Designation: D790 – 15$^{\varepsilon 2}$

Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials[1]

This standard is issued under the fixed designation D790; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

ε[1] NOTE—Editorially corrected 4.3 in January 2016.
ε[2] NOTE—Editorial corrections were made in February 2016.

1. Scope*

1.1 These test methods are used to determine the flexural properties of unreinforced and reinforced plastics, including high modulus composites and electrical insulating materials utilizing a three-point loading system to apply a load to a simply supported beam (specimen). The method is generally applicable to both rigid and semi-rigid materials, but flexural strength cannot be determined for those materials that do not break or yield in the outer surface of the test specimen within the 5.0 % strain limit.

1.2 Test specimens of rectangular cross section are injection molded or, cut from molded or extruded sheets or plates, or cut from molded or extruded shapes. Specimens must be solid and uniformly rectangular. The specimen rests on two supports and is loaded by means of a loading nose midway between the supports.

1.3 Measure deflection in one of two ways; using crosshead position or a deflectometer. Please note that studies have shown that deflection data obtained with a deflectometer will differ from data obtained using crosshead position. The method of deflection measurement shall be reported.

NOTE 1—Requirements for quality control in production environments are usually met by measuring deflection using crosshead position. However, more accurate measurement may be obtained by using an deflection indicator such as a deflectometer.

NOTE 2—Materials that do not rupture by the maximum strain allowed under this test method may be more suited to a 4-point bend test. The basic difference between the two test methods is in the location of the maximum bending moment and maximum axial fiber stresses. The maximum axial fiber stresses occur on a line under the loading nose in 3-point bending and over the area between the loading noses in 4-point bending. A four-point loading system method can be found in Test Method D6272.

1.4 The values stated in SI units are to be regarded as the standard. The values provided in parentheses are for information only.

1.5 *The text of this standard references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.*

1.6 *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.*

NOTE 3—This standard and ISO 178 address the same subject matter, but differ in technical content.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing
D638 Test Method for Tensile Properties of Plastics
D883 Terminology Relating to Plastics
D4000 Classification System for Specifying Plastic Materials
D4101 Specification for Polypropylene Injection and Extrusion Materials
D5947 Test Methods for Physical Dimensions of Solid Plastics Specimens
D6272 Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials by Four-Point Bending
E4 Practices for Force Verification of Testing Machines
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E2309 Practices for Verification of Displacement Measuring

[1] These test methods are under the jurisdiction of ASTM Committee D20 on Plastics and are the direct responsibility of Subcommittee D20.10 on Mechanical Properties.

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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.

***A Summary of Changes section appears at the end of this standard**

Systems and Devices Used in Material Testing Machines

2.2 *ISO Standard:*[3]

ISO 178 Plastics—Determination of Flexural Properties

3. Terminology

3.1 *Definitions*—Definitions of terms applying to these test methods appear in Terminology D883 and Annex A2 of Test Method D638.

4. Summary of Test Method

4.1 A test specimen of rectangular cross section rests on two supports in a flat-wise position and is loaded by means of a loading nose located midway between the supports. Unless testing certain laminated materials (see 7 for guidance), a support span-to-depth (of specimen) ratio 16:1 shall be used. The specimen is deflected until rupture occurs in the outer surface of the test specimen or until a maximum strain (see 5.1.6) of 5.0 % is reached, whichever occurs first.

4.2 *Procedure A* is designed principally for materials that break at comparatively small deflections and it shall be used for measurement of flexural properties, particularly flexural modulus, unless the material specification states otherwise. Procedure A employs a strain rate of 0.01 mm/mm/min (0.01 in./in./min) and is the preferred procedure for this test method.

4.3 *Procedure B* is designed principally for those materials that do not break or yield in the outer surface of the test specimen within the 5.0 % strain limit when Procedure A conditions are used. Procedure B employs a strain rate of 0.10 mm/mm/min (0.10 in./in./min).

4.4 Type I tests utilize crosshead position for deflection measurement.

4.5 Type II tests utilize an instrument (deflectometer) for deflection measurement.

4.6 The procedure used and test type shall be reported

NOTE 4—Comparative tests may be run in accordance with either procedure, provided that the procedure is found satisfactory for the material being tested. Tangent modulus data obtained by Procedure A tends to exhibit lower standard deviations than comparable results obtained by means of Procedure B.

