



Designation: ~~D6641/D6641M-01~~^{ε1} Designation: D 6641/D 6641M – 09

Standard Test Method for ~~Determining the Compressive Properties of Polymer Matrix Composite Laminates~~ Materials Using a Combined Loading Compression (CLC) Test Fixture¹

This standard is issued under the fixed designation D 6641/D 6641M; 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.

~~^{ε1}Note—The designation, D6641/D6641M, was editorially corrected to be a dual standard in December 2001.~~

1. Scope

1.1 This test method ~~establishes a procedure for determining~~ determines the compressive strength and stiffness properties of polymer matrix composite materials using a combined loading compression (CLC) (1)² ~~or comparable test fixture. This test method is applicable to general flat laminates that are balanced and symmetric and contain at least one 0° ply. The standard specimen is untabbed, and, thus, for strength determination, the laminate is limited to a maximum of 50% 0° plies, or equivalent (see test fixture. This test method is applicable to general composites that are balanced and symmetric. The specimen may be untabbed (Procedure A) or tabbed (Procedure B), as required. One requirement for a successful test is that the specimen ends do not crush during the test. Untabbed specimens are usually suitable for use with materials of low orthotropy, for example, fabrics, chopped fiber composites, and laminates with a maximum of 50% 0° plies, or equivalent (see 6.4). Materials of higher orthotropy, including unidirectional composites, typically require tabs.~~

1.2 The compressive force is introduced into the specimen by combined end- and shear-loading. In comparison, Test Method D 3410/D 3410M is a pure shear-loading compression test method and Test Method D 695 is a pure end-loading test method.

~~1.3 Unidirectional (0° ply orientation) composites can be tested to determine unidirectional composite modulus and Poisson's ratio, but not compressive strength.~~

1.3 Unidirectional (0° ply orientation) composites as well as multi-directional composite laminates, fabric composites, chopped fiber composites, and similar materials can be tested.

1.4 The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the test 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.

NOTE 1—Additional procedures for determining the compressive properties of polymer matrix composites may be found in Test Methods D 3410/D 3410M, D 5467, and D 695.

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:³

D 695 Test Method for Compressive Properties of Rigid Plastics

D 883 Terminology Relating to Plastics

D 3410/D 3410M Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading

D 3878 ~~Terminology for Composite Materials~~⁴ Terminology for Composite Materials

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

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 Boldface numbers in parentheses refer to the list of references at the end of this test method.

³ 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.

- [D 5379/D 5379M Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method](#)
- [D 5467/D 5467M Test Method for Compressive Properties of Unidirectional Polymer Matrix Composite Materials Using a Sandwich Beam](#)
- [D 5687/D 5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation](#)
- [E 4 Practices for Force Verification of Testing Machines](#)
- [E 6 Terminology Relating to Methods of Mechanical Testing](#)
- [E 122 Practice for Calculating Sample Size to Estimate, ~~with a~~ With Specified Tolerable Error, Precision, the Average for a Characteristic of a Lot or Process](#)
- [E 132 Test Method for Poisson's Ratio at Room Temperature](#)
- [E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods](#)
- [E 456 Terminology Relating to Quality and Statistics](#)
- [E 1309 Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases](#)
- [E 1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases](#)
- [E 1471 Guide for Identification of Fibers, Fillers, and Core Materials in Computerized Material Property Databases](#)
- [2.2 *ASTM Adjunct:*](#)
- [Combined Loading Compression \(CLC\) Test Fixture, D6641](#)
- [2.3 *Other Documents:*](#)
- [ANSI Y14.5-1999, "Dimensioning and Tolerancing—Includes Inch and Metric"](#)
- [ANSI B46.1-1995, "Surface Texture \(Surface Roughness, Waviness and Lay\)"](#)
- [Combined Loading Compression \(CLC\) Test Fixture, D 6641/D6641M⁴](#)

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.

