Designation: D7248/D7248M – 12

Standard Test Method for Bearing/Bypass Interaction Response of Polymer Matrix Composite Laminates Using 2-Fastener Specimens[1]

This standard is issued under the fixed designation D7248/D7248M; 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 uniaxial bearing/bypass interaction response of multi-directional polymer matrix composite laminates reinforced by high-modulus fibers by either double-shear tensile loading (Procedures A and C) or single-shear tensile or compressive loading (Procedure B) of a two-fastener specimen. The scope of this test method is limited to net section (bypass) failure modes. Standard specimen configurations using fixed values of test parameters are described for each procedure. A number of test parameters may be varied within the scope of the standard, provided that the parameters are fully documented in the test report. The composite material forms are limited to continuous-fiber or discontinuous-fiber (tape or fabric, or both) reinforced composites for which the laminate is balanced and symmetric with respect to the test direction. The range of acceptable test laminates and thicknesses are described in 8.2.1.

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

1.3 The two-fastener test configurations described in this test method are similar to those in Test Method D5961/D5961M as well as those used by industry to investigate the bearing portion of the bearing/bypass interaction response for bolted joints, where the specimen may produce either a bearing failure mode or a bypass failure mode. Should the test specimen fail in a bearing failure mode rather than the desired bypass mode, then the test should be considered to be a bearing dominated bearing/bypass test, and the data reduction and reporting procedures of Test Method D5961/D5961M should be used instead of those given in this standard.

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 may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
D883 Terminology Relating to Plastics
D2584 Test Method for Ignition Loss of Cured Reinforced Resins
D2734 Test Methods for Void Content of Reinforced Plastics
D3171 Test Methods for Constituent Content of Composite Materials
D3878 Terminology for Composite Materials
D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
D5687/D5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation
D5766/D5766M Test Method for Open-Hole Tensile Strength of Polymer Matrix Composite Laminates
D5961/D5961M Test Method for Bearing Response of Polymer Matrix Composite Laminates
D6484/D6484M Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates
D6742/D6742M Practice for Filled-Hole Tension and Compression Testing of Polymer Matrix Composite Laminates
E4 Practices for Force Verification of Testing Machines

[1] This test method 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.

E6 Terminology Relating to Methods of Mechanical Testing
E83 Practice for Verification and Classification of Extensometer Systems
E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E251 Test Methods for Performance Characteristics of Metallic Bonded Resistance Strain Gages
E456 Terminology Relating to Quality and Statistics
E1237 Guide for Installing Bonded Resistance Strain Gages
E1309 Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases
E1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases

2.2 *Other Document:*

MIL-HDBK-17 Polymer Matrix Composites, Vol 1, Section 7[3]

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 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 documents.

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 *gross bypass stress, f^{gr_byp}* [*ML*-1*T*-2], *n*—the gross bypass stress for tensile loadings is calculated from the total force bypassing the fastener hole.

3.2.2 *net bypass stress, f^{net_byp}* [*ML*-1*T*-2], *n*—the net bypass stress for tensile loading is calculated from the force bypassing the fastener hole minus the force reacted in bearing at the fastener.

NOTE 2—For compressive loadings the gross and net bypass stresses are equal and are calculated using the force that bypasses the fastener hole (since for the compressive loading case the bearing stress reaction is on the same side of the fastener as the applied force, the force reacted in bearing does not bypass the fastener hole).

NOTE 3—Several alternate definitions for gross and net bypass stress have been used historically in the aerospace industry. Comparison of data from tests conforming to this standard with historical data may need to account for differences in the bypass definitions.

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

3.2.4 *bearing chord stiffness, E^{br}* [*ML*-1*T*-2], *n*—the chord stiffness between two specific bearing stress or bearing strain points in the linear portion of the bearing stress/bearing strain curve.

3.2.5 *bearing force, P* [MLT^2], *n*—the in-plane force transmitted by a fastener to a specimen at the fastener hole.

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

3.2.7 *bearing strength, $F_x^{br\_byp}$* [*ML*-1*T*-2], *n*—the value of bearing stress occurring at the point of bypass (net section) failure.

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

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

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

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

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

3.2.11 *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.

3.2.12 *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.

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

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

3.2.13.1 *Discussion*—The width to diameter ratio may be either a nominal value determined from nominal dimensions or an actual value, determined as the ratio of the actual specimen width to the actual hole diameter.

3.2.14 *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 force capability of a bearing specimen.

3.2.15 *ultimate gross bypass strength, $F_x^{gr\_byp}$* [*ML*-1*T*-2], *n*—the value of gross bypass stress, in the direction specified by the subscript, at the maximum force capability of the specimen.

[3] Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, http://dodssp.daps.dla.mil.

3.2.16 *ultimate net bypass strength,* $F_x^{net\_byp}$ [ML-1T-2], *n*—the value of net bypass stress, in the direction specified by the subscript, at the maximum force capability of the specimen.

3.3 *Symbols:*

A = cross-sectional area of a specimen

CV = coefficient of variation statistic of a sample population for a given property (in percent)

d = fastener or pin diameter

D = specimen hole diameter

e = distance, parallel to applied force, from hole center to end of specimen; the edge distance

E_x^{br} = bearing chord stiffness in the test direction specified by the subscript

f = distance, parallel to applied force, from hole edge to end of specimen

$F_x^{br\_byp}$ = bearing stress at the ultimate bypass strength in the test direction specified by the subscript

$F_x^{gr\_byp\_c}$ = ultimate compressive gross bypass strength in the test direction specified by the subscript

$F_x^{gr\_byp\_t}$ = ultimate tensile gross bypass strength in the test direction specified by the subscript

$F_x^{net\_byp\_c}$ = ultimate compressive net bypass strength in the test direction specified by the subscript

$F_x^{net\_byp\_t}$ = ultimate tensile net bypass strength in the test direction specified by the subscript

g = distance, perpendicular to applied force, from hole edge to shortest edge of specimen

h = specimen thickness

k = calculation factor used in bearing equations to distinguish single-fastener tests from double-fastener tests

L_g = extensometer gage length

n = number of specimens per sample population

P = force carried by test specimen

P^f = force carried by test specimen at failure

P^{max} = maximum force carried by test specimen prior to failure

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

w = specimen width

x_i = test result for an individual specimen from the sample population for a given property

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

δ = extensional displacement

ε = general symbol for strain, whether normal strain or shear strain

ε^{br} = bearing strain

σ^{br} = bearing stress

w = specimen width

d_{csk} = countersink depth

d_{fl} = countersink flushness (depth or protrusion of the fastener in a countersunk hole)

4. Summary of Test Method

4.1 *Bearing/Bypass Procedures*—Definition of the uniaxial bearing/bypass interaction response requires data for varying

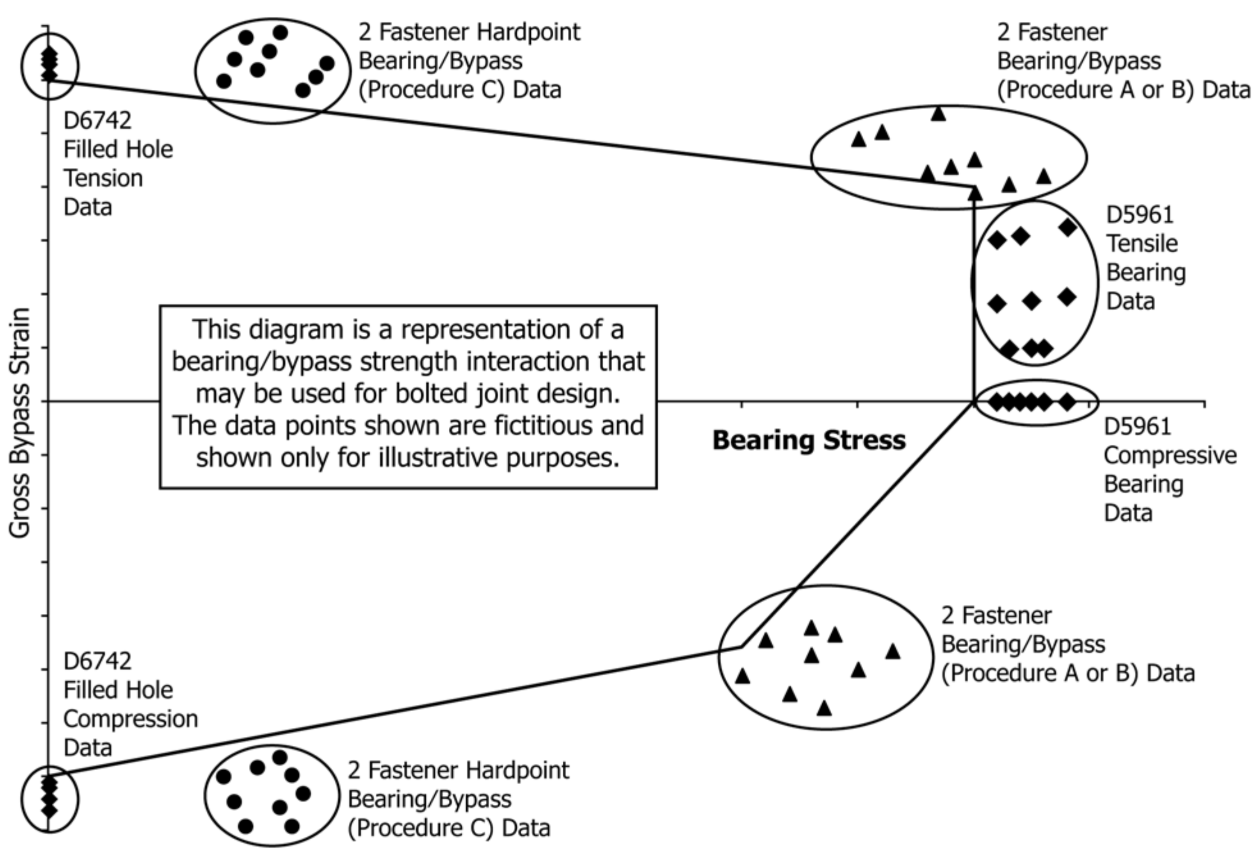


FIG. 1 Illustration of FHT, FHC, Bearing and Bearing/Bypass Bolted Joints Data and Bearing/Bypass Interaction Diagram (Refs 1-3)

amounts of bearing and bypass forces at a fastener hole. Fig. 1 shows a typical composite laminate bearing/bypass interaction diagram (Refs **1-3**),[4] along with illustrative data from various test types. Data from Practice D6742/D6742M and Test Method D5961/D5961M define the 100 % bypass and bearing ends of the interaction diagram. Rationale for the baseline bearing/bypass specimen geometry and fastener torques are given in 6.7 and 6.8. Procedures A and B of this test method provide data in the bypass/high bearing region, while Procedure C provides data in the bypass/low bearing region. More complicated test setups have been used to develop data across the full range of bearing/bypass interaction. This test method is limited to cases where the bearing and bypass loads are aligned in the same direction. It is also limited to uniaxial tensile or compressive bypass loads. Test procedures for cases where the bearing and bypass loads act at different directions, or cases with biaxial or shear bypass loads are outside the scope of this standard.

4.1.1 Ultimate strength for all procedures is calculated based on the specimen gross cross-sectional area, disregarding the presence of the hole. While the hole causes a stress concentration and reduced net section, it is common industry practice to develop notched design allowable strengths based on gross section stress to account for various stress concentrations (fastener holes, free edges, flaws, damage, and so forth) not explicitly modeled in the stress analysis. This is consistent with the ASTM D30 test methods for open and filled hole tension and compression strength (Test Methods D5766/D5766M, D6484/D6484M, and Practice D6742/D6742M).

4.2 *Procedure A, Bypass/High Bearing Double Shear:*

4.2.1 A flat, constant rectangular cross-section test specimen with two centerline holes located near the end of the specimen, as shown in the test specimen drawings of Figs. 2 and 3, is loaded at the hole in bearing. The bearing force is normally applied through a close-tolerance, lightly torqued fastener (or pin) that is reacted in double shear by a fixture similar to that shown in Figs. 4 and 5. The bearing force is created by pulling the assembly in tension in a testing machine. The difference from a standard "bearing" test is that the expected primary failure mode is net section tension, rather than a bearing mode.

4.2.2 Both the applied force and the associated deformation of the hole are monitored. The applied force is normalized by the projected hole area to create an effective bearing stress. The specimen is loaded until a two part failure is achieved.

NOTE 4—Should the test specimen fail in a bearing failure mode rather than the desired bypass (net tension or compression) mode, then the test should be considered to be a bearing dominated bearing/bypass test, and the data reduction and reporting procedures of Test Method D5961/D5961M should be used instead of those given in this standard.

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

4.2.3 The standard test configuration for this procedure has defined values for the major test parameters. However, the following variations in configuration are allowed and can be considered as being in accordance with this test method as long as the values of all variant test parameters are prominently documented with the results.

Parameter	Standard	Variation
Loading condition	double-shear	none
Loading type	tensile	none
Mating material	steel fixture	any, if documented
Number of holes	2	3
Countersink	none	none
Hole fit	tight	any, if documented
Fastener torque	9.0-10.7 N·m [90-95 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
w/D ratio	5	any, if documented
D/h ratio	1.2-2	any, if documented

4.3 *Procedure B, Bypass/High Bearing Single Shear:*

4.3.1 The flat, constant rectangular cross-section test specimen is composed of two like halves fastened together through two centerline holes located near one end of each half, as shown in the test specimen drawings of Figs. 6 and 7. The eccentricity in applied force that would otherwise result is minimized by a doubler bonded to each grip end of the specimen, resulting in a force line-of-action along the interface between the specimen halves, through the centerline of the hole(s).

4.3.1.1 *Unstabilized Configuration (No Support Fixture)*—The ends of the test specimen are gripped in the jaws of a test machine and loaded in tension.

4.3.1.2 *Stabilized Configuration (Using Support Fixture)*—The test specimen is face-supported in a multi-piece bolted support fixture, as shown in Fig. 8. The test specimen/fixture assembly is clamped in hydraulic wedge grips and the force is sheared into the support fixture and then sheared into the specimen. Either tensile or compressive force may be applied. The stabilization fixture is required for compressive loading. For tensile loading the fixture is optional, but is often used to simulate actual stabilized joint configurations.

4.3.2 Both the applied force and the associated deformation of the hole(s) are monitored. The applied force is normalized by the projected hole area to yield an effective bearing stress. The specimen is loaded until a two part failure is achieved.

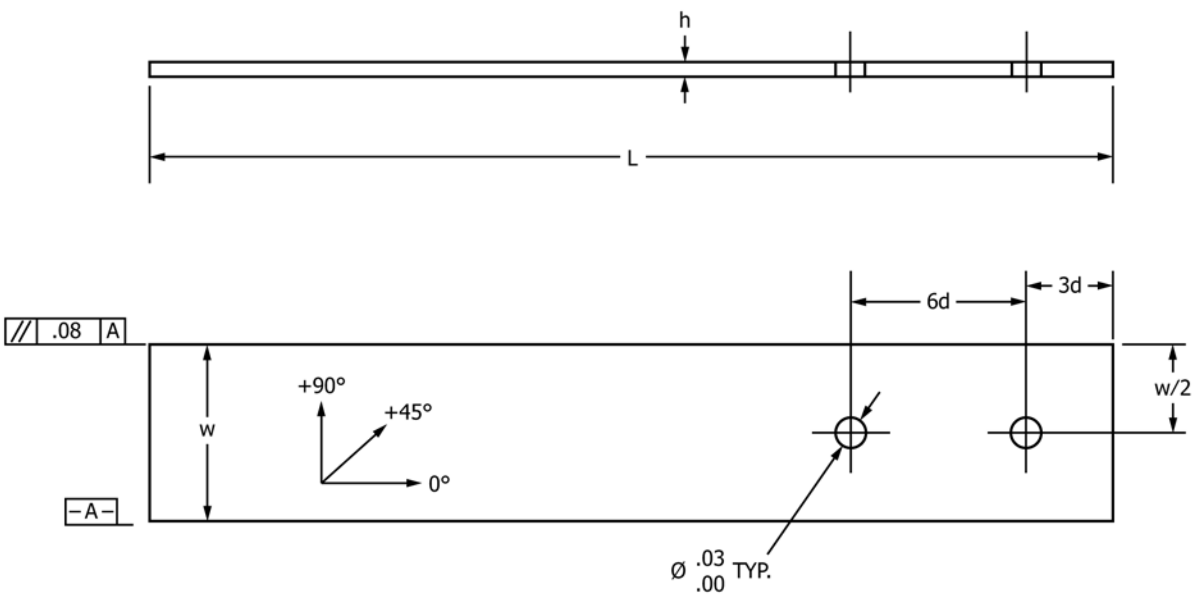
NOTE 5—Should the test specimen fail in a bearing failure mode rather than the desired net tension or compression, then the test should be considered to be a bearing dominated bearing/bypass test, and the data reduction and reporting procedures of Test Method D5961/D5961M should be used instead of those given in this standard.

4.3.3 The standard test configuration for this procedure has defined values for the major test parameters. However, the following variations in configuration are allowed and can be considered as being in accordance with this test method as long

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

NO DECIMAL	.X	.XX X
+/−3	+/−1	+/−.3

3. ALL ANGLES HAVE TOLERANCE OF +/− .5°
4. PLY ORIENTATION DIRECTION TOLERANCE RELATIVE TO $\boxed{-A-}$ WITHIN +/− .5°.
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 $\boxed{-A-}$, OVERALL LENGTH, HOLE DIAMETER, COUNTERSINK DETAILS, COUPON THICKNESS.



