



Standard Test Method for Flexural Properties of Polymer Matrix Composite Materials¹

This standard is issued under the fixed designation D 7264/D 7264M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method determines the flexural stiffness and strength properties of polymer matrix composites.

1.1.1 *Procedure A*—A three-point loading system utilizing center loading on a simply supported beam.

1.1.2 *Procedure B*—A four-point loading system utilizing two load points equally spaced from their adjacent support points, with a distance between load points of one-half of the support span.

NOTE 1—Unlike Test Method D 6272, which allows loading at both one-third and one-half of the support span, in order to standardize geometry and simplify calculations this standard permits loading at only one-half the support span.

1.2 For comparison purposes, tests may be conducted according to either test procedure, provided that the same procedure is used for all tests, since the two procedures generally give slightly different property values.

1.3 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.

1.4 *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 790 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
- D 2344/D 2344M Test Method for Short-Beam Strength of

Polymer Matrix Composite Materials and Their Laminates

- D 3878 Terminology for Composite Materials
 - D 5229/D 5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
 - D 5687/D 5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation
 - D 6272 Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials by Four-Point Bending
 - 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 18 Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials
 - E 122 Practice for Calculating Sample Size to Estimate, With a Specified Tolerable Error, the Average for a Characteristic of a Lot or Process
 - 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
- 2.2 *Other Documents:*
- ANSI Y14.5-1999 Dimensioning and Tolerancing—Includes Inch and Metric³
 - ANSI B46.1-1995 Surface Texture (Surface Roughness, Waviness and Lay)³

3. Terminology

3.1 *Definitions*—Terminology D 3878 defines the terms relating to high-modulus fibers and their composites. 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 documents.

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.

³ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 flexural strength, n —the maximum stress at the outer surface of a flexure test specimen corresponding to the peak applied force prior to flexural failure.

3.2.2 flexural modulus, n —the ratio of stress range to corresponding strain range for a test specimen loaded in flexure.

3.3 Symbols:

b = specimen width

CV = sample coefficient of variation, in percent

E_f^{chord} = flexural chord modulus of elasticity

E_f^{secant} = flexural secant modulus of elasticity

h = specimen thickness

L = support span

m = slope of the secant of the load-deflection curve

n = number of specimens

P = applied force

s_{n-1} = sample standard deviation

x_i = measured or derived property

\bar{x} = sample mean

δ = mid-span deflection of the specimen

ϵ = strain at the outer surface at mid-span of the specimen

σ = stress at the outer surface at mid-span of the specimen

4. Summary of Test Method

4.1 A bar of rectangular cross section, supported as a beam, is deflected at a constant rate as follows:

4.1.1 Procedure A—The bar rests on two supports and is loaded by means of a loading nose midway between the supports (see Fig. 1).

4.1.2 Procedure B—The bar rests on two supports and is loaded at two points (by means of two loading noses), each an equal distance from the adjacent support point. The distance between the loading noses (that is, the load span) is one-half of the support span (see Fig. 2).

4.2 Force applied to the specimen and resulting specimen deflection at the center of span are measured and recorded until the failure occurs on either one of the outer surfaces, or the deformation reaches some pre-determined value.

4.3 The major difference between four-point and three-point loading configurations is the location of maximum bending moment and maximum flexural stress. With the four-point configuration the bending moment is constant between the central force application members. Consequently, the maximum flexural stress is uniform between the central force application members. In the three-point configuration, the maximum flexural stress is located directly under the center

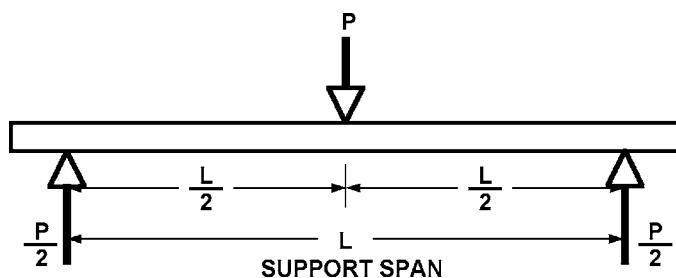


FIG. 1 Procedure A—Loading Diagram

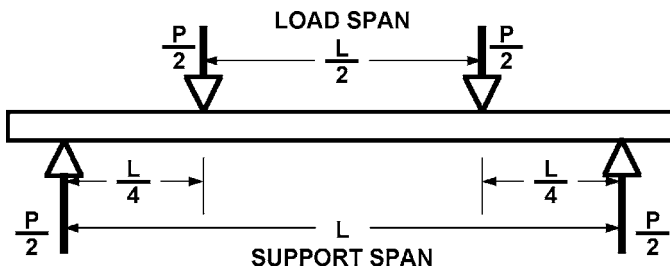


FIG. 2 Procedure B—Loading Diagram

force application member. Another difference between the three-point and four-point configurations is the presence of resultant vertical shear force in the three-point configuration everywhere in the beam except right under the mid-point force application member whereas in the four-point configuration, the area between the central force application members has no resultant vertical shear force. The distance between the outer support members is the same as in the equivalent three-point configuration.