3.2 *Symbols:*

- A —cross-sectional area of specimen in gage section
- B_y —face-to-face percent bending in specimen
- BF —back-out factor
- CV —sample coefficient of variation, in percent
- E^c —laminare compressive modulus
- F^{cu} —laminare ultimate compressive strength
- $F^{cu}_{0^\circ \text{plies}}$ —compressive stress in 0° plies at laminare failure
- F^{cr} —Euler buckling stress
- G_{xz} —through-thickness shear modulus of laminare
- G_{T2} —in-plane shear modulus of the 0° plies
- G_{T3}, G_{T3} —through-thickness shear moduli of the 0° plies
- h —specimen thickness
- I —moment of inertia of specimen cross section
- l_g —specimen gage length
- n —number of specimens
- P —load carried by test specimen
- P^f —load carried by test specimen at failure
- s —as used in a lay-up code, denotes that the preceding ply description for the laminare is repeated symmetrically about its midplane
- s_{n-1} —sample standard deviation
- V_0 —volume fraction of 0° plies in laminare
- V_{90} —volume fraction of 90° plies in laminare
- w —specimen gage width
- \bar{x} —sample mean (average)
- x_i —measured or derived property
- ϵ —indicated normal strain from strain transducer
- ϵ_x —laminare axial strain

⁴ Annual Book of ASTM Standards, Vol 15.05.

⁴ A detailed drawing for the fabrication of the test fixture shown in Figs. 1 and 2 is available from ASTM Headquarters. Order Adjunct No. ADJD6641.

ϵ_y —laminar in-plane transverse strain
 ϵ_1, ϵ_2 —strain gage readings
 ν_{xy}^c —compressive Poisson’s ratio

4. Summary of Test Method

4.1 A test fixture such as that shown in Figs. 1 and 2, or any comparable fixture, can be used to test the ~~untabbed~~ untabbed (Procedure A) or tabbed (Procedure B) straight-sided composite specimen of rectangular cross section shown schematically in Fig. 3. A typical specimen is 140 mm [5.5 in.] long and ± 213 mm [0.5 in.] wide, having an unsupported (gage) length of ± 213 mm [0.5 in.] when installed in the fixture. A gage length ~~between 12 mm and 25~~ greater or less than 13 mm [1.0 in.] is acceptable, subject to specimen buckling considerations (see 8.2). ~~This 12-mm~~ The 13-mm [0.5 in.] gage length provides sufficient space to install bonded strain gages when they are required. The fixture, which subjects the specimen to combined end- and shear-loading, is itself loaded in compression between flat platens in a universal testing machine. Load-strain data are collected until failure occurs (or until a specified strain level is achieved if only compressive modulus or Poisson’s ratio, or both, is ~~are~~ to be determined, and not the complete stress-strain curve to failure).

5. Significance and Use

~~5.1 This test method is designed to produce compressive property data for material specifications, research and development, quality assurance, and structural design and analysis. When specific laminates are tested (primarily of the [90/0]~~

5.1 This test method is designed to produce compressive property data for material specifications, research and development, quality assurance, and structural design and analysis. When tabbed (Procedure B) specimens, typically unidirectional composites, are tested, the CLC test method (combined shear end loading) has similarities to Test Methods D 3410/D 3410M (shear loading) and D 695 (end loading). When testing lower strength materials such that untabbed CLC specimens can be used (Procedure A), the benefits of combined loading become particularly prominent. It may not be possible to successfully test untabbed specimens of these same materials using either of the other two methods. When specific laminates are tested (primarily of the [90/0]_{ns} family, although other laminates containing a ~~maximum of 50%~~ at least one 0° plies can be used), the CLC data are frequently used to “back out” 0° ply strength, using laminar ~~laminar~~ lamination theory to calculate a 0° unidirectional lamina strength (1, 2). Factors that influence the compressive response include: type of material, methods of material preparation and lay-up, specimen stacking sequence, specimen preparation, specimen conditioning, environment of testing, speed of testing, time at temperature, void content, and volume percent reinforcement. Laminar ~~laminar~~ properties, Composite ~~composite~~ properties in the test direction; that may be obtained from this test method include:

- 5.1.1 Ultimate compressive strength,
- 5.1.2 Ultimate compressive strain,
- 5.1.3 Compressive (linear or chord) modulus of elasticity, and
- 5.1.4 Poisson’s ratio in compression.

