Designation: D 7078/D 7078M – 05

Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method[1]

This standard is issued under the fixed designation D 7078/D 7078M; 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 covers the determination of the shear properties of high-modulus fiber-reinforced composite materials by clamping the ends of a V-notched specimen between two pairs of loading rails. When loaded in tension, the rails introduce shear forces into the specimen through the specimen faces. In comparison, the specimen of Test Method D 5379/D 5379M is loaded through its top and bottom edges. Face loading allows higher shear forces to be applied to the specimen, if required. Additionally, the present test method utilizes a specimen with a larger gage section than the V-notched specimen of Test Method D 5379/D 5379M. In both test methods, the use of a V-notched specimen increases the gage section shear stresses in relation to the shear stresses in the vicinity of the grips, thus localizing the failure within the gage section while causing the shear stress distribution to be more uniform than in a specimen without notches. In comparison, Test Method D 4255/D 4255M utilizes an unnotched specimen clamped between two pairs of loading rails that are loaded in tension. Also in contrast to Test Method D 4255/D 4255M, the present test method provides specimen gripping without the need for holes in the specimen.

The composite materials are limited to continuous-fiber or discontinuous-fiber-reinforced composites in the following material forms:

1.1.1 Laminates composed only of unidirectional fibrous laminae, with the fiber direction oriented either parallel or perpendicular to the fixture rails.

1.1.2 Laminates of balanced and symmetric construction, with the 0° direction oriented either parallel or perpendicular to the fixture rails.

1.1.3 Laminates composed of woven, braided, or knitted fabric filamentary laminae.

1.1.4 Short-fiber-reinforced composites with a majority of the fibers being randomly distributed.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement

D 883 Terminology Relating to Plastics

D 2584 Test Method for Ignition Loss of Cured Reinforced Resins

D 2734 Test Methods for Void Content of Reinforced Plastics

D 3171 Test Methods for Constituent Content of Composite Materials

D 3878 Terminology for Composite Materials

D 4255/D 4255M Test Method for In-Plane Shear Properties of Polymer Matrix Composite Materials by the Rail Shear Method

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

D 5379/D 5379M Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method

D 6856 Guide for Testing Fabric-Reinforced Textile Composite Materials

E 4 Practices for Force Verification of Testing Machines

E 6 Terminology Relating to Methods of Mechanical Testing

E 111 Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus

E 122 Practice for Calculating of Sample Size to Estimate,

---

[1] This test method is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.04 on Lamina and Laminate Test Methods.

Current edition approved May 15, 2005. Published August 2005.

[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.

With a Specified Tolerable Error, the Average for Characteristic of a Lot or Process
E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E 251 Test Methods for Performance Characteristics of Metallic Bonded Resistance Strain Gages
E 456 Terminology Relating to Quality and Statistics
E 1237 Guide for Installing Bonded Resistance Strain Gages
E 1309 Guide for Identification of Fiber-Reinforced Polymer Matrix Composite Materials in Databases
E 1434 Guide for Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases

2.2 *Other Documents:*
ANSI Y14.5M-1982 Geometric Dimensioning and Tolerancing[3]
ANSI/ASME B 46.1-1985 Surface Texture (Surface Roughness, Waviness, and Lay)[3]

2.3 *ASTM Adjuncts:*
V-Notched Rail Shear Fixture Machining Drawings[4]

3. Terminology

3.1 *Definitions*—Terminology D 3878 defines terms relating to high-modulus fibers and their composites. Terminology D 883 defines terms relating to plastics. Terminology E 6 defines terms relating to mechanical testing. Terminology E 456 and Practice E 177 define terms relating to statistics. In the event of a conflict between terms, Terminology D 3878 shall have precedence over the other terminology standards.

NOTE 1—If the term represents a physical quantity, its analytical dimensions are stated immediately following the term (or letter symbol) in fundamental dimension form, using the following ASTM standard symbology for fundamental dimensions, shown within square brackets: [M] for mass, [L] for length, [T] for time, [Θ] for thermodynamic temperature, and [nd] for nondimensional quantities. Use of these symbols is restricted to analytical dimensions when used with square brackets, as the symbols may have other definitions when used without the brackets.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *in-plane shear*, *n*—shear associated with shear forces or deformation applied to the *1-2* material plane such that the resulting shear deformations occur in the plane of the laminate. (See also *material coordinate system*).

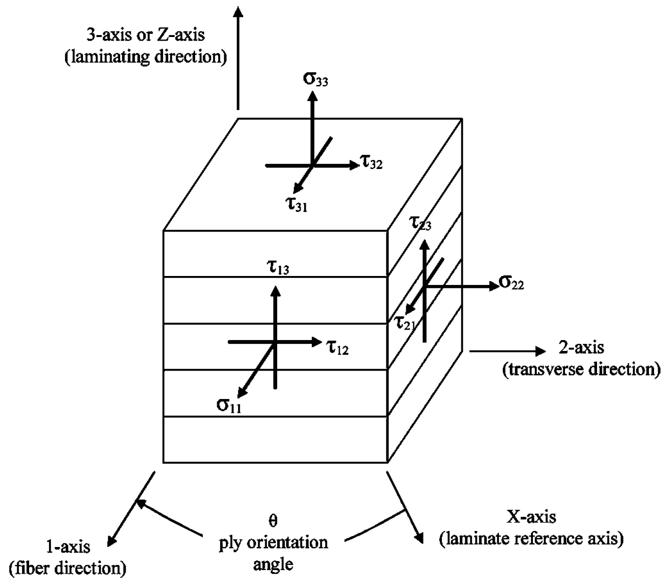


FIG. 1 Material Coordinate System

3.2.2 *interlaminar shear*, *n*—any of the shear properties describing the response resulting from a shear load or deformation applied to the *1-3* or *2-3* material planes. (See also *material coordinate system*).

3.2.3 *material coordinate system*, *n*—a Cartesian coordinate system describing the principal material coordinate system using *1, 2*, and *3* for the axes, as shown in Fig. 1.

3.2.4 *offset shear strength* $[M/(LT_2)]$, *n*—the shear stress a material sustains at the intersection of the shear stress versus engineering shear strain curve with a line parallel to a defined modulus and translated from the origin by a specified strain.

3.2.4.1 *Discussion*—The offset shear strength is a measure of the extent of material stress/strain linearity. (The material non-linearity in this definition neither assumes nor prohibits the presence of damage.) When comparing material offset strengths the same offset strain and modulus definition should be used. For material comparison in the absence of evidence suggesting the use of more appropriate values, an offset strain of 0.2 % should be used with the standard chord modulus. A graphical example of offset shear strength is shown in Fig. 2. For design, other offset strain and modulus definition combinations may be more suitable for specific materials and applications.

3.2.5 *shear strength* $[M/(LT_2)]$, *n*—the shear stress carried by a material at failure under a pure shear condition.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

[4] Available from ASTM Headquarters, 100 Barr Harbor Dr., PO Box C700, West Conshohocken, PA 19428-2959. Order Adjunct ADJD7078.

