



Designation: D7264/D7264M – 21

# Standard Test Method for Flexural Properties of Polymer Matrix Composite Materials<sup>1</sup>

This standard is issued under the fixed designation D7264/D7264M; 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 ( $\epsilon$ ) 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 D6272, 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 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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

Current edition approved Jan. 1, 2021. Published February 2021. Originally approved in 2006. Last previous edition approved in 2015 as D7264/D7264M – 15. DOI: 10.1520/D7264\_D7264M-21.

## 2. Referenced Documents

### 2.1 *ASTM Standards*:<sup>2</sup>

D790 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials

D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement

D883 Terminology Relating to Plastics

D2344/D2344M Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates

D2584 Test Method for Ignition Loss of Cured Reinforced Resins

D2734 Test Methods for Void Content of Reinforced Plastics

D3171 Test Methods for Constituent Content of Composite Materials

D3878 Terminology for Composite Materials

D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials

D5687/D5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation

D6272 Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials by Four-Point Bending

D6856 Guide for Testing Fabric-Reinforced “Textile” Composite Materials

E4 Practices for Force Verification of Testing Machines

E6 Terminology Relating to Methods of Mechanical Testing

E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E456 Terminology Relating to Quality and Statistics

### 2.2 *Other Documents*:<sup>3</sup>

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

<sup>2</sup> 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.

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

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

### 3. Terminology

3.1 *Definitions*—Terminology D3878 defines the terms relating to high-modulus fibers and their composites. Terminology D883 defines terms relating to plastics. Terminology E6 defines terms relating to mechanical testing. Terminology E456 and Practice E177 define terms relating to statistics. In the event of a conflict between terms, Terminology D3878 shall have precedence over the other documents.

#### 3.2 Definitions of Terms Specific to This Standard:

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

3.2.2 *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.

#### 3.3 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

$\delta$  = mid-span deflection of the specimen

$\epsilon$  = strain at the outer surface at mid-span of the specimen

$\sigma$  = 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).

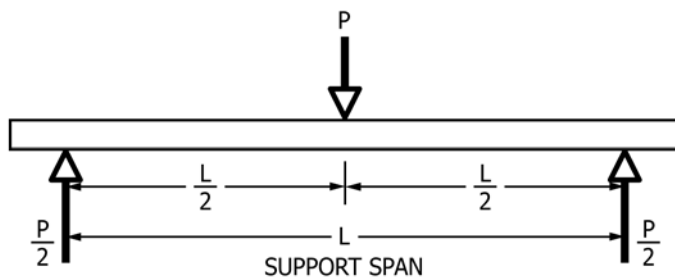


FIG. 1 Procedure A—Loading Diagram

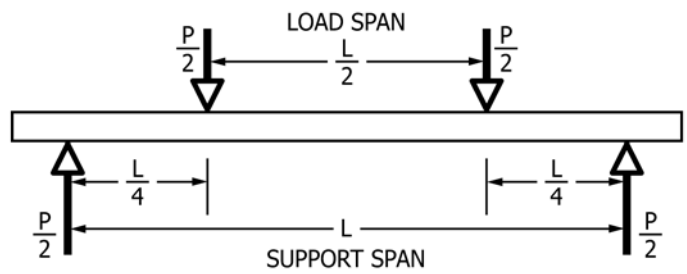


FIG. 2 Procedure B—Loading Diagram

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 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 D2344/D2344M.

### 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 D790 (a plastics-focused method covering three-point flexure) and D6272 (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 D2344/D2344M.

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 or testing environments, or both, and rate of straining. When evaluating several datasets, these parameters shall 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.

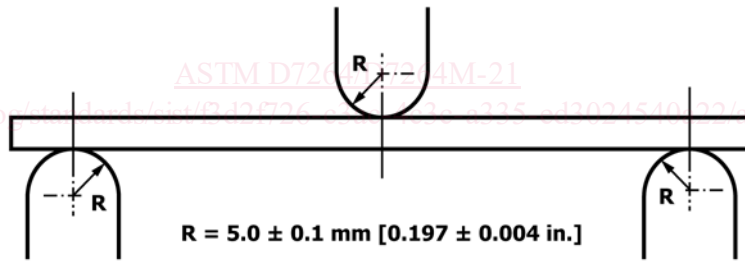
6.3 The calculation of the flexural properties in Section 13 of this standard is based on beam theory, while the specimens in general may be described as plates. The differences may in some cases be significant, particularly for laminates containing a large number of plies in the ±45° direction. The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

6.4 Loading noses shall 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 shall 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.