5. Significance and Use

5.1 Flexural properties as determined by this test method are especially useful for quality control and specification purposes. They include:

5.1.1 *Flexural Stress (σ_f)*—When a homogeneous elastic material is tested in flexure as a simple beam supported at two points and loaded at the midpoint, the maximum stress in the outer surface of the test specimen occurs at the midpoint. Flexural stress is calculated for any point on the load-deflection curve using equation (Eq 3) in Section 12 (see Notes 5 and 6).

NOTE 5—Eq 3 applies strictly to materials for which 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 if Eq 3 is used to calculate stress for materials that are not true Hookean materials. The equation is valid for obtaining comparison data and for specification purposes, but only up to a maximum fiber strain of 5 % in the outer surface of the test specimen for specimens tested by the procedures described herein.

NOTE 6—When testing highly orthotropic laminates, the maximum stress may not always occur in the outer surface of the test specimen.[4] Laminated beam theory must be applied to determine the maximum tensile stress at failure. If Eq 3 is used to calculate stress, it will yield an apparent strength based on homogeneous beam theory. This apparent strength is highly dependent on the ply-stacking sequence of highly orthotropic laminates.

5.1.2 *Flexural Stress for Beams Tested at Large Support Spans (σ_f)*—If support span-to-depth ratios greater than 16 to 1 are used such that deflections in excess of 10 % of the support span occur, the stress in the outer surface of the specimen for a simple beam is reasonably approximated using equation (Eq 4) in 12.3 (see Note 7).

NOTE 7—When large support span-to-depth ratios are used, significant end forces are developed at the support noses which will affect the moment in a simple supported beam. Eq 4 includes additional terms that are an approximate correction factor for the influence of these end forces in large support span-to-depth ratio beams where relatively large deflections exist.

5.1.3 *Flexural Strength (σ_{fM})*—Maximum flexural stress sustained by the test specimen (see Note 6) during a bending test. It is calculated according to Eq 3 or Eq 4. Some materials that do not break at strains of up to 5 % give a load deflection curve that shows a point at which the load does not increase with an increase in strain, that is, a yield point (Fig. 1, Curve b), *Y*. The flexural strength is calculated for these materials by letting *P* (in Eq 3 or Eq 4) equal this point, *Y*.

5.1.4 *Flexural Offset Yield Strength*—Offset yield strength is the stress at which the stress-strain curve deviates by a given strain (offset) from the tangent to the initial straight line portion of the stress-strain curve. The value of the offset must be given whenever this property is calculated.

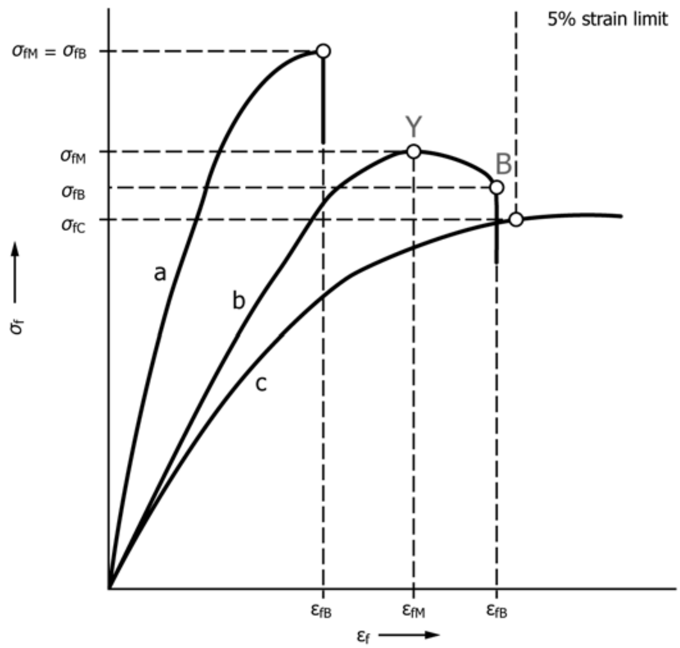
NOTE 8—Flexural Offset Yield Strength may differ from flexural strength defined in 5.1.3. Both methods of calculation are described in the annex to Test Method D638.