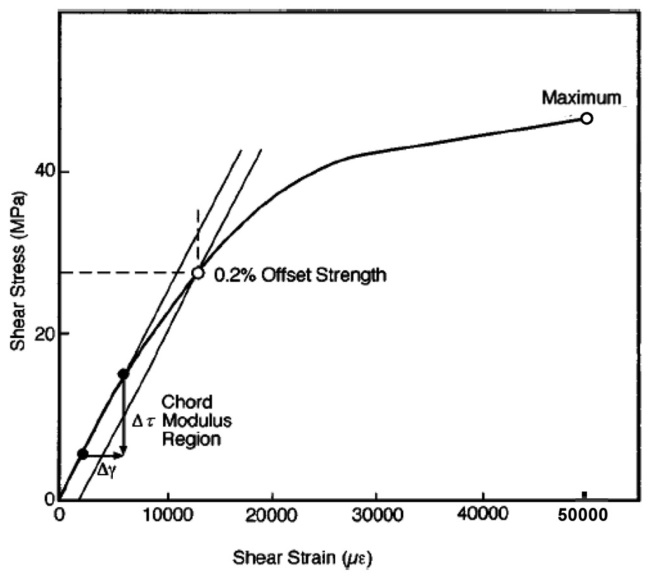


FIG. 2 Illustration of Modulus and Offset Strength Determination

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_1	=	coupon width between notches
d_2	=	notch depth
F^{su}	=	ultimate shear strength in the test direction
F^{u}	=	ultimate strength in the test direction
F° *(offset)*	=	the value of the shear stress at the intersection of the shear chord modulus of elasticity and the stress strain curve, when the modulus is offset along the shear strain axis from the origin by the reported strain offset value
G	=	shear modulus of elasticity in the test direction
h	=	overall coupon thickness
L	=	overall coupon length
n	=	number of coupons per sample population
P	=	load carried by test coupon
P^f	=	load carried by test coupon at failure
P^{max}	=	maximum load carried by test coupon before failure
r	=	notch radius
S_{n-1}	=	standard deviation statistic of a sample population for a given property
w	=	overall coupon 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
γ	=	engineering shear strain
ϵ	=	indicated normal strain from strain transducer or extensometer
σ	=	normal stress
τ	=	shear stress
θ	=	ply orientation angle

4. Summary of Test Method

4.1 A material coupon in the form of a flat rectangle with symmetrical centrally located V-notches, shown schematically in Fig. 3, is clamped to two fixture halves (pictured in Fig. 4, and shown schematically in Fig. 5 and in more detail in the machining drawings of ASTM Adjunct ADJD7078).[5] When loaded in tension using a mechanical testing machine, this fixture introduces shear forces in the specimen that produce failures across the notched specimen.

4.2 The specimen is inserted into the two fixture halves with the notches located along the line of the applied load. The two halves of the assembled fixture are extended by a testing machine while monitoring load. The relative displacement between the two fixture halves produces shear stresses in the notched specimen. By placing two strain gage elements, oriented at ±45° to the loading axis, in the middle of the specimen and along the loading axis, the shear strain response of the material can be measured.

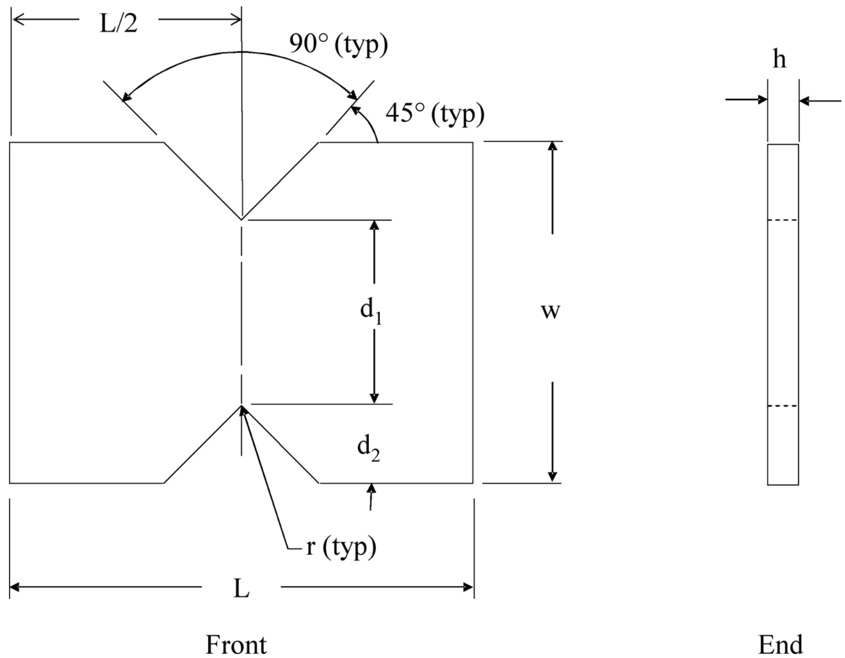
4.3 The notches influence the shear strain distribution in the central region of the coupon, producing a more uniform distribution than without notches. As a result of the reduced specimen width due to the notches, the average shear stress is increased relative to the unnotched width.

5. Significance and Use

5.1 This shear test is designed to produce shear property data for material specifications, research and development, quality assurance, and structural design and analysis. Either in-plane or interlaminar shear properties may be evaluated, depending upon the orientation of the material coordinate system relative to the loading axis. Factors that influence the shear response and should therefore be reported include: material, methods of material preparation and lay-up, specimen stacking sequence, specimen preparation, specimen conditioning, environment of testing, specimen alignment and gripping, speed of testing, time at temperature, void content, and volume percent reinforcement.

5.2 In anisotropic materials, properties may be obtained in any of the six possible shear planes by orienting the testing plane of the specimen with the desired material plane (*1-2* or *2-1*, *1-3* or *3-1*, *2-3* or *3-2*). Only a single shear plane may be evaluated for any given specimen. Properties, in the test direction, which may be obtained from this test method, include the following:

[5] The fixture and specimen were developed at the University of Utah (1-3). This work followed an earlier investigation on an improved rail shear test method at the University of Wyoming Composite Materials Research Group (4 and 5). The numbers in parentheses refer to the references listed at the end of the standard.



Nominal Specimen Dimensions

d_1 = 31.0 mm [1.20 in.]
d_2 = 12.7 mm [0.50 in.]
h = as required
L = 76.0 mm [3.0 in.]
r = 1.3 mm [0.05 in.]
w = 56.0 mm [2.20 in.]