6. Interferences

6.1 Because of partial end loading of the specimen in this test method, it is important that the ends of the specimen be machined flat, parallel to each other, and perpendicular to the long axis of the coupon (see Fig. 3), just as for Test Method D 695. Improper

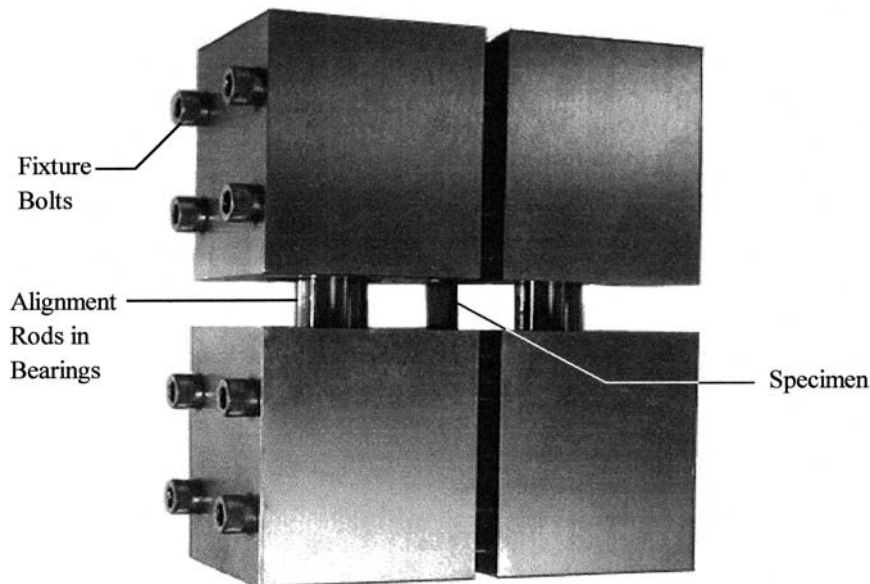
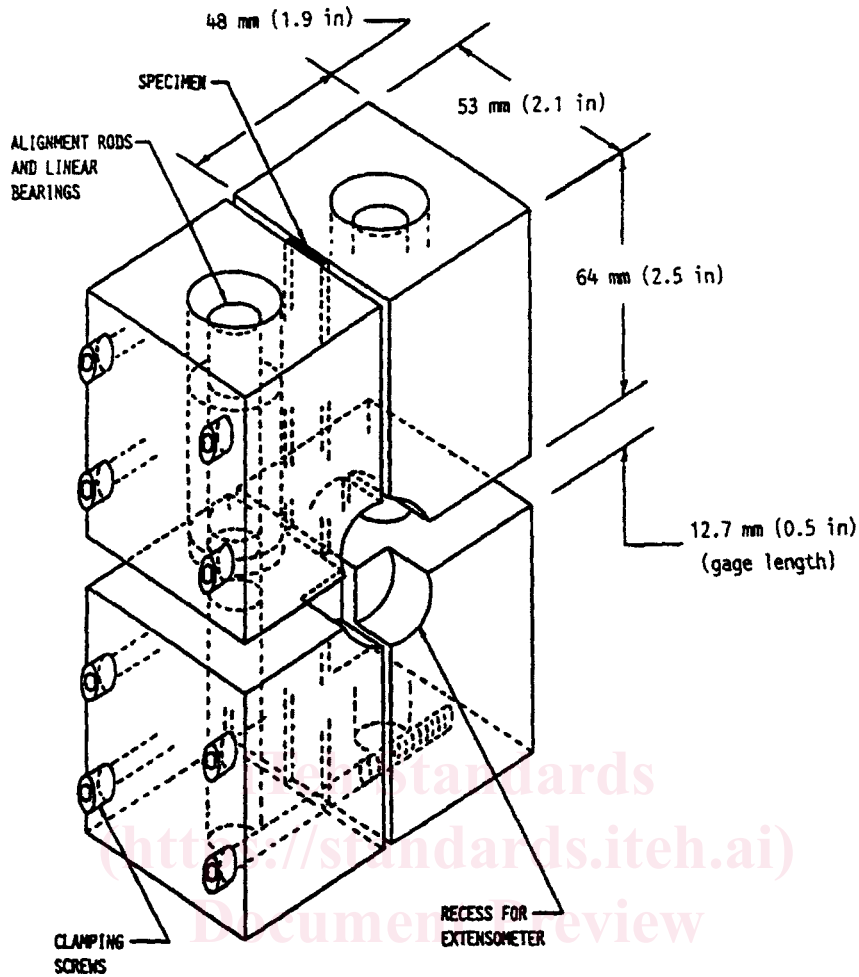


FIG. 1 Photograph of a Typical Combined Loading Compression (CLC) Test Fixture



Note: Using standard M6×1 (1/4-in.-28 UNF) screws, the bolt torque required to test most composite material specimens successfully is typically between 2.5 and 3.0 N·m [20 and 25 in.-lb.].

