**Designation: D 6641/D 6641M – 01$^{\epsilon 1}$**

# Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture[1]

$\epsilon^1$ NOTE—The designation, D 6641/D 6641M, was editorially corrected to be a dual standard in December 2001.

## 1. Scope

1.1 This test method establishes a procedure for determining 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 6.4).

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.

1.4 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:*

D 695 Test Method for Compressive Properties of Rigid Plastics[3]

D 883 Terminology Relating to Plastics[3]

D 3410/D 3410M Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading[4]

D 3878 Terminology for Composite Materials[4]

D 5467 Test Method for Compressive Properties of Unidirectional Polymer Matrix Composites Using a Sandwich Beam[4]

D 5687/D 5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation[4]

E 4 Practices for Force Verification of Testing Machines[5]

E 6 Terminology Relating to Methods of Mechanical Testing[5]

E 122 Practice for Calculating Sample Size to Estimate, with a Specified Tolerable Error, the Average for a Characteristic of a Lot or Process[6]

E 132 Test Method for Poisson's Ratio at Room Temperature[5]

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[6]

E 456 Terminology Relating to Quality and Statistics[6]

E 1309 Guide for Identification of Fiber-Reinforced Polymer Matrix Composite Materials in Databases[4]

E 1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases[4]

E 1471 Guide for Identification of Fibers, Fillers, and Core Materials in Computerized Material Property Databases[4]

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

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

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

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

2.2 *ASTM Adjunct:*

Combined Loading Compression (CLC) Test Fixture, D 6641[7]

2.3 *Other Documents:*[8]

ANSI Y14.5-1999, "Dimensioning and Tolerancing—Includes Inch and Metric"

ANSI B46.1-1995, "Surface Texture (Surface Roughness, Waviness and Lay)"

## 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
$E^c$—laminate compressive modulus
$F^{cu}$—laminate ultimate compressive strength
$F^{cu}{}_{0°plies}$—compressive stress in 0° plies at laminate failure
$F^{cr}$—Euler buckling stress
$G_{xz}$—through-thickness shear modulus of laminate
$G_{12}$—in-plane shear modulus of the 0° plies
$G_{13}$, $G_{23}$—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 laminate is repeated symmetrically about its midplane
$s_{n-1}$—sample standard deviation
$V_0$—volume fraction of 0° plies in laminate
$V_{90}$—volume fraction of 90° plies in laminate
$w$—specimen gage width
$\bar{x}$—sample mean (average)
$x_i$—measured or derived property
$\epsilon$—indicated normal strain from strain transducer
$\epsilon_x$—laminate axial strain
$\epsilon_y$—laminate in-plane transverse strain
$\epsilon_1, \epsilon_2$—strain gage readings
$\nu_{xy}{}^c$—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, straight-sided composite specimen of rectangular cross section shown schematically in Fig. 3. A typical specimen is 140 mm [5.5 in.] long and 12 mm [0.5 in.] wide, having an unsupported (gage) length of 12 mm [0.5 in.] when installed in the fixture. A gage length between 12 mm and 25 mm [1.0 in.] is acceptable, subject to specimen buckling considerations (see 8.2). This 12-mm 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 to be determined, and not the complete stress-strain curve to failure).