4.4 The test geometry is chosen to limit out-of-plane shear deformations and avoid the type of short beam failure modes that are interrogated in Test Method D 2344/D 2344M.

5. Significance and Use

5.1 This test method determines the flexural properties (including strength, stiffness, and load/deflection behavior) of polymer matrix composite materials under the conditions defined. Procedure A is used for three-point loading and Procedure B is used for four-point loading. This test method was developed for optimum use with continuous-fiber-reinforced polymer matrix composites and differs in several respects from other flexure methods, including the use of a standard span-to-thickness ratio of 32:1 versus the 16:1 ratio used by Test Methods D 790 (a plastics-focused method covering three-point flexure) and D 6272 (a plastics-focused method covering four-point flexure).

5.2 This test method is intended to interrogate long-beam strength in contrast to the short-beam strength evaluated by Test Method D 2344/D 2344M.

5.3 Flexural properties determined by these procedures can be used for quality control and specification purposes, and may find design applications.

5.4 These procedures can be useful in the evaluation of multiple environmental conditions to determine which are design drivers and may require further testing.

5.5 These procedures may also be used to determine flexural properties of structures.

6. Interferences

6.1 Flexural properties may vary depending on which surface of the specimen is in compression, as no laminate is perfectly symmetric (even when full symmetry is intended); such differences will shift the neutral axis and will be further affected by even modest asymmetry in the laminate. Flexural properties may also vary with specimen thickness, conditioning and/or testing environments, and rate of straining. When evaluating several datasets these parameters should be equivalent for all data in the comparison.

6.2 For multidirectional laminates with a small or moderate number of laminae, flexural modulus and flexural strength may be affected by the ply-stacking sequence and will not necessarily correlate with extensional modulus, which is not stacking-sequence dependent.

6.3 The calculation of the flexural properties in Section 13 of this standard is based on beam theory, while the specimens in general may be described as plates. The differences may in some cases be significant, particularly for laminates containing a large number of plies in the $\pm 45^\circ$ direction. The deviations from beam theory decrease with decreasing width.

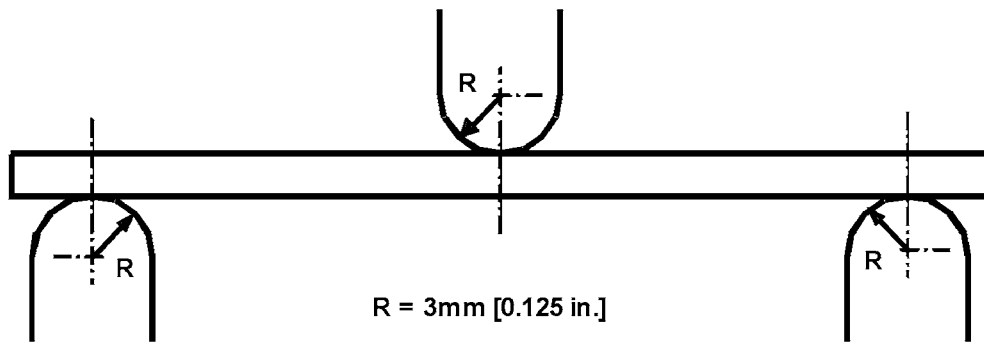
6.4 Loading noses may be fixed, rotatable or rolling. Typically, for testing composites, fixed or rotatable loading noses are used. The type of loading nose can affect results, since non-rolling paired supports on either the tension or compression side of the specimen introduce slight longitudinal forces and resisting moments on the beam, which superpose with the intended loading. The type of supports used is to be reported as described in Section 14. The loading noses should also uniformly contact the specimen across its width. Lack of

uniform contact can affect flexural properties by initiating damage by crushing and by non-uniformly loading the beam. Formulas used in this standard assume a uniform line loading at the specimen supports across the entire specimen width; deviations from this type of loading is beyond the scope of this standard.

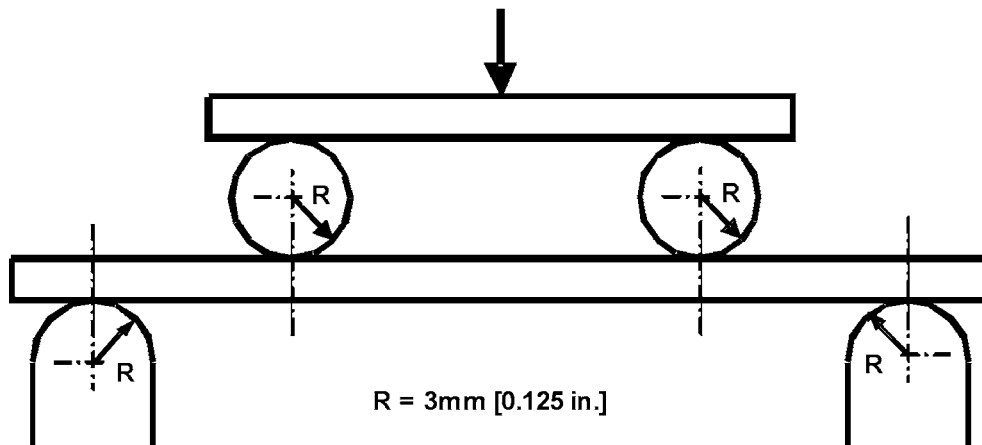
7. Apparatus

7.1 *Testing Machine*—Properly calibrated, which can be operated at a constant rate of crosshead motion, and in which the error in the force application system shall not exceed $\pm 1\%$ of the full scale. The force indicating mechanism shall be essentially free of inertia lag at the crosshead rate used. Inertia lag shall not exceed 1% of the measured force. The accuracy of the testing machine shall be verified in accordance with Practices E 4.