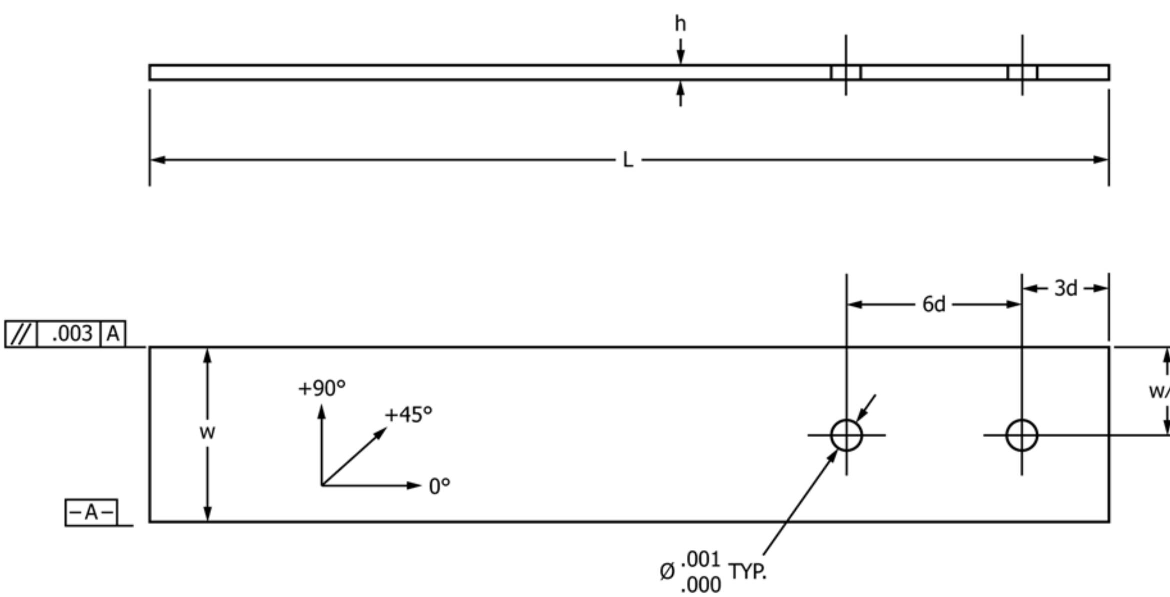
Parameters	Standard Dimensions (mm)
fastener diameter, d	6+0.00/−0.03
hole diameter, Ø	6+0.03/−0.00
thickness range, h	2−5
length, L	200
width, w	30+/−1
edge distance, e	18+/−1
countersink	none

FIG. 2 Double-Shear, Two-Fastener Test Specimen Drawing (SI)

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:

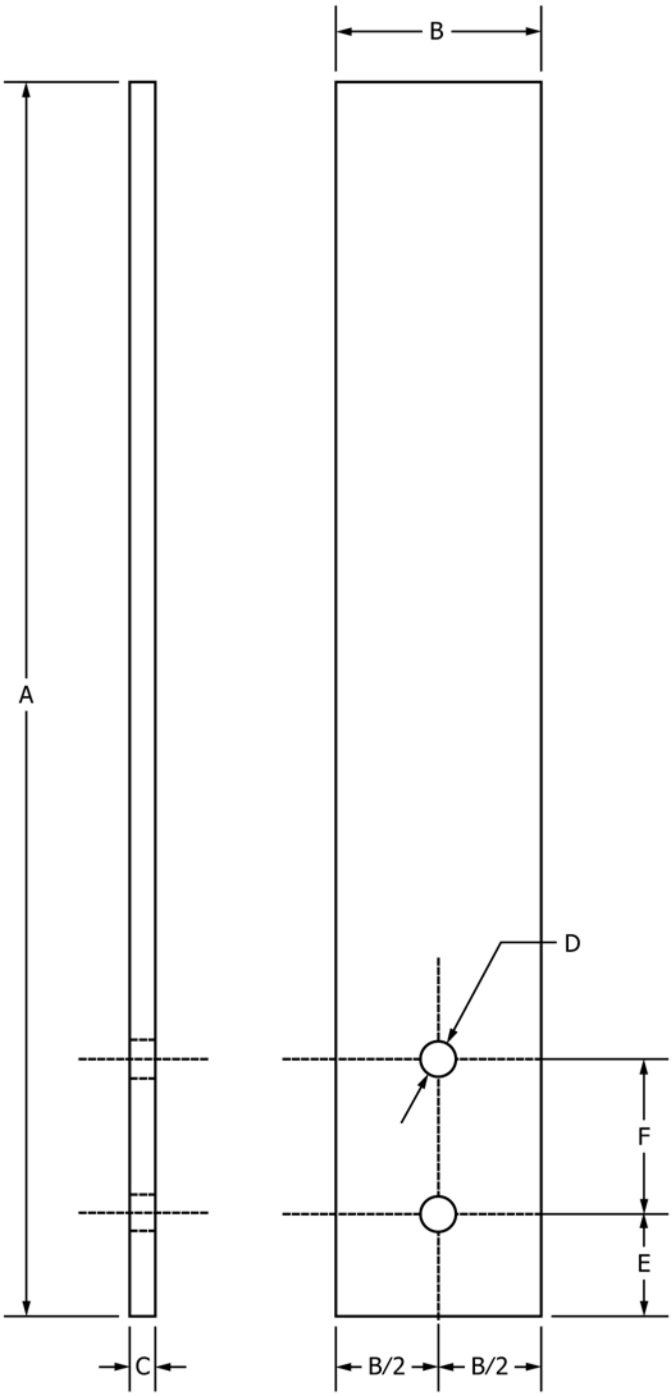
.X	.XX	.XXX
+/–.1	+/–.03	+/–.003

3. ALL ANGLES HAVE TOLERANCE OF +/– .5°.
4. PLY ORIENTATION DIRECTION TOLERANCE RELATIVE TO [–A–] WITHIN +/– .5°.
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, COUNTERSINK DETAILS, COUPON THICKNESS.



Parameters	Standard Dimensions (inches)
fastener diameter, d	0.250+0.000/–0.001
hole diameter, Ø	0.250+0.001/–0.000
thickness range, h	0.080–0.208
length, L	8.00
width, w	1.25+/–0.03
edge distance, e	0.75+/–0.03
countersink	none

FIG. 3 Double-Shear, Two-Fastener Test Specimen Drawing (Inch-Pound)



Recommended Material: 17-4PH Stainless Steel 1 GPa [145 ksi] yield stress						
	A	B	C	D	E	F
mm	200	30	3	6	18	36
inch	8.00	1.25	0.12	0.25	0.75	1.50

FIG. 4 Fixture Loading Plate for Procedure A (2 Required)

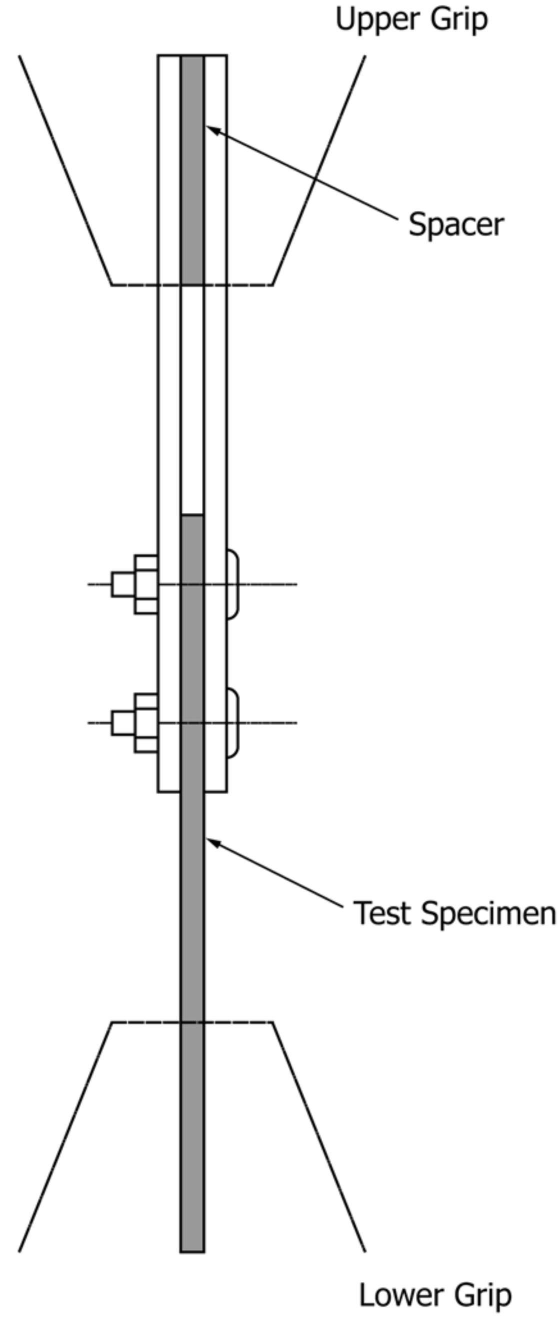


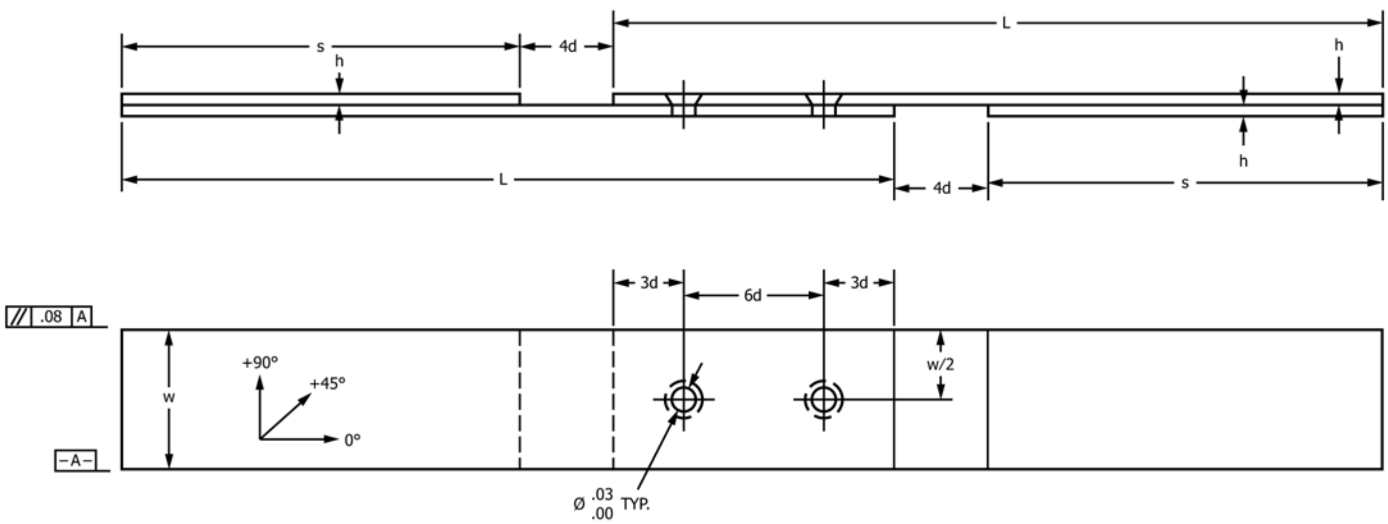
FIG. 5 Fixture Assembly for Procedure A

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 MM WITH DECIMAL TOLERANCES AS FOLLOWS:

NO DECIMAL	.X	.XX X
+/–3	+/–1	+/–.3

3. ALL ANGLES HAVE TOLERANCE OF +/– .5°.
4. PLY ORIENTATION DIRECTION TOLERANCE RELATIVE TO –A– WITHIN +/– .5°.
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, COUNTERSINK DETAILS, COUPON THICKNESS, DOUBLER MATERIAL, DOUBLER ADHESIVE.



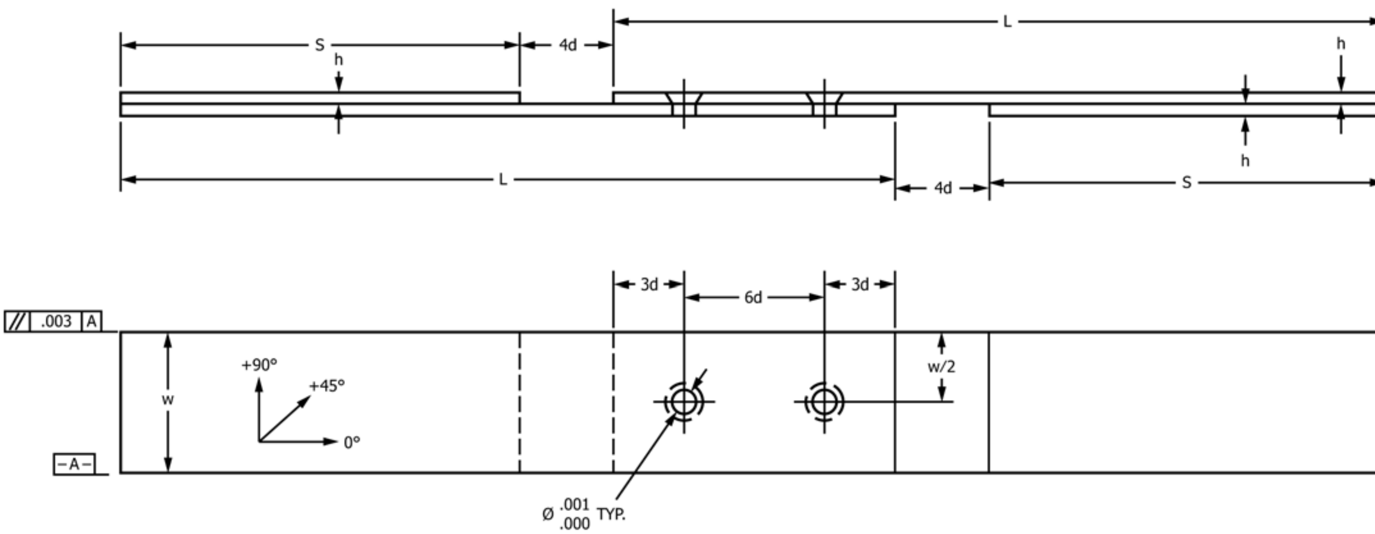
Parameters	Standard Dimensions of Specimen (mm) without support fixture	Standard Dimensions of Specimen (mm) with support fixture
fastener diameter, d	6 + 0.00/–0.03	6 + 0.00/–0.03
hole diameter, Ø	6 + 0.03/–0.00	6 + 0.03/–0.00
thickness range, h	2–5	2–5
length, L	210	210
width, w	30 +/– 1	30 +/– 1
edge distance, e	18 +/– 1	18 +/– 1
countersink	none (optional)	none (optional)
doubler length, s	108	108

FIG. 6 Single-Shear, Two-Fastener Test Specimen Drawing (SI)

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	+/–.003

3. ALL ANGLES HAVE TOLERANCE OF +/– .5°.
4. PLY ORIENTATION DIRECTION TOLERANCE RELATIVE TO $\boxed{-A-}$ WITHIN +/– .5°.
5. FINISH ON MACHINED EDGES NOT TO EXCEED 64 $\surd$ 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 $\boxed{-A-}$, OVERALL LENGTH, HOLE DIAMETER, COUNTERSINK DETAILS, COUPON THICKNESS, DOUBLER MATERIAL, DOUBLER ADHESIVE.