5.1.5 *Flexural Stress at Break (σ_{fB})*—Flexural stress at break of the test specimen during a bending test. It is calculated according to Eq 3 or Eq 4. Some materials give a load deflection curve that shows a break point, *B*, without a yield point (Fig. 1, Curve a) in which case $\sigma_{fB} = \sigma_{fM}$. Other materials give a yield deflection curve with both a yield and a break point, *B* (Fig. 1, Curve b). The flexural stress at break is calculated for these materials by letting *P* (in Eq 3 or Eq 4) equal this point, *B*.

5.1.6 *Stress at a Given Strain*—The stress in the outer surface of a test specimen at a given strain is calculated in accordance with Eq 3 or Eq 4 by letting *P* equal the load read from the load-deflection curve at the deflection corresponding to the desired strain (for highly orthotropic laminates, see Note 6).

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

[4] For a 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.



NOTE 1—Curve a: Specimen that breaks before yielding.
Curve b: Specimen that yields and then breaks before the 5 % strain limit.
Curve c: Specimen that neither yields nor breaks before the 5 % strain limit.

FIG. 1 Typical Curves of Flexural Stress (σ_f) Versus Flexural Strain (ε_f)

5.1.7 *Flexural Strain,* ε_f—Nominal fractional change in the length of an element of the outer surface of the test specimen at midspan, where the maximum strain occurs. Flexural strain is calculated for any deflection using Eq 5 in 12.4.

5.1.8 *Modulus of Elasticity:*

5.1.8.1 *Tangent Modulus of Elasticity*—The tangent modulus of elasticity, often called the "modulus of elasticity," is the ratio, within the elastic limit, of stress to corresponding strain. It is calculated by drawing a tangent to the steepest initial straight-line portion of the load-deflection curve and using Eq 6 in 12.5.1 (for highly anisotropic composites, see Note 15).

NOTE 9—Shear deflections can seriously reduce the apparent modulus of highly anisotropic composites when they are tested at low span-to-depth ratios.[4] For this reason, a span-to-depth ratio of 60 to 1 is recommended for flexural modulus determinations on these composites. Flexural strength should be determined on a separate set of replicate specimens at a lower span-to-depth ratio that induces tensile failure in the outer fibers of the beam along its lower face. Since the flexural modulus of highly anisotropic laminates is a critical function of ply-stacking sequence, it will not necessarily correlate with tensile modulus, which is not stacking-sequence dependent.

5.1.8.2 *Secant Modulus*—The secant modulus is the ratio of stress to corresponding strain at any selected point on the stress-strain curve, that is, the slope of the straight line that joins the origin and a selected point on the actual stress-strain curve. It shall be expressed in megapascals (pounds per square inch). The selected point is chosen at a pre-specified stress or strain in accordance with the appropriate material specification or by customer contract. It is calculated in accordance with Eq 6 by letting m equal the slope of the secant to the load-deflection curve. The chosen stress or strain point used for the determination of the secant shall be reported.

5.1.8.3 *Chord Modulus* (E_f)—The chord modulus is calculated from two discrete points on the load deflection curve. The selected points are to be chosen at two pre-specified stress or strain points in accordance with the appropriate material specification or by customer contract. The chosen stress or strain points used for the determination of the chord modulus shall be reported. Calculate the chord modulus, E_f using Eq 7 in 12.5.2.

5.2 Experience has shown that flexural properties vary with specimen depth, temperature, atmospheric conditions, and strain rate as specified in Procedures A and B.

5.3 Before proceeding with these test methods, refer to the ASTM specification of the material being tested. Any test specimen preparation, conditioning, dimensions, or testing parameters, or combination thereof, covered in the ASTM material specification shall take precedence over those mentioned in these test methods. Table 1 in Classification System D4000 lists the ASTM material specifications that currently exist for plastics.

6. Apparatus

6.1 *Testing Machine*—A testing machine capable of being operated at constant rates of crosshead motion over the range indicated and comprised of the following:

6.1.1 *Load Frame*—The stiffness of the testing machine shall be such that the total elastic deformation of the system does not exceed 1 % of the total deflection of the test specimen during testing, or appropriate corrections shall be made.

6.1.1.1 *Fixed Member*—A fixed or essentially stationary member holding the specimen supports;

6.1.1.2 *Movable Member*—A movable member carrying the loading nose.

