Designation: D7078/D7078M – 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 D7078/D7078M; 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 D5379/D5379M 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 D5379/D5379M. 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 D4255/D4255M utilizes an unnotched specimen clamped between two pairs of loading rails that are loaded in tension. Also in contrast to Test Method D4255/D4255M, 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]

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
D4255/D4255M Test Method for In-Plane Shear Properties of Polymer Matrix Composite Materials by the Rail Shear Method
D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
D5379/D5379M Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method
D6856 Guide for Testing Fabric-Reinforced "Textile" Composite Materials
E4 Practices for Force Verification of Testing Machines
E6 Terminology Relating to Methods of Mechanical Testing
E111 Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus
E122 Practice for Calculating Sample Size to Estimate, With

[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.

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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.

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 Gauges
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 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 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 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*).

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.

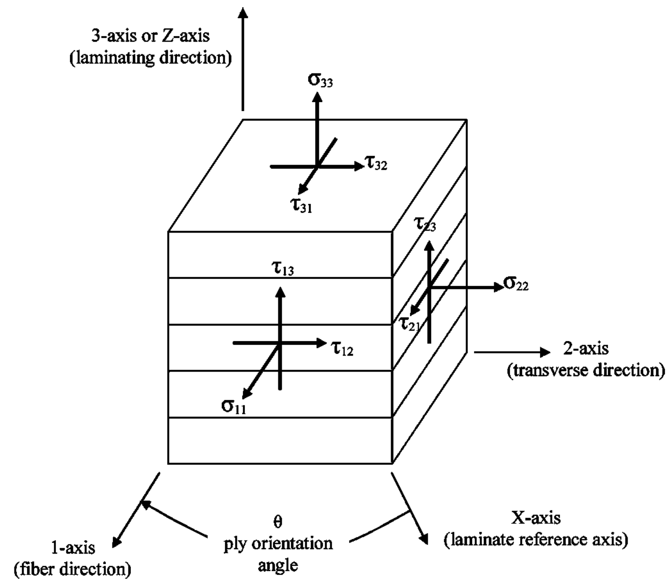


FIG. 1 Material Coordinate System

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.

3.3 *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

[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.

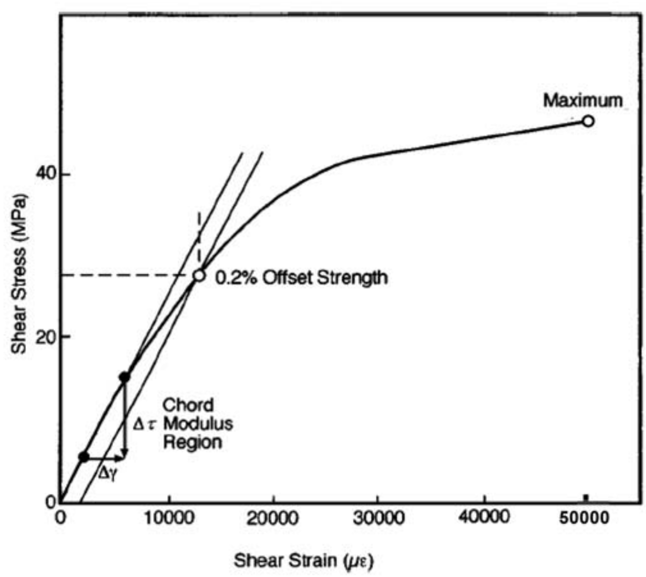


FIG. 2 Illustration of Modulus and Offset Strength Determination

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:

5.2.1 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.

6. Interferences

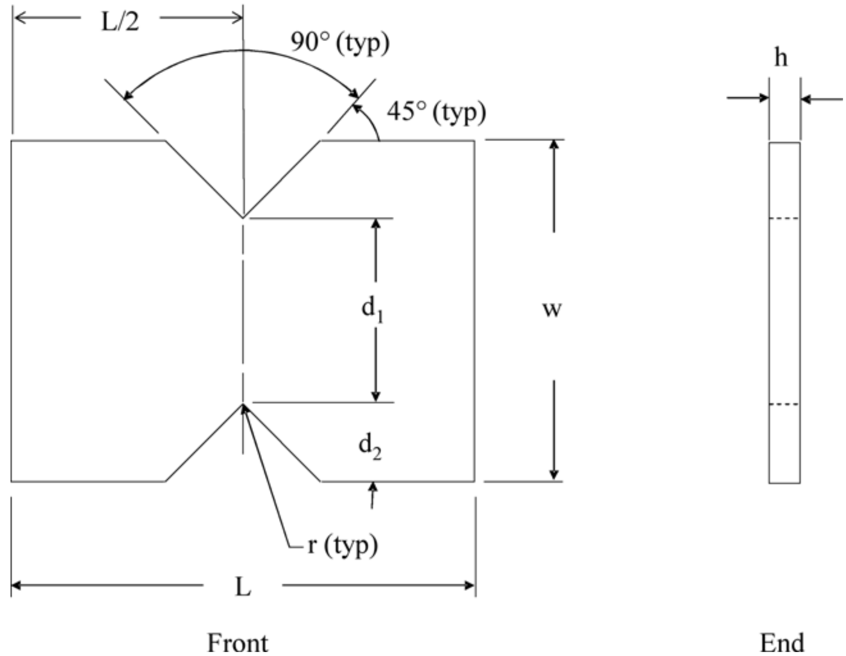
6.1 *Material and Specimen Preparation*—Poor material fabrication practices, lack of control of fiber alignment, and damage induced by improper specimen machining are known causes of high material data scatter in composites.