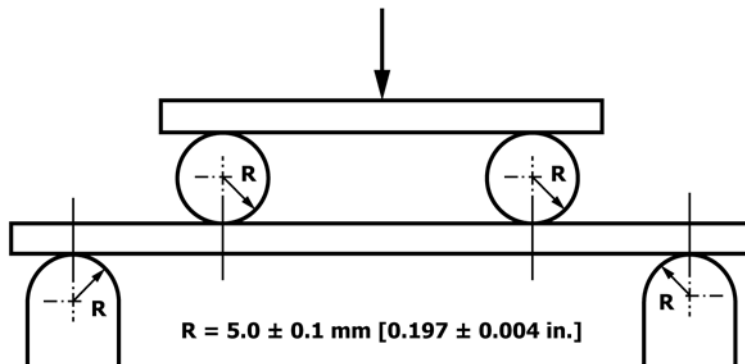
**7. Apparatus**

7.1 *Testing Machine*—The testing machine shall be properly calibrated and operate at a constant rate of crosshead motion with the error in the force application system not exceeding ±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 E4.

7.2 *Loading Noses and Supports*—The loading noses and supports shall have cylindrical contact surfaces with a hardness ≥55 HRC and shall have finely ground surfaces free of



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)

indentation and burrs, with all sharp edges relieved. The radii of the loading nose and supports shall be  $5.0 \pm 0.1$  mm [ $0.197 \pm 0.004$  in.], as shown in Fig. 3, unless otherwise specified or agreed upon between the interested parties. Loading noses and supports shall be arranged in a fixed, rotatable, or rolling arrangement. Typically, with composites, rotatable or fixed arrangements are used.

7.3 *Micrometers and Calipers*—For width and thickness measurements, the micrometers shall use a 4 to 8 mm [0.16 to 0.32 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 use of alternative measurement devices is permitted if specified (or agreed to) by the test requestor and reported by the testing laboratory. 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  $\pm 0.02$  mm [ $\pm 0.001$  in.] is adequate for thickness and width measurement, while an instrument with an accuracy of  $\pm 0.1$  mm [ $\pm 0.004$  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  $\pm 1$  % 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  $\pm 3$  °C [ $\pm 5$  °F] and the required vapor level to within  $\pm 3$  % relative humidity, as outlined in Test Method D5229/

D5229M. 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  $\pm 3$  °C [ $\pm 5$  °F] and the required vapor level to within  $\pm 5$  % relative humidity.

## 8. Test Specimens

8.1 *Specimen Preparation*—Guide D5687/D5687M provides recommended specimen preparation practices and shall 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 D6856. 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 shall not

### DRAWING NOTES:

1. DRAWING INTERPRETATION PER ANSI Y14.5-1999 AND ANSI B46.1-1995.
2. SEE 8.2 AND 11.3 OF THIS TEST STANDARD FOR THE REQUIRED VALUES OF SPAN AND OVERALL LENGTH.