6.1.2 *Loading Noses and Supports*—The loading nose and supports shall have cylindrical surfaces.

6.1.2.1 The radii of the loading nose and supports shall be 5.0 ± 0.1 mm (0.197 ± 0.004 in.) unless otherwise specified in an ASTM material specification or as agreed upon between interested parties.

6.1.2.2 *Other Radii for Loading Noses and Supports*—Alternative loading noses and supports are permitted to be used in order to avoid excessive indentation or failure due to stress concentration directly under the loading nose or if required by an ASTM material specification. If alternative loading nose and support radii are used, the dimensions of the loading nose and supports shall be clearly identified in the test report and reference shall be made to any applicable specifications.

(1) Alternative supports shall have a minimum radius of 3.2 mm (⅛ in.) When testing specimens 3.2 mm or greater in depth, the radius of the loading nose and supports are permitted to be up to 1.6 times the specimen depth.

(2) The arc of the loading nose in contact with the specimen shall be sufficiently large to prevent contact of the specimen with the sides of the nose. Alternative loading noses shall be sufficiently large to prevent contact of the specimen with the sides of the nose. The maximum radius of the loading nose shall be no more than four times the specimen depth.

6.1.3 *Drive Mechanism*—A drive mechanism for imparting to the movable member a uniform, controlled velocity with respect to the stationary member, with this velocity to be regulated as specified in Procedure A or B.

6.1.4 *Load Indicator*—A suitable load-indicating mechanism capable of showing the total load applied to specimen when in position on the flex fixture. This mechanism shall be essentially free of inertia lag at the specified rate of testing and shall indicate the load with an accuracy of ±1 % of the indicated value, or better. The accuracy of the testing machine shall be verified in accordance with Practices E4.

6.1.5 *Deflection Measuring Device*—The deflection measuring device used shall be selected from the following two choices:

6.1.5.1 *Type I—Crosshead Position Indicating System*—A suitable deflection indicating mechanism capable of showing the amount of change in crosshead movement. This mechanism shall be essentially free of inertial lag at the specified rate of testing and shall indicate the crosshead movement. The crosshead position indicating system shall be verified in accordance with Practice E2309 and minimally meets the requirements of a Class D system.

6.1.5.2 *Type II—Deflection Indicator (Deflectometer)*—A suitable instrument for more accurately determining the deflection of the specimen distance between two designated points. This instrument shall be essentially free of inertia at the specified speed of testing. The deflection indicator system shall be verified in accordance with Practice E2309 and minimally meets the requirements of a Class B system.

NOTE 10—It is desirable, but not essential, that this instrument automatically record this distance, or any change in it, as a function of the load on the test specimen or of the elapsed time from the start of the test, or both. If only the latter is obtained, it has been found useful to also record load-time data.

6.2 *Micrometers*—Apparatus for measuring the width and thickness of the test specimen shall comply with the requirements of Test Method D5947.

7. Test Specimens

7.1 Test specimens that are cut from sheets, plates, or molded or extruded shapes, or molded to the desired finished dimensions are acceptable. The actual dimensions used shall be measured in accordance with Test Methods D5947. The depth of the specimen shall be defined as the thickness of the material. The depth shall not exceed the width (see Note 11). The crosssection of the specimens shall be rectangular with opposite sides flat and parallel (±0.2 mm) and adjacent sides perpendicular along the full length of the specimen.

7.2 Whenever possible, the original surface of the sheet shall be unaltered. However, where testing machine limitations make it impossible to follow the above criterion on the unaltered sheet, one or both surfaces shall be machined to provide the desired dimensions, and the location of the specimens with reference to the total depth shall be noted. Consequently, any specifications for flexural properties on thicker sheets must state whether the original surfaces are to be retained or not. When only one surface was machined, it must be stated whether the machined surface was on the tension or compression side of the beam. Any necessary polishing of specimens shall be done only in the lengthwise direction of the specimen.

NOTE 11—The value obtained on specimens with machined surfaces may differ from those obtained on specimens with original surfaces.

