion*—Two types of bearing strengths are commonly identified, and noted by an additional superscript: offset strength and ultimate strength.

3.2.5 *bearing stress*, σ^{br} $[ML^{-1}T^{-2}]$, *n*—the bearing load divided by the bearing area.

3.2.6 *diameter to thickness ratio, D/h* [*nd*], *n—in a bearing coupon*, the ratio of the hole diameter to the coupon thickness.

3.2.6.1 *Discussion*—The diameter to thickness ratio may be either a nominal value determined from nominal dimensions or an actual value determined from measured dimensions.

3.2.7 *edge distance ratio, e/D* [*nd*], *n—in a bearing coupon*, the ratio of the distance between the center of the hole and the coupon end to the hole diameter.

3.2.7.1 *Discussion*—The edge distance ratio may be either a nominal value determined from nominal dimensions or an actual value determined from measured dimensions.

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

3.2.9 *offset bearing strength*, F_x^{bro} $[ML^{-1}T^{-2}]$, *n*—the value of bearing stress, in the direction specified by the subscript, at the point where a bearing chord stiffness line, offset along the bearing strain axis by a specified bearing strain value, intersects the bearing stress/bearing strain curve.

3.2.9.1 *Discussion*—Unless otherwise specified, an offset bearing strain of 2 % is to be used in this test method.

3.2.10 *orthotropic material*, *n*—a material with a property of interest that, at a given point, possesses three mutually perpendicular planes of symmetry defining the principal material coordinate system for that property.

3.2.10.1 *Discussion*—As viewed from the principal material coordinate system of an orthotropic elastic material, extensional stresses are totally uncoupled from shear strains and the shear moduli are totally independent of the other elastic constants (unlike a metal, which is isotropic and that has a shear modulus that is dependent upon Young's modulus and Poisson's ratio). An orthotropic material has 9 independent elastic constants. The general concept of orthotropy also applies to material properties other than elastic, such as thermal, electromagnetic, or optical, although the number of independent constants and the type of mathematical transformation may differ, depending upon the order of the tensor of the property. The behavior of an orthotropic material as viewed from the principal material coordinate system is called *specially orthotropic*. However, if the material behavior is evaluated from another coordinate system coupling terms may appear in the stress/strain relation. While the material itself remains specially orthotropic, from this other coordinate system the material behavior is then called *generally orthotropic*.

3.2.11 *pitch distance ratio, w/D* [nd], *n—in a bearing coupon*, the ratio of specimen width to hole diameter.

3.2.11.1 *Discussion*—The pitch distance ratio may be either a nominal value determined from nominal dimensions or an actual value, determined as the ratio of the actual distance between the center of the hole and the nearest side-edge to the actual hole diameter.

3.2.12 *ply orientation*, θ, *n*—the angle between the reference axis and the ply principal axis, expressed in degrees, with a range of $-90° < \theta \leq 90°$. The ply orientation is expressed as a positive quantity when taken from the reference direction to the ply principal axis, following a right-handed Cartesian coordinate system.

3.2.12.1 *Discussion*—The reference direction is usually related to a direction of load application or a major geometric feature of a component.

3.2.13 *ply principal axis*, *n*—the coordinate axis in the plane of a lamina that is used as the reference direction for that lamina.

3.2.13.1 *Discussion*—The ply principal axis will, in general, be different for each ply of a laminate. The angle made by this axis relative to the reference axis is the ply orientation. The convention is to align the ply principal axis with a material feature that is the direction of maximum stiffness (such as the fiber direction for unidirectional tape or the warp direction for fabric-reinforced material). Conventions for other laminated material forms have not yet been established.

3.2.14 *principal material coordinate system*, *n*—a coordinate system with axes that are normal to the planes of symmetry inherent to a material.

3.2.14.1 *Discussion*—Common usage, at least for Cartesian axes (123, *xyz*, etc.), generally assigns the coordinate system axes to the normal directions of planes of symmetry in order that the highest property value in a normal direction (for elastic properties, the axis of greatest stiffness would be 1 or *x*, and the lowest (if applicable) would be 3 or *z*). Anisotropic materials do not have a principal material coordinate system due to the total lack of symmetry, while, for isotropic materials, any coordinate system is a principal material coordinate system. In laminated composites the principal material coordinate system has meaning only with respect to an individual orthotropic lamina. The related term for laminated composites is reference coordinate system.

3.2.15 *quasi-isotropic laminate, n*—a balanced and symmetric laminate for which a constitutive property of interest, at a given point, displays isotropic behavior in the plane of the laminate. Common quasi-isotropic laminates are [0/±60]s and [0/±45/90]s.