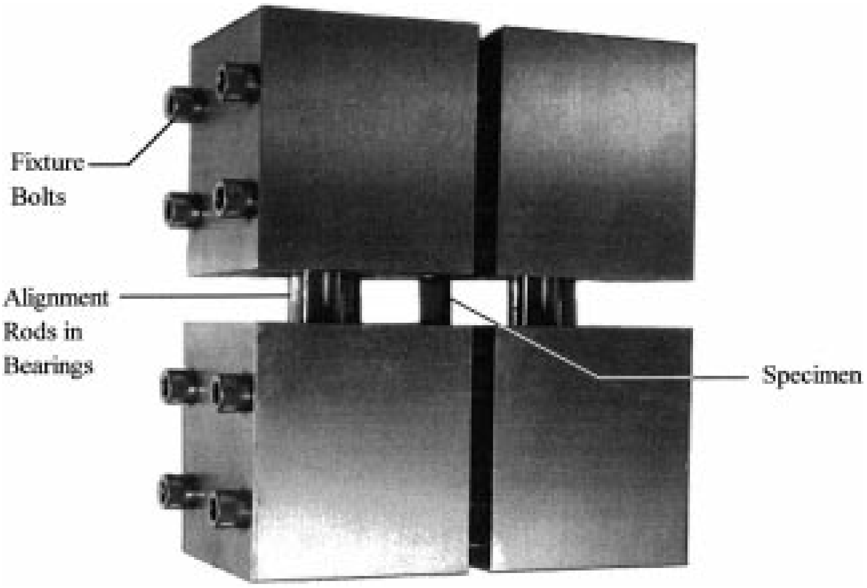

FIG. 1 Photograph of a Typical Combined Loading Compression (CLC) Test Fixture

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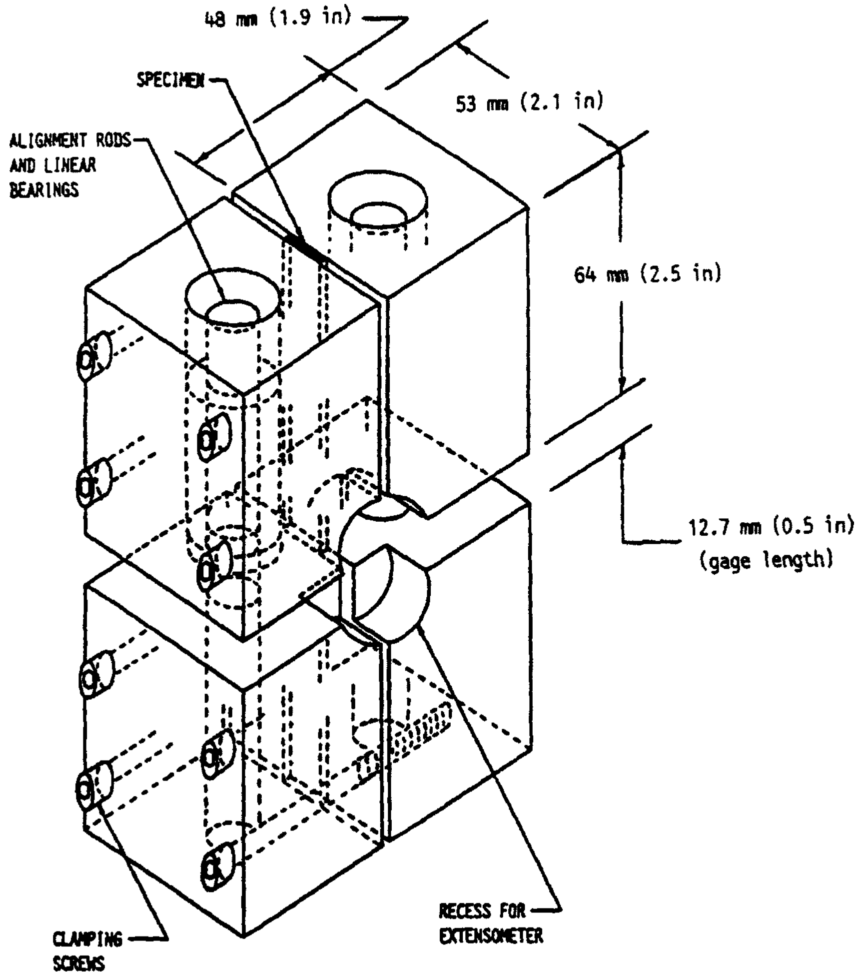
[7] A detailed drawing for the fabrication of the test fixture shown in Figs. 1 and 2 is available from ASTM Headquarters. Order Adjunct No. ADJD6641.

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



Note: Using standard ¼-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**

## 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 $[90/0]_{ns}$ family, although other laminates containing a maximum of 50 % 0° plies can be used), the data are frequently used to “back out” 0° ply strength, using laminate 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. Laminate 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.