7.2 *Loading Noses and Supports*—The loading noses and supports shall have cylindrical contact surfaces of radius 3.00 mm [0.125 in.] as shown in Fig. 3, with a hardness of 60 to 62 HRC, as specified in Test Methods E 18, and shall have finely



Three-Point Loading Configuration with Fixed Supports and Loading Nose



Four-Point Loading Configuration with Fixed Supports and Rolling Loading Noses

FIG. 3 Example Loading Nose and Supports for Procedures A (top) and B (bottom)

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ground surfaces free of indentation and burrs with all sharp edges relieved. Loading noses and supports may be arranged in a fixed, rotatable or rolling arrangement. Typically, with composites, rotatable or fixed arrangements are used.

7.3 *Micrometers*—For width and thickness measurements the micrometers shall use a 4 to 7 mm [0.16 to 0.28 in.] nominal diameter ball-interface on an irregular surface such as the bag side of a laminate, and a flat anvil interface on machined edges or very smooth tooled surfaces. A micrometer or caliper with flat anvil faces shall be used to measure the length of the specimen. The accuracy of the instrument(s) shall be suitable for reading to within 1 % or better of the specimen dimensions. For typical section geometries, an instrument with an accuracy of ± 0.02 mm [± 0.001 in.] is desirable for thickness and width measurement, while an instrument with an accuracy of ± 0.1 mm [± 0.004 in.] is adequate for length measurement.

7.4 *Deflection Measurement*—Specimen deflection at the common center of the loading span shall be measured by a properly calibrated device having an accuracy of ± 1 % or better of the expected maximum displacement. The device shall automatically and continuously record the deflection during the test.

7.5 *Conditioning Chamber*—When conditioning materials at non-laboratory environments, a temperature/vapor-level controlled environmental conditioning chamber is required that shall be capable of maintaining the required temperature to within $\pm 1^\circ\text{C}$ [$\pm 2^\circ\text{F}$] and the required vapor level to within ± 3 % relative humidity, as outlined in Test Method [D 5229/D 5229M](#). Chamber conditions shall be monitored either on an automated continuous basis or on a manual basis at regular intervals.

7.6 *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 test specimen at the required temperature

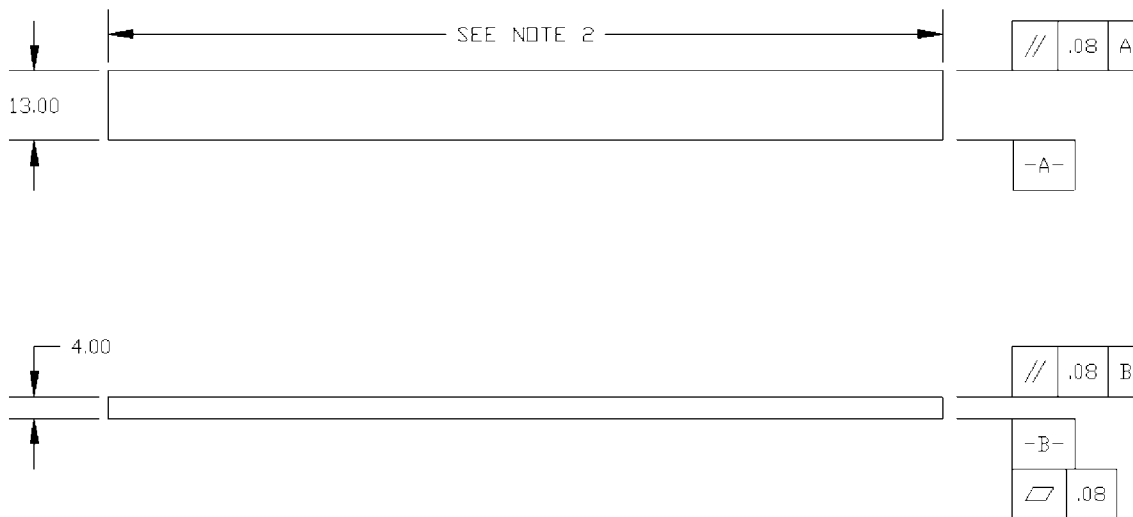
within $\pm 3^\circ\text{C}$ [$\pm 5^\circ\text{F}$] and the required vapor level to within ± 5 % relative humidity.

8. Test Specimens

8.1 *Specimen Preparation*—Guide [D 5687/D 5687M](#) provides recommended specimen preparation practices and should be followed when practical.

