INTERNATIONAL

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Standard Test Methods for Bend Testing of Metallic Flat Materials for Spring Applications Involving Static Loading[1]

This standard is issued under the fixed designation E855; 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 standard describes three test methods[2] for determining the modulus of elasticity in bending, the bending proof strength, and the offset yield strength in bending of metallic strips or sheets intended for the use in flat springs:

1.1.1 *Test Method A*—a cantilever beam test,

1.1.2 *Test Method B*—a three-point beam test (that is, a beam resting on two supports and centrally loaded), and

1.1.3 *Test Method C*—a four-point beam test (that is, a beam resting on two supports and loaded at two points equally spaced from each support).

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.3 *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.*

1.4 *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.*

2. Referenced Documents

2.1 The following documents of the issue in effect on date of use of these test methods form a part of these test methods to the extent referenced herein:

2.2 *ASTM Standards:*[3]

E4 Practices for Force Verification of Testing Machines

E6 Terminology Relating to Methods of Mechanical Testing

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

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 Definitions of terms common to mechanical testing:

3.1.1 The terms bend test, chord modulus, gauge length, modulus of elasticity, proportional limit, springback, stress-strain curve, tangent modulus, testing machine, yield strength, and Young's modulus are used as defined in Terminology E6.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 In addition to the terms in Terminology E6, the following descriptions of terms apply in connection with these test methods for determining bend properties:

3.2.2 *bending stress at the outer fiber,* σ_b *[FL^{-2}]*—the nominal stress in the outer fiber of a beam resulting from application of a bending moment.

3.2.3 *elastic limit in bending [FL^{-2}]*—the greatest bending stress that a material is capable of sustaining without permanent strain remaining after complete release of the bending moment.

3.2.4 *modulus of elasticity in bending,* E_b *[FL^{-2}]*—the ratio of bending stress at the outer fiber to corresponding strain below the elastic limit in bending.

3.2.5 *span length, L [L]*—the distance between supports.

3.2.6 *bending proof strength,* σ_p *[FL^{-2}]*—the nominal bending stress at the outer fiber of a beam that results in a specific permanent strain in the outer fibers upon unloading.

3.2.7 *cyclic bending yield strength [FL^{-2}]*—the maximum nominal stress in uniform cyclic bending resulting from a given plastic deformation in the outer fibers of a beam.

[1] These test methods are under the jurisdiction of ASTM Committee E28 on Mechanical Testing and are the direct responsibility of Subcommittee E28.02 on Ductility and Formability.

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[2] Method D, which appeared in the last previous edition, was dropped because of the unavailability of commercial testing equipment.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.8 *offset yield strength in bending* [FL^{-2}]—the nominal stress in the outer fibers of a beam in bending at which a specified limiting deviation from proportionality of bending stress at the outer fiber to bending strain is exhibited.

3.2.8.1 *Discussion*—The deviation is expressed in terms of strain.

4. Significance and Use

4.1 Measurements of bending proof strength, offset yield strength in bending, and modulus of elasticity in bending should be made for materials whose principal stressing mode is bending. For many materials, the tensile and compressive moduli are somewhat different. Since the modulus of elasticity in bending is a combination of the tensile and compressive moduli, it is often different from each of them.

4.2 Precise measurements of the modulus of elasticity in bending offset yield strength in bending, and bending proof strength require due regard for numerous variables that can affect their determination. These include (*1*) material characteristics such as specimen orientation with respect to the rolling direction, grain size, residual stresses, previous strain history, dimensions and specimen preparation, orientation of deformed grains relative to the direction of the normal stress; and (*2*) test conditions, such as temperature, temperature variations, condition of the test equipment, and adherence to the test procedure.

4.3 *Fundamental Assumptions:*

4.3.1 The test section of the specimen is subjected to uniform bending moment, which produces a uniform strain at the outer fiber throughout the gauge length of the specimen (applies to Test Method C only).

4.3.2 The neutral axis is located at the centerline of the thickness of the test specimen.

4.3.3 Transverse cross sections of the beam remain plane and normal to the longitudinal fiber of the beam during bending.

4.3.4 The effect of shear stresses is negligible.

TEST METHOD A—CANTILEVER BEAM TEST

5. Scope

5.1 This test method covers the determination of the modulus of elasticity in bending and the offset yield strength in bending of flat metallic strips or sheets for spring applications. The test procedure involves measurements of the applied moment and the corresponding deflection angle of a cantilever beam. The thickness range covered is 0.015 in. to 0.130 in. (0.38 mm to 3.30 mm). This test method should not be used for nonlinear elastic materials.