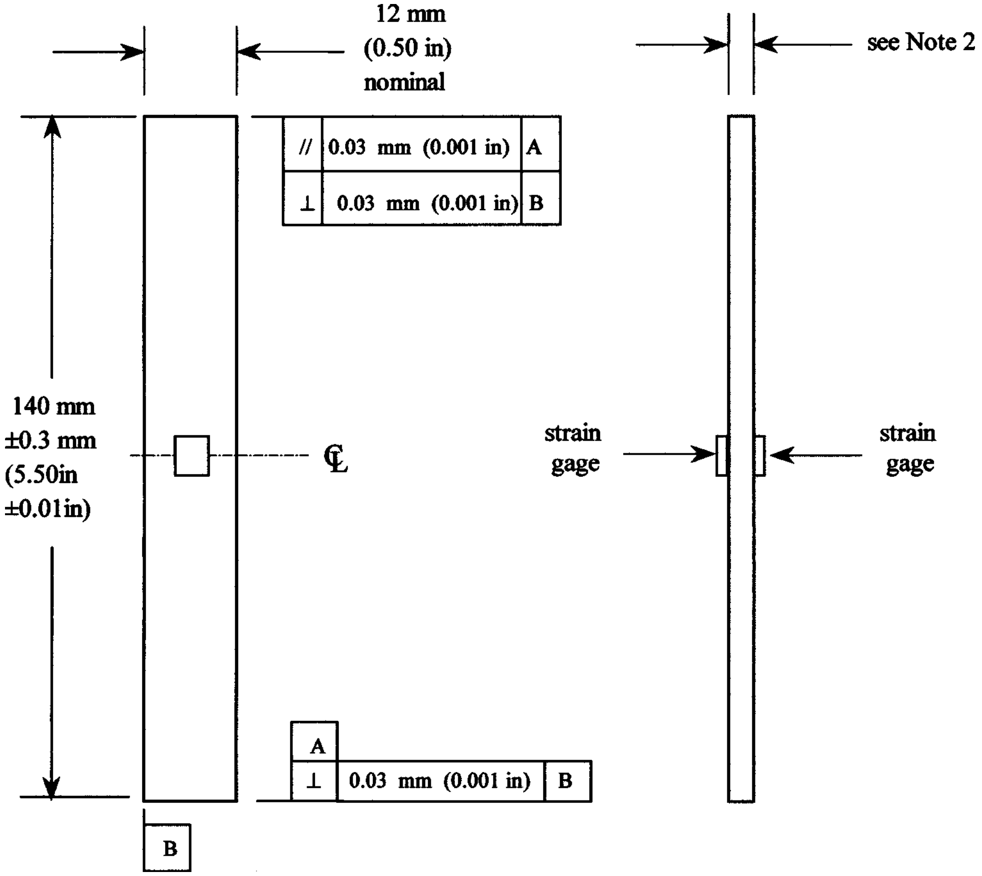
## 6. Interferences

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 parallel to each other and perpendicular to the long axis of the coupon (see Fig. 3). Improper 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. 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.

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 10.1).

6.4 Continuous-fiber-reinforced laminates having more than 50 % axially oriented (0°) plies may require higher than



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.].

(2) Nominal specimen 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 width or 0.06 mm [0.002 in.] along the specimen length.

(3) 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**

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).

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 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 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 **(1, 5)**. An untabbed thickness-tapered specimen, although nonstandard, has also been used to test successfully 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 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.

7.5 *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 *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) 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 *Data Acquisition Equipment*—Equipment capable of recording load 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 rectangular strip of the laminate 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 (see also Section 10). 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 12 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 12 mm [0.50 in.] are not typically used. It is sometimes desirable to use specimens wider than normal, 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 required depends on a number of factors in addition to gage length **(1, 4)**.

$$h \geq \frac{l_g}{0.9069\sqrt{\left(1-\frac{1.2F^{cu}}{G_{xz}}\right)\left(\frac{E^f}{F^{cu}}\right)}} \tag{1}$$

where:

$h$ = specimen thickness, mm [in.],
$l_g$ = length of gage section, mm [in.],
$F^{cu}$ = expected ultimate compressive strength, MPa [psi],
$E^f$ = expected flexural modulus, MPa [psi], and
$G_{xz}$ = through-the-thickness (interlaminar) shear modulus, MPa [psi].

NOTE 2—Eq 1 is derived from the following expression for the Euler buckling stress for a pin-ended column of length $l_g$ (an assumption which is strictly not valid for the specimen gage length $l_g$), modified for shear deformation effects. The $E^f$ in Eq 1 and Eq 2 is the flexural modulus of the specimen. For the intended purpose, the approximation of using the compressive modulus $E^c$ in place of the flexural modulus $E^f$ may be valid.