Parameters	Standard Dimensions of Specimen (inches)	
	without support fixture	with support fixture
fastener diameter, d	0.250+0.000/–0.001	0.250+0.000/–0.001
hole diameter, Ø	0.250+0.001/–0.000	0.250+0.001/–0.000
thickness range, h	0.080–0.208	0.080–0.208
length, L	8.25	8.25
width, w	1.25+/–0.03	1.25+/–0.03
edge distance, e	0.75+/–0.03	0.75+/–0.03
countersink	none (optional)	none (optional)
doubler length, s	4.25	4.25

FIG. 7 Single-Shear, Two-Fastener Test Specimen Drawing (Inch-Pound)

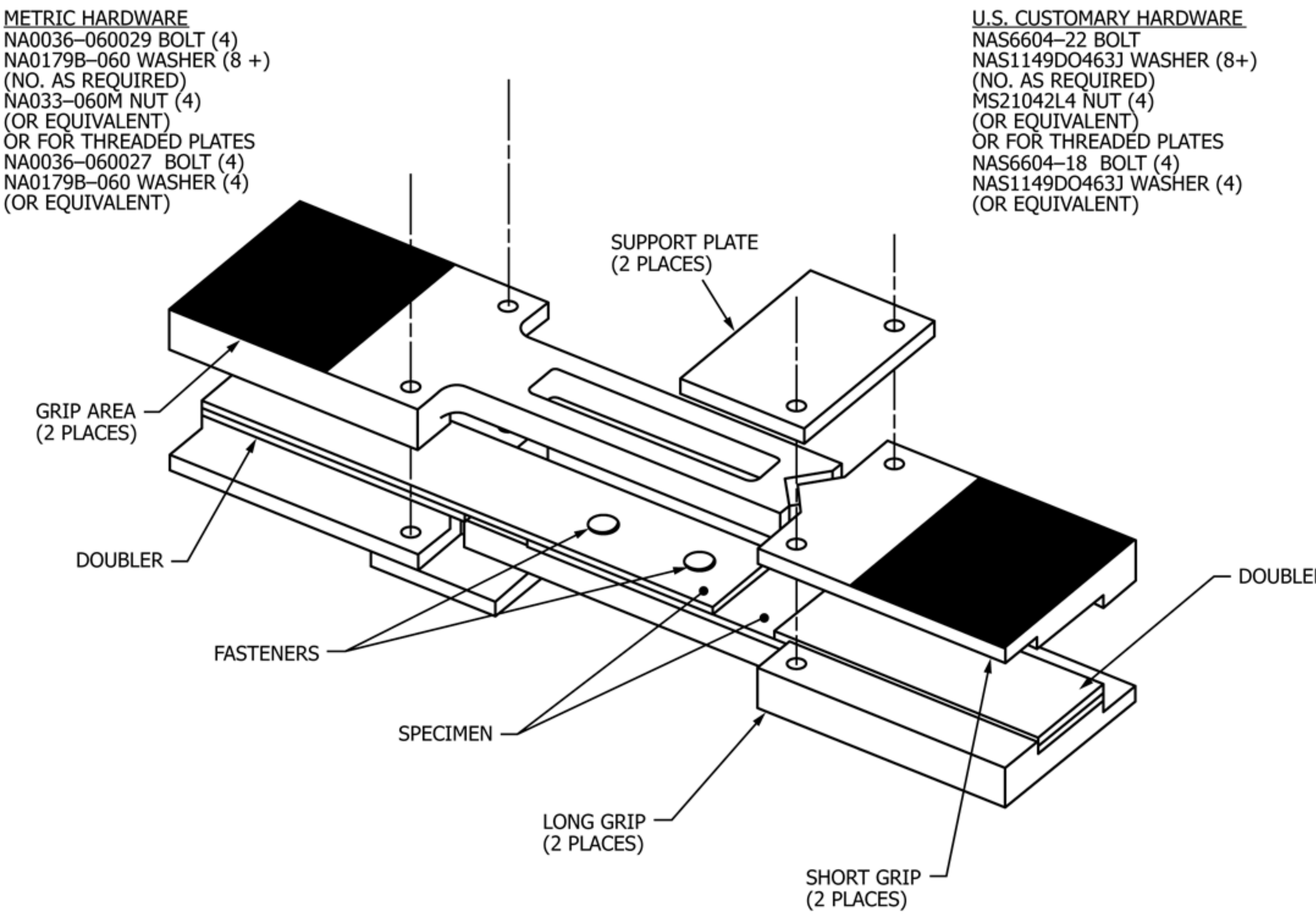


FIG. 8 Support Fixture Assembly for Procedure B (for details of the Support Fixture see Test Method D5961/D5961M)

Parameter	Standard	Variation
Loading condition	single-shear	none
Loading type	tensile	compressive
Support fixture	no for tensile load yes for compressive load	yes, if documented
Number of holes	2	3
Countersunk holes	no	yes, if documented
Grommets	no	yes, if documented
Mating material	same laminate	any, if documented
Hole fit	tight	any, if documented
Fastener torque	9.0-10.7 N·m [80-95 lbf-in.] for tensile load 2.2-3.4 N·m [20-30 lbf-in.] for compressive load	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
w/D ratio	5	any, if documented
D/h ratio	1.2-2	any, if documented

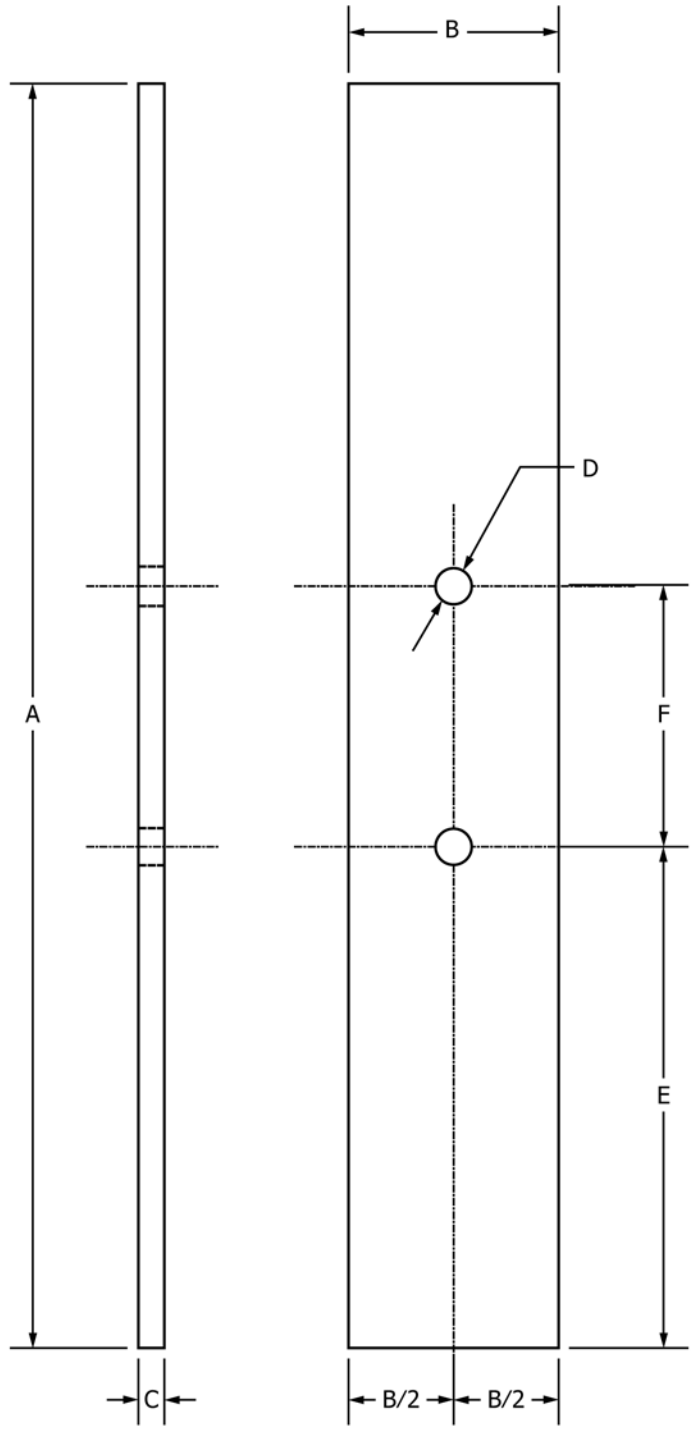
4.4 *Procedure C, Bypass/Low Bearing Double Shear:*

4.4.1 A flat, constant rectangular cross-section test specimen with two centerline holes located in the middle of the specimen, as shown in the test specimen drawing of Fig. 9. Two doubler plates, Fig. 10, are attached to the specimen as shown in Fig. 11 to act as a "hardpoint" which induces bearing forces in the test specimen and plates. The ends of the test specimen are gripped in the jaws of a test machine and loaded in tension or compression.

4.4.1.1 *Unstabilized Configuration (No Support Fixture)*—The ends of the test specimen are gripped in the jaws of a test machine and loaded in tension.

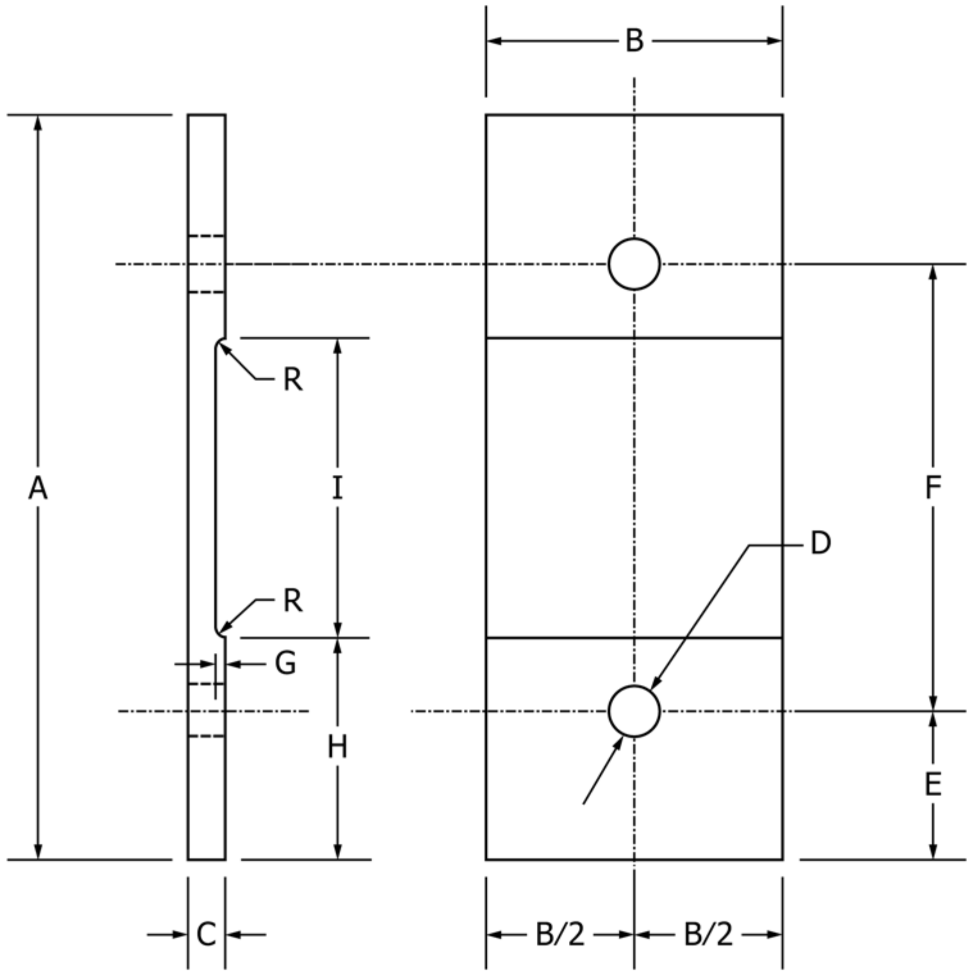
4.4.1.2 *Stabilized Configuration (Using Support Fixture)*—The test specimen is face-supported in a multi-piece bolted support fixture, as shown in Fig. 8. The test specimen/fixture assembly is clamped in hydraulic wedge grips and the force is sheared into the support fixture and then sheared into the specimen. Tensile or compressive force is applied. The stabilization fixture is required for compressive loading and is optional for tensile loading .

4.4.2 The amount of force that is transferred through the double plates is determined from the measurement of strain in the plates and test specimen. The force-strain response of the doubler plates and test specimen must be determined using a determinant test setup prior to the bearing/bypass test. Due to uncertainties in the hole tolerances and fastener flexibilities, calculation of the doubler plate forces is not sufficiently



	A	B	C	D	E	F
mm	344	36	3	6	147	50
inch	13.50	1.50	0.12	0.25	5.75	2.00

FIG. 9 Double-Shear, 2-Fastener Hardpoint Test Specimen Drawing



Recommended Material: 17-4PH Stainless Steel, 1.0 GPa [145 ksi] yield stress									
	A	B	C	D	E	F	G	H	I
mm	90	36	5	6	20	50	1.5	30	30
inch	3.5	1.50	0.20	0.25	0.75	2.00	0.06	1.12	1.25

FIG. 10 Procedure C Doubler Plate Drawing

reliable for data reduction (equations are provided in this test method for estimating the fastener loads for the purposes of specimen design).

4.4.3 Both the applied force and the associated deformation of the hole(s) are monitored. The applied force is normalized by the projected hole area to yield an effective bearing stress. The specimen is loaded until a two part failure is achieved.

4.4.4 The standard test configuration for this procedure has defined values for the major test parameters. However, the following variations in configuration are allowed and can be considered as being in accordance with this test method as long as the values of all variant test parameters are prominently documented with the results.

Parameter	Standard	Variation
Loading condition	double-shear	none
Loading type	tensile	compressive
Doubler plate material	steel	yes, if documented
Number of holes	2	none
Countersunk holes	no	none
Hole fit	tight	any, if documented
Fastener torque	9.0-10.7 N·m [80-95 lbf-in.] for tensile load 2.2-3.4 N·m [20-30 lbf-in.] for compressive load	any, if documented
Laminate	quasi-isotropic	any, if documented
Fastener diameter	6 mm [0.250 in.]	any, if documented
w/D ratio	5	any, if documented
D/h ratio	1.2-2	any, if documented

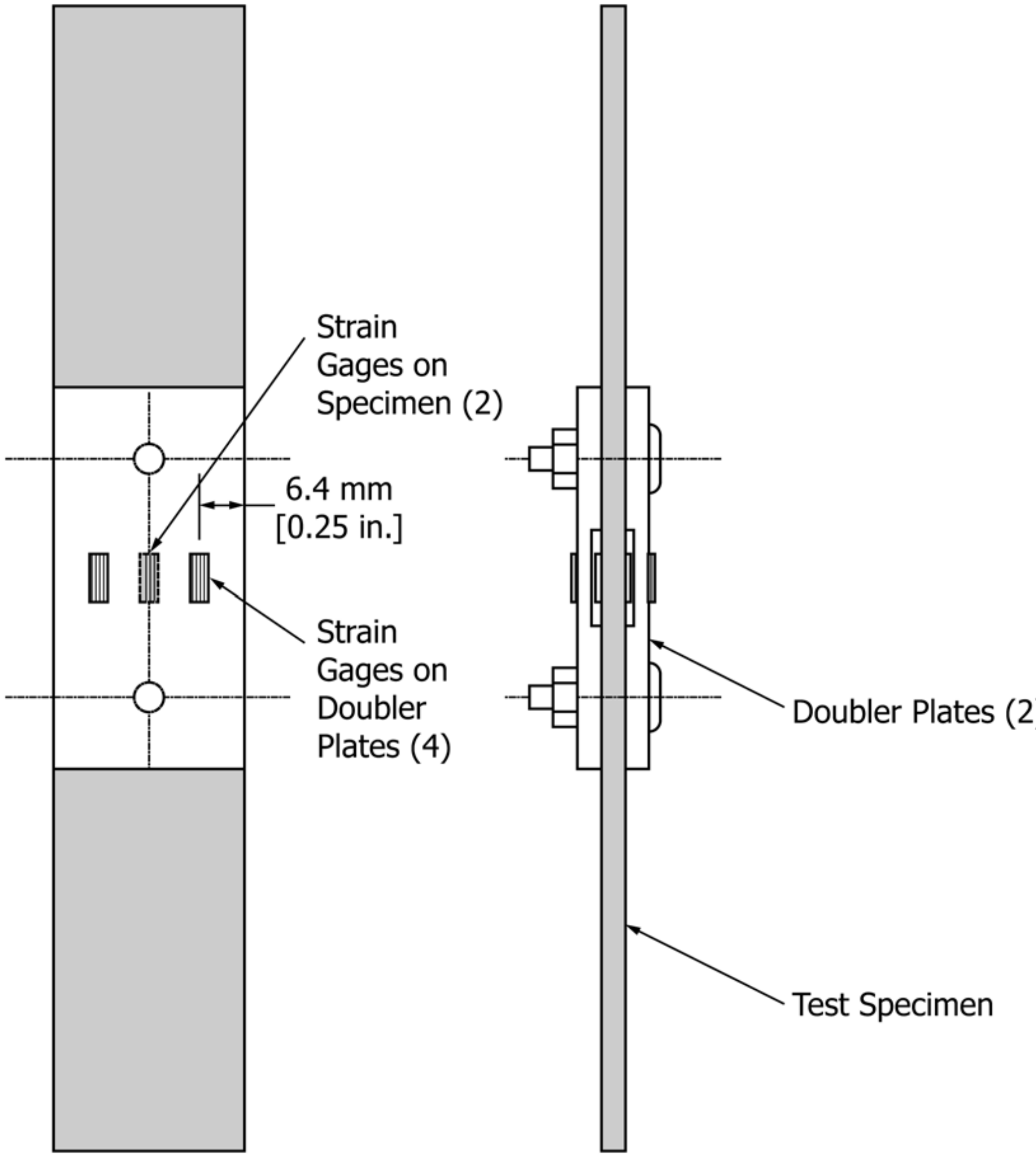


FIG. 11 (a) Tensile Loading—Procedure C Test Specimen and Doubler Plate Assembly

5. Significance and Use

5.1 This test method is designed to produce bearing/bypass interaction response data for research and development, and for structural design and analysis. The standard configuration for each procedure is very specific and is intended as a baseline configuration for developing structural design data.

5.1.1 *Procedure A,* the bypass/high bearing double-shear configuration is recommended for developing data for specific applications which involve double shear joints.

5.1.2 *Procedure B,* the bypass/high bearing single-shear configuration is more useful in the evaluation of typical joint configurations. The specimen may be tested in either an unstabilized (no support fixture) or stabilized configuration. The unstabilized configuration is intended for tensile loading and the stabilized configuration is intended for compressive loading. These configurations, particularly the stabilized configuration, have been extensively used in the development of design allowables data. 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.

5.1.3 *Procedure C,* the bypass/low bearing double-shear hardpoint configuration is recommended for determining the effect of low bearing stress levels on bypass strength. While a similar single-shear configuration could be tested, there is insufficient experience with a single-shear configuration to recommend its use at this time.