8.2 *Specimen Size* is chosen such that the flexural properties are determined accurately from the tests. For flexural strength, the standard support span-to-thickness ratio is chosen such that failure occurs at the outer surface of the specimens, due only to the bending moment (see Notes 2 and 3). The standard span-to-thickness ratio is 32:1, the standard specimen thickness is 4 mm [0.16 in.], and the standard specimen width is 13 mm [0.5 in.] with the specimen length being about 20 % longer than the support span. See [Figs. 4 and 5](#) for a drawing of the standard test specimen in SI and inch-pound units, respectively. For fabric-reinforced textile composite materials, the width of the specimen shall be at least two unit cells, as defined in Guide [D 6856](#). If the standard specimen thickness cannot be obtained in a given material system, an alternate specimen thickness shall be used while maintaining the support span-to-thickness ratio [32:1] and specimen width. Optional support span-to-thickness ratios of 16:1, 20:1, 40:1, and 60:1 may also be used provided it is so noted in the report. Also, the data obtained from a test using one support span-to-thickness ratio may not be compared with the data from another test using a different support span-to-thickness ratio.

8.2.1 Shear deformations can significantly reduce the apparent modulus of highly orthotropic laminates when they are tested at low support span-to-thickness ratios. For this reason, a high support span-to-thickness ratio is recommended for flexural modulus determinations. In some cases, separate sets of specimens may have to be used for modulus and strength determination.

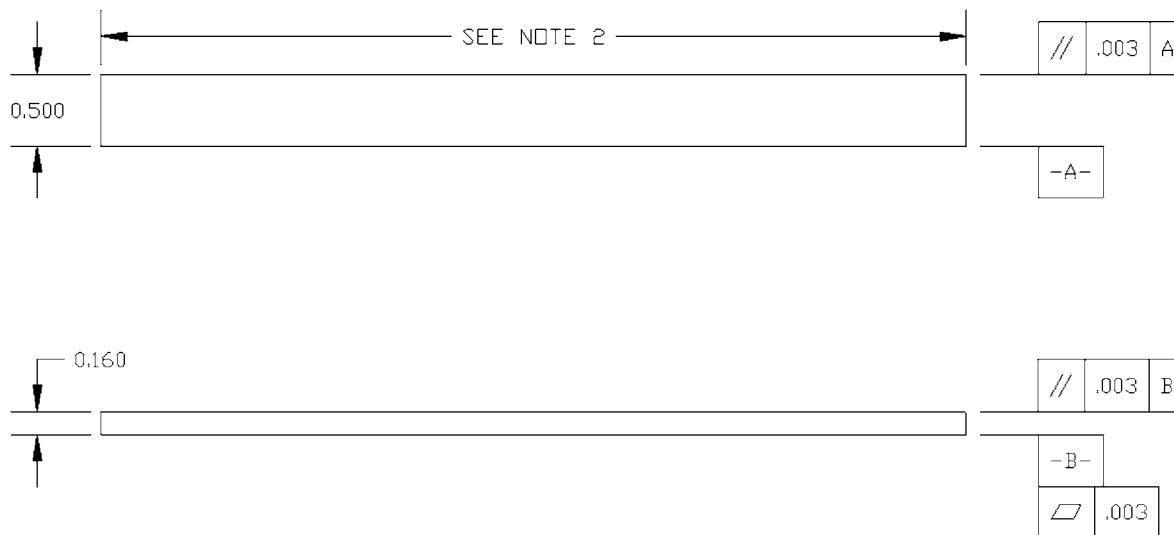


NOTE 1—Drawing interpretation per [ANSI Y14.5-1999](#) and [ANSI B46.1-1995](#).

NOTE 2—See 8.2 and 11.3 of this test standard for the required values of span and overall length.

FIG. 4 Standard Flexural Test Specimen Drawing (SI)

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NOTE 1—Drawing interpretation per ANSI Y14.5-1999 and ANSI B46.1-1995.

NOTE 2—See 8.2 and 11.3 of this test standard for the required values of span and overall length.

FIG. 5 Standard Flexural Test Specimen Drawing (Inch-Pound)

NOTE 2—A support span-to-thickness ratio of less than 32:1 may be acceptable for obtaining the desired flexural failure mode when the ratio of the lower of the compressive and tensile strength to out-of-plane shear strength is less than 8, but the support span-to-thickness ratio must be increased for composite laminates having relatively low out-of-plane shear strength and relatively high in-plane tensile or compressive strength parallel to the support span.

NOTE 3—While laminate stacking sequence is not limited by this test method, significant deviations from a lay-up of nominal balance and symmetry may induce unusual test behaviors and a shift in the neutral axis.

9. Number of Test Specimens

9.1 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. Report the method of sampling.

10. Conditioning

10.1 The recommended pre-test specimen condition is effective moisture equilibrium at a specific relative humidity as established by Test Method D 5229/D5229M; however, if the test requester does not explicitly specify a pre-test conditioning environment, conditioning is not required and the test specimens may be tested as prepared.

NOTE 4—The term *moisture*, as used in Test Method D 5229/D5229M, includes not only the vapor of a liquid and its condensate, but the liquid itself in large quantities, as for immersion.

10.2 The pre-test specimen conditioning process, to include specified environmental exposure levels and resulting moisture content, shall be reported with the data.