Eq 1 may be rewritten in the form of Eq 2 **(6)**.

$$F_{cr} = \frac{\pi^2 E^f}{\frac{l_g^{\,2} A}{I} + 1.2\pi^2 \frac{E^f}{G_{xz}}} \tag{2}$$

where:

$F_{cr}$ = predicted Euler buckling stress, MPa [psi],
$A$ = specimen cross-sectional area, mm$^2$ [in.$^2$], and
$I$ = minimum moment of inertia of specimen cross section, mm$^4$ [in.$^4$].

Eq 2 can be used to estimate the applied stress, $F_{cr}$, on the test specimen at which Euler buckling is predicted to occur for the specific specimen configuration of interest. Practical experience has shown that Eq 1 and Eq 2 are reliable for conventional carbon fiber/polymer matrix composites, and that as a general guide, keeping the predicted value $F_{cr}$ of buckling stress at least 20 % above the expected compressive strength is usually sufficient **(1, 4)**. Other composites may require different percentages.

A value of the laminate through-the-thickness (interlaminar) shear modulus, $G_{xz}$, as required in Eq 1 and 2, may not be available in the form of experimental data. In this case, an estimate can be made using a simple rule-of-mixtures relation. For example, for a $[90/0]_{ns}$ laminate this value can be estimated using Eq 3 **(4)**.

$$G_{xz} = G_{13}V_0 + G_{23}V_{90} \tag{3}$$

where:

$G_{13}, G_{23}$ = through-the-thickness (interlaminar) shear moduli of the 0° plies, MPa [psi] (Note: $G_{13} = G_{12}$ for a laminate consisting of unidirectional plies),

$V_0$ = volume fraction of 0° plies, and

$V_{90}$ = volume fraction of 90° plies.

Corresponding relations can be derived for laminates of other configurations **(4)**.

In lieu of making such calculations, simply assuming a value of $G_{xz}$ of approximately 4 GPa [0.60 Msi] is a reasonable estimate for most polymer matrix composite materials tested at room temperature **(4)**. This and Eq 3 are offered only as estimates, to serve as a starting point when designing a test specimen of a material with an unknown $G_{xz}$. The absence of specimen buckling must eventually be verified experimentally.

The specimen can be thinner if only modulus is being determined, as the required applied load may then be significantly lower than the buckling load.

There is no specific upper limit on specimen thickness. One practical limitation is the increasing difficulty of applying a uniform pressure over the ends of a specimen of progressively larger cross-sectional area. Another is the need to apply increasing clamping forces to prevent end crushing as the specimen becomes thicker (by maintaining the desired ratio of end loading to shear loading). As discussed in 6.4, the induced stress concentrations in the specimen by the test fixture increase as the clamping force increases. Note that increasing the width of the specimen does not alleviate this condition.

## 9. Procedure

9.1 *Before Test*:

9.1.1 Inspect the test fixture to ensure that it is operating smoothly and that the gripping and loading surfaces are not damaged and are free of foreign matter. Any bolt threads and fixture threads shall also 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.

9.1.2 For nonambient temperature testing, preheat or precool the test chamber as required in the applicable specifications or test instructions.

9.1.3 Condition and store specimens in accordance with applicable specifications or test instructions.

9.1.4 Measure the specimen width and thickness to a precision of 0.0025 mm [0.0001 in.], recording the average of three measurements. The width and thickness measurements shall be made in the gage section of the specimen, taking care not to measure directly over the strain gage or gage adhesive. Measure the specimen length to a precision of 0.025 mm [0.001 in.].

9.2 *Specimen Installation When Using a Fixture of the Type Shown in Figs. 1 and 2*:

9.2.1 Loosen the screws in both halves of the test fixture sufficiently to accommodate the specimen thickness to be tested.

9.2.2 Remove the upper half of the fixture from the lower half. Place the lower half of the fixture on a flat surface with the alignment rods pointing upward. It is helpful to perform this operation on a granite surface plate or similar hard flat surface.

9.2.3 Place the test specimen in the test fixture. Ensure that the end of the specimen is flush with the bottom surface of the fixture and in contact with the flat surface plate while slightly tightening the four screws in the lower half of the fixture ("finger tight").