FIG. 3 V-Notched Rail Shear Test Specimen Schematic

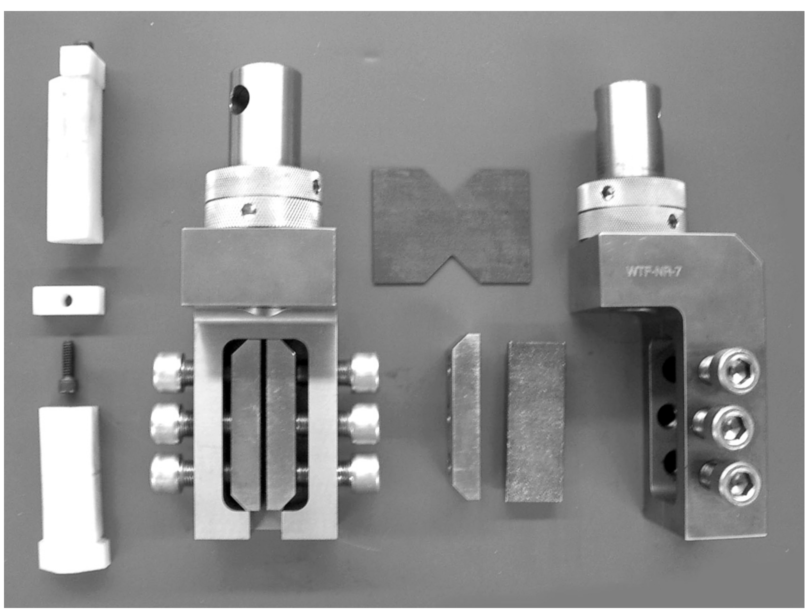


FIG. 4 Partially Assembled Fixture with Specimen and Spacer Blocks

5.2.1 Shear stress versus engineering shear strain response,

5.2.2 Ultimate shear strength,

5.2.3 Ultimate engineering shear strain,

5.2.4 Shear chord modulus of elasticity,

5.2.5 Transition strain.

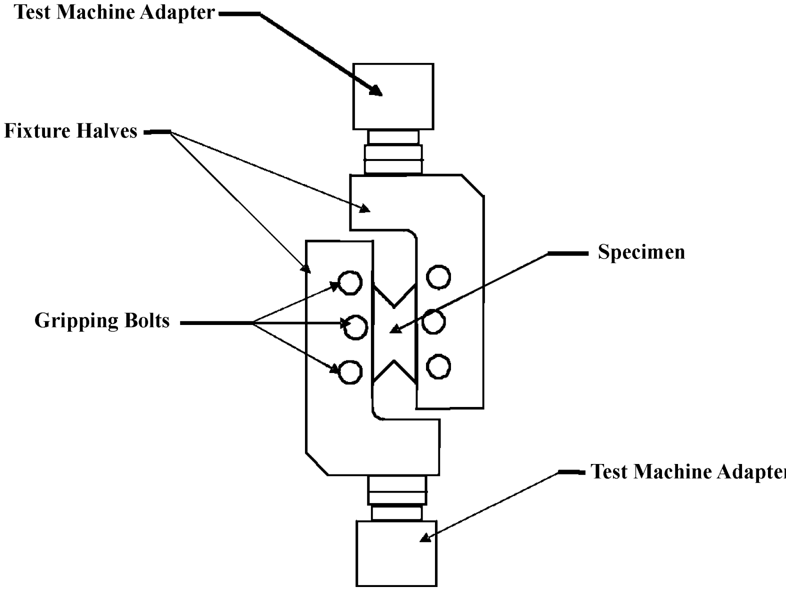


FIG. 5 Assembled V-Notched Rail Shear Apparatus

6. Interferences

6.1 *Material and Specimen Preparation*—Poor material fabrication practices, lack of control of fiber alignment, and damage induced by improper specimen machining are known causes of high material data scatter in composites.

6.2 *Elastic Modulus Measurement*—Shear modulus calculations in this test method assume a uniform distribution of shear stress and shear strain in the region of the specimen between the notch tips. The actual uniformity is dependent on the material orthotropy, the direction of loading, and the notch geometry (notch angle, notch depth, and notch radius). Referring to the fiber orientations in Fig. 6, detailed stress analysis (1)[6] has shown that $[0]_n$ specimens produce an elastic modulus measurement that is too high (5-10 % too high for carbon/epoxy), whereas $[0/90]_{ns}$ specimens produce a relatively accurate elastic modulus measurement. Further, stress analysis has shown that specimens with between 25 % and 100 % ±45° plies produce relatively accurate elastic laminate modulus measurements.

6.3 *Specimen Geometry Modifications*—Variations in the notch geometry (notch angle, notch depth, and notch radius) affect the degree of nonuniformity of shear stress and shear strain in the region of the specimen between the notches. Recommendations for notch dimensions versus the degree of material orthotropy have not been fully developed. Thus, a single notch geometry has been adopted. Variations to the notch angle, notch depth, and notch radius for the purpose of increasing the uniformity of the shear stress/shear strain distributions for a particular material and laminate are acceptable when the variations are clearly noted in the report.

6.4 *Load Eccentricity*—Twisting of the specimen during loading can occur, affecting strength results, and especially elastic modulus measurement. Twisting may occur due to an out-of-tolerance fixture, an out-of-tolerance specimen, or from a specimen that is improperly installed in the fixture. It is recommended that at least one specimen of each sample be tested with back-to-back two-element strain gages to evaluate the degree of twist. Evaluate the percent twist for the specimen by substituting the shear modulus from each side, G_a and G_b, into $|(G_a - G_b)/(G_a + G_b)| \times 100$, evaluated at 0.004 engineering shear strain. If the amount of twist is greater than 3 %, the specimens should be examined for cause of the twisting, and corrected, if possible. If no cause is apparent or correction possible, and the twisting persists, the shear modulus measurement should be made using the average response of back-to-back two-element strain gages.

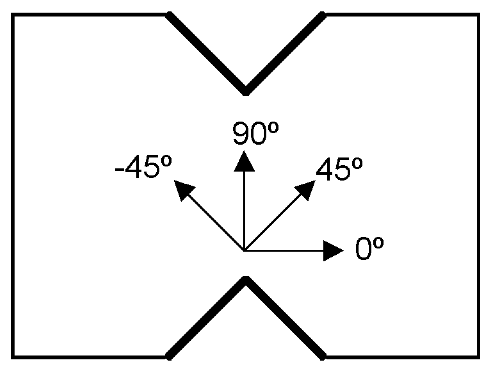


FIG. 6 Fiber Orientations in V-Notched Shear Specimen

6.5 *Determination of Failure*—Referring to the fiber orientations in Fig. 6:

6.5.1 *$[0]_n$ Unidirectional Specimens*—The use of $[0]_n$ unidirectional specimens is not recommended, since they produce shear modulus measurements that are too high (5-10 % too high for carbon/epoxy). A visible crack typically develops in $[0]_n$ unidirectional specimens at the notch root, causing a small drop in load (5 to 10 % of ultimate load) before ultimate failure. The small load drop accompanying the notch root crack

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

is not considered the failure load; rather the load that accompanies failure in the test section shall be used as the failure load.

6.5.2 *$[90]_n$ Unidirectional Specimens*—The use of $[90]_n$ unidirectional specimens is not recommended, since no reinforcing fibers span the width of the specimen between the fixture halves. Therefore, the specimen is subject to damage or failure when loading into the test fixture.

6.5.3 *$[0/90]_{ns}$ Tape and Fabric Specimens*—The shear failure load may be lower than the maximum load attainable during the test. For such laminates, the fibers may rotate following shear failure, subsequently allowing the fibers to carry a major portion of the load. In such cases, the shear failure load can often be determined by correlating visual observation of failure in the test section with a load drop or by a sustained increase in the slope of the load-displacement plot.

6.5.4 *Tape and Fabric Specimens with at Least 25 % ±45º Plies*—High shear strength rail shear specimens, especially thin ones, can buckle during load application. Buckling can be detected by strain gage readings from opposite faces of the specimens diverging by more than 10 % during loading. Data measured with the specimen in a buckled state are not representative of the material shear properties. Modulus data must be checked to confirm that buckling has not occurred in the modulus measurement range. Strength measurements must be checked to confirm that shear strength has not been influenced by specimen buckling. Failure by buckling should not be interpreted as indicating the maximum shear strength.

6.5.5 Ply delamination is another possible failure mode for tape and fabric laminates containing a large number of ±45° plies. This failure reflects instability of ±45° plies with compressive stresses in the fiber direction as contrasted to the overall specimen buckling failure previously described. Additionally, ply delamination may result from interlaminar stresses produced in multidirectional laminates under shear loading. Differences in strain gage readings due to ply delamination may not be noticeable, but the failure can be identified by delaminated plies in contrast to fiber breakage.

7. Apparatus

7.1 *Micrometers*—A micrometer with a 4- to 5-mm [0.16- to 0.20-in.] nominal diameter double-ball interface shall be used to measure the thickness of the specimen. A micrometer with a flat anvil interface shall be used to measure the width of the specimen. The accuracy of the instruments shall be suitable for reading to within 1 % of the sample width and thickness. For typical specimen geometries, an instrument with an accuracy of ±2.5 μm [±0.0001 in.] is adequate for thickness measurement, while an instrument with an accuracy of ±25 μm [±0.001 in.] is adequate for width measurement.