3.2.15.1 *Discussion*—Usually a quasi-isotropic laminate refers to elastic properties, for which case, the laminate contains equal numbers of identical plies at k orientations such that the angles between the plies are $180i/k$, ($i = 0, 1, \ldots, k-1$); $k \geq 3$. Other material properties may follow different rules. For example, thermal conductivity becomes quasi-isotropic for $k \geq 2$, while strength properties generally are not capable of true quasi-isotropy, only approximating this behavior.

3.2.16 *reference coordinate system, n*—a coordinate system for laminated composites used to define ply orientations. One of the reference coordinate system axes (normally the Cartesian x-axis) is designated the reference axis, assigned a position, and the ply principal axis of each ply in the laminate is referenced relative to the reference axis to define the ply orientation for that ply.

3.2.17 *specially orthotropic, adj*—a description of an orthotropic material as viewed in its principal material coordinate system. In laminated composites a specially orthotropic laminate is a balanced and symmetric laminate of the [0:i/90:j]*ns* family as viewed from the reference coordinate system, such that the membrane-bending coupling terms of the stress/strain relation are zero.

3.2.18 *tracer yarn, n*—a small filament-count tow of a fiber type that has a color that contrasts with the surrounding material form, used for directional identification in composite material fabrication.

3.2.18.1 *Discussion*—Aramid tracer yarns are commonly used in carbon fiber composites and carbon tracer yarns are commonly used in aramid or glass fiber composites.

3.2.19 *ultimate bearing strength,* F_x^{bru} $[ML^{-1}T^{-2}]$, *n*—the value of bearing stress, in the direction specified by the subscript, at the maximum load capability of a bearing coupon.

3.3 *Symbols:*

3.3.1 A—minimum cross-sectional area of a coupon.

3.3.2 CV—coefficient of variation statistic of a sample population for a given property (in percent).

3.3.3 d—fastener or pin diameter.

3.3.4 D—coupon hole diameter.

3.3.5 e—distance, parallel to load, from hole center to end of coupon; the edge distance.

3.3.6 E_x^{br}—bearing chord stiffness in the test direction specified by the subscript.

3.3.7 f—distance, parallel to load, from hole edge to end of coupon.

3.3.8 F_x^{bru}—ultimate bearing strength in the test direction specified by the subscript.

3.3.9 $F_x^{bro}(e\%)$—offset bearing strength (at e % bearing strain offset) in the test direction specified by the subscript.

3.3.10 g—distance, perpendicular to load, from hole edge to shortest edge of coupon.

3.3.11 h—coupon thickness.

3.3.12 k—calculation factor used in bearing equations to distinguish single-fastener tests from double-fastener tests.

3.3.13 K—calculation factor used in bearing equations to distinguish single-shear tests from double-shear tests in a single bearing strain equation.

3.3.14 L_g—extensometer gage length.

3.3.15 n—number of coupons per sample population.

3.3.16 P—load carried by test coupon.

3.3.17 P^f—load carried by test coupon at failure.

3.3.18 P^{max}—maximum load carried by test coupon prior to failure.

3.3.19 s_{n-1}—standard deviation statistic of a sample population for a given property.

3.3.20 w—coupon width.

3.3.21 x_i—test result for an individual coupon from the sample population for a given property.

3.3.22 $\bar{x}$—mean or average (estimate of mean) of a sample population for a given property.

3.3.23 δ—extensional displacement.

3.3.24 ϵ—general symbol for strain, whether normal strain or shear strain.

3.3.25 ϵ^{br}—bearing strain.

3.3.26 σ^{br}—bearing stress.

4. Summary of Test Method

4.1 *Procedure A, Double Shear*:

4.1.1 A flat, constant rectangular cross-section coupon with a centerline hole located near the end of the coupon, as shown in the coupon drawings of Figs. 1 and 2, is loaded at the hole in bearing. The bearing load is normally applied through a close-tolerance, lightly torqued fastener (or pin)[8] that is reacted in double shear by a fixture similar to that shown in Figs. 3 and 4. The bearing load is created by pulling the assembly in tension in a testing machine.

4.1.2 Both the applied load and the associated deformation of the hole are monitored. The hole deformation is normalized by the hole diameter to create an effective bearing strain. Likewise, the applied load is normalized by the projected hole area to create an effective bearing stress. The coupon is loaded until a load maximum has clearly been reached, whereupon the test is terminated so as to prevent masking of the true failure mode by large-scale hole distortion, in order to provide a more representative failure mode assessment. Bearing stress versus bearing strain for the entire loading regime is plotted, and failure mode noted. The ultimate bearing strength of the material is determined from the maximum load carried prior to test termination.