9.2.4 Turn the upper half of the fixture upside down and place it on the flat surface.

9.2.5 Turn the lower half of the fixture upside down and insert its alignment rods and the free end of the mounted specimen into the inverted upper half of the fixture. Make sure the end of the specimen is flush with the end of the upper half of the fixture and in contact with the flat surface plate. If the upper half will not slide freely into the lower half, slightly loosen the two screws in the lower half that are closest to the gage section, while restraining the upper half so that it does not slide down too far and damage the strain gages or other transducers, if present.

9.2.6 Slightly tighten the four screws in the upper half of the fixture (finger tight).

9.2.7 Place the assembled fixture on its side with the screws on top. Torque all eight of the 6-mm (0.25-in.) diameter screws to 2.5 to 3.0 N-m [20 to 25 in.-lb], in three or four approximately equal increments, using a diagonal tightening pattern at each end so the fixture surfaces are uniformly clamped against the surfaces of the test specimen.

NOTE 3—The required torque may vary depending on the type of material and the thickness of the specimen being tested. A torque of 2.5 to 3.0 N-m [20 to 25 in.-lb] has been found to be sufficient for most materials of typical specimen thicknesses, for example, 2.0 to 3.0 mm [0.080 to 0.120 in.] thick **(1, 4)**. If the torque is too low for a given configuration, the ends of the specimen may crush. If the torque is excessive, the high clamping force will induce detrimental stress concentrations in the specimen at the ends of the gage section and lead to premature failures. Thus, a torque just sufficient to prevent end crushing should be used. This may require several trials when testing an unfamiliar material. However, it has been shown that the acceptable range of torque is very broad **(4)**.

9.2.8 Place the assembled fixture between well-aligned, fixed (as opposed to spherical-seat) flat platens (platen surfaces parallel within 0.03 mm [0.001 in.] across the fixture base) in the testing machine. One fixed and one spherical seat platen can be used as an alternative, but is not the preferred configuration **(4)**. If the platens are not sufficiently hardened, or simply to protect the platen surfaces, a hardened plate (with parallel surfaces) can be inserted between each end of the fixture and the corresponding platen.

9.2.9 If strain gages or other transducers are being used, attach the lead wires to the data acquisition apparatus. To determine the compressive modulus of the laminate, the laminate stress must be measured at two specified strain levels, typically 1000 and 3000 microstrain (see 11.2). Often back-to-back strain gages are used. If bending of the specimen is occurring at any strain level, the strains measured on the opposite faces of the specimen will not be equal. The average of these two values is the desired strain since the amount of bending does not affect the average strain. However, just as in the discussion of compressive strength (see 10.2), the percent bending must be kept to less than 10 % (see also Test Method D 3410/D 3410M).

9.3 *Loading*—Load the specimen in compression to failure at a nominal rate of 1.3 mm/min [0.05 in./min], while recording load, displacement, and strain data. Loading time to failure should be 1 to 10 min. If only modulus is being determined, load the specimen approximately 10 % beyond the upper end of the strain range being used to determine modulus.

9.4 *Data Recording*—Record load versus strain (or displacement) continuously or at frequent regular intervals. If a transition region or initial ply failures are noted, record the load, strain, and mode of damage at such points. If the specimen is to be failed, record the maximum load, the failure load, and the strain (or transducer displacement) at, or as near as possible to, the moment of failure.

## 10. Validation

10.1 Inspect the tested specimen and note the type and location of the failure. For valid tests, final failure of the specimen will occur within the gage section. The failure mode may be brooming, transverse or through-thickness shear, longitudinal splitting, or delamination, among possibly other forms **(3)**. Which failure modes are deemed acceptable will be governed by the particular material, laminate configuration, and application. Acceptable failure modes are illustrated in Test Method D 3410/D 3410M. Minor end crushing before final failure in the gage section sometimes occurs. If this end crushing arrests, and a valid gage section failure ultimately is achieved, end crushing does not invalidate the test. In general, failures that initiate elsewhere within the gripped length do not arrest and hence invalidate the test.

10.2 The occurrence of Euler buckling invalidates the test. Euler buckling failures cannot be detected by visual inspection of the specimen during or after the test. Only the use of back-to-back strain gages or similar instrumentation provides a reasonable indication.