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,

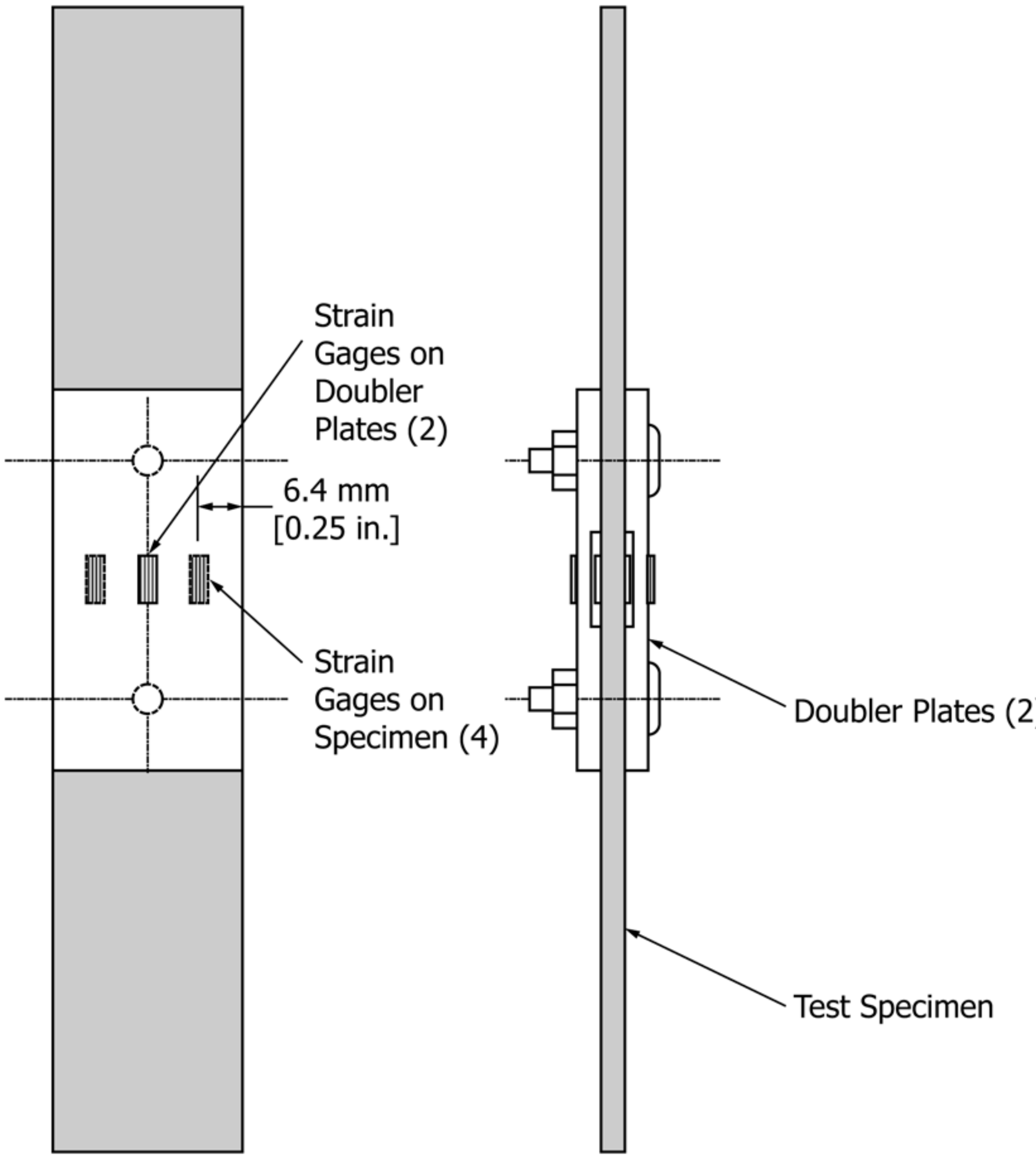


FIG. 11 (b) Compressive Loading—Procedure C Test Specimen and Doubler Plate Assembly *(continued)*

specimen alignment and gripping, speed of testing, time held at test temperature, void content, and volume percent reinforcement.

5.3 Specific factors that influence the bearing/bypass interaction response of composite laminates and should therefore be reported include not only the loading method (either Procedure A or B) and loading type (tension or compression) but the following (for both procedures): edge distance ratio, width to diameter 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, type of grommet (if used), type of mating material, and type of support fixture (if used). Properties, in the test direction, which may be obtained from this test method include the following:

5.3.1 Filled hole tensile bearing/bypass strength.

5.3.2 Filled hole compressive bearing/bypass strength.

5.3.3 Bearing stress/bypass strain curve.

6. Interferences

6.1 *Material and Specimen Preparation*—Bearing/bypass response is sensitive to poor material fabrication practices (including lack of control of fiber alignment), damage induced by improper specimen machining (hole preparation is especially critical), 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 D5687/D5687M 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.

6.3 *Cleanliness*—The degree of cleanliness of the mating surfaces has been found to produce significant variations in test results.

6.4 *Eccentricity (Procedure B only)*—A loading eccentricity is created in single-shear tests by the offset, in one plane, of the line of action of force between each half of the test specimen. This eccentricity creates a moment that, particularly in clearance hole tests, rotates the fastener, resulting in an uneven contact stress distribution through the thickness of the specimen. The effect of this eccentricity upon test results is strongly dependent upon the degree of clearance in the hole, the size of the fastener head, the mating area, the coefficient of friction between the specimen and the mating material, the thickness and stiffness of the specimen, the thickness and stiffness of the mating material, and the configuration of the support fixture. Consequently, results obtained from this procedure where the support fixture is used may not accurately replicate behavior in other structural configurations.

6.5 *Hole Preparation*—Due to the dominating presence of the filled hole(s), results from this test method are relatively insensitive to parameters that would be of concern in an unnotched tensile or compressive property test. However, since the filled hole(s) dominates the strength, consistent preparation of the hole(s) without damage to the laminate is important to meaningful results. Damage due to hole preparation will affect strength results. Some types of damage, such as delaminations, can blunt the stress concentration due to the hole, increasing the force carrying capacity of the coupon and the calculated strength. Other types of damage can reduce the calculated strength.

6.6 *Fastener-Hole Clearance*—Compressive bearing/bypass results are affected by the clearance arising from the difference between hole and fastener diameters. Clearance can change the observed specimen behavior by delaying the onset of bearing damage. Tensile bearing/bypass results are also affected by clearance, but to a lesser degree than under compressive loads. Hole clearance also effects the proportion of force transferred in each fastener, and the proportions can change as the force is increased during the test. Damage due to insufficient clearance during fastener installation will affect strength results. Countersink flushness (depth or protrusion of the fastener head in a countersunk hole) will affect strength results and may affect the observed failure mode. For these reasons, both the hole and fastener diameters must be accurately measured and recorded. A typical aerospace tolerance on fastener-hole clearance is +75/–0 µm [+0.003/–0.000 in.] for structural fastener holes.

6.7 *Fastener Torque/Pre-load*—Results are affected by the installed fastener pre-load (clamping pressure). Laminates can exhibit significant differences in both failure force and failure mode due to changes in fastener pre-load under both tensile and compressive loading. The critical pre-load condition (that is, either high or low clamping pressure) can vary depending upon the type of loading, the laminate stacking sequence and the desired failure mode. For compressive loaded bearing/bypass, the nominal test configuration uses a relatively low level of fastener installation torque to give conservative results. For tensile loaded bearing/bypass, the nominal test configuration uses a high level of fastener installation torque (full fastener installation torque) since this usually gives conservative results. Fastener torque levels used for bearing/bypass test specimens should correspond to the torque levels that give the most conservative results for corresponding filled hole tension and filled hole compression tests of the same material and layup (see Practice D6742/D6742M).

6.8 *Specimen Geometry*—Results are affected by the ratio of specimen width to hole diameter (w/D); this ratio should be maintained at 5 to avoid bearing failure modes, unless the experiment is investigating the influence of this ratio, or invalid (bearing) failure modes occur. If bearing failures occur with w/D = 5 specimens, then the width should be reduced; with some layups having low bearing capabilities, w/D values as low as 3 may be required to obtain a bypass failure mode. Results may also be affected by the spacing distance between the two fasteners; the baseline distance is equal to 6D. Results may also be affected by the distance between the end hole and the end of the specimen, with small end distances potentially resulting in invalid shear-out failure modes; the baseline end distance to diameter ratio is 3D unless the experiment is investigating the influence of this ratio. Results may also be affected by the ratio of hole diameter to thickness; the preferred ratio is the range from 1.5-3.0 unless the experiment is investigating the influence of this ratio. Results may also be affected by the ratio of countersunk (flush) head depth to thickness; the preferred ratio is the range from 0.0-0.7 unless the experiment is investigating the influence of this ratio. Results may also be affected by the ratio of ungripped specimen length to specimen width; this ratio should be maintained as shown, unless the experiment is investigating the influence of this ratio.

6.9 *Material Orthotropy*—The degree of laminate orthotropy strongly affects the failure mode and measured bearing/bypass strengths. Bearing/bypass strength results should only be reported when appropriate and valid failure modes are observed, in accordance with 11.5.

6.10 *Thickness Scaling*—Thick composite structures do not necessarily fail at the same strengths as thin structures with the same laminate orientation (that is, strength does not always scale directly with thickness). Thus, data gathered using these procedures may not translate directly into equivalent thick-structure properties.

6.11 *Environment*—Results are affected by the environmental conditions under which the tests are conducted. Laminates tested in various environments can exhibit significant differences in both bearing/bypass strength and failure mode. Experience has demonstrated that elevated temperature, humid environments are generally critical for bearing failure modes, while bypass dominated failure modes can be critical at either cold or hot/wet conditions, depending on the material and layup. Therefore, critical environments must be assessed independently for each material system, stacking sequence, and torque condition tested.

6.12 *Fastener Force Ratios*—The ratio of force in each of the two fasteners (Procedures A and B) or the ratio of the force in the doubler plates to the total force (Procedure C) may vary with the applied force level during the test. This variation in load transfer can result from the onset of bearing damage, fastener bending and frictional effects.

7. Apparatus

7.1 *Micrometers*—The micrometer(s) shall use a 4 to 6-mm [0.16 to 0.25-in.] nominal diameter ball-interface on irregular surfaces such as the bag-side of a laminate, and a flat anvil interface on machined edges or very smooth tooled surfaces. The instrument(s) shall have an accuracy of ±2.5 µm [±0.0001 in.] for thickness measurement, and an accuracy of ±25 µm [±0.001 in.] for width measurement.

NOTE 6—The accuracies given above are based on achieving measurements that are within 1 % of the sample width and thickness.

7.2 *Loading Fasteners or Pins*—The fastener (or pin) type shall be specified as an initial test parameter and reported. The assembly torque (if applicable) shall be specified as an initial test parameter and reported. This value may be a measured torque or a specification torque for fasteners with lock-setting features. If washers are utilized, the washer type, number of washers, and washer location(s) shall be specified as initial test parameters and reported. The reuse of fasteners is not recommended due to potential differences in through-thickness clamp-up for a given torque level, caused by wear of the threads or deformation of the locking features.

7.3 *Torque Wrench*—If using a torqued fastener, a torque wrench used to tighten the fastener shall be capable of determining the applied torque to within ±10 % of the desired value.

7.4 *Fixture:*

7.4.1 *Procedure A*—The force shall be applied to the specimen by means of a double-shear clevis similar to that shown in Figs. 4 and 5, using the loading fasteners or pins. The fixture shall allow a bearing strain indicator to monitor the hole deformation relative to the fixture as shown in Fig. 12.

NOTE 7—The double shear loading straps do not have the bosses around the hole as used for the Test Method D5961/D5961M bearing test method in order to more closely simulate actual joint configurations and to simplify the fixture. With flat loading straps the through-thickness clamp-up force will be distributed over a larger area and therefore the specimen is expected to experience greater bearing damage and lower (conservative) bearing/bypass strengths.

7.4.2 *Procedure B*—The force shall be applied to the specimen by means of a mating single-shear attachment (normally identical to the specimen) using two fasteners. The mating material, thickness, edge distance, length, and hole clearance shall be specified as part of the test parameters. The line of action of the force shall be adjusted by specimen doublers to be coincident and parallel to the interface between the test specimen and the joint mate. If the mating attachment is permanently deformed by the test, it shall be replaced after each test, as required. The mating attachment and support fixture (if used) will allow a bearing strain indicator to measure the required hole deformation relative to the mating attachment, as shown in Fig. 12.

7.4.3 *Procedure C*—Doubler plates, Fig. 10, are attached to the test specimen using two fasteners. In some cases it may be desirable to use doubler plates that are more closely matched in stiffness to the test laminate, particularly when testing soft laminate materials or layups. These plates may typically be reused, as the force transferred into the plates is relatively small. The holes in the plates should be examined for bearing deformation after each use and replaced if deformation is observed. If the doubler plates are replaced, the new plates shall be calibrated in accordance with . For tensile tests, two axial strain gages shall be mounted on each doubler plate at the locations shown in Fig. 11a. For compressive tests, one axial strain gage shall be mounted on each doubler plate at the location shown in Fig. 11b.

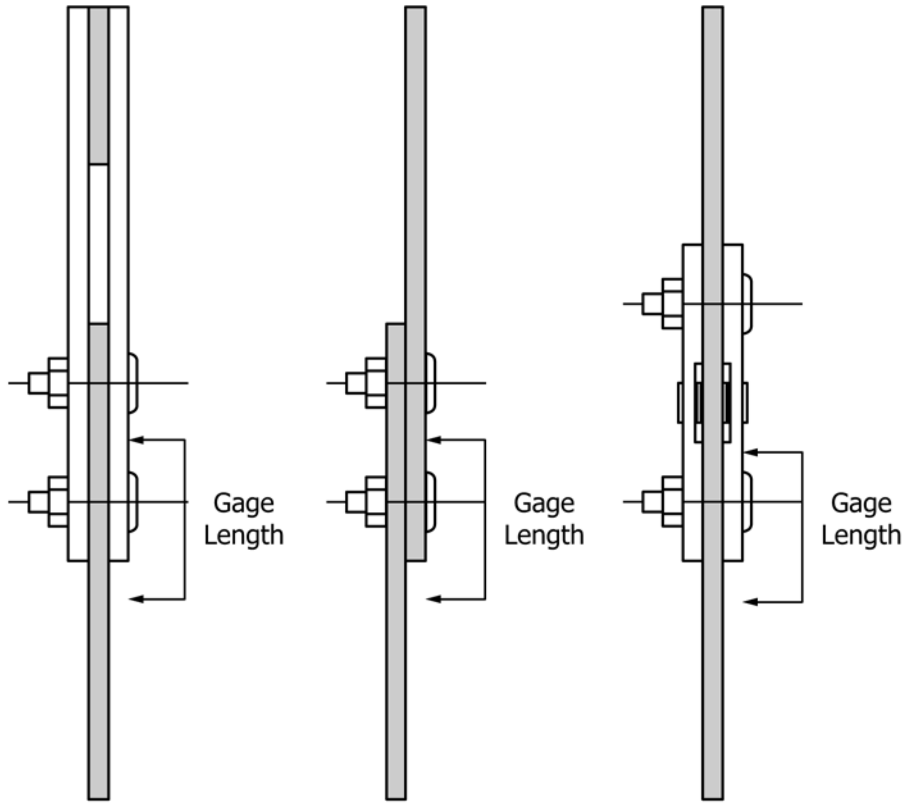
7.5 *Support Fixture (Procedure B and Procedure C with Compressive Loading)*—If compressive loads are applied or if requested in the test plan, a support fixture shall be used to stabilize the specimen. The fixture is a face-supported test fixture as shown in Fig. 8. The fixture consists of two short-grip/long-grip assemblies, two support plates, and stainless steel shims as required to maintain a nominally zero (0.00 to 0.12-mm [0.000 to 0.005-in.] tolerance) gap between the support plates and the long grips. If this gap does not meet the minimum requirement, shim the contact area between the support plate and the short grip with stainless steel shim stock. If the gap is too large, shim between the support plate and the long grip, holding the shim stock on the support plate with tape. The fixture should be checked for conformity to engineering drawings. Each short-grip/long-grip assembly is line-drilled and must be used as a matched set. The threading of the support plate is optional. The fixture is hydraulically gripped on each end and the force is sheared by means of friction through the fixture and into the test specimen. A cutout exists on both faces of the fixture for a thermocouple, fastener(s) and surface-mounted extensometer. The long and short fixtures have an undercut along the corner of the specimen grip area so that specimens are not required to be chamfered and to avoid damage caused by the radius. The fixtures also allow a slight clearance between the fixture and the gage section of the specimen, in order to minimize grip failures and friction effects. This fixture does not allow specimens to be end loaded.

7.5.1 *Support Fixture Details*—The detailed drawings for manufacturing the support fixture are contained in Test Method D5961/D5961M. Other fixtures that meet the requirements of this section may be used. The following general notes apply to these figures:

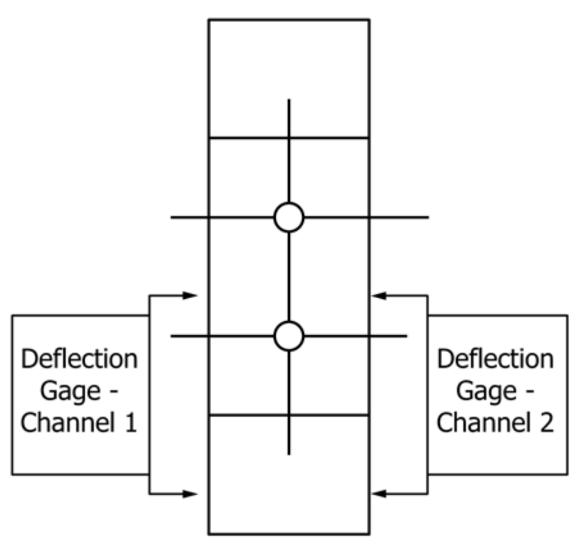
7.5.1.1 Machine surfaces to a 3.2 [125] finish unless otherwise specified.

7.5.1.2 Break all edges.

7.5.1.3 Specimen-gripping area shall be thermal sprayed using high-velocity oxygen fueled (HVOF), electro-spark deposition (ESD), or equivalent process.



(a) Side Views Showing Transducer Gage Lengths



(b) Matched Transducers of Bearing/Bypass Strain Indicator Mounted on Coupon Edge (Single Shear Configuration Shown)

FIG. 12 Transducer Gage Length and Location

7.5.1.4 The test fixture may be made of low-carbon steel for ambient temperature testing. For non-ambient environmental conditions, the recommended fixture material is a non-heat-treated ferritic or precipitation-hardened stainless steel (heat treatment for improved durability is acceptable but not required).

NOTE 8—Experience has shown that fixtures may be damaged in use; thus, periodic re-inspection of the fixture dimensions and tolerances is important.