FIG. 2 Dimensioned Sketch of a Typical Combined Loading Compression (CLC) Test Fixture

preparation may result in premature end crushing of the specimen during loading, excessive induced bending, or buckling, potentially invalidating the test.

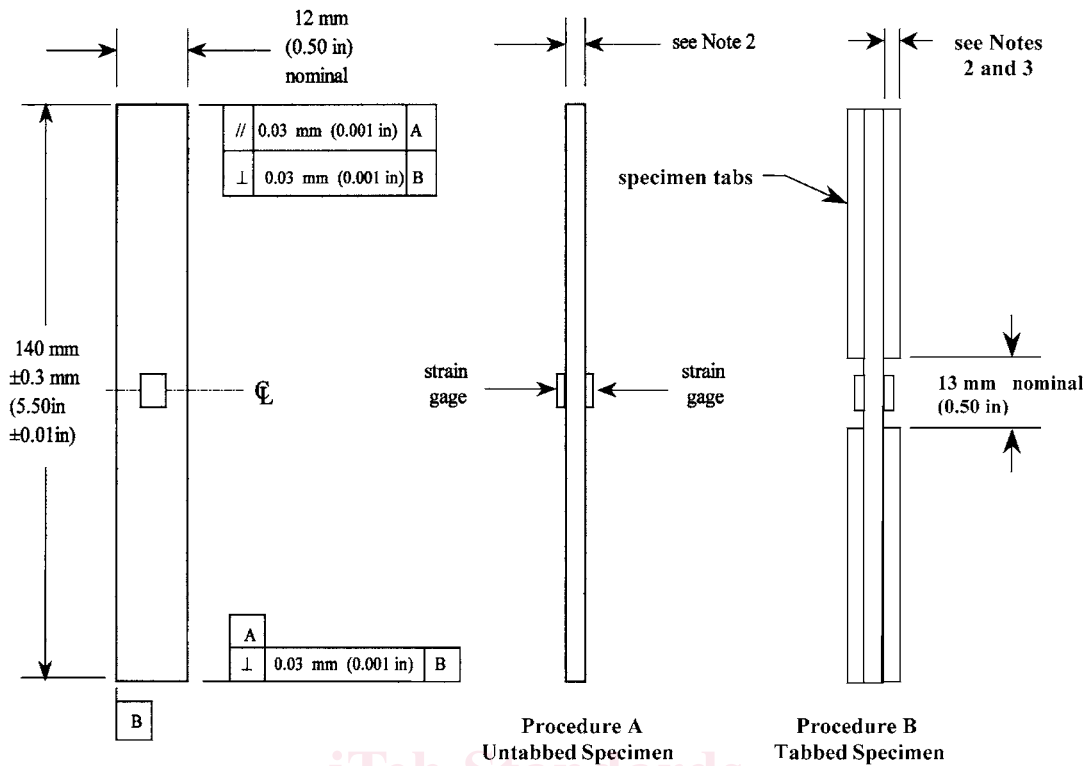
6.2 Erroneously low laminate compressive strengths will be produced as a result of Euler column buckling if the specimen is too thin in relation to the gage length (see 8.2). In such cases, the specimen thickness must be increased or the gage length reduced below the minimum gage length required. A practical limit on reducing gage length is maintaining adequate space in which to attach strain gages, if required. A gage length of at least about 9 mm [0.35 in.] is typically required for this purpose. Bending or buckling, or both, can usually only be detected by the use of back-to-back strain gages mounted on the faces of the specimen or by examining the specimen failure mode (3). Bending and buckling are not visually obvious during the test, or from an examination of the specimen failure mode.

6.3 For a valid test, final failure of the specimen must occur within the gage section. Which failure modes are deemed acceptable will be governed by the particular material, laminate configuration, and application (see 10.11.2.1).

6.4 Untabbed (Procedure A) specimens of continuous-fiber-reinforced laminates having more than 50 % axially oriented (0°) plies may require higher than acceptable fixture clamping forces to prevent end crushing. Therefore, such specimens are considered nonstandard. Excessive clamping forces induce at the ends of the gage section local stress concentrations that may produce erroneously low strength results (see 9.2.7.11.2.7). In such cases, the specimen must be tabbed (Procedure B).

6.5 If the outermost plies of the laminate are oriented at 0°, the local stress concentrations at the ends of the specimen gage section may lead to premature failure of these primary load-bearing plies, producing erroneously low laminate strength results. This is particularly true for specimens with low numbers of plies, since then the outer plies represent a significant fraction of the total number of plies (1).