10.3 If there is no explicit conditioning process, the conditioning process shall be reported as “unconditioned” and the moisture content as “unknown.”

11. Procedure

11.1 Condition the specimens as required. Store the specimens in the conditioned environment until test time.

11.2 Following final specimen machining and any conditioning but before testing, measure and record the specimen width and thickness at the specimen mid-section, and the specimen length, to the specified accuracy.

11.3 Measure the span accurately to the nearest 0.1 mm [0.004 in.] for spans less than 63 mm [2.5 in.] and the nearest 0.3 mm [0.012 in.] for spans greater than or equal to 63 mm [2.5 in.]. Use the measured span for all calculations. See Annex A1 for information on the determination of and setting of the span.

11.4 *Speed of Testing*—Set the speed of testing at a rate of crosshead movement of 1.0 mm/min [0.05 in./min] for a specimen with standard dimensions. For specimens with dimensions that vary greatly from the standard dimensions, a crosshead rate that will give a similar rate of straining at the outer surface can be obtained via the method outlined in Test Methods D 790 for Procedure A and Test Method D 6272 for Procedure B.

11.5 Align the loading nose(s) and supports so that the axes of the cylindrical surfaces are parallel. For Procedure A, the loading nose shall be midway between the supports. For Procedure B, the load span shall be one-half of the support span and symmetrically placed between the supports. The parallelism may be checked by means of plates with parallel grooves into which the loading nose(s) and supports will fit when properly aligned. Center the specimen on the supports, with the long axis of the specimen perpendicular to the loading noses and supports. See Annex A1 for setting and measuring span.

11.6 Apply the force to the specimen at the specified crosshead rate. Measure and record force-deflection data at a

rate such that a minimum of 50 data points comprise the force deflection curve. (A higher sampling rate may be required to properly capture any nonlinearities or progressive failure of the specimen.) Measure deflection by a transducer under the specimen in contact with it at the center of the support span, the transducer being mounted stationary relative to the specimen supports. Do not use the measurement of the motion of the loading nose relative to the supports as this will not take into account the rotation of the specimen about the load and support noses, nor account for the compliance in the loading nose or crosshead.

11.7 *Failure Modes*—To obtain valid flexural strength, it is necessary that the specimen failure occurs on either one of its outer surfaces, without a preceding interlaminar shear failure or a crushing failure under a support or loading nose. Failure on the tension surface may be a crack while that on the compression surface may be local buckling. Buckling may be manifested as fiber micro-buckling or ply-level buckling. Ply-level buckling may result in, or be preceded by delamination of the outer ply.

11.7.1 *Failure Identification Codes*—Record the mode, area, and location of failure for each specimen. Choose a standard failure identification code based on the three-part code shown in Fig. 6. A multimode failure can be described by including each of the appropriate failure-mode codes between the parentheses of the M failure mode.

12. Validation

12.1 Values for properties at failure shall not be calculated for any specimen that breaks at some obvious, fortuitous flaw, unless such flaws constitute a variable being studied. Specimens that fail in an unacceptable failure mode shall not be included in the flexural property calculations. Retests shall be made for any specimen for which values are not calculated. If a significant fraction (>50 %) of the specimens fail in an unacceptable failure mode then the span-to-thickness ratio (for excessive shear failures) or the loading nose diameter (crushing under the loading nose) should be reexamined.

13. Calculation

NOTE 5—In determination of the calculated value of some of the properties listed in this section it is necessary to determine if the toe compensation (see Annex A2) adjustment must be made. This toe compensation correction shall be made only when it has been shown that the toe region of the curve is due to take up of the slack, alignment, or seating of the specimen and is not an authentic material response.

13.1 *Maximum Flexural Stress, Procedure A*—When a beam of homogenous, elastic material is tested in flexure as a

beam simply supported at two points and loaded at the midpoint, the maximum stress at the outer surface occurs at mid-span. The stress may be calculated for any point on the load-deflection curve by the following equation (Note 6):

$$\sigma = \frac{3PL}{2bh^2} \tag{1}$$

where:

- σ = stress at the outer surface at mid-span, MPa [psi],
- P = applied force, N [lbf],
- L = support span, mm [in.],
- b = width of beam, mm [in.], and
- h = thickness of beam, mm [in.].

NOTE 6—Eq 1 applies strictly to materials for which the stress is linearly proportional to strain up to the point of rupture and for which the strains are small. Since this is not always the case, a slight error will be introduced in the use of this equation. The equation will however, be valid for comparison data and specification values up to the maximum fiber strain of 2 % for specimens tested by the procedure herein described. It should be noted that the maximum ply stress may not occur at the outer surface of a multidirectional laminate.⁴ Laminated beam theory must be applied to determine the maximum tensile stress at failure. Thus, Eq 1 yields an apparent strength based on homogeneous beam theory. This apparent strength is highly dependent on the ply-stacking sequence for multidirectional laminates.