4.1.3 The standard test configuration for this procedure does not allow any variation of the major test parameters. However, the following variations in configuration are allowed, but can be considered as being in accordance with this test method only as long as the values of all variant test parameters are prominently documented with the results.

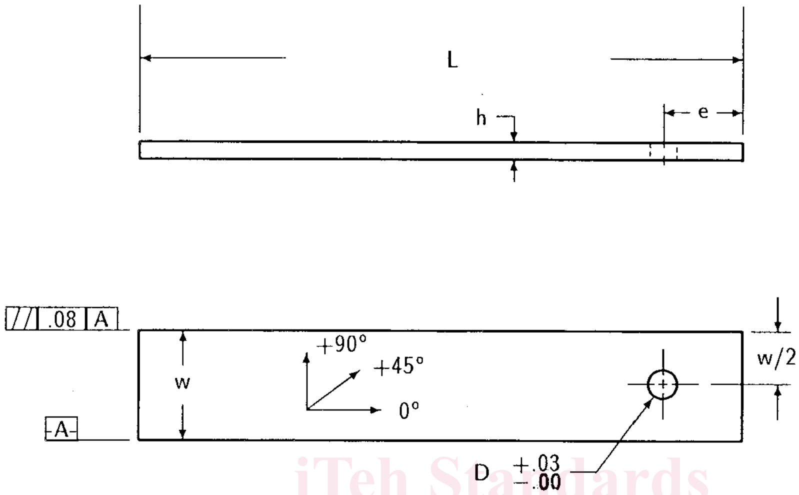
[8] Variations in hole clearance and fastener torque are allowed if recorded.

DRAWING NOTES:

1. INTERPRET DRAWING IN ACCORDANCE WITH ANSI Y14.5M-1982, SUBJECT TO THE FOLLOWING:
2. ALL DIMENSIONS IN MILLIMETRES WITH DECIMAL TOLERANCES AS FOLLOWS:

NO DECIMAL	.X	.XX
± 3	± 1	± .3

3. ALL ANGLES HAVE TOLERANCE OF ± .5°.
4. PLY ORIENTATION DIRECTION TOLERANCE RELATIVE TO -A- IS RECOMMENDED TO BE WITHIN ± .5°. (See Section 6.1.)
5. FINISH ON MACHINED EDGES NOT TO EXCEED 1.6√ (SYMBOLOGY IN ACCORDANCE WITH ASA B46.1, WITH ROUGHNESS HEIGHT IN MICROMETRES.)
6. VALUES TO BE PROVIDED FOR THE FOLLOWING, SUBJECT TO ANY RANGES SHOWN ON THE FIELD OF DRAWING: MATERIAL, LAY-UP, PLY ORIENTATION REFERENCE RELATIVE TO -A-, OVERALL LENGTH, HOLE DIAMETER, AND COUPON THICKNESS.



Parameter	Standard Dimension, mm
fastener or pin diameter, d	6 +0.00/−0.03
hole diameter, D	6 +0.03/−0.00
thickness range, h	3-5
length, L	135
width, w	36 ±1
edge distance, e	18 ±1
countersink	none

FIG. 1 Double-Shear Test Specimen Drawing (SI)

Parameter	Standard	Variation
Loading condition:	double-shear	none
Mating material:	steel fixture	none
Number of holes:	1	none
Countersink:	none	none
Fit:	tight	any, if documented
Fastener torque:	2.2–3.4 N·m [20–30 lbf-in.]	any, if documented
Laminate:	quasi-isotropic	any, if documented
Fastener diameter:	6 mm [0.250 in.]	any, if documented
Edge distance ratio:	3	any, if documented
Pitch distance ratio:	6	any, if documented
D/h ratio:	1.2–2	any, if documented

4.2 *Procedure B, Single Shear*:

4.2.1 The flat, constant rectangular cross-section coupon is composed of two like halves fastened together through one or two centerline holes located near one end of each half, as shown in the coupon drawings of Figs. 5 and 6. The ends of the coupon are gripped in the jaws of a test machine and loaded in tension. The eccentricity in applied load that would otherwise result is minimized by a doubler bonded to each grip end of the coupon, resulting in a load line-of-action along the interface between the coupon halves, through the centerline of the hole(s).