7.2 *Torque Wrench*—For measuring bolt torque of clamping bolts. Required to be calibrated within the torque range used.

7.3 *Angle Measuring Device*—For measuring the specimen notch angle, accurate to within ±1°.

7.4 *Radius Measuring Device*—For measuring the specimen notch radius, accurate to within ±0.25 mm [±0.01 in.].

7.5 *Testing Machine*—The testing machine shall be in conformance with Practices E 4 and shall satisfy the following requirements:

7.5.1 *Testing Machine Heads*—The testing machine shall have both an essentially stationary head and a movable head.

7.5.2 *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 11.3.

7.5.3 *Load Indicator*—The testing machine load-sensing device shall be capable of indicating the total load 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 load with an accuracy over the load range(s) of interest of within ±1 % of the indicated value. The load range(s) of interest may be fairly low for modulus evaluation, much higher for strength evaluation, or both, as required.

NOTE 2—Obtaining precision load data over a large range of interest in the same test, such as when both elastic modulus and ultimate load are being determined, place extreme requirements on the load cell and its calibration. For some equipment a special calibration may be required. For some combinations of material and load cell, simultaneous precision measurement of both elastic modulus and ultimate strength may not be possible, and measurement of modulus and strength may have to be performed in separate tests using a different load cell range for each test.

7.5.4 *Fixturing*—The fixture used shall be a two-rail fixture shown schematically in Fig. 5, and in more detail in the machining drawings of ASTM Adjunct ADJD7078. Each half of the fixture contains a side rail and two gripping plates that have a high coefficient of friction thermal spray coating on the gripping surface. Three bolts apply pressure to each gripping plate to secure the specimen during loading. The fixture shown is loaded in tension. Optional spacer blocks, used to maintain specimen alignment when installing in the fixture halves, are shown in Fig. 4.

7.5.5 *Attachments to Testing Machine*—Both of the testing machine heads shall be capable of being attached to one half of the V-notched rail shear fixture. If required, one of the interfaces may be capable of relieving minor misalignments between the heads, such as a universal joint.

7.6 *Strain Indicating Device*—Bonded resistance strain gages shall be used to measure strain. A minimum of two gage elements are required, centered between the notch tips in the gage section of the specimen. The gage elements shall be mounted at the +45° and -45° orientations shown in Fig. 6. If specimen twisting is a concern, then two gage elements on each side of the specimen should be measured simultaneously to allow for a correction as a result of any twisting of the specimen, as discussed in Section 6. The output from each pair of gage elements may be monitored individually and the outputs summed following the test. Additionally, each pair of gage elements may be wired as a half-bridge such that the recorded strain is the sum of the absolute value of the response of each gage element, thus yielding the engineering shear strain response directly.

7.6.1 *Bonded Resistance Strain Gage Selection*—Strain gage selection is based on the type of material to be tested. An active gage length of 1.5 mm [0.062 in.] is recommended for composite laminates fabricated from unidirectional layers. Larger strain gage sizes may be more suitable for some textile fabric laminates. When the strain gage elements are mounted at

+45° and -45° to the loading axis, the width of the gage elements should not be so large as to extend significantly beyond the area in which shear strain is relatively uniform (see Note 3). Gage calibration certification shall comply with Test Method E 251. Strain gages with a minimum normal strain range of approximately 3 % (yielding 6 % engineering shear strain) 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 composites follow. A general reference on the subject is Tuttle and Brinson (6). Specific guidelines on the selection of strain gage size for use on textile fabric laminates is provided in Guide D 6856.

NOTE 3—A typical gage would have a 0.062- to 0.125-in. active gage length, 350-Ω resistance, a strain rating of 3 % or higher, and the appropriate environmental resistance and thermal coefficient.

7.6.1.1 Surface preparation of fiber-reinforced composites in accordance with Guide E 1237 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.

7.6.1.2 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.

7.6.1.3 Consideration of some form of temperature compensation is recommended, even when testing at standard laboratory atmosphere. Temperature compensation is required when testing in nonambient temperature environments.

7.6.1.4 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.

7.7 *Conditioning Chamber*—When conditioning materials at nonlaboratory 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 vapor level to within ±3 %. Chamber conditions shall be monitored either on an automated continuous basis or on a manual basis at regular intervals.

7.8 *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.

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, such as in the case of a designed experiment. For statistically significant data, consult the procedure outlined in Practice E 122. Report the method of sampling.

NOTE 4—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 coupon), then another traveler coupon of the same nominal thickness and appropriate size (but without tabs) shall be used to determine when equilibrium has been reached for the specimens being conditioned.

8.2 *Geometry*—The special coupon is a flat rectangle with symmetrical centrally located V-notches. It is recommended that laminates be at least 1.3 mm [0.050 in.] thick, since thin laminates may buckle prior to shear failure. Significantly thicker specimens, particularly those with a significant number of ±45º plies, may have shear strengths exceeding the rail-clamping capacity of the test fixture. The mandatory requirements are described in 8.2.1. Recommendations on parameters that are not required are discussed in 8.2.2.

8.2.1 *Specimen Requirements*:

8.2.1.1 *Shape, Dimensions, Tolerances, and Configuration*—The required specimen shape, dimensions, and tolerances are described in Fig. 7 (SI) and Fig. 8 (inch-pound). If required, adjust the standard notch angle of 90°, notch depth of 12.5 mm [0.50 in.], and notch radius of 1.3 mm [0.050 in.] to meet special material requirements, but any deviation from these values must be recorded with the test results, and the standard tolerances on these features still apply. As discussed in Section 6, the $[0/90]_{ns}$ specimen has been found to provide a more accurate elastic modulus determination, shows less variation in the strength results, and is generally preferred over either the $[0]_n$ or the (not recommended) $[90]_n$ specimens.

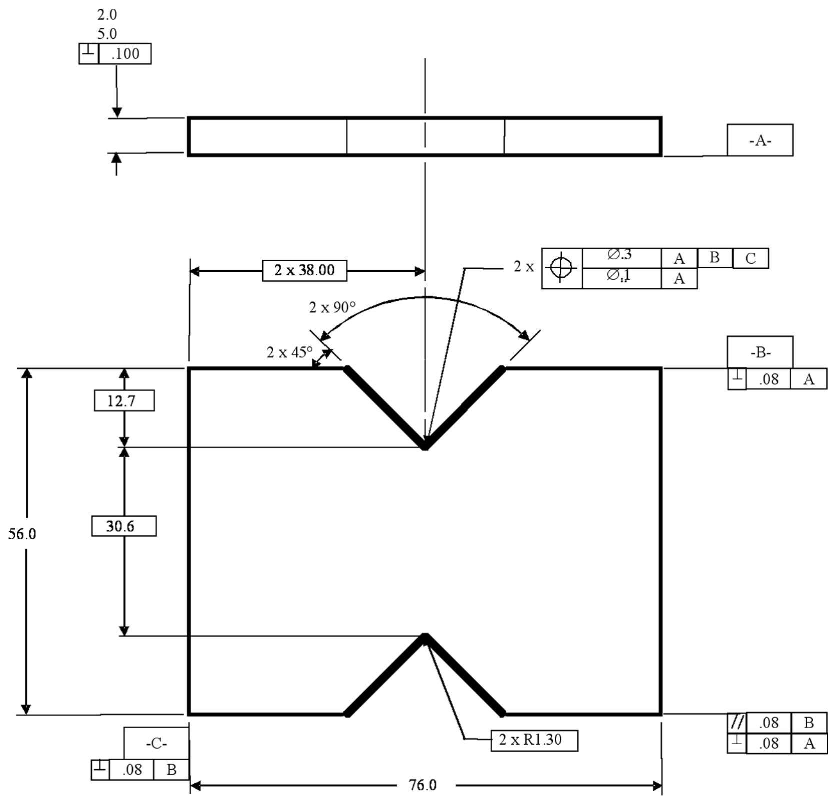
8.2.2 *Specific Recommendations*:

8.2.2.1 *Specimen Thickness*—A wide range is allowed in the requirement for specimen thickness to allow the user some flexibility in unusual cases. When possible, however, the specimen thickness should be kept in the range from 2 to 5 mm [0.080 to 0.200 in.].