6. Summary of Test Method

6.1 The test specimen is loaded as a simple cantilever beam, and the bending moment is measured at predetermined increments of angular deflection. When the maximum desired deflection is reached, the bending moment is removed and the permanent set angle resulting from the bend is recorded. All testing is performed under conditions of plane strain (that is, ratio of specimen width/thickness >10). The bending moment and deflection data obtained are normalized with regard to specimen geometry. These normalized terms are then plotted to produce a stress-strain curve for cantilever bending that is similar to a stress-strain curve for tension or compression. The modulus of elasticity in bending and the offset yield strength in bending are determined from the bending stress-strain curve using a procedure similar to that used for tensile stress-strain curves.

7. Significance and Use

7.1 Values of offset yield strength in bending and modulus of elasticity in bending are useful to spring designers to determine spring constants and permissible maximum deflection of flat springs. The offset yield strength in bending as determined by this test method is not necessarily equal to either the yield strength in tension, the cyclic bending yield strength, or to bending proof strengths determined by other methods.

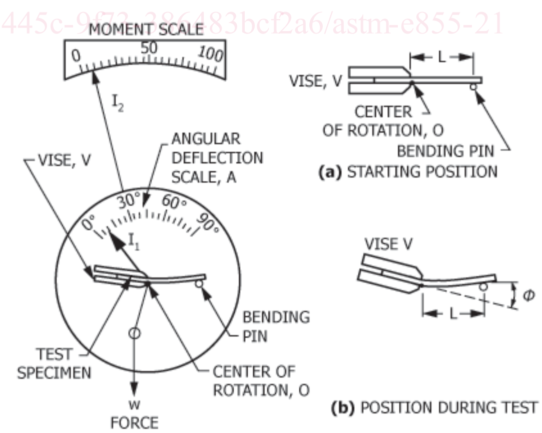
7.2 The test method can also serve the following purposes:

7.2.1 For research and development to study the effects of metallurgical variables, such as composition, heat treatment, fabrication operations, and alloy development.

7.2.2 For information or specification purposes, to provide a manufacturing quality control where suitable correlations have been established with service behavior.

7.3 Due to necessary approximations in this test method regarding the specimen's deflection, *D*, and span length, *L*, the maximum deflection angle is 30°. These approximations are explained in Appendix X1.

7.4 Rate of loading is controlled only to the extent that the rate of angular change of the rotating jaw is fixed at 58°/min to 66°/min. Actual rate of stressing will depend on the specimen width and thickness and the weight of the pendulum.



(Test Method A)

FIG. 1 Cantilever Beam Test Apparatus

8. Apparatus

8.1 The cantilever beam test apparatus[4] shown in Fig. 1 consists of the following components:

[4] The Olsen Stiffness Tester meets the requirements of this test method.

8.1.1 *Specimen Holder,* A vise, *V*, to which an angular deflection indicator, I_1, is attached. The specimen holder is rotates about point *O*.

8.1.2 *Pendulum Weighing System,* composed of a set of detachable weights, an angular deflection scale, A, with a moment indicator, I_2, a bending pin that transmits the bending force of the pendulum weighing system to the free end of the test specimen, and a weight to counter-balance the bending pin. The pendulum weighing system pivots about point *O*. For a pendulum weighing system (Fig. 2) having no internal moments, the total bending moment, *M*, is:

$$M = w\, d \sin\theta \quad (1)$$

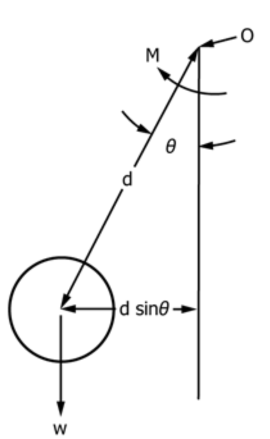
where:

M = bending moment at angle θ, lbf·in (N·m),
w = total force applied by pendulum weighing system, lbf (N),
d = length of the pendulum arm, in (m), and
θ = angle through which the pendulum weighing system rotates, rad.