6.6 The compressive strength and stiffness properties of other unidirectional composites as well as all laminate configurations may also be determined using this same untabbed specimen-test method, subject to some limitations (1). One limitation is that the fixture clamping forces induced by the applied bolt torques required to successfully fail the composite before specimen end crushing must not induce significant stress concentrations at the ends of the gage section (4). Such stress concentrations will



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Notes:

- (1) The specimen ends must be parallel to each other within 0.03 mm [0.001 in.] and also perpendicular to the longitudinal axis of the specimen within 0.03 [0.001 in.], for both Procedures A and B.
- (2) Nominal specimen and tabbing thickness can be varied, but must be uniform. Thickness irregularities (for example, thickness taper or surface imperfections) shall not exceed 0.03 mm [0.001 in.] across the specimen or tab width or 0.06 mm [0.002 in.] along the specimen grip length or tab length.
- (3) Tabs are typically square-ended and on the order of 1.6 mm [0.06 in.] thick, but thickness can be varied as required, as discussed in 8.2.
- (4) The faces of the specimen may be lapped slightly to remove any local surface imperfections and irregularities, thus providing flatter surfaces for more uniform gripping by the fixture.

FIG. 3 Typical Test Specimen Configuration

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degrade the measured compressive strength. For example, testing an untabbed high-strength unidirectional composite is likely to be unsuccessful because of the excessive clamping forces required to prevent specimen end crushing, whereas a lower strength unidirectional composite may be successfully tested using acceptable clamping forces. The use of a tabbed specimen to increase the bearing area at the specimen ends is possible, although nonstandard, and not desirable as tabs also induce stress concentrations at the ends of the gage section when necessary (1, 5). An untabbed thickness-tapered specimen, although nonstandard, has also been used to test successfully test high-strength unidirectional composites (5).

6.7 In multidirectional laminates, edge effects can affect the measured strength and modulus of the laminate.

7. Apparatus and Supplies

7.1 *Micrometers and Calipers*—A micrometer having a suitable-size 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, shall be used. A caliper of suitable size can also be used on machined edges or very smooth tooled surfaces. The accuracy of these instruments shall be suitable for reading to within 1 % of the sample length, width and thickness. For typical specimen geometries, an instrument with an accuracy of ±2.5 μm [±0.0001 in.] is desirable for thickness and width measurement, while an instrument with an accuracy of ±25 μm [±0.001 in.] is desirable for length measurements.

7.2 *Torque Wrench*—Calibrated within the torque range required.

7.3 *Testing Machine*—A calibrated testing machine shall be used which can be operated at constant crosshead speed over the specified range. The test machine mechanism shall be essentially free from inertial lag at the crosshead speeds specified. The machine shall be equipped with an appropriate load-measuring/force-measuring device (for example, a load cell). The accuracy of the test machine shall be in accordance with Practices E 4.

7.4 *Environmental Chamber*—A chamber capable of enclosing the test fixture and specimen while they are mounted in the testing machine, and capable of achieving the specified heating/cooling rates, test temperatures, and environments, shall be used when nonambient conditions are required during testing. *Conditioning Chamber*—When conditioning materials in other than ambient laboratory environments, a temperature-/moisture-level controlled environmental conditioning chamber is required that shall be capable of maintaining the required relative temperature to within ±3°C [±5°F] and the required relative vapor level to

within $\pm 5\%$. Chamber conditions shall be monitored either on an automated continuous basis or on a manual basis at regular intervals.

7.5 Environmental Chamber—A chamber capable of enclosing the test fixture and specimen while they are mounted in the testing machine, and capable of achieving the specified heating/cooling rates, test temperatures, and environments, shall be used when nonambient conditions are required during testing. This chamber shall be capable of maintaining the gage section of the test specimen within $\pm 3^\circ\text{C}$ [$\pm 5^\circ\text{F}$] of the required test temperature during the mechanical test. In addition, the chamber may have to be capable of maintaining environmental conditions such as fluid exposure or relative humidity during the test.

7.6 Compression Fixture—A test fixture such as that shown in Figs. 1 and 2, or a comparable fixture, shall be used. The fixture shown introduces a controllable ratio of end loading to shear loading into the specimen, by controlling the torque applied to the clamping screws.