8.3 *Material Orientation*—Perform shear tests in any of the six material shear planes, as defined by Fig. 1 and by proper orientation of the laminate when fabricating and machining the specimen as illustrated by Fig. 9.

NOTE 5—For example: the *1-2* plane is located in the plane formed by the *1* and *2* axes and is oriented on the specimen so that the *1*-direction (the first digit of the plane) is along the length of the specimen (*X*-direction in Fig. 9).

8.3.1 *1-2 and 2-1 Shear Properties*—The material properties in the *1-2* and *2-1* planes are in-plane properties for laminated composites. Prepare specimens for evaluation of these properties by cutting coupons from a $[0]_n$, $[90]_n$, or $[0/90]_{ns}$ laminate, so that the 0° direction is either along the length of the specimen (*X*-direction in Fig. 9) or in the direction



NOTE—Interpret Fig. 7 in accordance with ANSI Y14.5M-1982, subject to the following:

(*1*) All dimensions in millimetres with decimal tolerances as follows:

No decimal	0.X	0.XX
±3	±1	±0.3

(*2*) All angles have a tolerance of ±0.5°.
(*3*) Ply orientation direction tolerance relative to –A- (or to –B-) within ±0.5°.
(*4*) Finish on machined edges not to exceed 1.6 √. Finish on V-notch not to exceed 0.8 √ (symbology is in accordance with ANSI/ASME B46.1-1985, with roughness height in micrometers.)
(*5*) Values to be provided for the following, subject to any ranges shown on the field of Fig. 7: material, lay-up, and ply orientation reference relative to –A-, and coupon thickness.

FIG. 7 V-Notched Rail Shear Specimen Drawing (SI)

of the loading axis, as appropriate. As discussed in sections 6.2 and 6.5, the use of $[0]_n$ and $[90]_n$ unidirectional laminates is not recommended.

8.3.2 *1-3 and 2-3 Shear Properties*—The material properties in the *1-3* and *2-3* planes are interlaminar properties for laminated composites. Prepare specimens for evaluation of these properties by cutting coupons from a thick (56-mm [2.20-in.]) $[0]_n$ or $[90]_n$ laminate. The thick laminate may be manufactured several ways. The procedures in 8.3.2.1 or 8.3.2.2 are equally acceptable. The procedure in 8.3.2.3 should be used only if neither of the first two are possible, as the bondlines can influence the results.

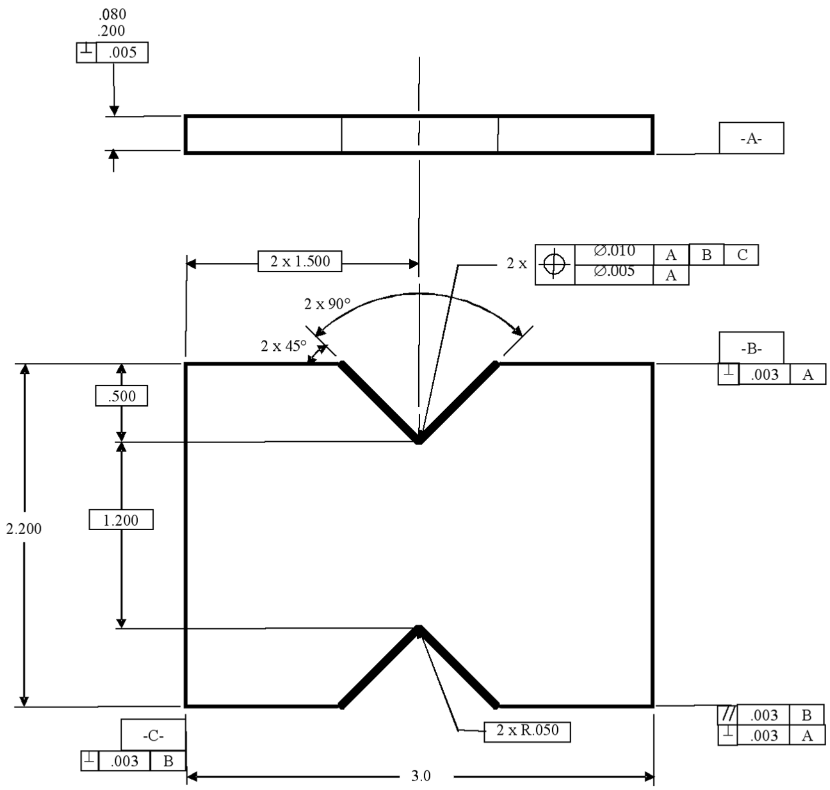
8.3.2.1 Cocure the laminate to the final panel thickness in a single operation.

8.3.2.2 Bond or co-bond in two or more operations to achieve the final panel thickness, using for the test section a precured laminate that is greater than 31 mm [1.20 in.] thick to which has been symmetrically bonded on each side additional laminate to total the 56-mm [2.20-in.] total panel thickness.

8.3.2.3 Bond together in two or more operations, using uniformly thin layers of adhesive, a minimum number of precured laminates to achieve the 56-mm [2.20-in.] total panel thickness.

NOTE 6—The number of bondlines traversing the notched section and the thickness of the bondlines should be minimized to prevent the adhesive from influenceing the test results. The cumulative thickness of all adhesive bondlines traversing the notched section should be less than 5 % of the coupon width between notches.

8.3.3 *3-1 and 3-2 Shear Properties*—The material properties in the *3-1* and *3-2* planes are interlaminar properties for laminated composites. Prepare specimens for evaluation of these properties by cutting coupons from a $[0]_n$ or $[90]_n$ laminate that is prepared as follows: Bond or co-bond in two or more operations a number of precured layers, using for the test section a precured laminate which is as thick as possible (preferably greater than the width of the test section; at least 6 mm [0.25 in.] thick), to which has been symmetrically bonded



NOTE—Interpret Fig. 8 in accordance with ANSI Y14.5M-1982, subject to the following:

(*1*) All dimensions in inches with decimal tolerances as follows:

	0.X	0.XX	0.XXX	
2.200		±0.1	±0.03	0.010

(*2*) All angles have a tolerance of ±0.5°.
(*3*) Ply orientation direction tolerance relative to –A- (or to –B-) within ±0.5°.
(*4*) Finish on machined edges not to exceed 64 √. Finish on V-notch not to exceed 32 √ (symbology is in accordance with ANSI/ASME B46.1-1985, with roughness height in microinches.)
(*5*) Values to be provided for the following, subject to any ranges shown on the field of Fig. 8: material, lay-up, and ply orientation reference relative to –A-, and 2.200 coupon thickness.

FIG. 8 V-Notched Rail Shear Specimen Drawing (Inch-Pound)

on each side additional laminate of the same material to total the 76-mm [3.0-in.] total length.

8.4 *Specimen Preparation*:

8.4.1 *Panel Fabrication*—Control of fiber alignment is critical. Improper fiber alignment will influence the measured properties. Erratic fiber alignment will also increase the coefficient of variation. The preparation method used shall be reported.