NOTE 9—The Test Method D5961/D5961M support fixture has been successfully used for 30 mm [1.25 in.] wide bearing/bypass tests provided careful specimen alignment is achieved. Optional spacers should be added to the fixture to reduce the grip area width to 30.5 mm [1.27 in.]. Such spacers should be thinner than the test sample (to ensure the fixture adequately seats against the specimen surfaces) and should be no longer than the short grips, to ensure that they do not provide a contacting surface which could restrict the motion of the long grip and permit load to be transferred through the fixture. Alternately, a reduced width fixture may be fabricated. Similarly, wider fixtures of the same basic design may be used for specimens that are wider than 36 mm [1.5 in.].

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

7.6.1 *Testing Machine Configuration*—The testing machine shall have both an essentially stationary head and a movable head. A short loading train and rigidly mounted hydraulic grips shall be used for Procedure B when using the support fixture.

7.6.2 *Drive Mechanism*—The testing machine drive mechanism 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 as specified in 11.4.

7.6.3 *Force Indicator*—The testing machine force-sensing device shall be capable of indicating the total force being carried by the test specimen. This device shall be essentially free from inertia-lag at the specified rate of testing and shall indicate the force with an accuracy over the force range(s) of interest of within ±1 % of the indicated value.

7.6.4 *Grips*—Each head of the testing machine shall be capable of holding one end of the test assembly so that the direction of force applied to the specimen is coincident with the longitudinal axis of the specimen. Wedge grips shall apply sufficient lateral pressure to prevent slippage between the grip face and the test specimen or support fixture.

7.7 *Bearing Deformation Indicator*—Bearing deformation data shall be determined by a indicator device able to measure longitudinal hole deformation simultaneously on opposite edges of the specimen, as shown in Fig. 12 (the average of which corrects for in-plane joint rotation). The arms of the indicator device must fit within the stabilization fixture when a specimen with a width less than 38 mm [1.5 in.] is tested in the standard fixture. Transducer gage lengths on the order of 50 mm [2.0 in.] are typically used. The transducers of the bearing deformation indicator may provide either individual signals to be externally averaged or an electronically averaged signal. The indicator may consist of two matched strain-gage extensometers or displacement transducers such as LVDTs or DCDTs. Attachment of the bearing deformation indicator to the specimen shall not cause damage to the specimen surface. Transducers shall satisfy, at a minimum, Practice E83, Class B-2 requirements for the displacement range of interest, and shall be calibrated over that range in accordance with Practice E83. The transducers shall be essentially free of inertia-lag at the specified speed of testing.

NOTE 10—A matched set of extensometers mounted on opposite faces would be required to quantify and correct for out-of-plane joint rotation, which is the primary variable of concern in a single-shear loading configuration.

7.8 *Conditioning Chamber*—When conditioning materials at non-laboratory environments, a temperature-/vapor-level controlled environmental conditioning chamber is required that shall be capable of maintaining the required temperature to within ±3°C [±5°F] and the required relative humidity level to within ±3 %. Chamber conditions shall be monitored either on an automated continuous basis or on a manual basis at regular intervals.

7.9 *Environmental Test Chamber*—An environmental test chamber is required for test environments other than ambient testing laboratory conditions. This chamber shall be capable of maintaining the gage section of the test specimen at the required test environment during the mechanical test.

7.10 *Strain-Indicating Device*—Strain data, when required, shall be determined by means of bonded resistance strain gages.

7.10.1 *Bonded Resistance Strain Gage Selection*—Strain gage selection is based on the type of material to be tested. A minimum active gage length of 3 mm [0.125 in.] is recommended for composite laminates fabricated from unidirectional layers. Larger strain gage sizes may be more suitable for some textile fabrics. Gage calibration certification shall comply with Test Method E251. Strain gages with a minimum normal strain range of approximately 3% are recommended. When testing textile fabric laminates, gage selection should consider the use of an active gage length that is at least as great as the characteristic repeating unit of the fabric. Some guidelines on the use of strain gages on composite materials follow.

7.10.1.1 Surface preparation of fiber-reinforced composites in accordance with Guide E1237 can penetrate the matrix material and cause damage to the reinforcing fibers, resulting in improper coupon failures. Reinforcing fibers should not be exposed or damaged during the surface preparation process. The strain gage manufacturer should be consulted regarding surface preparation guidelines and recommended bonding agents for composites, pending the development of a set of standard practices for strain gage installation surface preparation of fiber-reinforced composite materials.

7.10.1.2 Consideration should be given to the selection of gages having larger resistances to reduce heating effects on low conductivity materials. Resistances of 350 Ω or higher are preferred. Additional consideration should be given to the use of the minimum possible gage excitation voltage consistent with the desired accuracy (1 to 2 V is recommended) to reduce the power consumed by the gage. Heating of the coupon by the gage may affect the performance of the material directly or it may affect the indicated strain as a result of a difference between the gage temperature compensation factor and the coefficient of thermal expansion of the coupon material.

7.10.1.3 Consideration of some form of temperature compensation is recommended, even when testing at standard laboratory atmosphere. Temperature compensation may be required when testing in non-ambient temperature environments.

7.10.1.4 Consideration should be given to the transverse sensitivity of the selected strain gage. The strain gage manufacturer should be consulted for recommendations on transverse sensitivity corrections and effects on composites.

8. Sampling and Test Specimens

8.1 *Sampling*—Test at least five specimens per test condition unless valid results can be gained through the use of fewer specimens, as in the case of a designed experiment. For statistically significant data the procedures outlined in Practice E122 should be consulted. The method of sampling shall be reported.

NOTE 11—If specimens are to undergo environmental conditioning to equilibrium, and are of such type or geometry that the weight change of the material cannot be properly measured by weighing the specimen itself (such as a tabbed mechanical specimen), then use a traveler specimen of the same nominal thickness and appropriate size (but without tabs) to determine when equilibrium has been reached for the specimens being conditioned.

8.2 *Geometry:*

8.2.1 *Stacking Sequence*—The standard laminate shall have multidirectional fiber orientations (fibers shall be oriented in a minimum of two directions), and balanced and symmetric stacking sequences. For tensile loaded specimens, nominal thickness shall be 2.5 mm [0.10 in.], with a permissible range of 2 to 5 mm [0.080 to 0.208 in.], inclusive. For compressive loaded specimens, nominal thickness shall be 4 mm [0.160 in.], with a permissible range of 2.5 to 5 mm [0.100 to 0.208 in.], inclusive. Fabric laminates containing satin-type weaves shall have symmetric warp surfaces, unless otherwise specified and noted in the report.

NOTE 12—Typically, a $[45_i/0_j/{-45}_i/90_k]_{ms}$ tape or $[45_i/0_j]_{ms}$ fabric laminate should be selected such that a minimum of 5 % of the fibers lay in each of the four principal orientations. This laminate design has been found to yield the highest likelihood of acceptable failure modes.

8.2.2 *Configuration: Procedure A*—The geometry of the specimen for Procedure A is shown in Figs. 2 and 3.

8.2.3 *Configuration: Procedure B*—The geometry of the specimen for Procedure B is shown in Figs. 6 and 7. Note that the countersinks shown in the drawings are optional. If the specimen is using countersunk fasteners, both countersinks must be on the same side of the specimen, as shown. Note that if the support fixture is used, the length of each specimen half and doubler must be adjusted as shown in Figs. 6 and 7 to accommodate loading with the fixture.

NOTE 13—In the D5961/D5961M Bearing Test Method, for a double-fastener specimen using countersunk fasteners, the countersinks are located on opposing faces of the specimen in order to provide an exact 50:50 force split between the two fasteners. This configuration has the potential to produce a net section failure mode at the first fastener (nearest the grips) rather than a pure bearing failure mode; however, this fastener location does not have the countersink and therefore is not valid for a bypass failure mode. At the expense of not achieving an exact 50:50 force transfer between the 2 fasteners, the bearing/bypass specimen requires that the countersinks be located on the same side of the specimen.

8.2.3.1 *Grip End Doubler Material*—The use of continuous E-glass fiber-reinforced polymer matrix materials (woven or unwoven) in a [0/90] *ns* laminate configuration is recommended for grip end doublers with the unsupported single-shear test configuration. The doubler material is commonly laid-up at 45° to the loading direction to provide a soft interface. The use of doublers made from the same laminate as the specimen being tested is recommended for stabilized single-shear tests, as this ensures that the doublers are the same thickness as the laminate being tested, which is critical for the stabilized single shear test fixture.

8.2.3.2 *Adhesive*—Any high-elongation (tough) adhesive system that meets the environmental requirements may be used when bonding doublers to the material under test. A uniform bondline of minimum thickness is desirable to reduce undesirable stresses in the assembly. It is not necessary to bond the doublers to the specimen when using a stabilization fixture.

8.2.4 *Configuration: Procedure C*—The geometry of the specimen for Procedure C is shown in Fig. 9. Strain gages as shown in Fig. 11 are recommended to provide additional data to determine the proportion of force transferred to the doubler plates. The following equations may be used to estimate the proportion of force transferred to the doubler plates for test specimen design purposes. These equations assume the two fasteners and the two doubler plates are identical. The fastener flexibility equation is obtained from Ref (**4**). These equations shall not be used for test data calculations.

$$k = \frac{2C_P}{(2C_P + C_S + 2C_F)} \tag{1}$$

$$C_P = \frac{L}{t_P w_P E_{xP}} \tag{2}$$

$$C_S = \frac{L}{t_S w_S E_{xS}} \tag{3}$$

$$C_F = \frac{8(2t_S + t_P)(1+\nu_F)}{3\pi E_F d^2} + \frac{(64)(8t_S^3 + 16t_S^2 t_P + 8t_S t_P^2 + t_P^3)}{192\pi E_F d^4} + \frac{2t_S + t_P}{t_S t_P E_F} + \frac{1}{t_S E_{xS}} + \frac{2}{t_P E_{xP}} \tag{4}$$

where:

k = estimate of proportion of total force transferred through fasteners to doubler plates,
C_P = plate (specimen) flexibility,
C_S = doubler plate flexibility,
C_F = fastener flexibility (Ref **1**),
t_P = test specimen laminate thickness, mm [in.],
t_S = doubler plate thickness, mm [in.],
w_P = test specimen width, mm [in.],
w_S = doubler plate width, mm [in.],
E_{xP} = test specimen laminate modulus, MPa [psi],
E_{xS} = doubler plate modulus in axial (x) direction, MPa [psi],
E_F = fastener modulus, MPa [psi],
ν_F = fastener Poisson's ratio,
d = fastener diameter, mm [in.], and
L = distance between fastener centerlines, mm [in.].

8.3 *Specimen Preparation*—Guide D5687/D5687M provides recommended specimen preparation practices and should be followed where practical.

8.3.1 *Panel Fabrication*—Control of fiber alignment is critical. Improper fiber alignment will reduce the measured properties. The panel(s) must be flat and of uniform thickness to ensure even loading. Erratic fiber alignment will also increase the coefficient of variation. Report the panel fabrication method.

8.3.2 *Machining Methods*—Specimen preparation is extremely important for this specimen. Take precautions when cutting specimens from plates to avoid notches, undercuts, rough or uneven surfaces, or delaminations due to inappropriate machining methods. Obtain final dimensions by water-lubricated precision sawing, milling, or grinding. The use of diamond tooling has been found to be extremely effective for many material systems. Edges should be flat and parallel within the specified tolerances. Machining tolerances and surface finish requirements are as noted in Figs. 1 and 2, and Figs. 5 and 6. Record and report the specimen cutting and hole preparation methods.

8.3.3 *Hole Drilling*—Holes should be drilled undersized and reamed to final dimensions. Special care shall be taken to ensure that creation of the specimen hole does not delaminate or otherwise damage the material surrounding the hole. Specimens with more than one fastener hole should be match drilled with the loading plates (Procedure A), mating specimen part (Procedure B), or doubler straps (Procedure C) to ensure that the fasteners can be installed.

8.3.4 *Labeling*—Label the specimens so that they will be distinct from each other and traceable back to the raw material, and in a manner that will both be unaffected by the test and not influence the test.

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 Unless explicitly specified by the test requestor no pre-test conditioning shall be performed and the test specimens shall 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 14—The recommended pre-test specimen condition is effective moisture equilibrium at a specific relative humidity per Test Method D5229/D5229M.

NOTE 15—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."

11. Procedure

11.1 *Parameters to Be Specified Prior to Test:*

11.1.1 The specimen sampling method, test procedure (A, B or C), specimen type and geometry, fastener type and material, countersink angle and depth (if appropriate), fastener torque (if appropriate), use of washers (if appropriate), type of loading (tensile or compressive), support fixture (if appropriate), cleaning process, and conditioning travelers (if required).

11.1.2 The properties to report, offset bearing strain value, and data reporting format desired.

NOTE 16—Unless otherwise specified, an offset bearing strain of 2 % shall be used.

NOTE 17—Determine specific material property, accuracy, and data reporting requirements prior to test for proper selection of instrumentation and data recording equipment. Estimate specimen failure stress and bearing strain levels to aid in transducer selection, calibration of equipment, and determination of equipment settings.

11.1.3 The environmental conditioning test parameters.

11.1.4 If performed, extensometer requirements and related calculations.

11.1.5 If performed, the sampling method, specimen geometry, and test parameters used to determine density and reinforcement volume.

11.2 *Before Test:*

11.2.1 Report any deviations from this test method, whether intentional or inadvertent.

11.2.2 If specific gravity, density, reinforcement volume, or void volume are to be reported, then obtain these samples from the same panels being bearing tested. Specific gravity and density may be evaluated by means of Test Methods D792. Volume percent of the constituents may be evaluated by one of the matrix digestion procedures of Test Method D3171, or, for certain reinforcement materials such as glass and ceramics, by the matrix burn-off technique of Test Method D2584. The void content equations of Test Method D2734 are applicable to both Test Method D2584 and the matrix digestion procedures.

11.2.3 Condition the specimens as required. Store the specimens in the conditioned environment until test time, if the test environment is different than the conditioning environment.

11.2.4 Following final specimen machining and any conditioning, but before testing, measure the specimen width, w, and the specimen thickness, h, in the vicinity of each hole. Measure each hole diameter, D, distance from hole edge to closest specimen side, f, and distance from hole edge to specimen end, g. Measure the fastener or pin diameter, d, at the bearing contact location, the countersink depth, d_{csk} (if appropriate), and the countersink flushness, d_{fl} (if appropriate). The accuracy of all measurements shall be within 1 % of the dimension, unless otherwise specified in this test method. Record the dimensions to three significant figures in units of millimeters [inches].

11.3 *Specimen and Doubler Plate Force-Strain Calibration—Procedure C Only:*

11.3.1 *Doubler Plate*—For purposes of accurately determining the force transferred into the doubler plates, a calibration of the force applied by the fastener to the doubler and the strain measured by the strain gages on the doubler must be determined using a determinant loading setup. Assemble each of the doubler plates with two or four loading straps, as shown in Fig. 13. For doubler plates with the recess for strain gages on the specimen, assemble the two doubler plates back-to-back to avoid excessive bending which could occur if the plates are tested individually. Torque the fasteners to 0.6-1.2 N·m [5-10 lbf-in.]. Test each of the doubler plates as follows:

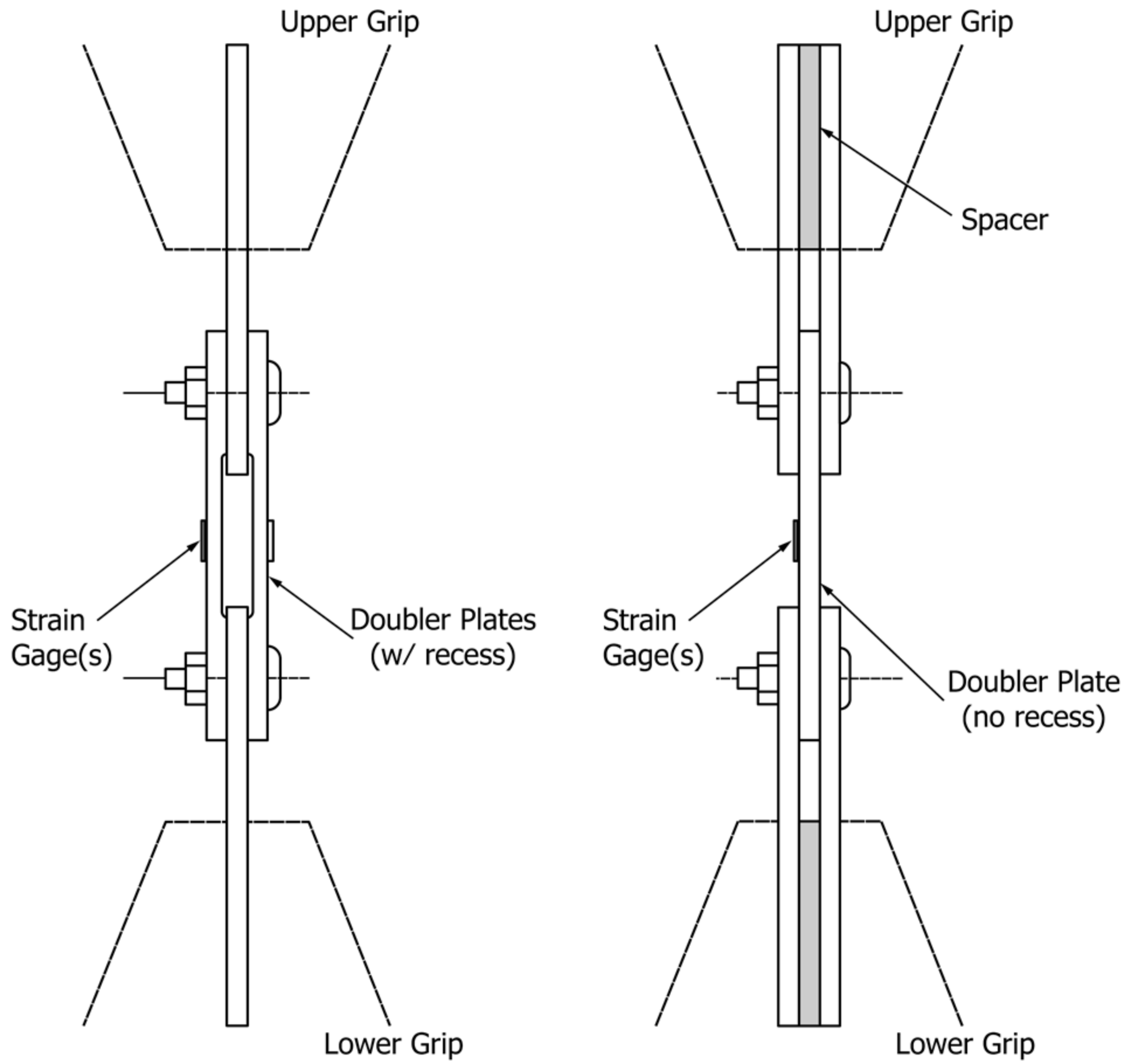


FIG. 13 Doubler Plate Force-Strain Calibration Setup—Procedure C

11.3.1.1 Assign a unique identification number to each doubler plate and mark the number on the plate. Assign a unique strain gage number to each gage on each doubler plate and mark the gage numbers on the plate.