7.6

7.7 Strain-Indicating Device—Longitudinal strain shall be simultaneously measured on opposite faces of the specimen to allow for a correction as a result of any bending of the specimen, and to enable detection of Euler (column) buckling. Back-to-back strain measurement shall be made for all five specimens when the minimum number of specimens allowed by this test method are tested. If more than five specimens are to be tested, then a single strain-indicating device may be used for the number of specimens greater than the five, provided the total number of specimens are tested in a single test fixture and load frame throughout the tests, that no modifications to the specimens or test procedure are made throughout the duration of the tests, and provided the bending requirement (see 10.3 and 10.4, 12.3 and 12.4) is met for the first five specimens. If these conditions are not met, then all specimens must be instrumented with back-to-back devices. When Poisson's ratio is to be determined, the specimen shall be instrumented to measure strain in the lateral direction using the same type of transducer. The same type of strain transducer shall be used for all strain measurements on any single coupon. Strain gages are recommended because of the short gage length of the specimen. Attachment of the strain-indicating device to the coupon shall not cause damage to the specimen surface.

7.7

7.8 Data Acquisition Equipment—Equipment capable of recording load/force and strain data is required.

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, the procedures outlined in Practice E 122 should be consulted. The method of sampling shall be reported.

8.2 Geometry—The test specimen is an untabbed (Procedure A) or tabbed (Procedure B) rectangular strip of the laminate/composite to be tested, as shown in Fig. 3. A guide to preparation of flat composite panels, with processing guidelines for specimen preparation, is presented in Guide D 5687/D 5687M. Specimen dimensions and tolerances must be in compliance with the requirements of Fig. 3. If axial strain is to be measured (for example, to monitor specimen bending, to determine the axial compressive modulus, or to obtain a stress-strain curve), two single-element axial strain gages or similar transducers are typically mounted back-to-back on the faces of the specimen, in the center of the gage section, as shown in Fig. 3. As noted also in 6.6, for materials with a sufficiently high compressive strength in the direction of loading, end crushing or an untabbed specimen cannot be prevented by increasing fixture clamping force alone. It then becomes necessary to use tabs, to increase the load-bearing area at the specimen ends. While tapered tabs would be potentially beneficial in reducing stress concentrations in the specimen at the tab ends, they increase the effective unsupported length (gage length) of the specimen, increasing the possibility of inducing specimen buckling. Thus, untapered (square-ended) tabs are recommended. For many polymer-matrix composites, glass fabric/epoxy tabs have been found to perform well (1, 4). This material has a favorable combination of compliance, shear strength and toughness. Note that tabs having a low stiffness, yet sufficiently strong to transmit the induced forces, are desired. Thus, tabs of the same material as the specimen are normally not desired, contrary to common beliefs (6). For specimen thicknesses on the order of 2.5 mm [0.10 in.] thick or less, tabs on the order of 1.6 mm [0.06 in.] thick have been found to be adequate (1, 4). For thicker specimens, thicker tabs may be required, a tab thickness limit being reached when the tab adhesive is no longer able to transfer the induced shear forces. In this case, the practical solution is to reduce the specimen thickness. If axial strain is to be measured (for example, to monitor specimen bending, to determine the axial compressive modulus, or to obtain a stress-strain curve), two single-element axial strain gages or similar transducers are typically mounted back-to-back on the faces of the specimen, in the center of the gage section, as shown in Fig. 3 (see also Section 10.12). If in-plane transverse strain is also to be measured (for example, to calculate the in-plane compressive Poisson's ratio), an additional single-element strain gage oriented in the transverse direction on one face of the specimen may be used. Alternatively, one or more strain gage rosettes may be used.

8.2.1 Specimen Width—The nominal specimen width shall be ± 213 mm [0.50 in.]. However, other widths may be used. For example, the fixture shown in Figs. 1 and 2 can accommodate specimens up to a maximum width of 30 mm [1.2 in.]. In order to maintain a representative volume of material within the gage section, specimens narrower than ± 213 mm [0.50 in.] are not typically used. It is sometimes desirable to use specimens wider than normal/nominal, for example, if the material architecture is coarse (as for a coarse-weave fabric), again to maintain a representative gage section volume of material being tested.

8.2.2 Specimen Thickness—Although no specific specimen thickness is required, some limitations exist. The thickness must be sufficient to preclude Euler column buckling of the specimen. Eq 1 may be used to estimate the minimum thickness to be used for strength determinations (see also Test Method D 3410/D 3410M). As indicated in Eq 1, the minimum specimen thickness