8.4.2 *Machining Methods*—Specimen preparation is extremely important for this specimen. The specimens may be molded individually to avoid edge and cutting effects or they may be cut from plates. If they are cut from plates, take precautions to avoid splintering, chips and gouges, undercuts, rough or uneven surfaces, or delamination as a result of 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.

8.4.2.1 *Notch Preparation*—Take care to avoid delaminating specimens during notch machining. Stacking and clamping of the specimens in a vise, with a dummy specimen on the backside, has been found to be an effective method of preventing delamination during machining. Machining methods that have worked well for notch preparation include precision grinding and precision milling.

8.4.3 *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.

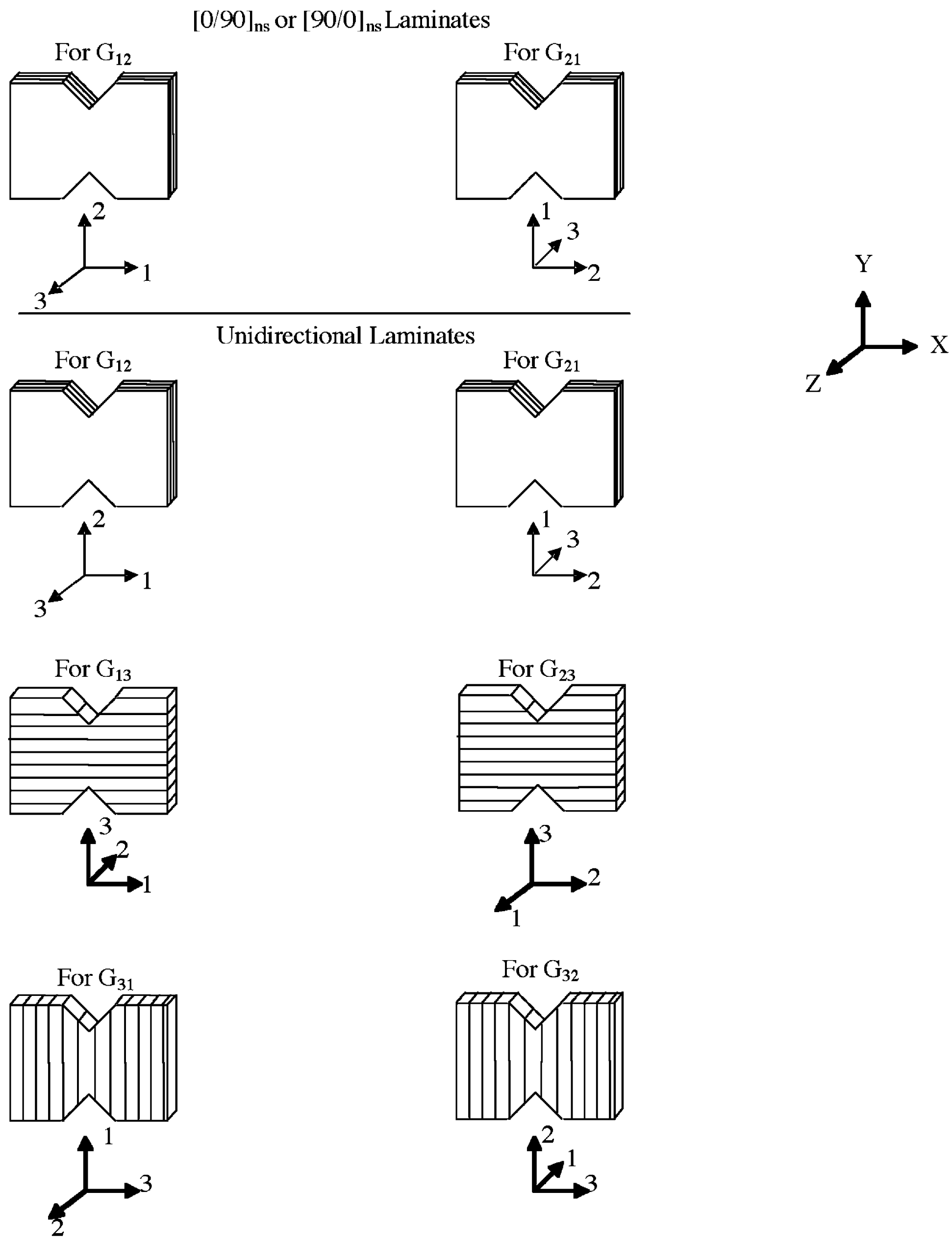


FIG. 9 Orientation of Material Planes

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 *Polymer Matrix Composites*—Unless a different environment is specified as part of the experiment, condition the test specimens in accordance with Procedure C of Test Method D 5229/D 5229M and store and test at standard laboratory atmosphere (23 ± 2°C [73.4 ± 3.6°F] and 50 ± 10 % relative humidity).

10.2 *Nonpolymeric Materials*—No conditioning environment is required.

11. Procedure

11.1 *Parameters to Be Specified Before Test*:

11.1.1 The shear specimen sampling method, coupon type and geometry, and conditioning travelers (if required).

11.1.2 The shear properties and data reporting format desired.

NOTE 7—Specific material property, accuracy, and data reporting requirements should be determined before test for proper selection of instrumentation and data recording equipment. Estimates of operating stress and strain levels should also be made to aid in strain gage selection, calibration of equipment, and determination of equipment settings.

11.1.3 The environmental conditioning test parameters.

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

11.2 *General Instructions*:

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, obtain these samples from the same panels being shear tested. Specific gravity and density may be evaluated by means of Test Method D 792. Volume percent of the constituents may be evaluated by one of the matrix digestion procedures of Test Method D 3171 or, for certain reinforcement materials such as glass and ceramics, by the matrix burn-off technique of Test Method D 2584. The void content equations of Test Methods D 2734 are applicable to both Test Method D 2584 and the matrix digestion procedures.

11.2.3 Following any conditioning, but before the shear testing, measure and report the specimen width across the notch, d_1, to the nearest 25 µm [0.001 in.] and the specimen thickness at the notch, h, to the nearest 2.5 µm [0.0001 in.]. Calculate the cross-sectional area as follows:

$$A = d_1 \times h \tag{1}$$

Record the area so obtained as the cross-sectional area for the specimen, A, in units of mm^2 [$in.^2$]. Verify that the notch angle, depth, and radius satisfy the required tolerances.

11.2.4 Mount the strain gages such that the gage elements are oriented at +45° and -45° to the loading axis and centered between the notches.

11.3 *Speed of Testing*—Set the speed of testing to produce a nearly constant strain rate in the gage section. If strain control is not available on the testing machine, this may be approximated by repeated monitoring and adjusting of the rate of load application to maintain a nearly constant strain rate, as measured by strain gage response versus time. Select the strain rate so as to produce failure within 1 to 10 min. If the ultimate strain of the material cannot be reasonably estimated, conduct initial trials using standard speeds until the ultimate strain of the material and the compliance of the system are known, and the strain rate can be adjusted. The suggested standard speeds are as follows:

11.3.1 *Strain-Controlled Tests*—A standard engineering shear strain rate of 0.01 min^{-1}.

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

NOTE 8—Use of a fixed head speed in testing machine systems with a high compliance will result in a strain rate that is much lower than required.

11.4 *Test Environment*—Condition the specimen to the desired moisture profile and, if possible, test under the same conditioning fluid exposure level. 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. Modifications to the test environment shall be recorded.

11.4.1 Store the specimen in the conditioned environment until test time, if the testing area environment is different than the conditioning environment.

11.5 *Specimen Insertion and Strain Gage Connection*:

11.5.1 *Connect Gages*—Connect the specimen strain gages into the data acquisition circuitry and perform any necessary preliminary calibrations.