11.3.1.2 *Speed of Testing*—A standard head displacement rate of 2 mm/min [0.05 in./min] is recommended.

11.3.1.3 *Test Environment*—Test the doubler assembly at the same temperature as the test specimen will be tested.

11.3.1.4 Insert the specimen into the test machine, attaching loading interfaces or tightening grips as required.

11.3.1.5 Attach the strain gages to the recording instrumentation. Remove any remaining pre-load and zero the strain gages. Record the doubler and strain gage numbers. Record a unique calibration loading run identification number.

11.3.1.6 Apply the force to the doubler assembly at the specified rate while recording data. Load the assembly to a maximum force equal to:

$$P_{max} = (1.1)(\text{Expected Bearing/Bypass Specimen Failure Load})(k\ (\text{from Eq 1}))(\#\ \text{plates})/2 \quad (5)$$

where:

(# plates) = the number of double plates in the doubler calibration assembly, Fig. 13.

NOTE 18—Take care when selecting the maximum force for the doubler plate calibration that bearing deformation or damage is not introduced in the doubler during the calibration test.

NOTE 19—Every doubler plate used for testing shall be calibrated. Traceability of the calibration load-strain data for each doubler strain gage must be maintained.

11.3.1.7 Record force versus strain continuously, or at intervals of 2-3 data recordings per second with a target minimum of 100 data points per test.

11.3.2 *Test Laminate Plate*—While the strain data from the doubler plates can be used to determine the force transferred into the doubler plates, it is recommended that the strain in the test laminate also be measured during the bearing/bypass tests. To use this strain data, a force-strain calibration of the strain measured by the strain gages on the test laminate must be determined. For tensile loaded tests, install fasteners into the specimen holes (install a nut to prevent loss of the fastener pin during test; torquing of collars/nuts is not required), as shown in Fig. 14a; for compressive loaded tests install fasteners into the specimen holes (install a nut to prevent loss of the fastener pin during test; torquing of collars/nuts is not required) and assemble the test laminate with the Fig. 8 support fixture, as shown in Fig. 14b. Torque the fixture fasteners to 0.6-1.2 N·m [5-10 lbf-in.]. Test each of the doubler plates as follows:

11.3.2.1 Assign a unique strain gage number to each gage on each test laminate and mark the gage numbers on the plate.

11.3.2.2 *Speed of Testing*—A standard head displacement rate of 2 mm/min [0.05 in./min] is recommended.

11.3.2.3 *Test Environment*—Test the doubler assembly at the same temperature as the test specimen will be tested.

11.3.2.4 Insert the specimen into the test machine, attaching loading interfaces or tightening grips as required.

11.3.2.5 Attach the strain gages to the recording instrumentation. Remove any remaining pre-load and zero the strain gages. Record the specimen and strain gage numbers. Record a unique calibration loading run identification number.

11.3.2.6 Apply the force to the assembly at the specified rate while recording data. Load the assembly to a maximum force equal to P_{max} from Eq 5; however, P_{max} should not be greater than 80 % of the expected bearing yield strength for the laminate.

11.3.2.7 Record force versus strain continuously, or at intervals of 2-3 data recordings per second with a target minimum of 100 data points per test.

NOTE 20—For a group of identical test specimens (same material, layup, thickness, geometry, test environment, etc.), it is acceptable to only perform the force-strain calibration procedure for one of the test specimens, provided that the strain gage types and locations are identical for all of the specimens.

NOTE 21—Traceability of the calibration load-strain data for each test laminate gage must be maintained.

11.4 *Specimen Assembly:*

11.4.1 *Cleaning*—Clean the specimen hole, surrounding clamping area, and fastener or pin shank. If the fastener threads

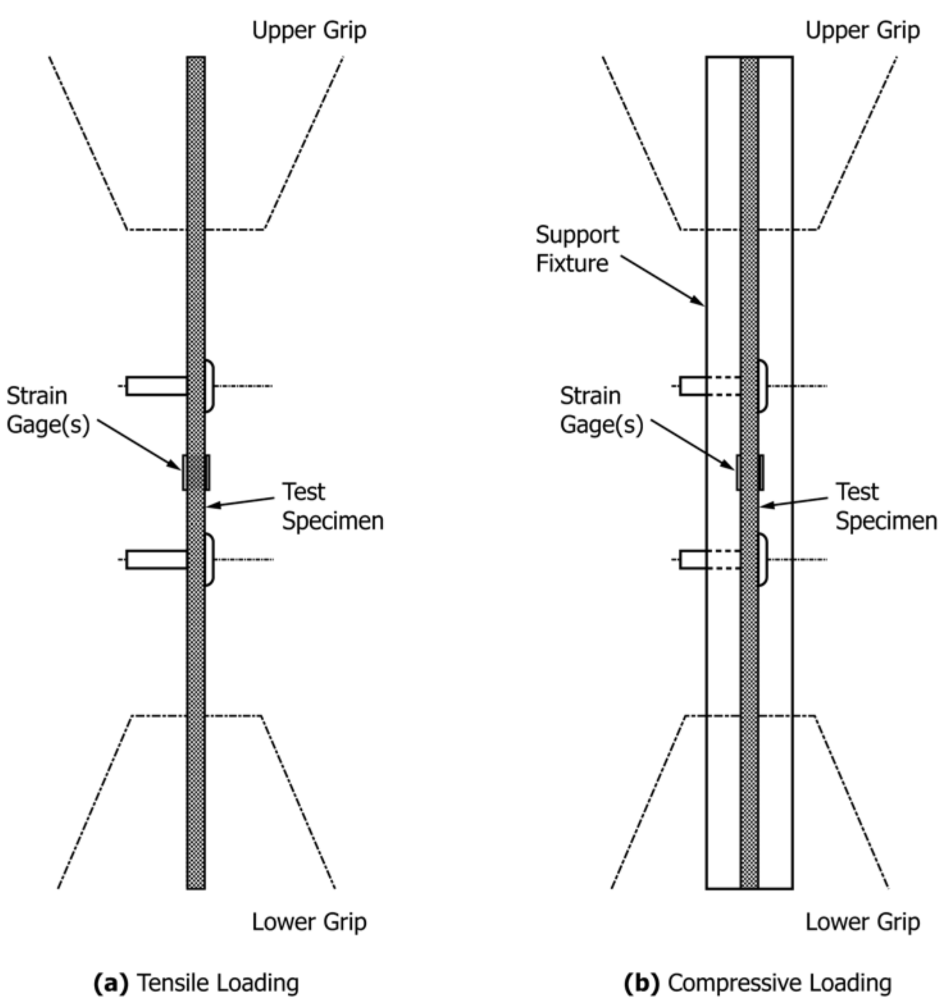


FIG. 14 Test Specimen Force-Strain Calibration Setup—Procedure C

are required to be lubricated, apply the lubricant to the nut threads instead of the fastener threads and take extreme care not to accidentally transfer any of the lubricant to the fastener shank, the specimen hole, or to the clamping area during assembly and torquing. Record and report cleaning method and lubricant used, if any.

11.4.2 *Specimen Assembly*—Assemble the test specimen to the double-shear fixture (Procedure A), mating attachment (Procedure B) or doubler plates (Procedure C) with the specified fasteners or pins (and washers if specified).

11.4.3 *Fastener Torquing*—If using torqued fasteners, tighten the fasteners to the required value using a calibrated torque wrench. Record and report the actual torque value.

11.5 *Test Procedure:*

11.5.1 *Speed of Testing*—Set the speed of testing so as to produce failure within 1 to 10 min. If the ultimate failure stress and bearing strain of the material cannot be reasonably estimated, initial trials should be conducted using standard speeds until the ultimate bearing strain of the material and the compliance of the system are known, and speed of testing can be adjusted. The suggested standard speeds are:

11.5.1.1 *Bearing Strain-Controlled Tests*—A standard bearing-strain rate of 0.01 min^{-1}.

11.5.1.2 *Constant Head-Speed Tests*—A standard head displacement rate of 2 mm/min [0.05 in./min].

11.5.2 *Test Environment*—If possible, test the specimen under the same fluid exposure level used for conditioning. However, cases such as elevated temperature testing of a moist specimen place unrealistic requirements on the capabilities of common testing machine environmental chambers. In such cases the mechanical test environment may need to be modified, for example, by testing at elevated temperature with no fluid exposure control, but with a specified limit on time to failure from withdrawal from the conditioning chamber. Record any modifications to the test environment.

11.5.3 *Specimen Installation:*

11.5.3.1 *Procedures A, B and C (No Support Fixture)*—Insert the specimen into the test machine, attaching loading interfaces or tightening grips as required.

11.5.3.2 *Procedure B or C (With Support Fixture)*—Install the test specimen into the support fixture such that the machined ends of the specimen are flush with the ends of the fixture halves. This should result in the specimen hole(s)/fastener(s) being centered in the fixture cutout. Tighten the four bolts just enough to hold the specimen in place during fixture installation.

11.5.4 *Fixture Insertion (Procedure B or C With Support Fixture):*

11.5.4.1 Place the fixture in the grips of the testing machine, taking care to align the long axis of the gripped fixture with the test direction. When inserting the fixture into the grip-jaws, grip the outer portion of the fixture up to the bolts, approximately 80 mm [3 in.].

11.5.4.2 Tighten the grips, recording the pressure used on the hydraulic grips. The ends of the grip-jaws on wedge-type grips should be even with each other following insertion to avoid inducing a bending moment which could result in premature failure of the specimen.

11.5.4.3 Re-torque the four bolts to approximately 7 N-m [60 lbf-in.] after hydraulic gripping pressure is applied.

11.5.4.4 Check the gaps between the support plates and the long grip portion of the support fixture using a feeler gage, and shim as required in Fig. 9.

11.5.4.5 Check that the gap between the gage section of the specimen and the long grip portion of the support fixture is 0.05 ± 0.05 mm [0.002 ± 0.002 in.] using a feeler gage. A gap outside of this tolerance range is indicative of one of the following: improper assembly, an out-of-tolerance specimen, damaged fixtures, or a combination thereof.

11.5.5 *Complete Bearing Deformation Indicator Installation*—Attach the bearing deformation indicator to the edges of the specimen as shown in Fig. 12 to provide the average displacement across the loaded hole(s) at the edge of the specimen. Attach the recording instrumentation to the indicator. Remove any remaining pre-load and zero the indicator. For Procedure B specimens, one end of the indicator shall be on the edge of the specimen between the two fasteners and the other end on the edge of the mating specimen.

11.5.6 *Strain Gages (Procedure C)*—Attach the strain gages to the recording instrumentation. Remove any remaining preload and zero the strain gages. Record the doubler plate identification numbers. Record the doubler plate and test laminate strain gage numbers.

TABLE 1 Five-Place Failure Mode Codes (see also Fig. 15, Figs. 18-21)

First Character		Second Character		Third Character		Fourth Character		Fifth Character	
Failure Type (see Fig. 18)	Code	Failure Type (see Fig. 15)	Code	Net Area Failure Type	Code	Failure Area	Code	Net Area Failure Location	Code
Lateral (Net Area) Tension or Compression	L	First (grip) hole	1	Angled	A	Inside grip/tab	I	Middle, center of hole	M
Invalid Modes (report per D5961/D5961M)		Second (end) hole	2	edge Delamination	D	At grip/tab	A	Offset from center of hole	O
Bearing	B	Both holes	B	Grip/tab	G	<1W from grip/tab	W	offset at Fastener edge	F
Cleavage	C	Fastener	F	Lateral	L	Gage	G	Various	V
Fastener or pin	F	Unknown	U	Multi-mode	M(xyz)	Multiple areas	M	Unknown	U
Multi-mode	M(xyz)			long, Splitting	S	Various	V		
Shearout	S			eXplosive	X	Unknown	U		
Tearout	T			Other	O				
Other	O								

11.5.7 *Loading*—Apply the force to the specimen at the specified rate while recording data. The specimen is loaded until the force has dropped off at least 30 % from a previously attained maximum force value. Unless specimen rupture is specifically desired, 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 and to prevent support fixture damage (if used). In compressive loading care should be taken to ensure that the stabilization plates do not self-contact by terminating compressive test loading when head displacement has reached a maximum of 4.5 mm [0.18 in.] (90 % of nominal end gap distance) to prevent support fixture damage.

11.5.8 *Data Recording*—Record force versus bearing deformation (or hole displacement) and force versus strain continuously, or at intervals of 2-3 data recordings per second with a target minimum of 100 data points per test. If a transition region or initial ply failures are noted, record the load, bearing deformation, and mode of damage at such points. If the specimen is to be failed, record the maximum load, the failure load, and the bearing deformation (or hole displacement) at, or as near as possible to, the moment of rupture.

NOTE 22—Other valuable data that can be useful in understanding testing anomalies and gripping or specimen slipping problems includes force versus head displacement data and force versus time data.

NOTE 23—A difference in the bearing stress/bearing deformation or load/bearing deformation slope between bearing deformation readings when instrumentation is mounted on the opposite edges of the specimen as shown in Fig. 12 indicates in-plane (edgewise) joint rotation in the specimen.

11.6 *Failure Mode*—Record the mode and location of failure of the specimen. Note that the intention of this test method is to determine the effect of bearing stress on the net section bypass strength of the material. In some cases specimens that fail in a net section mode will also exhibit bearing damage at the fastener holes; this combined mode is within the scope of this method. The evaluation of specimens that produce only bearing failure modes is beyond the scope of this test method. Net section stress results shall not be reported under this test method for specimens exhibiting primary bearing or cleavage failure modes; however specimens failing in a bearing failure mode may be analyzed and reported using the procedures of Test Method D5961/D5961M. Choose, if possible, a standard description using the five-part failure mode code shown in Table 1. A multimode failure can be described by including each of the appropriate failure-type codes between the parentheses of the M failure-type code.

12. Validation

12.1 Values for ultimate 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 Should the test specimen fail in a bearing failure mode rather than the desired net tension or compression, then the test should be considered to be a bearing dominated bearing/bypass test, and the data reduction and reporting procedures of Test Method D5961/D5961M should be used instead of those given in this standard.

12.3 Any failure in a sample population occurring away from the fastener hole(s) shall be cause to reexamine 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 (if appropriate), specimen thickness taper, and uneven machining of specimen ends.

13. Calculation

NOTE 24—Presentation and calculation of results by this test method is based on normalizing total joint force and overall joint displacement to the response at a single hole. In the case of a double-shear test there is no adjustment necessary in either force or displacement. However, for a single-shear test (assuming like specimen halves), the total joint displacement is approximately twice the elongation of a given hole. For a double-fastener test, the hole force is approximately one half the total force. This is the source of the k force factors and the K displacement factor used in the following equations.

NOTE 25—The hole diameter is ignored in the bypass strength calculation; the gross cross-sectional area is used.

NOTE 26—Two different bypass strengths are calculated (gross and net bypass) because different definitions for bypass stress are used in bearing/bypass interaction analysis methods in the aerospace industry. See Fig. 15. The gross bypass stress for tensile loadings is calculated from the total force bypassing the fastener hole; the net bypass stress for tensile loading is calculated from the force bypassing the fastener hole minus the force reacted in bearing at the fastener. For compressive loadings the gross and net bypass strengths are equal and are calculated using the force that bypasses the fastener hole (since for the compressive loading case the bearing stress reaction is on the same side of the fastener as the applied load, the force reacted in bearing does not bypass the fastener hole).

13.1 *Width to Diameter Ratio*—Calculate the actual specimen width to diameter ratio using measured values with Eq 6, and report the result to three significant digits.

$$w/D \text{ ratio} = w/D \tag{6}$$

where:

w = width of specimen across hole, mm [in.], and
D = hole diameter, mm [in.].

13.2 *Edge Distance Ratio*—Calculate the actual specimen edge distance ratio using measured values with Eq 7, and report the result to three significant digits.

$$e/D = (g + D/2)/D \tag{7}$$

where:

e/D = actual edge distance ratio, and
g = distance from hole edge to specimen end, mm [in.].

13.3 *Diameter to Thickness Ratio*—Calculate the actual diameter to thickness ratio, as shown in Eq 8. Report both the nominal ratio calculated using the nominal values and the actual ratio calculated with measured dimensions.

$$D/h \text{ ratio} = \frac{D}{h} \tag{8}$$

where:

h = specimen thickness near hole (nominal or actual, as specified), mm [in.].