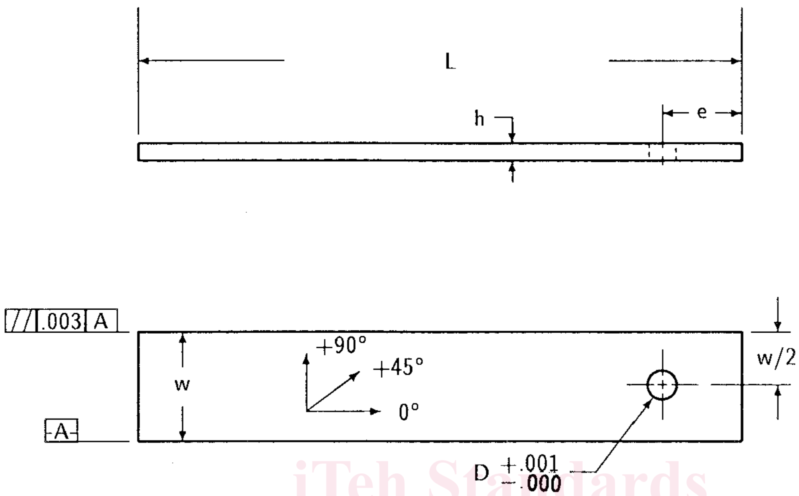
4.2.2 Both the applied load and the associated deformation of the hole(s) are monitored. The deformation of the hole(s) is normalized by the hole diameter (a factor of two used to adjust for hole deformation occurring in the two halves) to result in an effective bearing strain. Likewise, the applied load is normalized by the projected hole area to yield an effective bearing stress. The coupon is loaded until a load maximum has clearly been reached, whereupon the test is terminated so as to prevent masking of the true failure mode by large-scale hole distortion, in order to provide a more representative failure mode assessment. Bearing stress versus bearing strain for the entire loading regime is plotted, and failure mode noted. The ultimate bearing strength of the material is determined from the maximum load carried prior to test termination.

4.2.3 The standard test configuration for this procedure does not allow any variation of the major test parameters. However, the following variations in configuration are allowed, but can be considered as being in accordance with this test method only as long as the values of all variant test parameters are prominently documented with the results.

DRAWING NOTES:
1. INTERPRET DRAWING IN ACCORDANCE WITH ANSI Y14.5M-1982, SUBJECT TO THE FOLLOWING:
2. ALL DIMENSIONS IN INCHES WITH DECIMAL TOLERANCES AS FOLLOWS:

.X	.XX	.XXX
± .1	± .03	± .01

3. ALL ANGLES HAVE TOLERANCE OF ± .5°.
4. PLY ORIENTATION DIRECTION TOLERANCE RELATIVE TO -A- IS RECOMMENDED TO BE WITHIN ± .5°. (See Section 6.1.)
5. FINISH ON MACHINED EDGES NOT TO EXCEED 64√ (SYMBOLOGY IN ACCORDANCE WITH ASA B46.1, WITH ROUGHNESS HEIGHT IN MICROINCHES.)
6. VALUES TO BE PROVIDED FOR THE FOLLOWING, SUBJECT TO ANY RANGES SHOWN ON THE FIELD OF DRAWING: MATERIAL, LAY-UP, PLY ORIENTATION REFERENCE RELATIVE TO -A-, OVERALL LENGTH, HOLE DIAMETER, AND COUPON THICKNESS.



Parameter	Standard Dimension, in.
fastener or pin diameter, d	0.250 +0.000/−0.001
hole diameter, D	0.250 +0.001/−0.000
thickness range, h	0.125-0.208
length, L	5.5
width, w	1.5 ±0.03
edge distance, e	0.75 ±0.03
countersink	none

FIG. 2 Double-Shear Test Specimen Drawing (inch-pound)