13.2 *Maximum Flexural Stress, Procedure B*—When a beam of homogeneous, elastic material is tested in flexure as a beam simply supported at two outer points and loaded at two central points separated by a distance equal to 1/2 the support span and at equal distance from the adjacent support point, the maximum stress at the outer surface occurs between the two central loading points that define the load span (Fig. 2). The stress may be calculated for any point on the load-deflection curve by the following equation (Note 7):

$$\sigma = \frac{3PL}{4bh^2} \tag{2}$$

where:

- σ = stress at the outer surface in the load span region, MPa [psi],
- P = applied force, N [lbf],
- L = support span, mm [in.],
- b = width of beam, mm [in.], and

⁴ For the theoretical details, see Whitney, J. M., Browning, C. E., and Mair, A., "Analysis of the Flexure Test for Laminated Composite Materials," *Composite Materials: Testing and Design (Third Conference)*, ASTM STP 546, 1974, pp. 30-45.

First Character		Second Character		Third Character	
Failure Mode	Code	Failure Area	Code	Failure Location	Code
Tension	T	At loading nose	A	Top	T
Compression	C	Between loading noses	B	Bottom	B
Buckling	B	at Support nose	S	Left	L
interlaminar Shear	S	between Load and support nose	L	Right	R
Multi-mode	M(xyz)	Unknown	U	Middle	M
Other	O			Various	V
				Unknown	U

FIG. 6 Flexure Test Specimen Three-Part Failure Identification Code

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h = thickness of beam, mm [in.].

NOTE 7—The limitations defined for Eq 1 in Note 6 apply also to Eq 2.

13.3 *Flexural Strength*—The flexural strength is equal to the maximum stress at the outer surface corresponding to the peak applied force prior to failure. (for multidirectional laminates, see Note 6). It is calculated in accordance with Eq 1 and 2 by letting P equal the peak applied force.

13.4 *Flexural Stress at a Given Strain*—The maximum flexural stress at any given strain may be calculated in accordance with Eq 1 and 2 by letting P equal the applied force read from the force-deflection curve at the deflection corresponding to the desired strain (for multidirectional laminates, see Note 6). Equations for calculating strains from the measured deflection are given in 13.5 and 13.6.

13.5 *Maximum Strain, Procedure A*—The maximum strain at the outer surface also occurs at mid-span, and it may be calculated as follows:

$$\epsilon = \frac{6\delta h}{L^2} \quad (3)$$

where:

- ϵ = maximum strain at the outer surface, mm/mm [in./in.],
- δ = mid-span deflection, mm [in.],
- L = support span, mm [in.], and
- h = thickness of beam, mm [in.].

13.6 *Maximum Strain, Procedure B*—The maximum strain at the outer surface also occurs at mid-span, and it may be calculated as follows:

$$\epsilon = \frac{4.36\delta h}{L^2} \quad (4)$$

where:

- δ = mid-span deflection, mm [in.],
- ϵ = maximum strain at the outer surface, mm/mm [in./in.],
- L = support span, mm [in.], and
- h = thickness of beam, mm [in.].

13.7 Flexural Modulus of Elasticity:

13.7.1 *Flexural Chord Modulus of Elasticity*—The flexural chord modulus of elasticity is the ratio of stress range and corresponding strain range. For calculation of flexural chord modulus, the recommended strain range is 0.002 with a start point of 0.001 and an end point 0.003. If the data is not available at the exact strain range end points (as often occurs with digital data), use the closest available data point. Calculate the flexural chord modulus of elasticity from the stress-strain data using Eq 5 (for multidirectional or highly orthotropic composites, see Note 8).

$$E_f^{chord} = \frac{\Delta\sigma}{\Delta\epsilon} \quad (5)$$

where:

- E_f^{chord} = flexural chord modulus of elasticity, MPa [psi],
- $\Delta\sigma$ = difference in flexural stress between the two selected strain points, MPa [psi], and
- $\Delta\epsilon$ = difference between the two selected strain points (nominally 0.002).

13.7.1.1 Report the chord modulus of elasticity in MPa [psi] for the strain range 0.001 to 0.003. If a different strain range is used in the calculations, also report the strain range used.

NOTE 8—Shear deformation can seriously reduce the apparent flexural modulus of highly orthotropic laminates when they are tested at low span-to-thickness ratios.⁵ For this reason, a high span-to-thickness ratio is recommended for flexural modulus determinations. In some cases, separate sets of specimens may have to be used for modulus and strength determination.

13.7.2 *Flexural Secant Modulus of Elasticity*—The flexural secant modulus of elasticity is the ratio of stress to corresponding strain at any given point on the stress-strain curve. The flexural secant modulus is same as the flexural chord modulus in which the initial strain point is zero. It shall be expressed in MPa [psi]. It is calculated as follows (for multidirectional or highly orthotropic composites, see Note 8):

13.7.2.1 *For Procedure A:*

$$E_f^{secant} = \frac{L^3 m}{4bh^3} \quad (6)$$

where:

- E_f^{secant} = flexural secant modulus of elasticity, MPa [psi],
- L = support span, mm [in.],
- b = width of beam, mm [in.],
- h = thickness of beam, mm [in.] and
- m = slope of the secant of the force-deflection curve.

13.7.2.2 *For Procedure B:*

$$E_f^{secant} = \frac{0.17L^3 m}{bh^3} \quad (7)$$

where E_f^{secant} , m , L , b , and h are the same as for Eq 6.