10.3 Although the specimen does not buckle, the induced bending may be excessive. This can be due to imperfections in the test specimen, the test fixture, or the testing procedure. Eq 4 is to be used to calculate percent bending. Additional details are given in Test Method D 3410/D 3410M.

$$B_y = percent\ bending = \frac{\epsilon_1 - \epsilon_2}{\epsilon_1 + \epsilon_2} \times 100 \quad (4)$$

where:

$\epsilon_1$ = indicated strain from Gage 1 and

$\epsilon_2$ = indicated strain from Gage 2.

The sign of the calculated Percent Bending indicates the direction in which the bending is occurring. This information is useful in determining if the bending is being induced by a systematic error in the test specimen, testing apparatus, or test procedure, rather than by random effects from test to test.

10.4 For the test results to be considered valid, percent bending in the specimen shall be less than 10 % as determined by Eq 4. Determine percent bending at the midpoint of the strain range used for chord modulus calculations (see 11.2). The same requirement shall be met at the failure strain for the strength and strain-to-failure data to be considered valid. This requirement shall be met for all five of the specimens requiring back-to-back strain measurement. If possible, a plot of percent bending versus average strain should be recorded to aid in the determination of failure mode.

10.4.1 Although extreme amounts of bending (greater than 40 to 50 %) will decrease the measured compressive strength, it has been found that as much as 30 to 40 % bending may have no significant effect on the compressive strength value obtained **(4)**. However, the presence of large amounts of bending does suggest some irregularity in specimen preparation or testing procedure. Thus, achievement of less than 10 % bending at failure is required for the test to be considered valid (see also Test Method D 3410/D 3410M). The use of back-to-back strain gages on the first few specimens of a group (the gages being centered within the gage length on the opposite faces of the test specimen) provides a good indication of the general bending response of the group. However, it does not guarantee that all subsequent specimens of the group will fail at an acceptable level of bending. The use of back-to-back strain instrumentation on all specimens is the only way of ensuring this. However, if the back-to-back strain instrumentation used on a representative sample of the specimens indicates acceptable percent bending and the absence of Euler buckling (see 7.6), and the compressive strengths of all specimens tested are similar, there is reasonable assurance that bending and buckling did not influence the results **(4)**.

## 11. Calculation

11.1 *Laminate Compressive Strength*—Calculate the compressive strength of the laminate using Eq 5:

$$F^{cu} = \frac{P_f}{wh} \quad (5)$$

where:

$F^{cu}$ = laminate compressive strength, MPa [psi],

$P_f$ = maximum load to failure, N [lbf],

$w$ = specimen gage width, mm [in.], and

$h$ = specimen gage thickness, mm [in.].

11.2 *Laminate Compressive Modulus*—A chord modulus is to be calculated over a range of axial strain, $\epsilon_x$, of 1000 to 3000 microstrain and reported to three significant figures. This strain range is specified to represent the lower half of the stress-strain curve. For materials that fall below 6000 $\mu\epsilon$, a strain range of 25 to 50 % of ultimate is recommended. However, for some materials another range may be more appropriate. Other definitions of chord modulus may be evaluated and reported at the user's discretion. If such data are generated and reported, report also the definitions used, the strain range used, and the results to three significant figures. Calculate this compressive modulus using Eq 6:

$$E^c = \frac{P_2 - P_1}{(\epsilon_{x2} - \epsilon_{x1})\, w\, h} \tag{6}$$

where:

$E^c$ = compressive modulus, MPa [psi],
$P_1$ = load at $\epsilon_{x1}$, N [lbf],
$P_2$ = load at $\epsilon_{x2}$, N [lbf],
$\epsilon_{x1}$ = actual strain nearest lower end of strain range used,
$\epsilon_{x2}$ = actual strain nearest upper end of strain range used,
$w$ = specimen gage width, mm [in.], and
$h$ = specimen gage thickness, mm [in.]

11.3 *Compressive Poisson's Ratio*:

11.3.1 *Compressive Poisson's Ratio By Chord Method*—Use the same strain range as for calculating the laminate compressive modulus (see 11.2). Determine the transverse strain, $\epsilon_y$, at each of the two $\epsilon_x$ strain range end points. Calculate Poisson's ratio using Eq 7 and report to three significant figures.

$$\nu_{xy}{}^{c} = -(\epsilon_{y2} - \epsilon_{y1})/(\epsilon_{x2} - \epsilon_{x1}) \tag{7}$$

Other definitions of Poisson's ratio may be evaluated and reported at the user's discretion. If such data are generated and reported, report also the definitions used, the strain range used, and the results to three significant figures. Test Method E 132 provides additional guidance in the determination of Poisson's ratio.