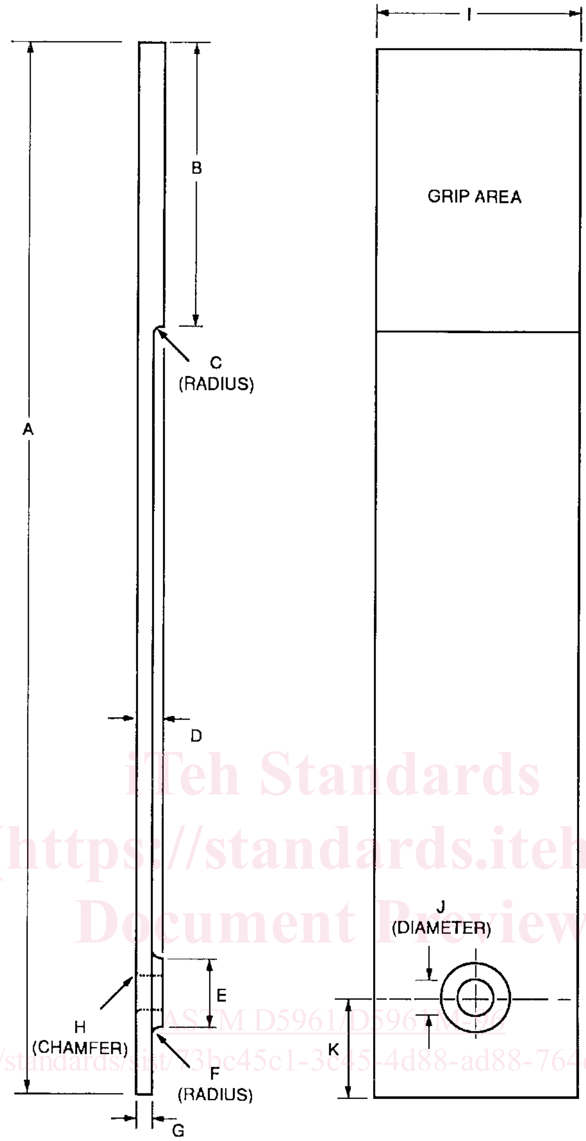
Parameter	Standard	Variation
Loading condition:	single-shear	none
Number of holes:	1	1 or 2
Countersunk holes:	no	yes, if documented
Grommets:	no	yes, if documented
Mating material:	same laminate	any, if documented
Fit:	tight	any, if documented
Fastener torque:	2.2–3.4 N·m [20–30 lbf-in.]	any, if documented
Laminate:	quasi-isotropic	any, if documented
Fastener diameter:	6 mm [0.250 in.]	any, if documented
Edge distance ratio:	3	any, if documented
Pitch distance ratio:	6	any, if documented
D/h ratio:	1.2–2	any, if documented

5. Significance and Use

5.1 This test method is designed to produce bearing response data for material specifications, research and development, quality assurance, and structural design and analysis. The standard configuration for each procedure is very specific and is intended primarily for development of quantitative double- and single-shear bearing response data for material comparison and specification. Procedure A, the double-shear configuration, with a single fastener, is particularly recommended for basic material evaluation and comparison. Procedure B, the single-shear, single- or double-fastener configuration is more useful in evaluation of specific joint configurations. The variants of either procedure provide flexibility in the conduct of the test, allowing adaptation of the test setup to a specific application. However, the flexibility of test parameters allowed by the variants makes meaningful comparison between datasets difficult if the datasets were not tested using identical test parameters.

5.2 General factors that influence the mechanical response of composite laminates and should therefore be reported include the following: material, methods of material preparation and lay-up, specimen stacking sequence, specimen preparation, specimen conditioning, environment of testing, specimen alignment and gripping, speed of testing, time at temperature, void content, and volume percent reinforcement.

5.3 Specific factors that influence the bearing response of composite laminates and should therefore be reported include not only the loading method (either Procedure A or B) but the following: (for both procedures) edge distance ratio, pitch distance ratio, diameter to thickness ratio, fastener torque, fastener or pin material, fastener or pin clearance; and (for Procedure B only) countersink angle and depth of countersink,



Recommended Material: 17-4PH Stainless Steel, 1 GPa [145 ksi] yield											
	A	B	C	D	E	F	G	H	I	J	K
mm	200	50	2	5	13	2	3	1	36	6	20
inch	7.75	2.00	0.06	0.20	0.50	0.06	0.12	0.04	1.50	0.25	0.75

FIG. 3 Fixture Loading Plate for Procedure A (2 Req'd)

type of grommet (if used), type of mating material, and number of fasteners. Properties, in the test direction, which may be obtained from this test method include the following:

5.3.1 Ultimate bearing strength,

5.3.2 Bearing chord stiffness,

5.3.3 Offset bearing strength, and

5.3.4 Bearing stress/bearing strain curve.

6. Interferences

6.1 *Material and Specimen Preparation*—Bearing response is sensitive to poor material fabrication practices (including lack of control of fiber alignment, damage induced by improper coupon machining (especially critical is hole preparation), and torqued fastener installation. Fiber alignment relative to the specimen coordinate axis should be maintained as carefully as possible, although there is currently no standard procedure to ensure or determine this alignment. A practice that has been found satisfactory for many materials is the addition of small amounts of tracer yarn to the prepreg parallel to the 0° direction, added either as part of the prepreg production or as part of panel fabrication. See Guide D 5687/D 5687M for further information on recommended specimen preparation practices.

6.2 *Restraining Surfaces*—The degree to which out-of-plane hole deformation is possible, due to lack of restraint by the fixture or the fastener, has been shown to affect test results in some material types.

6.3 *Cleanliness*—The degree of cleanliness of the mating