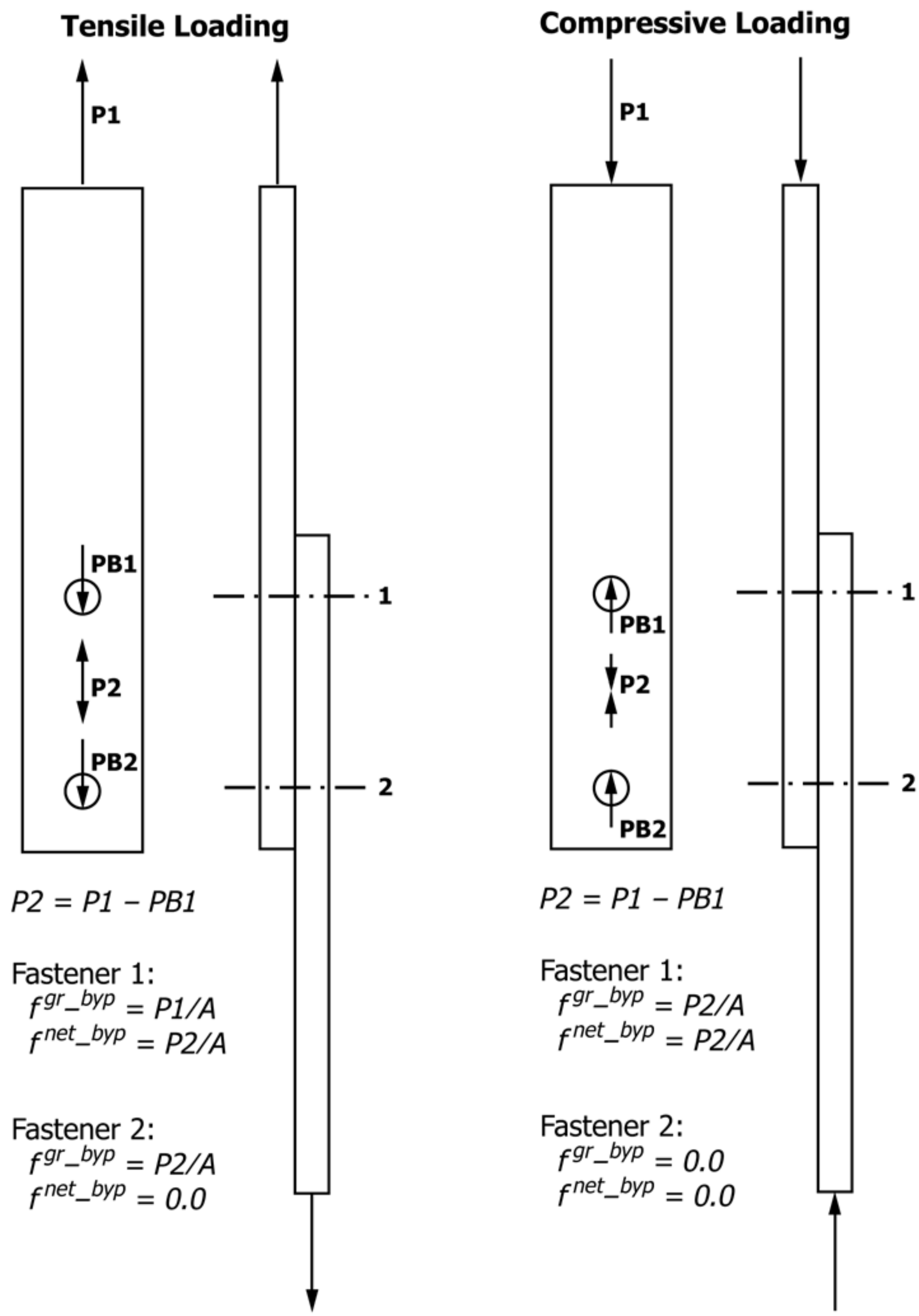


FIG. 15 Illustration of Gross and Net Bypass Stress

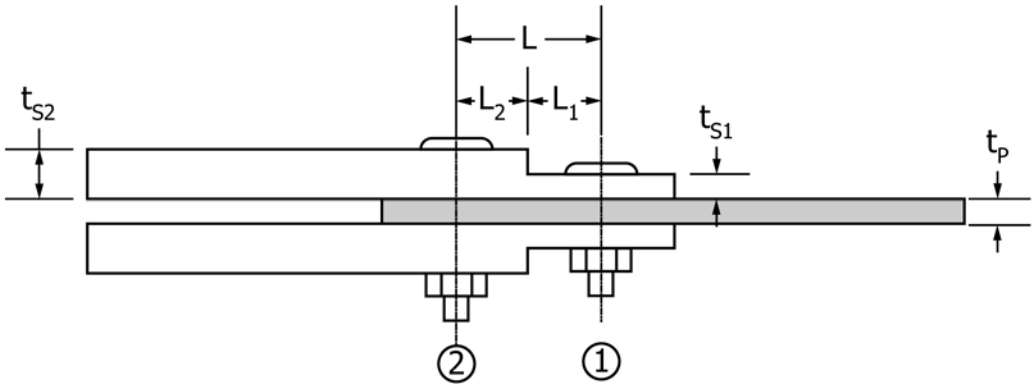


FIG. 16 Procedure A Double Shear Joint Geometric Parameters

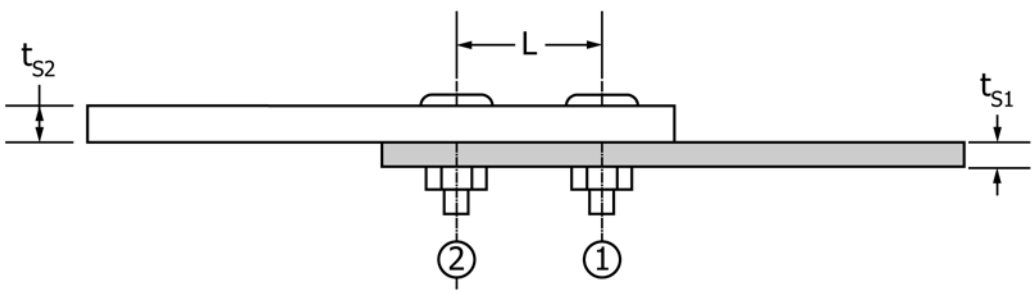


FIG. 17 Procedure B Single Shear Joint Geometric Parameters

13.4 *Countersink Depth to Thickness Ratio*—If a countersunk (flush) fastener is installed in the hole(s), calculate the actual countersink depth to thickness ratio, as shown in Eq 9. Report both the nominal ratio calculated using nominal values and the actual ratio calculated with measured dimensions.

$$d_{csk}/h \text{ ratio} = \frac{d_{csk}}{h} \tag{9}$$

where:

d_{csk} = fastener countersink depth, mm [in.].

13.5 *Fastener Force Proportions—Procedure A*—Calculate the proportion of force that is transferred through fasteners 1 and 2 using Eq 10 and referring to Fig. 16 (the fastener flexibility equations are obtained from Ref **4**).

$$k_1 = \frac{2C_P + C_{F2}}{(2C_P + C_S + C_{F1} + C_{F2})} \tag{10}$$

$$k_2 = 1 - k_1$$

$$C_P = \frac{L}{t_P w_P E_{xP}} \tag{11}$$

$$C_S = \frac{L_1}{t_{S1} w_{S1} E_{xS1}} + \frac{L_2}{t_{S2} w_{S2} E_{xS2}} \tag{12}$$

$$C_{F1} = \frac{8(2t_{S1} + t_P)(1 + \nu_{F1})}{3\pi E_{F1} d_1^2} + \frac{(64)(8t_{S1}^3 + 16t_{S1}^2 t_P + 8t_{S1} t_P^2 + t_P^3)}{192\pi E_{F1} d_1^4} + \frac{2t_{S1} + t_P}{t_{S1} t_P E_{F1}} + \frac{1}{t_{S1} E_{xS1}} + \frac{2}{t_P E_{xP}} \tag{13}$$

$$C_{F2} = \frac{8(2t_{S2} + t_P)(1 + \nu_{F2})}{3\pi E_{F2} d_2^2} + \frac{(64)(8t_{S2}^3 + 16t_{S2}^2 t_P + 8t_{S2} t_P^2 + t_P^3)}{192\pi E_{F2} d_2^4} + \frac{2t_{S2} + t_P}{t_{S2} t_P E_{F2}} + \frac{1}{t_{S2} E_{xS2}} + \frac{2}{t_P E_{xP}} \tag{14}$$

where:

k_1, k_2 = proportion of total force transferred through fastener #1 and fastener #2,
C_P = plate (specimen) flexibility,
C_S = loading strap flexibility,
C_{F1}, C_{F2} = fastener flexibilities (Ref **1**),
t_P = test specimen laminate thickness, mm [in.],
t_{S1}, t_{S2} = loading strap thicknesses, mm [in.],
w_P = test specimen width, mm [in.],
w_{S1}, w_{S2} = loading strap widths, mm [in.],
E_{xP} = test specimen laminate modulus in axial (x) direction, MPa [psi],
E_{xS1}, E_{xS2} = loading strap modulus in axial (x) direction, MPa [psi],
E_{F1}, E_{F2} = fastener modulus, MPa [psi],
ν_{F1}, ν_{F2} = fastener Poisson's ratio,
d_1, d_2 = fastener diameters, mm [in.],
L = distance between fastener centerlines, mm [in.], and
L_1, L_2 = distances from fastener centerline to step in strap thickness, mm [in.] (for constant thickness straps, use $L_1 = L$, $L_2 = 0$).

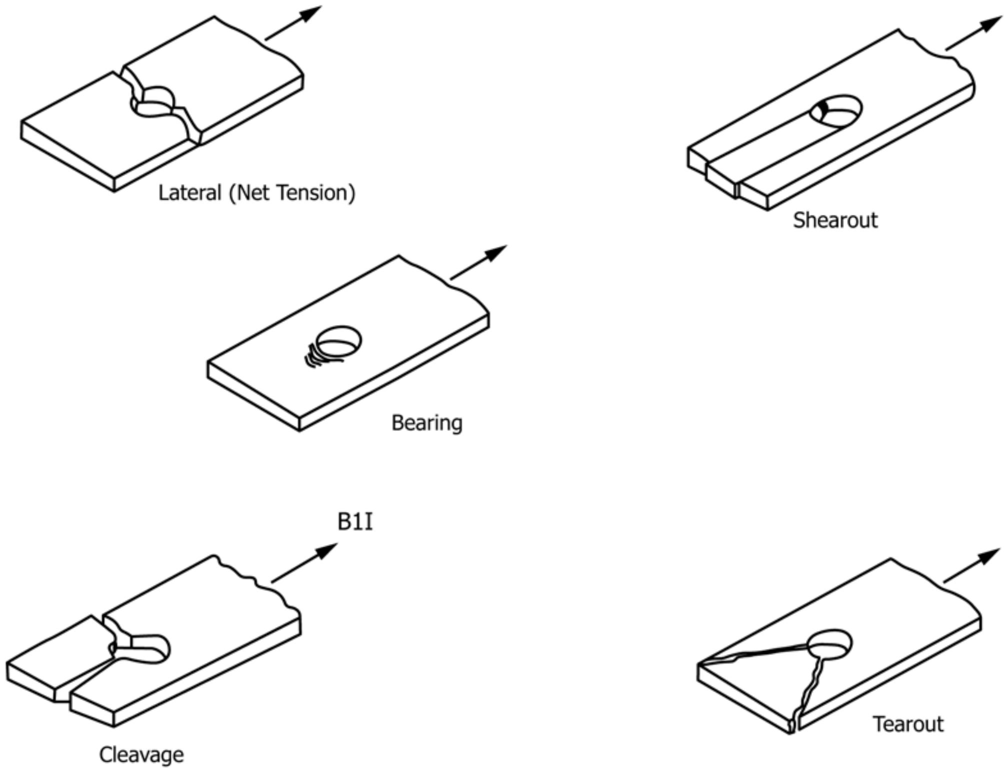


FIG. 18 General Bearing/Bypass Test Failure Modes

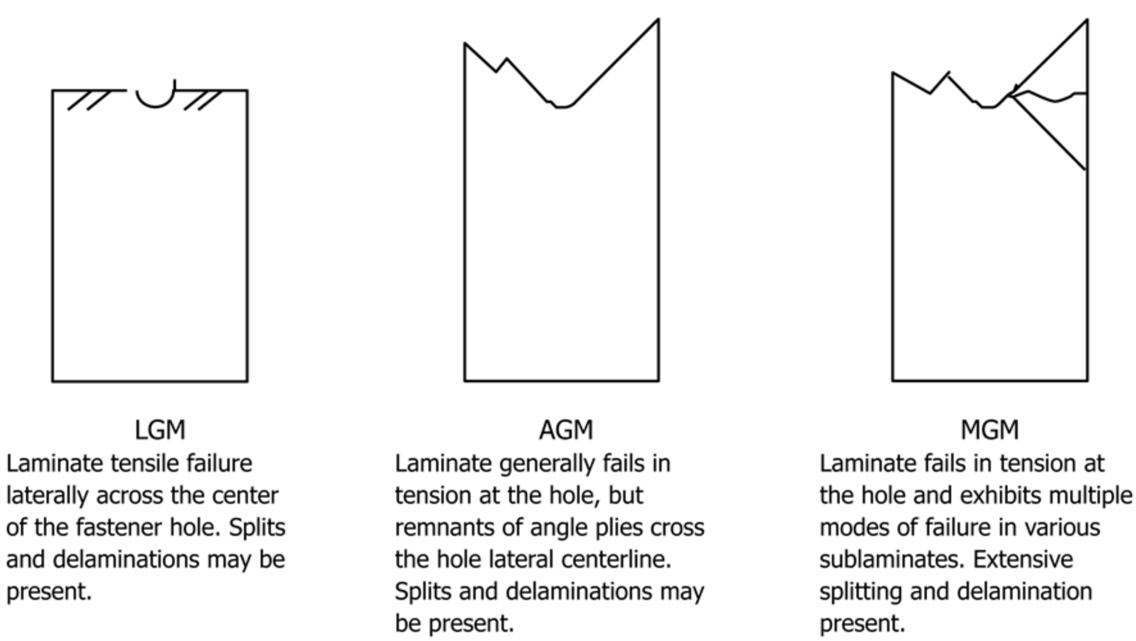


FIG. 19 Acceptable Tensile Bypass Failure Modes

13.6 *Fastener Force Proportions—Procedure B*—For single shear tests with identical straps, the force transferred in each fastener is 50 % of the total force:

$$k_1 = k_2 = 0.50 \tag{15}$$

NOTE 27—For tests with countersunk head fasteners with the heads on the same side, the force split between the two fasteners will not be exactly 50:50. However, this is generally ignored in the bearing/bypass data reduction due to the difficulty in determining accurate fastener flexibilities.

13.6.1 For single shear joints with non-identical straps or two different fasteners, or both, calculate the proportion of force that is transferred through fasteners 1 and 2 using Eq 16 and referring to Fig. 17 (the fastener flexibility equations are obtained from Ref **4**).

$$k_1 = \frac{C_{S1}+C_{F2}}{(C_{S1}+C_{S2}+C_{F1}+C_{F2})} \tag{16}$$

$$k_2 = 1 - k_1$$

$$C_{S1} = \frac{L}{t_{S1}w_{S1}E_{xS1}} \tag{17}$$

$$C_{S2} = \frac{L}{t_{S2}w_{S2}E_{xS2}} \tag{18}$$

$$C_{F1} = \frac{32(t_{S1}+t_{S2})(1+\nu_{F1})}{9\pi E_{F1}d_1^2} + \frac{(64)(t_{S1}^3+5t_{S1}^2t_{S2}+5t_{S1}t_{S2}^2+t_{S2}^3)}{40\pi E_{F1}d_1^4} + \frac{t_{S1}+t_{S2}}{t_{S1}t_{S2}E_{F1}} + \frac{1}{t_{S1}E_{xS1}} + \frac{1}{t_{S2}E_{xS2}} \tag{19}$$

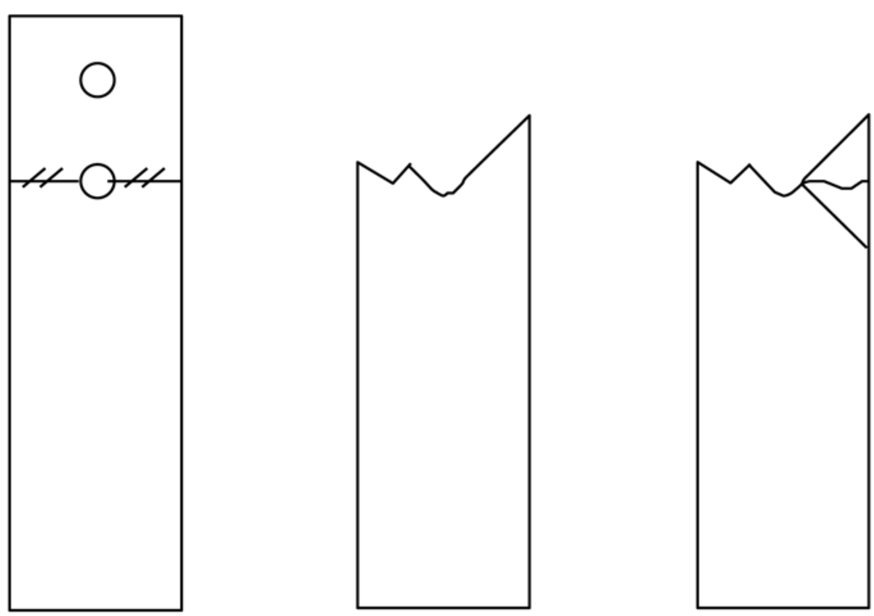
$$C_{F2} = \frac{32(t_{S1}+t_{S2})(1+\nu_{F2})}{9\pi E_{F2}d_2^2} + \frac{(64)(t_{S1}^3+5t_{S1}^2t_{S2}+5t_{S1}t_{S2}^2+t_{S2}^3)}{40\pi E_{F2}d_2^4} + \frac{t_{S1}+t_{S2}}{t_{S1}t_{S2}E_{F2}} + \frac{1}{t_{S1}E_{xS1}} + \frac{1}{t_{S2}E_{xS2}} \tag{20}$$

where:

k_1, k_2 = proportion of total force transferred through fastener #1 and fastener #2,
C_{S1} = strap #1 flexibility,
C_{S2} = strap #2 flexibility,
C_{F1}, C_{F2} = fastener flexibilities (Ref **1**),
t_{S1}, t_{S2} = strap thicknesses, mm [in.],
w_{S1}, w_{S2} = strap widths, mm [in.],
E_{xS1}, E_{xS2} = strap modulus in axial (x) direction, MPa [psi],
E_{F1}, E_{F2} = fastener modulus, MPa [psi],
ν_{F1}, ν_{F2} = fastener Poisson's ratio,
d_1, d_2 = fastener diameters, mm [in.], and
L = distance between fastener centerlines, mm [in.].