13.7.3 Chord modulus of elasticity shall be reported although other definitions of moduli may also be used. However, when other definitions of moduli are used, it should be clearly indicated in the report.

13.8 *Statistics*—For each series of tests calculate the average value, standard deviation, and coefficient of variation for each property determined:

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

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

$$CV = 100 \cdot \frac{s_{n-1}}{\bar{x}}$$

where:

- \bar{x} = average value or sample mean,
- x_i = value of single measured or derived property,
- n = number of specimens,
- s_{n-1} = estimated standard deviation,
- CV = coefficient of variation in percentage.

⁵ For discussion of these effects, see Zweben C., Smith, W. S., and Wardle, M. W., "Test Methods for Fiber Tensile Strength, Composite Flexural Modulus, and Properties of Fabric-Reinforced Laminates," *Composite Materials: Testing and Design (Fifth Conference)*, ASTM STP 674, 1979, pp. 228-262.

14. Report

14.1 The information reported for this test method includes material identification and mechanical testing data. These data shall be reported in accordance with Guides E 1309 and E 1471. At a minimum, the following should be reported:

14.1.1 The revision level or date of issue of the test method used.

14.1.2 The date(s) and location(s) of the testing.

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

14.1.4 The test Procedure used (A or B).

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

14.1.6 Identification of the material tested including: material specification, material type, material designation, manufacturer, manufacturer's lot or batch number, source (if not from the manufacturer), date of certification, expiration of certification, filament diameter, tow or yarn filament count and twist, sizing, form or weave, fiber areal weight, matrix type, prepreg matrix content, and prepreg volatiles content.

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

14.1.8 Ply orientation stacking sequence of the laminate.

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

14.1.10 Average ply thickness of the material.

14.1.11 Results of any nondestructive evaluation tests.

14.1.12 Method of preparing the test specimens, including specimen labeling scheme and method, specimen geometry, sampling method, and specimen cutting method.

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

14.1.14 Type of test machine, grips, jaws, alignment data, and data acquisition sampling rate and equipment type.

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

14.1.16 Conditioning parameters and results, and the procedure used if other than that specified in this test method.

14.1.17 Relative humidity and temperature of the testing laboratory.

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

14.1.19 Number of specimens tested.

14.1.20 Load-span length, support-span length, and support span-to-thickness ratio.

14.1.21 Loading and support nose type and dimensions.

14.1.22 Speed of testing.

14.1.23 Transducer placement on the specimen, transducer type, and calibration data for each transducer used.

14.1.24 Force-deflection curves for each specimen. Note method and offset value if toe compensation was applied to force-deflection curve.

14.1.25 Tabulated data of flexural stress versus strain for each specimen.

14.1.26 Individual flexural 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.

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

14.1.28 Strain range used for the flexural chord modulus of elasticity determination.

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

14.1.30 If an alternate definition of flexural 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.

14.1.31 Individual values of the alternate (see above) flexural modulus of elasticity, and the average value, standard deviation, and coefficient of variation (in percent) for the population.

14.1.32 Individual maximum flexural stresses, and the average, standard deviation, and coefficient of variation (in percent) values for the population. Note any test in which the failure load was less than the maximum load before failure.

14.1.33 For flexural modulus only tests: maximum load applied, strain at maximum applied load, and calculated flexural modulus of elasticity (E_f).

14.1.34 Individual maximum flexural strains and the average, standard deviation, and coefficient of variation (in percent) values for the population. Note any test that was truncated to 2 % strain.

14.1.35 Failure mode and location of failure for each specimen.

15. Precision and Bias

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

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

16. Keywords

16.1 fiber-reinforced composites; flexural properties; stiffness; strength

(Mandatory Information)

A1. MEASURING AND SETTING SPAN

A1.1 For flexural fixtures that have adjustable spans, it is important that the span between the supports is maintained constant or the actual measured span is used in the calculation of flexural stress, flexural modulus and strain, and the loading noses are positioned and aligned properly with respect to the supports. Some simple steps as follows can improve the repeatability of results when using adjustable span fixtures.

A1.2 *Measurement of Span:*

A1.2.1 This technique is needed to ensure that the correct span, not an estimated span, is used in calculation of results.

A1.2.2 Scribe a permanent line or mark at the exact center of the support where the specimen makes complete contact. The type of mark depends on whether the supports are fixed or rotatable (see Figs. A1.1 and A1.2).

A1.2.3 Using a vernier caliper with pointed tips that is readable to at least 0.1 mm [0.004 in.], measure the distance between the supports, and use this measurement of span in the calculations.

A1.3 *Setting the Span and Alignment of Loading Nose(s)*—To ensure a constant day-to-day setup of the span and ensure the alignment and proper positioning of the loading nose(s), simple jigs should be manufactured for each of the standard setups used. An example of a jig found to be useful is shown in Fig. A1.3.