NOTE 9—It is highly desirable, though not required, to be able to watch strain-gage response during specimen installation as an aid to minimize undesirable preloading of the specimen.

11.5.2 *Zero Load*—Verify load-cell calibration and zero the load display. The load shall be able to be observed during specimen installation to minimize undesirable preload on the specimen.

11.5.3 *Inspect the Fixture*—Examine the fixture for signs of wear in the grip area, clamping bolts, and connecting pins. Correct any deficiencies in the fixture. All bolt threads and fixture threads shall be clean and lubricated. A powdered graphite lubricant is suggested; oils can spread onto the surfaces of the fixture, promoting the accumulation of debris on them during subsequent testing. Inspect the gripping surfaces to ensure that they are not damaged and are free of foreign matter. Examine the gripping surfaces for residue from previous test specimens. If necessary, clean the gripping surfaces. A brass wire brush is suggested for removing residue from the gripping surfaces.

11.5.4 *Loosen Gripping Bolts*—Loosen the gripping bolts of each fixture half sufficiently to allow the specimen thickness to be freely inserted into the cavity between the gripping plates with clearance.

11.5.5 *Insert Specimen into First Fixture Half*—Place the specimen loosely into one fixture half with the spacer block (optional) in place and adjust the strain gage lead wires. The end blocks of the spacer should be tightened so that the spacer attaches securely to the fixture half. Adjust the three clamping bolts in one side of the fixture half such that the specimen is aligned with centering scribe marks on the spacer. Hand-tighten the three clamping bolts on the other side of the fixture half to lightly grip the specimen. Ensure that the notches on the specimen are aligned with the spacer blocks, as shown in Fig. 10. Tighten each clamping bolt to a value ½ of the maximum clamping torque. Finally tighten each bolt to the required clamping torque. A bolt torque of 55 N-m [40 ft-lb] is recommended.

NOTE 10—The required bolt torque may vary depending on the type of material and the thickness of the specimen being tested. A torque of 45 to 55 N-m [35 to 40 ft-lb] has been found to be sufficient for most materials of typical specimen thicknesses. If the torque is too low for a given configuration, the specimen may slip relative to the gripping surfaces. If the torque is excessive, the high clamping force will induce detrimental stress concentrations in the specimen at the sides of the gage section and may lead to premature failures. Thus, a minimal value of bolt torque sufficient to prevent specimen slippage should be used. This may require several trials when testing an unfamiliar material. However, it has been shown that the acceptable range of bolt torques is very broad (1).

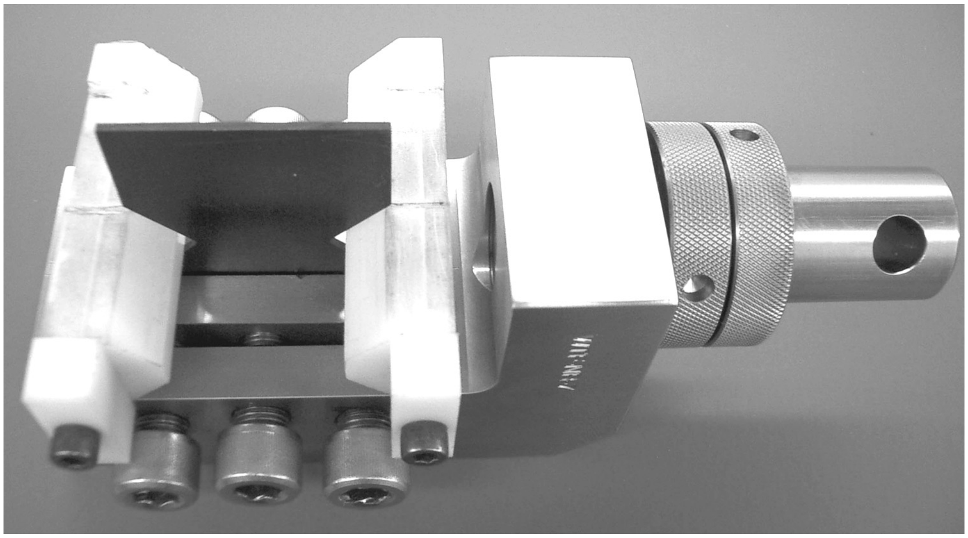


FIG. 10 Use of Spacers for Specimen Alignment

11.5.6 *Zero Strain Gages*—Zero the strain gage outputs with the specimen inserted into one fixture half.

11.5.7 *Insert Specimen into Second Fixture Half*—Place the second fixture half onto the specimen. The two spacer blocks (optional) used for orienting the specimen in the first fixture half are used to orient the second fixture half and obtain the proper spacing between fixture halves. It may be necessary to loosen the spacer end blocks to attach the second fixture half. The spacer end blocks should be retightened to secure the spacers to the fixture. The clamping bolts are tightened in the same manner of the first rail. This assembly is shown in Fig. 11.

11.6 *Fixture Installation*—Attach the test fixture halves to the upper and lower test machine heads. The adapters that are shown in the test fixture drawings are optional and are test machine dependent.

NOTE 11—This test is run in tension in a testing machine with a stationary head and a moving head. While a vertical testing machine is not a requirement of this test method, for ease of description the instructions that follow assume the use of a vertical testing machine. The location of the moving head relative to the stationary head, as long as they create tension, or to which head the load transducer is attached are not important.

11.7 *Remove Spacer*—Remove the screws holding the spacer end blocks. Each spacer should now freely slide out of the assembled fixture.

11.8 *Loading*—Apply the load to the specimen at the specified rate until failure, while recording data.

11.9 *Data Recording*—Record load versus strain and load versus head displacement continuously, or at frequent regular intervals. If a load-strain or load-displacement discontinuity occurs or initial ply failures are observed, record the load, strain, and mode of damage at such points. If the specimen is to be failed, record the maximum load before failure and the strain at, or as near as possible to, the moment of rupture. If ultimate failure does not occur within 5 % strain, the data shall be truncated to this value. Guidance on interpretation of failure load is given in Section 6.

11.10 *Failure Mode*—Record the mode and location of failure of the specimen.

12. Calculation

12.1 *Shear Stress/Ultimate Strength*—Calculate the ultimate strength using Eq 2 and report the results to three significant figures. If the shear modulus is to be calculated, determine the shear stress at each required data point using Eq 3.

$$F^u = P^u/A \quad (2)$$

$$\tau_i = P_i/A \quad (3)$$

where:

F^u = ultimate strength, MPa [psi];
P^u = the lower of ultimate or load at 5 % engineering shear strain, N [lbf];
τ_i = shear stress at ith data point, MPa [psi];
P_i = load at ith data point, N [lbf]; and
A = cross-sectional area from 11.2.3, mm² [in.²].

12.2 *Shear Strain/Ultimate Strain*—If shear modulus or ultimate strain is to be calculated, determine the engineering shear strain from the indicated normal strains at +45° and -45° at each required data point using Eq 4. The ultimate engineering shear strain is determined from Eq 5. Report the results to three significant figures.

$$\gamma_i = |\epsilon_{+45}| + |\epsilon_{-45}| \quad (4)$$

$$\gamma^u = \text{min of 5 \% or } \gamma \text{ at ultimate load} \quad (5)$$

where:

γ_i = engineering shear strain at ith data point, με;
ϵ_{+45} = + 45° normal strain at ith data point, με;
ϵ_{-45} = –45° normal strain at ith data point, με; and
γ^u = ultimate engineering shear strain, με.

12.3 *Shear Modulus of Elasticity*:

NOTE 12—To minimize potential effects of twisting, it is recommended that the strain data used for modulus of elasticity determination be the average of the indicated strains from each side of the specimen, as discussed in Section 6.