7.3 *Sheet Materials (Except Laminated Thermosetting Materials and Certain Materials Used for Electrical Insulation, Including Vulcanized Fiber and Glass Bonded Mica):*

7.3.1 *Materials 1.6 mm (1⁄16 in.) or Greater in Thickness*—Specimen width shall not exceed one fourth of the support span for specimens greater than 3.2 mm (1⁄8 in.) in depth. Specimens 3.2 mm or less in depth shall be 12.7 mm (1⁄2 in.) in width. The specimen shall be long enough to allow for overhanging on each end of at least 10 % of the support span, but in no case less than 6.4 mm (1⁄4 in.) on each end. Overhang shall be sufficient to prevent the specimen from slipping through the supports. A support span of 16 ± 1 times the depth of the specimen is used for these specimens.

7.3.2 *Materials Less than 1.6 mm (1⁄16 in.) in Thickness*—The specimen shall be 50.8 mm (2 in.) long by 12.7 mm (1⁄2 in.) wide, tested flatwise on a 25.4-mm (1-in.) support span.

NOTE 12—Use of the formulas for simple beams cited in these test methods for calculating results presumes that beam width is small in comparison with the support span. Therefore, the formulas do not apply rigorously to these dimensions.

NOTE 13—Where machine sensitivity is such that specimens of these dimensions cannot be measured, wider specimens or shorter support spans, or both, may be used, provided the support span-to-depth ratio is at least 14 to 1. All dimensions must be stated in the report (see also Note 12).

7.4 *Laminated Thermosetting Materials and Sheet and Plate Materials Used for Electrical Insulation, Including Vulcanized Fiber and Glass-Bonded Mica*—For paper-base and fabric-base grades over 25.4 mm (1 in.) in nominal thickness, the specimens shall be machined on both surfaces to a depth of 25.4 mm. For glass-base and nylon-base grades, specimens over 12.7 mm (0.5 in.) in nominal depth shall be machined on both surfaces to a depth of 12.7 mm. The support span-to-depth ratio shall be chosen such that failures occur in the outer fibers of the specimens, due only to the bending moment. As a general rule, support span-to-specimen depth ratios of 16:1 are satisfactory when the ratio of the tensile strength to shear strength is less than 8 to 1, but the support span-to-depth ratio must be increased for composite laminates having relatively low shear strength in the plane of the laminate and relatively high tensile strength parallel to the support span (32:1 or 40:1 are recommended). When laminated materials exhibit low compressive strength perpendicular to the laminations, they shall be loaded with a large radius loading nose (up to four times the specimen depth to prevent premature damage to the outer fibers.

7.5 *Molding Materials (Thermoplastics and Thermosets)*—The preferred specimen dimensions for molding materials is 12.7 mm (0.5 in.) wide, 3.2 mm (0.125 in.) thick, and 127 mm (5.0 in.) long. They are tested flatwise on the support span, resulting in a support span-to-depth ratio of 16:1 (tolerance ±1). Thicker specimens are to be avoided if they exhibit significant sink marks or bubbles when molded.

7.6 *High-Strength Reinforced Composites, Including Highly Orthotropic Laminates*—The span-to-depth ratio shall be chosen such that failure occurs in the outer fibers of the specimens and is due only to the bending moment. As a general rule, support span-to-depth ratios of 16:1 are satisfactory when the ratio of the tensile strength to shear strength is less than 8 to 1, but the support span-to-depth ratio must be increased for composite laminates having relatively low shear strength in the plane of the laminate and relatively high tensile strength parallel to the support span (32:1 or 40:1 are recommended). For some highly anisotropic composites, shear deformation can significantly influence modulus measurements, even at span-to-depth ratios as high as 40:1. Hence, for these materials, an increase in the span-to-depth ratio to 60:1 is recommended to eliminate shear effects when modulus data are required, it should also be noted that the flexural modulus of highly anisotropic laminates is a strong function of ply-stacking sequence and will not necessarily correlate with tensile modulus, which is not stacking-sequence dependent.

8. Number of Test Specimens

8.1 Test at least five specimens for each sample in the case of isotropic materials or molded specimens.

8.2 For each sample of anisotropic material in sheet form, test at least five specimens cut in the desired direction. For the purposes of this test, "lengthwise" designates the principal axis of anisotropy and shall be interpreted to mean the direction of the sheet known to be stronger in flexure. "Crosswise" indicates the sheet direction known to be the weaker in flexure and shall be at 90° to the lengthwise direction. The direction of test, whether it be lengthwise, crosswise, or some angle relative to these shall be noted in the report.