13.7 *Fastener Force Proportions—Procedure C*—For hard-point tests with identical doubler straps, calculate the proportion of force that is transferred through the doubler plates and the specimen using Eq 21:

$$k_D = \frac{(P_{D1}+P_{D2})}{P} \qquad k_S = \frac{P_S}{P} \tag{21}$$



LGM

Laminate compressive failure laterally across the center of the fastener hole (0-degree ply dominated kinking/buckling).

AGM

Laminate generally fails in compression at the hole, but remnants of angle plies cross the hole lateral centerline (+/–45 degree ply dominated matrix failure).

MGM

Laminate fails in compression at the hole and exhibits multiple modes of failure in various sublaminates.

FIG. 20 Acceptable Compressive Bypass Failure Modes Near Center of Hole

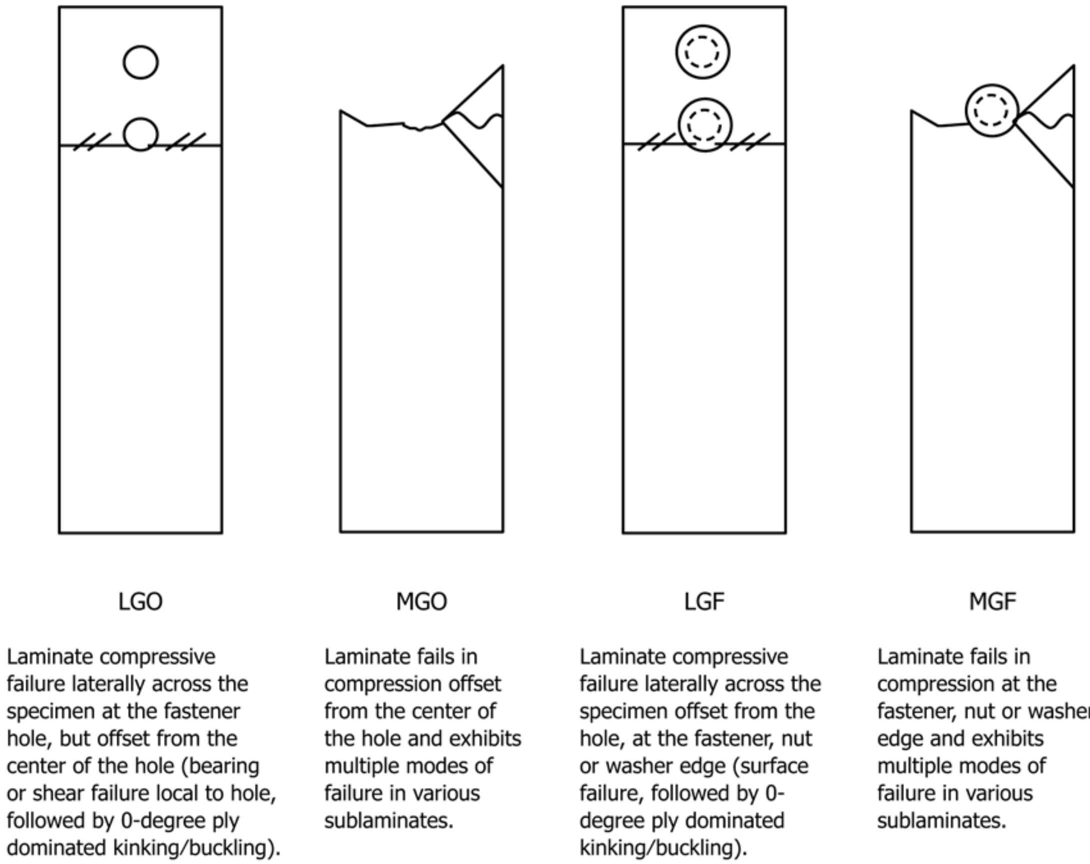


FIG. 21 Acceptable Compressive Bypass Failure Modes Offset From Center of Hole

where:

k_D = proportion of total force transferred through doubler plates,
k_S = proportion of total force transferred through specimen,
P = total force applied to specimen, N [lbf],
P_S = force in specimen between fasteners, N [lbf], and
P_{D1}, P_{D2} = force in doubler plates, N [lbf].

13.7.1 Determine the force in each doubler plate separately, using the following procedure:

13.7.1.1 Determine the strain, ε_{Di}, for each strain gage on the doubler plate from the recorded force-strain data at $P = P_{max}$.

NOTE 28—Do not average the load-strain curves for the gages on the doubler plates. A force must be determined separately for each strain gage using the corresponding calibration load-strain data.

13.7.1.2 Determine the force, P_{Di}, corresponding to the strain, ε_{Di}, using the force-strain calibration data obtained using the procedure in 11.3.1. If two doubler plates are tested back-to-back in the calibration step, divide the force by 2.

13.7.1.3 Average the forces determined from the strain gages on the doubler plate:

$$P_{D1} = \frac{\sum_{i=1}^{n} P_{Di}}{n} \tag{22}$$

where:

n = number of strain gages on the doubler plate.

13.7.1.4 Repeat for the second doubler plates to obtain P_{D2}.

13.7.1.5 Calculate k_D using Eq 21 using $P = P_{max}$.

13.7.2 If the specimen has strain gages installed, then:

13.7.2.1 Determine the strain, ε_{Si}, for each strain gage on the specimen from the recorded force-strain data at $P = P_{max}$.

NOTE 29—Do not average the load-strain curves for the gages on the specimen. A force must be determined separately for each strain gage using the corresponding calibration load-strain data.

13.7.2.2 Determine the force, P_{Si}, corresponding to the strain, ε_{Si}, using the force-strain calibration data obtained using the procedure in 11.3.2.

NOTE 30—Determining the force P_{Si}, will likely require extrapolation of the specimen calibration force-strain curve since it may not be possible to load the specimen in the calibration step to a sufficiently high force level without causing damage or failure of the specimen. Linear extrapolation of the last 20 % of the calibration force-strain curve is recommended as a starting point; the extrapolation may have to be adjusted if the sum of k_D and k_S is not sufficiently close to 1.0.

13.7.2.3 Calculate k_S using Eq 21 using P_S and $P = P_{max}$.

13.7.2.4 The sum of k_D and k_S determined using the doubler plate and specimen strain gages should approximately equal 1.0. If the sum is not close to 1.0, investigate the force-strain data from the calibration and bearing/bypass test runs for anomalies or inconsistencies.

NOTE 31—For tension loading tests, the value for k_D is likely to be more accurate than the value for k_S. For compressive loading tests, the value for k_S is likely to be more accurate than the value for k_D. Therefore, these values are recommended for use in calculating the bypass strengths in 13.8 and 13.9. In cases where the sum of k_D and k_S at the specimen failure force is not equal to 1.0, the values of k_D and k_S should be calculated and plotted over the range of applied force. These plots along with a plot of bearing stress versus bearing strain should be examined carefully to determine if nonlinear response occurred in the test laminate prior to failure. In some cases where bearing damage occurs, it may be appropriate to use values of k_D or k_S at a force level around the onset of bearing damage.

In the tensile loaded specimen, the gages on the doublers are towards the outside of the plates, in the area of higher stress since the doubler plates are loaded in tension. The gages on the specimen are on the specimen centerline (to avoid interference with the doubler gages), and therefore are in a lower stress area (force shadow of the holes). Therefore, it is thought that the doubler gage values and calibration is more reliable for the tensile loaded configuration.

In the compressive loaded specimen, the gages on the doublers are on the centerline of the plates, in the area of higher stress since the doubler plates are loaded in compression through the holes. The gages on the specimen are towards the edges (to avoid interference with the doubler gages), and therefore are in a higher stress area as a majority of the force bypasses the holes. Since it is expected that more force remains in the specimen relative to the force in the doublers, it is thought that the specimen gage values and calibration is more reliable for the compressive loaded configuration.

13.8 *Ultimate Bypass Strength—Tensile Loading:*

13.8.1 *Ultimate Gross Bypass Strength*—Calculate the ultimate tensile gross bypass strength for all Procedures using Eq 23 and report the results to three significant figures.

$$F_x^{gr\_byp\_t} = P_{max}/A \tag{23}$$

where:

$F_x^{gr\_byp\_t}$ = ultimate tensile gross bypass strength, MPa [psi],
P_{max} = maximum force prior to failure, N [lbf], and
A = gross cross-sectional area (disregarding hole) (using nominal or actual thickness, as specified) = $h \times w$, mm^2 [in.^{2}].

13.8.2 *Ultimate Net Bypass Strength*—Calculate the ultimate tensile net bypass strength using Eq 24 and report the results to three significant figures.

$$F_x^{net\_byp\_t} = (1 - k)P_{max}/A \tag{24}$$

where:

$F_x^{net\_byp\_t}$ = ultimate tensile net bypass strength, MPa [psi], and
k = Procedure A—k_1 from 13.5
= Procedure C—k_D from 13.7
= Procedure B—use k_1 from 13.6 for calculating bypass strength of strap #1; use k_2 from 13.6 for calculating bypass strength of strap #2.

13.9 *Ultimate Bypass Strength—Compressive Loading:*

13.9.1 *Ultimate Gross and Net Bypass Strength*—Calculate the ultimate compressive gross and net bypass strengths using Eq 25 and report the results to three significant figures.

$$F_x^{gr\_byp\_c} = F_x^{net\_byp\_c} = (1 - k)P_{max}/A \tag{25}$$

where:

$F_x^{gr\_byp\_c}$ = ultimate compressive gross bypass strength, MPa [psi], and
$F_x^{net\_byp\_c}$ = ultimate compressive net bypass strength, MPa [psi].

k = Procedure A—k_1 from 13.5
= Procedure C—(1- k_s) from 13.7
= Procedure B—use k_1 from 13.6 for calculating bypass strength of strap #1; use k_2 from 13.6 for calculating bypass strength of strap #2.

13.10 *Bearing Stress/Strength*—Determine the bearing stress at each required data point with Eq 26. Calculate the ultimate bearing strength using Eq 27. Report the results to three significant digits.

$$\sigma_i^{br} = kP_i/hD \tag{26}$$

$$F^{br\_byp} = kP_{max}/hD \tag{27}$$

where:

F^{br_byp} = bearing stress at ultimate bypass strength, MPa [psi],
σ_i^{br} = bearing stress at i-th data point, MPa [psi],
P_i = force at i-th data point, N [lbf],
h = specimen thickness (nominal or actual, as specified), mm [in.], and
D = hole diameter, mm [in.].

NOTE 32—While the desired failure mode for the bearing/bypass test is net section failure, the bearing stress that corresponds to the calculated bypass stress value at P_{max} must be calculated and reported. The bearing stress value is used in combination with the bypass stress in plotting the data on a bearing/bypass interaction envelope.

13.11 *Bearing Strain*—Determine the average bearing strain for each displacement value recorded using Eq 28 and report the results to three significant digits.

$$\varepsilon_i^{br} = \frac{(\delta_{1i} + \delta_{2i})/2}{K \times D} \tag{28}$$

where:

ε_i^{br} = bearing strain, microstrain,
δ_{1i} = extensometer-1 displacement at i-th data point, mm [in.],
δ_{2i} = extensometer-2 displacement at i-th data point, mm [in.], and
K = 1.0 for Procedures A and C, 2.0 for Procedure B.

NOTE 33—The value for the K factor for Procedures A and C assumes that there is no bearing deformation in the loading straps and doubler straps, respectively. The value for the K factor for Procedure B assumes that one-half of the bearing deformation occurs in each strap—this may not be appropriate for straps that are significantly different in modulus, thickness or bearing stiffness.

13.12 *Statistics*—For each series of tests, calculate the average value, standard deviation, and coefficient of variation (in percent) for each property determined:

$$\bar{x} = \frac{\left(\sum_{i=1}^{n} x_i\right)}{n} \tag{29}$$

$$s_{n-1} = \sqrt{\left(\sum_{i=1}^{n} x_i^2 - n\bar{x}^2\right)/(n-1)} \tag{30}$$

$$CV = 100 \times s_{n-1}/\bar{x} \tag{31}$$

where:

$\bar{x}$ = sample mean (average),
s_{n-1} = sample standard deviation,
CV = sample coefficient of variation, %,
n = number of tested specimens, and
x_i = measured or derived property.

14. Report

14.1 Report the following information, or references pointing to other documentation containing this information, to the maximum extent applicable (reporting of items beyond the control of a given testing laboratory, such as might occur with material details or panel fabrication parameters, shall be the responsibility of the requestor):

NOTE 34—Guides E1309 and E1434 contain data reporting recommendations for composite materials and composite material mechanical tests. While these guides do not yet cover bearing/bypass response testing, they remain a valuable resource that should be consulted. A revision to the guides that adds the necessary additional fields is underway.

14.1.1 The test method and revision level or date of issue.

14.1.2 The procedure used and whether the specimen configuration was standard or variant.

14.1.3 The date(s) and location(s) of the test.

14.1.4 The name(s) of the test operator(s).

14.1.5 Any variations to this test method, anomalies noticed during testing, or equipment problems occurring during testing.

14.1.6 Identification of the material tested including: material specification, material type, material designation, 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, form or weave, fiber areal weight, matrix type, prepreg matrix content, and prepreg volatiles content.

14.1.7 Description of the fabrication steps used to prepare the laminate including: fabrication start date, fabrication end date, process specification, cure cycle, consolidation method, and a description of the equipment used.

14.1.8 Ply orientation stacking sequence of the laminate.

14.1.9 If requested, report density, volume percent reinforcement, and void content test methods, specimen sampling method and geometries, test parameters, and test results.

14.1.10 Average ply thickness of the material.

14.1.11 Results of any nondestructive evaluation tests.

14.1.12 Method of preparing the test specimen, including specimen labeling scheme and method, specimen geometry, sampling method, specimen cutting method, identification of tab geometry, tab material, and tab adhesive used.

14.1.13 Fastener or pin type and material, location of fastener head (bag side or tool side, if appropriate), washer type and material (if appropriate), number of washers (if appropriate), washer location (if appropriate), fastener or pin diameter, fastener installation torque (if appropriate), lubricant (if appropriate), hole clearance, countersink angle and depth (if appropriate), grommet, mating material, and number of fasteners.

14.1.14 Fastener or pin and specimen cleaning method.

14.1.15 Calibration dates and methods for all measurement and test equipment.

14.1.16 Type of test machine, grips, jaws, grip pressure, alignment results, and data acquisition sampling rate and equipment type.

14.1.17 The width and thickness dimensions of each test specimen. Report all individual measurements and the average width and thickness values.

14.1.18 Measured and nominal values of specimen hole diameter, specimen edge distance ratio, specimen width to diameter ratio, specimen hole diameter to thickness ratio, and specimen countersink depth to thickness ratio (if appropriate).

14.1.19 Type of loading (tensile or compressive), support fixture configuration (if used), gaps between support plates and long grips, and between long grips and the test specimen gage section, as measured by feeler gages.

14.1.20 Conditioning parameters and results, use of travelers and traveler geometry, and the procedure used if other than that specified in the test method.

14.1.21 Relative humidity and temperature of the testing laboratory.

14.1.22 Environment of the test machine environmental chamber (if used) and soak time at environment.

14.1.23 Number of specimens tested.

14.1.24 Speed of testing.

14.1.25 Bearing deformation indicator placement on the specimen, and transducer type for each transducer used.

14.1.26 Bearing stress/bearing strain curves and tabulated data of bearing stress versus bearing strain for each specimen.

14.1.27 Individual ultimate gross and net bypass strengths and average value, standard deviation, and coefficient of variation (in percent) for the populations. Note if the failure force was less than the maximum force prior to failure.

14.1.28 Individual ultimate bearing strengths and average value, standard deviation, and coefficient of variation (in percent) for the population. Note if the failure force was less than the maximum force prior to failure.

14.1.29 Individual bearing strains at failure and the average value, standard deviation, and coefficient of variation (in percent) for the population.

14.1.30 Load/displacement curves and tabulated data of force versus displacement for each specimen.

14.1.31 Individual values of failure force.

14.1.32 Failure mode and location of failure for each specimen.

15. Precision and Bias

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

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

16. Keywords

16.1 bearing/bypass properties; bearing strength; bypass strength; composite materials

REFERENCES

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(3) Grant, P., and Sawicki, A., "Relationship Between Failure Criteria, Allowables Development, and Qualification of Composite Structure," *Proceedings of the American Helicopter Society National Technical Specialists' Meeting on Rotorcraft Structures*, Williamsburg, VA, 1995.

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