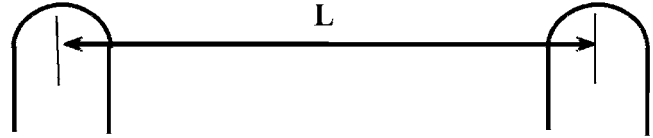


FIG. A1.1 Markings on Fixed Specimen Supports

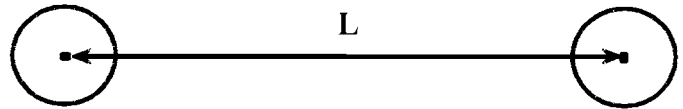


FIG. A1.2 Markings on Rotatable Specimen Supports

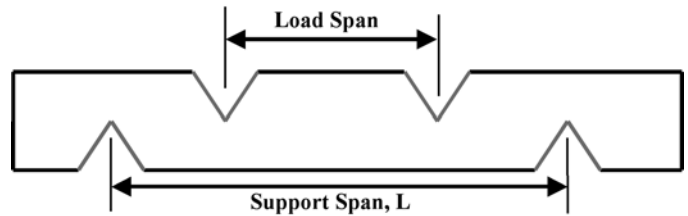


FIG. A1.3 Fixture Used to Align Loading Noses and Supports

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A2. TOE COMPENSATION

A2.1 In a typical force-deflection curve (see Fig. A2.1) there is a toe region, AC, which does not represent a property of the material. It is an artifact caused by a take-up of slack and alignment, or seating of the specimen. In order to obtain correct values of such parameters as flexural modulus, and deflection at failure, this artifact must be compensated for to give the corrected zero point on the deflection, or extension axis.

A2.2 In the case of a material exhibiting a region of Hookean (linear) behavior (see Fig. A2.1), a continuation of the linear (CD) region is constructed through the zero axis. This intersection (B) is the corrected zero deflection point from which all deflections must be measured. The slope can be determined by dividing the change in force between any two points along the line CD (or its extension) by the change in deflection at the same two points (measured from Point B, defined as zero-deflection).

A2.3 In the case of a material that does not exhibit any linear region (see Fig. A2.2), the same kind of toe correction of zero-deflection point can be made by constructing a tangent to the maximum slope at the inflection Point H'. This is extended to intersect the deflection axis at Point B', the corrected zero-deflection point. Using Point B' as zero deflection, the force at any point (G') on the curve can be divided by the deflection at that point to obtain a flexural chord modulus (slope of Line B'G').

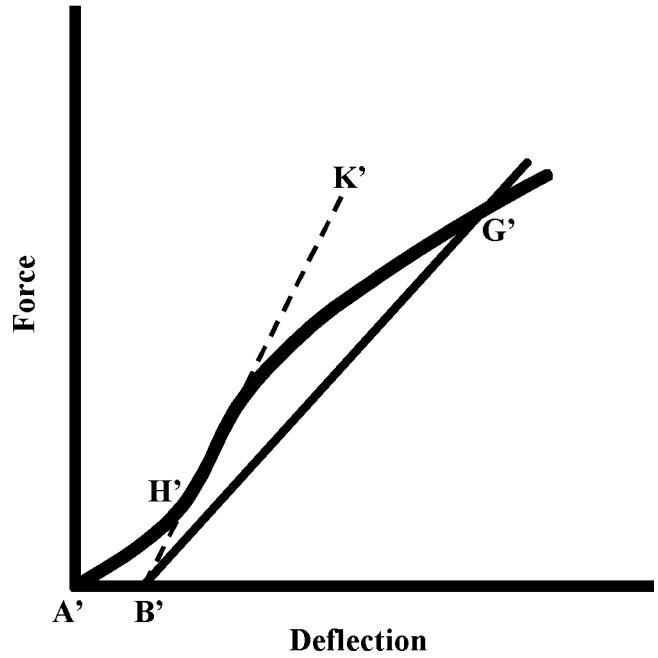


FIG. A2.2 Material without a Hookean Region

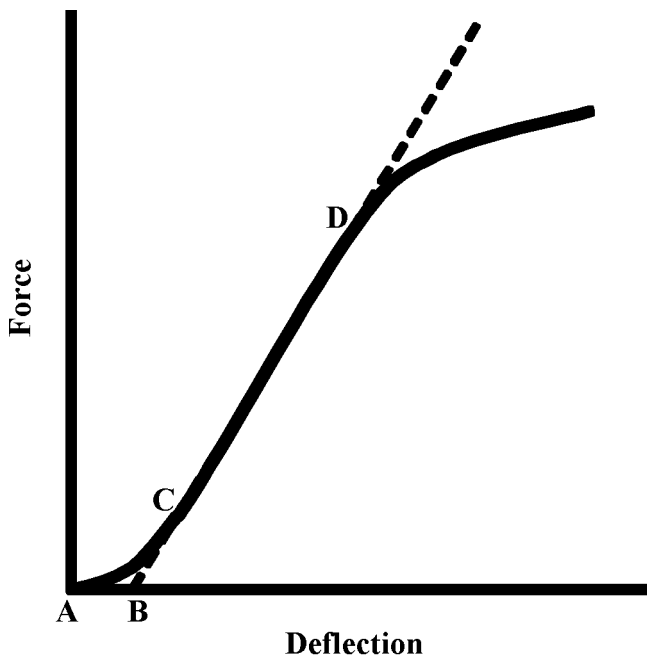


FIG. A2.1 Material with a Hookean Region

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