8.1.3 *Angular Deflection Scale, A,* is graduated in degrees of arc and indicates the angle through which the vise has been turned relative to the pendulum weighing system. This is the difference between the angle through which the vise has been turned and the angle through which the pendulum weighing system has been deflected, and is designated as angle φ. The bending pin has a diameter of 0.25 in. (6.35 mm), and the distance between the clamping point (that is, center of rotation of the pendulum weighing system) and the center of the bending pin is 2.0 in. (50.8 mm). The reason for specifying the diameter and location of the bending pin is explained in Appendix X1.

8.1.4 *Moment Scale*—This stationary moment scale measures the applied moment as a function of the pendulum weighing system's rotation θ. A full scale reading of 100 corresponds to the pendulum weighing system's maximum bending moment, M_m. This system shall be calibrated such that the moment scale reading, *f*, is:

$$f = 100\, w\, d \sin\theta / M_m \quad (2)$$



(Test Method A)

FIG. 2 Schematic of Pendulum Weighing System

9. Test Specimens

9.1 Rectangular test specimens shall be used. Specimen orientation relative to the rolling direction shall be identified. Specimens with curvature due to coil set may be used if the ratio of the radius of curvature to thickness exceeds 500. However, the specimen shall not be twisted or wavy. No attempt shall be made to flatten or straighten specimens prior to testing. Care shall be exercised not to alter the microstructure during specimen preparation. All burrs shall be removed before testing.

NOTE 1—Testing machine capacity will determine the maximum allowable specimen size.

9.2 The minimum specimen thickness should be 0.015 in. (0.38 mm). The thickness shall be measured at the four corners and the center of the specimen. Specimens having thickness variations in excess of 2 % of the average (of these five measured thicknesses) shall not be tested. The instrument used to measure the thickness shall have a precision within 2 % of the average thickness.

NOTE 2—Eq 3 in 10.1 shows that the value of the modulus of elasticity in bending varies as the third power of thickness. Hence, thickness is by far the most critical measurement in the determination of the modulus. For example, an error in the thickness measurement of ±0.0001 in. (±0.0025 mm) for a specimen having the minimum recommended thickness of 0.015 in. (0.38 mm), the measurement is reproducible to within 0.67 % and the error in modulus of elasticity in bending attributable to the reproducibility of the thickness measurement is 2 %. Further, if the thickness actually varies by 2 % over the gauge section or by 0.0003 in. (0.0075 mm), the error in modulus of elasticity in bending attributable to actual thickness variation is 6 %, and the total error attributable to both measurement and actual variation is 8 %. Additional sources of uncertainty are the precisions of determining the span length, the specimen width, and the beam deflection.

9.3 The ratio of the specimen span length to thickness shall be greater than 15; consequently, since the span length is 2.0 in. (50.8 mm), the specimen thickness cannot exceed 0.13 in. (3.30 mm).

9.4 The width to thickness ratio shall be greater than 10. The width shall be measured at both ends and the center of the specimen. The maximum variation in width shall be less than or equal to 0.5 % of the average width. The minimum specimen width shall be 0.5 in. (12.7 mm). The specimen width shall not extend beyond the vise or the bending pin.

10. Procedure

10.1 Place the machine on a level surface. Set the bending span length to 2.0 in. (50.8 mm) and adjust the moment indicator to zero. For the best precision the maximum bending moment, M_m, should be chosen so that the moment scale reading is between 5 and 10 for an angular deflection of 3°. If this value is not known, estimated it as follows:

$$M_m = 25\, E_b\, b h^3 \frac{\varphi}{fL} \quad (3)$$

where:

M_m = pendulum's maximum bending moment, in·lbf (N·m),
E_b = modulus of elasticity in bending (can be approximated by Young's modulus) lbf/in.^{2} (Pa),

b = specimen width, in. (m),
h = specimen thickness, in. (m),
φ = angular deflection, rad (0.052 rad (3°) specified here),
f = moment scale reading (select 7.5 in this case), and
L = span length, 2 in. (50.8 mm).

10.2 Clamp the specimen firmly in the vise with its long edges approximately parallel to the face of the dial plate.

10.3 Manually rotate the vise to bring the specimen against the bending pin. When contact is made, set the angular deflection indicator to indicate zero angle.

10.4 Hold down the motor engaging lever and record the moment scale readings at increments of 2° angular deflection (φ) until the desired deflection, not exceeding 30°, is reached. unload the specimen. Read the permanent set angle resulting from the bend on the angular deflection scale with the specimen contacting the bending pin at zero force.