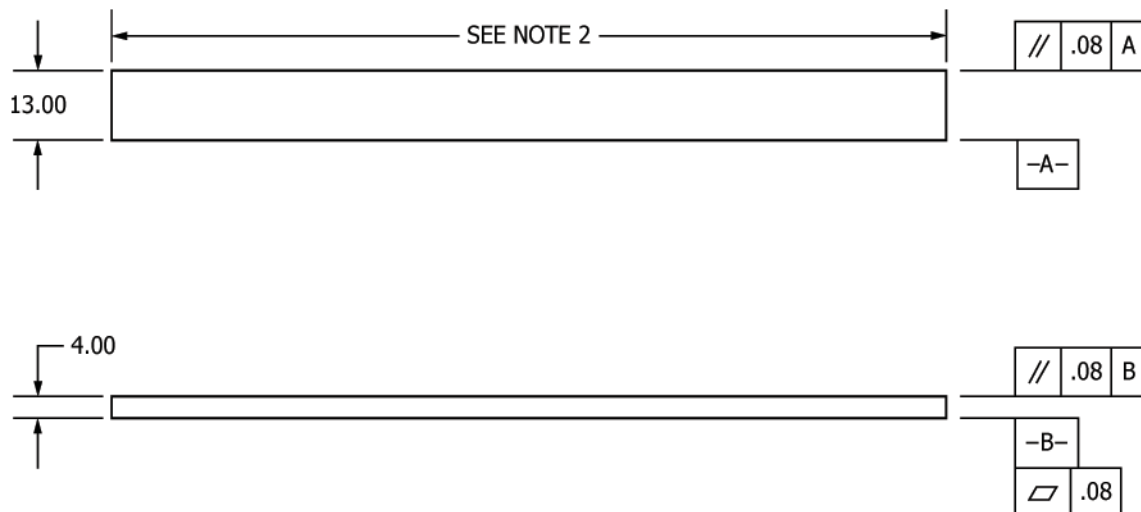
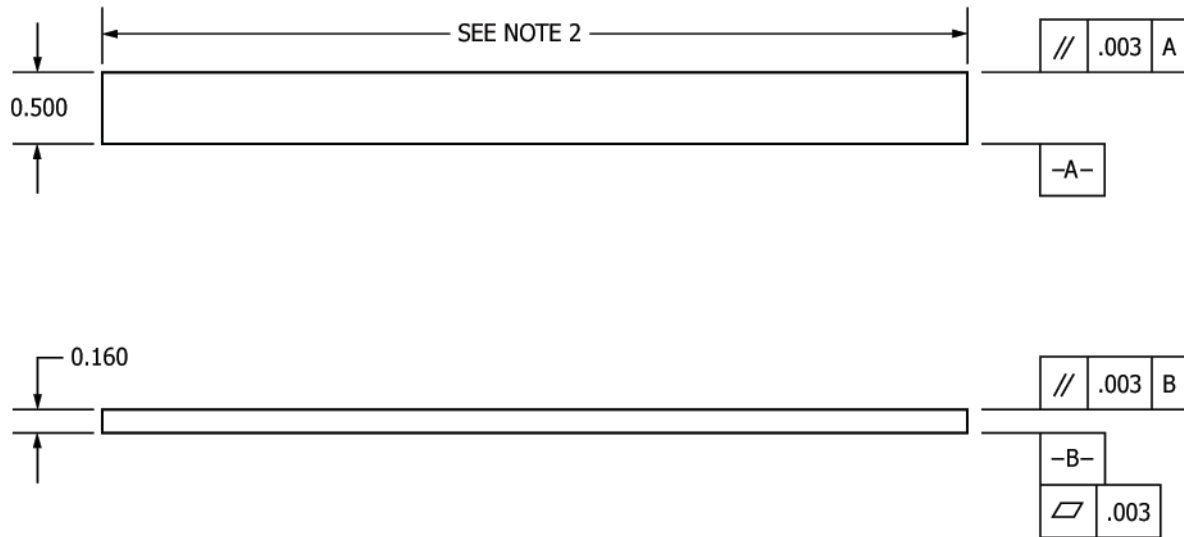


FIG. 4 Standard Flexural Test Specimen Drawing (SI)

**DRAWING NOTES:**

1. DRAWING INTERPRETATION PER ANSI Y14.5-1999 AND ANSI B46.1-1995.
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)**

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 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.

8.3 If specific gravity, density, reinforcement volume, or void volume are to be reported, then obtain these samples from the same panels as the test samples. Specific gravity and density may be evaluated by means of Test Methods D792. Volume percent of the constituents may be evaluated by one of the matrix digestion procedures of Test Method D3171, or, for certain reinforcement materials such as glass and ceramics, by the matrix burn-off technique of Test Method D2584. Void content may be evaluated from the equations of Test Method D2734 and is applicable to both Test Methods D2584 and D3171.

8.4 *Labeling*—Label the specimens so that they will be distinct from each other and traceable back to the raw material and in a manner that will both be unaffected by the test and not influence the test.

**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 E122 shall 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 D5229/D5229M; however, if the test requester does not explicitly specify a pre-test conditioning environment, conditioning is not required and the test specimens shall be tested as prepared.

NOTE 4—The term *moisture*, as used in Test Method D5229/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, *b*, and thickness, *h*, at the specimen mid-section, and the specimen length, to the accuracy specified in 7.3.

11.3 Measure the span,  $L$ , 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 **D790** for Procedure A and Test Method **D6272** for Procedure B. The use of an alternative test rate is permitted if specified (or agreed to) by the test requestor and reported by the testing laboratory.

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) shall 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 shall be calculated for any point on the load-deflection curve by the following equation (**Note 6**):

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

where:

- $\sigma$  = 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

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**

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.<sup>4</sup> 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 ½ 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 shall be calculated for any point on the load-deflection curve by the following equation (Note 7):

$$\sigma = \frac{3PL}{4bh^2} \quad (2)$$

where:

- $\sigma$  = 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
- $h$  = 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 shall 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 shall be calculated as follows:

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

where:

- $\varepsilon$  = maximum strain at the outer surface, mm/mm [in./in.],
- $\delta$  = 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 shall be calculated as follows:

$$\varepsilon = \frac{48\delta h}{11L^2} \quad (4)$$

where:

- $\delta$  = mid-span deflection, mm [in.],
- $\varepsilon$  = 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).

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

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
- $\Delta\varepsilon$  = 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.<sup>5</sup> 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:**

<sup>5</sup> 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.