9. Conditioning

9.1 *Conditioning*—Condition the test specimens in accordance with Procedure A of Practice D618 unless otherwise specified by contract or the relevant ASTM material specification. Conditioning time is specified as a minimum. Temperature and humidity tolerances shall be in accordance with Section 7 of Practice D618 unless specified differently by contract or material specification.

9.2 *Test Conditions*—Conduct the tests at the same temperature and humidity used for conditioning with tolerances in accordance with Section 7 of Practice D618 unless otherwise specified by contract or the relevant ASTM material specification.

10. Procedure

10.1 *Procedure A:*

10.1.1 Use an untested specimen for each measurement. Measure the width and depth of the specimen to the nearest 0.03 mm (0.001 in.) at the center of the support span. For specimens less than 2.54 mm (0.100 in.) in depth, measure the depth to the nearest 0.003 mm (0.0005 in.). These measurements shall be made in accordance with Test Methods D5947.

10.1.2 Determine the support span to be used as described in Section 7 and set the support span to within 1 % of the determined value.

10.1.3 For flexural fixtures that have continuously adjustable spans, measure the span accurately to the nearest 0.1 mm (0.004 in.) for spans less than 63 mm (2.5 in.) and to the nearest 0.3 mm (0.012 in.) for spans greater than or equal to 63 mm (2.5 in.). Use the actual measured span for all calculations. For flexural fixtures that have fixed machined span positions, verify the span distance the same as for adjustable spans at each machined position. This distance becomes the span for that position and is used for calculations applicable to all subsequent tests conducted at that position. See Annex A2 for information on the determination of and setting of the span.

10.1.4 Calculate the rate of crosshead motion as follows and set the machine for the rate of crosshead motion as calculated by Eq 1:

$$R = ZL^2/6d \tag{1}$$

where:

R = rate of crosshead motion, mm (in.)/min,
L = support span, mm (in.),
d = depth of beam, mm (in.), and
Z = rate of straining of the outer fiber, mm/mm/min (in./in./min). Z shall be equal to 0.01.

In no case shall the actual crosshead rate differ from that calculated using Eq 1, by more than ±10 %.

10.1.5 Align the loading nose and supports so that the axes of the cylindrical surfaces are parallel and the loading nose is midway between the supports. Center the specimen on the supports, with the long axis of the specimen perpendicular to the loading nose and supports. The loading nose should be close to, but not in contact with the specimen (see Note 14).

NOTE 14—The parallelism of the apparatus may be checked by means of a plate with parallel grooves into which the loading nose and supports will fit when properly aligned (see A2.3).

10.1.6 Apply the load to the specimen at the specified crosshead rate, and record simultaneous load-deflection data.

10.1.7 Measure deflection either by measurement of the motion of the loading nose relative to the supports (crosshead position) (Type I) or by a deflection indicator (deflectometer) under the specimen in contact with it at the center of the support span, the gauge being mounted stationary relative to the specimen supports (Type II). Load-deflection curves are used to determine the flexural strength, chord or secant modulus or the tangent modulus of elasticity, and the total work as measured by the area under the load-deflection curve. Perform the necessary toe compensation (see Annex A1) to correct for seating and indentation of the specimen and deflections in the machine.

10.1.8 Terminate the test when the maximum strain in the outer surface of the test specimen has reached 0.05 mm/mm (in./in.) or at break if break occurs prior to reaching the maximum strain (Notes 15 and 16). The deflection at which this strain will occur is calculated by letting r equal 0.05 mm/mm (in./in.) in Eq 2:

$$D = rL^2/6d \tag{2}$$

where:

D = midspan deflection, mm (in.),
r = strain, mm/mm (in./in.),

L = support span, mm (in.), and
d = depth of beam, mm (in.).

NOTE 15—For some materials that do not yield or break within the 5 % strain limit when tested by Procedure A, the increased strain rate allowed by Procedure B (see 10.2) may induce the specimen to yield or break, or both, within the required 5 % strain limit.

NOTE 16—Beyond 5 % strain, this test method is not applicable. Some other mechanical property might be more relevant to characterize materials that neither yield nor break by either Procedure A or Procedure B within the 5 % strain limit (for example, Test Method D638 may be considered).