NOTE 4—If bonded resistance strain gages are being used, the error produced by the transverse sensitivity effect on the transverse gage will generally be much larger for composites than for metals. An accurate measurement of Poisson's ratio requires correction for this effect. Contact the strain gage manufacturer for information on the use of correction factors for transverse sensitivity.

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

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

$$S_{n-1} = \sqrt{\frac{\left(\sum_{i=1}^{n} (x_i - \bar{x})^2\right)}{(n-1)}} \tag{9}$$

$$CV = 100 \cdot S_{n-1} / \bar{x} \tag{10}$$

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.

## 12. Report

12.1 Report the following information, if not previously provided:

12.1.1 Complete identification of the material, including lot and roll numbers (as applicable), and the laminate configuration.

12.1.2 Method of preparation of the test specimens, including process cycle(s).

12.1.3 Specimen pretest conditioning history.

12.1.4 Relative humidity and temperature conditions in the test laboratory.

12.1.5 Identification of test machine, load cell, test fixture, and data acquisition equipment.

12.1.6 Test parameters, including environment of the test and tolerances, dwell time at temperature and tolerances, fixture bolt torques used, and crosshead speed.

12.1.7 Dimensions of each specimen to at least three significant figures, including gage section width and thickness, and overall specimen length.

12.1.8 Nominal gage length (determined from fixture dimensions and nominal specimen overall length).

12.1.9 Load-strain data for each specimen for each strain gage used.

12.1.10 For strength and modulus tests: failure load, failure strain, calculated ultimate compressive strength ($F^{cu}$), and calculated compressive modulus ($E^c$). These values shall be reported to at least three significant figures.

12.1.11 For modulus only tests: maximum load applied, strain at maximum applied load, and calculated compressive modulus ($E^c$). These values shall be reported to at least three significant figures.

12.1.12 Strain range used for modulus calculation.

12.1.13 Description of failure mode and location (for strength tests).

12.1.14 Percent bending at strain range midpoint of chord modulus calculation (see 11.2), and at failure (if determined).

12.1.15 Identification of the facility and individuals performing the test.

12.1.16 Date of test.

12.1.17 Any deviations from this test method.

12.2 The information reported for this test method includes mechanical testing data; material and laminate identification data; and fiber, filler, and core material identification data. These data shall be reported in accordance with Guides E 1434, E 1309, and E 1471, respectively. Each data item discussed is identified as belonging to one of the following categories: (VT) required for reporting of a valid test result, (VM) required for valid traceability, (RT) recommended for maximum test method traceability, (RM) recommended for maximum material traceability, or (O) for optional data items. The following information applies to the use of these documents for reporting data:

12.2.1 *Guide E 1434*:

12.2.1.1 The response for Field A5, Type of Test, is "Compression."

12.2.1.2 Measured values will be reported for Fields F4 and F5. Nominal values are acceptable for Fields F7 to F9.

12.2.1.3 The failure identification code (in accordance with Test Method D 3410/D 3410M) will be reported in Fields H18 and K50. The failure location is optional in Fields H17 and K49 since the failure identification code includes this information.

12.2.1.4 Statistical parameters for specimen dimensions, maximum load, maximum transverse strain, and bending strain are optional. These include Fields K1 to K9, K19 to K21, and K30 to K34. The testing summary sub-block is also optional (Fields K14 to K18).

12.2.2 *Guide E 1309*:

12.2.2.1 The consolidation method should be reported as the process stage type in Field E2.

12.2.2.2 The nominal cure cycle is required for valid material traceability in one set of process stage conditions in Field E4. The actual cure cycle is recommended in a second set of process stage conditions in Field E4.

12.2.3 *Guide E 1471*:

12.2.3.1 Tow or yarn filament count and filament diameter should be included as dimension parameters in Field B2.

## 13. Precision and Bias

13.1 *Precision*—The data required for the development of a precision statement is not available for this test method. Committee D30 is currently planning a round-robin test series for this test method in order to determine precision.

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

## 14. Keywords

14.1 combined loading; composite materials; compressive modulus of elasticity; compressive properties; compressive strength; Poisson's ratio

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