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

[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.

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

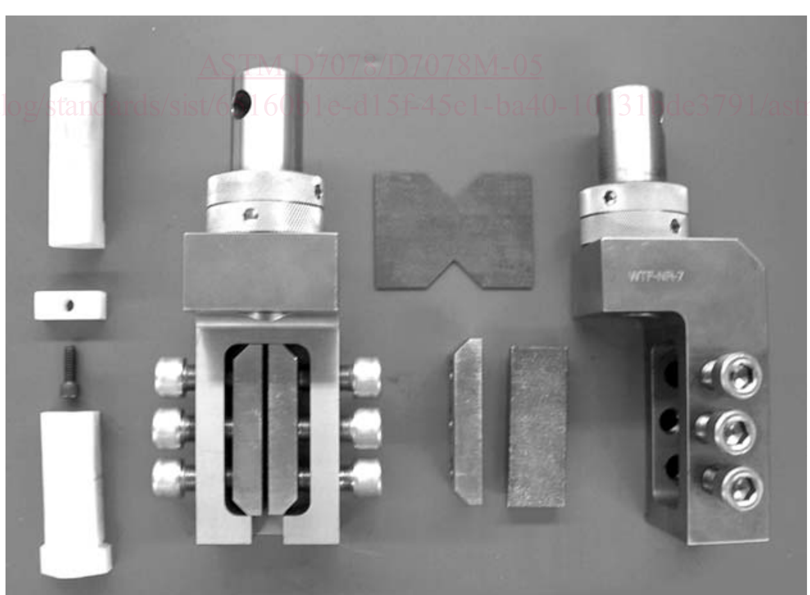


FIG. 4 Partially Assembled Fixture with Specimen and Spacer Blocks

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.

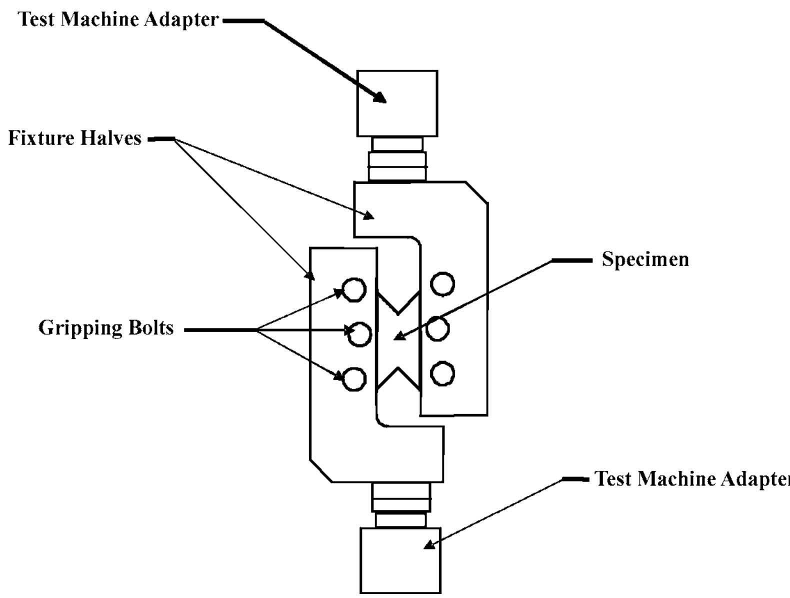


FIG. 5 Assembled V-Notched Rail Shear Apparatus

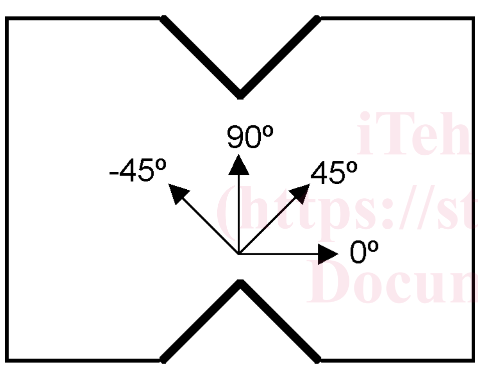


FIG. 6 Fiber Orientations in V-Notched Shear Specimen

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.

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 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 E4 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 E251. 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 D6856.

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 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.

7.6.1.2 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