10.2 *Procedure B:*

10.2.1 Use an untested specimen for each measurement.

10.2.2 Test conditions shall be identical to those described in 10.1, except that the rate of straining of the outer surface of the test specimen shall be 0.10 mm/mm (in./in.)/min.

10.2.3 If no break has occurred in the specimen by the time the maximum strain in the outer surface of the test specimen has reached 0.05 mm/mm (in./in.), discontinue the test (see Note 16).

11. Retests

11.1 Values for properties at rupture shall not be calculated for any specimen that breaks at some obvious, fortuitous flaw, unless such flaws constitute a variable being studied. Retests shall be made for any specimen on which values are not calculated.

12. Calculation

12.1 Toe compensation shall be made in accordance with Annex A1 unless it can be shown that the toe region of the curve is not due to the take-up of slack, seating of the specimen, or other artifact, but rather is an authentic material response.

12.2 *Flexural Stress (σ_f):*

$$\sigma_f = 3PL/2bd^2 \tag{3}$$

where:

σ = stress in the outer fibers at midpoint, MPa (psi),
P = load at a given point on the load-deflection curve, N (lbf),
L = support span, mm (in.),
b = width of beam tested, mm (in.), and
d = depth of beam tested, mm (in.).

NOTE 17—Eq 3 is not valid if the specimen slips excessively between the supports.

12.3 *Flexural Stress for Beams Tested at Large Support Spans (σ_f):*

$$\sigma_f = (3PL/2bd^2)[1 + 6(D/L)^2 - 4(d/L)(D/L)] \tag{4}$$

where:

σ_f, P, L, b, and d = the same as for Eq 3, and
D = deflection of the centerline of the specimen at the middle of the support span, mm (in.).

NOTE 18—When large support span-to-depth ratios are used, significant end forces are developed at the support noses, which will affect the moment in a simple supported beam. Eq 4 includes additional terms that are an approximate correction factor for the influence of these end forces in large support span-to-depth ratio beams where relatively large deflections exist.

12.4 *Flexural Strain, ε_f*—Nominal fractional change in the length of an element of the outer surface of the test specimen at midspan, where the maximum strain occurs. It may be calculated for any deflection using Eq 5:

$$\varepsilon_f = 6Dd/L^2 \tag{5}$$

where:

ε_f = strain in the outer surface, mm/mm (in./in.),
D = maximum deflection of the center of the beam, mm (in.),
L = support span, mm (in.), and
d = depth, mm (in.) of beam tested.

12.5 *Modulus of Elasticity:*

12.5.1 *Tangent Modulus of Elasticity:*

$$E_B = L^3 m/4bd^3 \tag{6}$$

where:

E_B = modulus of elasticity in bending, MPa (psi),
L = support span, mm (in.),
b = width of beam tested, mm (in.),
d = depth of beam tested, mm (in.), and
m = slope of the tangent to the initial straight-line portion of the load-deflection curve, N/mm (lbf/in.) of deflection.

12.5.2 *Chord Modulus (E_f)*—

$$E_f = (\sigma_{f2} - \sigma_{f1})/(\varepsilon_{f2} - \varepsilon_{f1}) \tag{7}$$

where:

σ_{f2} and σ_{f1} = the flexural stresses, calculated from Eq 3 or Eq 4 and measured at the predefined points on the load deflection curve, and ε_{f2} and
ε_{f1} = the flexural strain values, calculated from Eq 5 and measured at the predetermined points on the load deflection curve.

12.6 *Arithmetic Mean*—For each series of tests, the arithmetic mean of all values obtained shall be calculated to three significant figures and reported as the "average value" for the particular property in question.

12.7 *Standard Deviation*—The standard deviation (estimated) shall be calculated as follows and be reported to two significant figures:

$$s = \sqrt{\left(\sum X^2 - n\bar{X}^2\right)/(n-1)} \tag{8}$$

where:

s = estimated standard deviation,
X = value of single observation,
n = number of observations, and
$\bar{X}$ = arithmetic mean of the set of observations.

13. Report

13.1 Report the following information:

13.1.1 Complete identification of the material tested, including type, source, manufacturer's code number, form, principal dimensions, and previous history (for laminated materials, ply-stacking sequence shall be reported),

13.1.2 Method of specimen preparation,

13.1.3 Direction of cutting and loading specimens, when appropriate,