10.5 Test a minimum of six specimens from each sample. For specimens having an initial residual curvature, test half of the specimens with the concave surface facing upwards and half with the convex surface facing upwards. Deflect all specimens to the same maximum deflection angle, which shall be less than or equal to 30°.

10.6 Replication required for evaluating material variability within either the same sample or among several suppliers shall be covered in product specifications or upon agreement between supplier and user.

11. Calculation

11.1 Normalize the bending moment-deflection data with regard to specimen geometry and plot on coordinate paper with the bending stress at the outer fiber having ($3M_m f/50bh^2$) as the ordinate and the bending strain [(3/2) (φ h/L)] as the abscissa (see Appendix X1). These symbols are defined in 10.1. The resulting bending stress-strain curve is similar to a tension or compression stress-strain curve.

11.2 Determine the value of the modulus of elasticity in bending, E_b, from the slope of a straight line extending from the maximum deflection datum point (max) to the permanent set point (p.s.), that is:

$$E_b = \frac{\left(\dfrac{M_m f}{25bh^2}\right)}{(\varphi h/L)\mathrm{max} - (\varphi h/L)\mathrm{p.s.}} \tag{4}$$

11.3 The first step in constructing the bending stress-strain curve is to draw a straight line having slope E_b such that it passes through the origin. The actual data points for elastic loading may be slightly displaced from this line. Construct the non-linear portion of the bending stress-strain curve by drawing a curve through the remaining data points and connecting it with the modulus of elasticity in bending line.

11.4 Calculate offset yield strengths in bending from the bending stress-strain curve using a procedure analogous to that used for tensile or compressive stress-strain curves. The offset yield strengths in bending for strains of 0.01 %, 0.05 %, and 0.10 % should be determined, provided this does not require that the maximum allowable deflection angle of 30° be exceeded.

NOTE 3—These values of offset yield strengths in bending are not necessarily equal to either the yield strengths in tension, the cyclic bending yield strength, or to bending proof strengths determined by other methods.

12. Report

12.1 The following shall be included in the report.

12.1.1 Complete description of the material tested, including alloy, temper, and manufacturer's identification number,

12.1.2 Specimen dimensions and orientation relative to the rolling direction,

12.1.3 Test temperature, and

12.1.4 The modulus of elasticity in bending and an estimate of the precision of the value reported.

12.1.5 Offset yield strengths in bending, for strains of 0.01 %, 0.05 %, and 0.10 % within the limitation of a maximum deflection angle of 30°, plus an estimate of the precision of the values reported.

12.1.6 Estimate of the precision of the values reported.

13. Precision and Bias

13.1 *Precision:*

13.1.1 The precision of the values of the modulus of elasticity in bending and the offset yield strength in bending will depend on the precision of each of the values used in the calculations, as well as the mean and standard deviation of the values determined for each of the replicate tests. The report shall include an estimate of the precision of the values reported.

13.1.2 The following parameters will affect the results and can be quantified: precision of the applied forces, precision of the span length measurement, deviation of width measurements from the average value, deviation of thickness measurements from the average value, and precision of the deflection measurements.

13.2 *Bias*—A statement of bias requires a reference standard or a true property value based on many measurements of the property of the same material. Such standards or true values are presently not available for bending properties of metallic flat spring materials. Therefore, the bias of the test method is unknown.

TEST METHOD B: THREE-POINT BEAM TEST
TEST METHOD C: FOUR-POINT BEAM TEST

14. Scope

14.1 These test methods cover the determination of the modulus of elasticity in bending and the bending proof strength of flat metallic strips or sheets for spring applications. The test methods consist of deflection tests of a simple beam configuration subjected to either three- or four-point symmetrical loading. The thickness range covered is 0.010 in. to 0.050 in. (0.25 mm to 1.3 mm).

14.2 Thickness ranges outside of those specified may be agreed upon between suppliers and users.

15. Summary of Test Methods

15.1 The test specimen is loaded as a simple beam in either three- or four-point symmetrical loading. The modulus of elasticity in bending is obtained by force-deflection measurements at stresses below the elastic limit in bending. The bending proof strength is obtained by a stepwise increasing loading–unloading sequence carried out until a specified permanent strain is measured on unloading.

NOTE 4—In these test methods the specified permanent set corresponds to a maximum outer fiber strain after springback of 0.0001 in./in. (mm/mm).