12.3.1 *Shear Chord Modulus of Elasticity*—Calculate the shear chord modulus of elasticity using Eq 6, applied over a

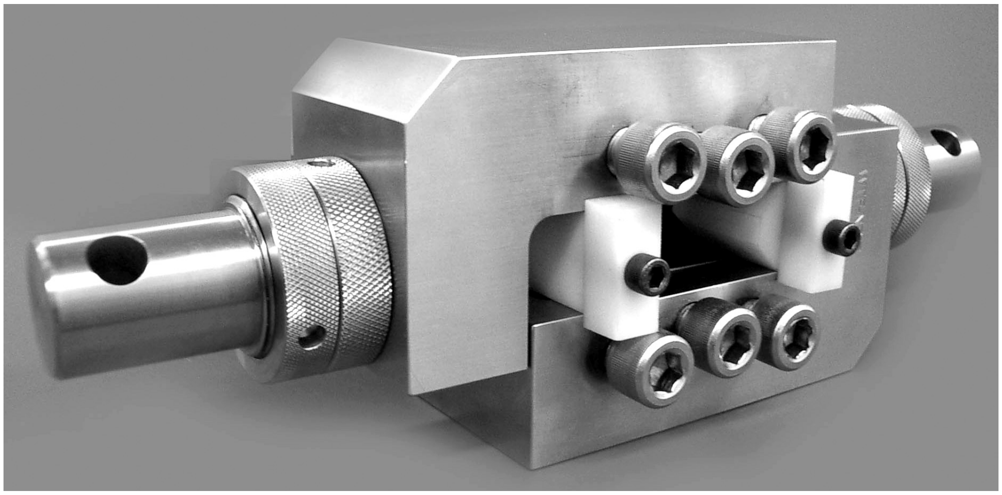


FIG. 11 Use of Spacers For Final Fixture Alignment

4000 ± 200-µϵ engineering shear strain range, starting with the lower strain point in the range of 1500 to 2500 µϵ inclusive. If data are not available at the exact strain range end points (as often occurs with digital data), use the closest available data point. Report the shear chord modulus of elasticity to three significant figures. Also report the strain range used in the calculation. A graphical example of shear chord modulus is shown in Fig. 2.

$$G^{chord} = \Delta\tau/\Delta\gamma \tag{6}$$

where:

G^{chord} = shear chord modulus of elasticity, GPa [psi];
$\Delta\tau$ = difference in applied shear stress between the two strain points; and
$\Delta\gamma$ = difference between the two engineering shear strain points (nominally 4000 µϵ).

12.3.2 *Shear Modulus of Elasticity (Other Definitions)*—Other definitions of elastic modulus may be evaluated and reported at the user's discretion. If such data is generated and reported, report also the definition used, the strain range used, and the results to three significant figures. Test Method E 111 provides additional guidance in the determination of modulus of elasticity.

NOTE 13—An example of another modulus definition is the secondary chord modulus of elasticity for materials that exhibit essentially bilinear stress-strain behavior.

12.4 *Offset Shear Strength*—Determine the offset shear strength by translating the shear chord modulus of elasticity line along the strain axis from the origin by a fixed strain value and extend this line until it intersects the stress-strain curve. Determine the shear stress that corresponds to the intersection point and report this value, to three significant digits, as the offset shear strength, along with the value of the offset strain, as in:

$$F^{o}\ (0.2\ \%\ \text{offset}) = 28\ \text{MPa} \tag{7}$$

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

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{8}$$

$$s_{n-1} = \sqrt{\frac{\sum_{i=1}^{n} x_i^2 - n\bar{x}^2}{n-1}} \tag{9}$$

$$CV = 100 \times \frac{s_{n-1}}{\bar{x}} \tag{10}$$

where:

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

13. Report

13.1 The data reported with this test method include mechanical testing data and material identification data and shall be in accordance with Guides E 1434 and E 1309, respectively. 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 of panel fabrication parameters, shall be the responsibility of the requestor):

13.1.1 The revision level or date of issue of this test method.

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

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

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

13.1.5 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, sizing, tow or yarn filament counts and twist, yarn spacings, fabric type, fiber areal weight, matrix type, prepreg matrix content, and prepreg volatiles content.

13.1.6 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.

13.1.7 Ply orientation stacking sequence of the laminate.

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

13.1.9 Average ply thickness of the material.

13.1.10 Results of any nondestructive evaluation tests.

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

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

13.1.13 Type of test machine, alignment results, and data acquisition sampling rate and equipment type.

13.1.14 Dimensions of each test specimen.

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

13.1.16 Relative humidity and temperature of the testing laboratory.

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

13.1.18 Number of specimens tested.

13.1.19 Speed of testing.

13.1.20 The strain-gage type, resistance, size, gage factor, temperature compensation method, transverse sensitivity, lead-wire resistance, and any correction factors used.

13.1.21 Load-displacement and stress-strain curves for each specimen.

13.1.22 Tabulated data of stress versus strain for each specimen.

13.1.23 Percent twisting results for each specimen so evaluated.

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

13.1.25 Individual ultimate engineering shear strains and the average value, standard deviation, and coefficient of variation (in percent) for the population. Note any test that was truncated to 5 % strain.

13.1.26 Strain range used for chord shear modulus determination.

13.1.27 If another definition of modulus of elasticity is used in addition to chord modulus, describe the method used, the resulting correlation coefficient (if applicable), and the strain range used for the evaluation.

13.1.28 Individual values of shear chord modulus of elasticity, and the average value, standard deviation, and coefficient of variation (in percent) for the population.

13.1.29 Individual values of offset shear strength with the value of the offset strain, along with the average, standard deviation, and coefficient of variation (in percent) values for the population.

13.1.30 Failure mode and location of failure for each specimen.

14. Precision and Bias

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

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

15. Keywords

15.1 composite materials; in-plane shear; interlaminar shear; shear modulus; shear properties; shear strength; shear testing

REFERENCES

(1) Adams, D. O., Moriarty, J. M., Gallegos, A. M., and Adams, D. F., "Development and Evaluation of the V-Notched Rail Shear Test for Composite Laminates," Federal Aviation Administration Report DOT/FAA/AR-03/63, FAA Office of Aviation Research, Washington, D.C., September, 2003.

(2) Adams, D. O., Moriarty, J. M., Gallegos, A. M., and Adams, D. F., "Development and Evaluation of a V-Notched Rail Shear Test," proceedings of the 2002 SAMPE Technical Conference, Baltimore, MD, November 5-8, 2002.

(3) Adams, D. O., Gallegos, A. M., Moriarty, J. M., and Adams, D. F., "A V-Notched Rail Shear Test for Composite Laminates," proceedings of the 2002 SEM Annual Conference, Milwaukee, WI, June 10-12, 2002.

(4) Hussain, A. K. and Adams, D. F., "The Wyoming-Modified Two-Rail Shear Test Fixture for Composite Materials," Journal of Composites Technology and Research, JCTRER, Vol 21, October 1999, pp. 215-223.

(5) Hussain, A. K. and Adams, D. F., "An Analytical and Experimental Evaluation of the Two-Rail Shear Test for Composite Materials," University of Wyoming Composite Materials Research Group Report UW-CMRG-R-98-105, February 1998.

(6) Tuttle, M. E., and Brinson, H. F., "Resistance-Foil Strain-Gage Technology as Applied to Composite Materials," *Experimental Mechanics*, Vol 24, No. 1, March 1984, pp. 54–65; errata noted in Vol 26, No. 2, June 1986, pp. 153–154.