16. Significance and Use

16.1 These test methods are useful for obtaining values of bending proof strength in bending and modulus of elasticity in bending. These values are useful to spring designers to determine spring constants and maximum permissible deflection of flat springs. These values of the bending proof strength determined by these test methods is not necessarily equal to either the yield strength in tension or to the cyclic bending yield strength.

16.2 These tests can also serve the following purposes:

16.2.1 For research and development to study the effects of metallurgical variables such as composition, heat treatment, fabrication operations, and alloy development.

16.2.2 For information or specification purposes, to provide a manufacturing quality control where suitable correlations have been established with service behavior.

16.3 For most loading systems and test specimens, effects of backlash, initial specimen curvature, and grip backlash introduce significant errors in the deflection or curvature measurement when applying a small force to the test specimen. Therefore, the modulus of elasticity in bending measurements should be made between a preload high enough to minimize these effects, and a higher force known to be below the proportional or elastic limit in bending. For linear elastic materials, the slope of the straight line portion of the bending stress-strain curve should be established. For non-linear elastic materials the chord or tangent modulus may be established for stress values ranging from the appropriate preload to the elastic limit in bending.

16.4 Because of difficulties associated with accurately establishing the origin of the bending stress-strain curve, due to the problems mentioned in 16.3, the secant modulus or initial tangent modulus should not be used.

17. Apparatus

17.1 The apparatus consists of two adjustable supports and a means for measuring deflection or curvature and for applying force.

17.1.1 *Supports*—The supports should have a 60° angle with a radius of 0.005 in. (0.13 mm) at the supporting edge. One knife edge should be straight, and the other should be convex with a 0.50 in. (13 mm) radius of curvature. Their mutual separation should be adjustable along the specimen longitudinal axis (Fig. 3).

17.1.2 *Force Application:*

17.1.2.1 *Force Applicator Geometry*—The force applicator shall have a 60° angle with a radius of 0.005 in. (0.13 mm). In the case of three-point loading the force is applied at midspan, using one such applicator as shown in Fig. 3. In the case of four-point loading, two force applicators are used, symmetrically spaced from the supports as shown in Fig. 4 and the distance between the force applicators shall equal ⅔ of the span length. One of the force applicators shall have a convex (0.50 in. (13 mm)) radius of curvature.

17.1.2.2 *Dead Weights*—Calibrated dead weights may be used with the force applicator. Any cumulative error in the dead-weights or the dead weight loading system shall not exceed 1.0 %.

17.1.2.3 *Testing Machines*—In determining the suitability of a testing machine, the testing machine should be verified under conditions approximating those under which the tests will be made, together with the force applicators, in accordance with Practices E4. Corrections may be applied for systematic errors in force. Any cumulative error in the machine loading system shall not exceed 1.0 %.

17.1.3 *Deflection Measurement Devices*—A deflectometer or a cathetometer should be used to determine the specimen deflection, δ, at midspan as shown in Fig. 3 and Fig. 4.

17.1.3.1 If, in the case of universal testing machines, the relative crosshead displacement is used as a measure of specimen deflection, proper correction shall be made for testing machine and load cell stiffness.

17.1.3.2 The elastic deflection used in determining the modulus of elasticity in bending, and the permanent set used in determining the bending proof strength, shall be measured

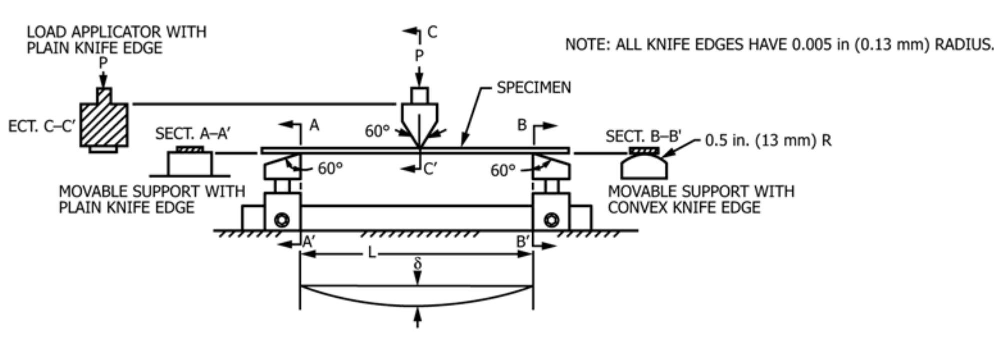


FIG. 3 Three-Point Bend Test