Designation: D ~~6109 – 97ε1~~ 6109 – 03

Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastic Lumber[1]

This standard is issued under the fixed designation D 6109; 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.

~~ε1 NOTE—Editorially corrected 1.1 in April 2002.~~

1. Scope*

1.1 These test methods cover the determination of flexural properties of plastic lumber with rectangular or square cross-sections. The test specimens are whole "as manufactured" pieces without any altering or machining of surfaces beyond cutting to length. As such, this is a test method for evaluating the properties of plastic lumber as a product and not a material property test method. Flexural strength cannot be determined for those products that do not break or that do not fail in the extreme outer fiber.

1.2 *Test Method A*— designed principally for products in the flat or "plank" position.

1.3 *Test Method B*— designed principally for those materials in the edgewise or "joist" position.

1.4 Plastic lumber is currently made predominately with recycled plastics where the product is non-homogeneous in the cross-section. However, this test method would also be applicable to similar manufactured plastic products made from virgin resins or other plastic composite materials.

1.5 The values stated in inch–pound units are to be regarded as the standard. The values given in parentheses are for information only.

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 regulator limitations prior to use.*

NOTE 1—There is no similar or equivalent ISO standard.

2. Referenced Documents

2.1 *ASTM Standards:*

D 198 Methods of Static Tests of Lumber in Structural Sizes[2]

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[1] These test methods are under the jurisdiction of ASTM Committee D-20 on Plastics and are the direct responsibility of Subcommittee D20.20 on Plastic Products (Section D20.20.01).

Current edition approved ~~July~~ March 10, ~~1997.~~ 2003. Published ~~February 1998.~~ April 2003. Originally approved in 1997. Last previous edition approved in 1997 as D 6109 - 97.

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

D 618 Practice for Conditioning Plastics for Testing[3]
D 883 Terminology Relating to Plastics[3]
D 4000 Classification System for Specifying Plastic Materials[4]
D 5033 Guide for the Development of Standards Relating to the Proper Use of Recycled Plastics[5]
D 5947 Test Methods for Physical Dimensions of Solid Plastics Specimens[5]
E 4 Practices for Force Verification of Testing Machines[6]
E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[7]

3. Terminology

3.1 *Definitions:* Definitions of terms applying to these test methods appear in Terminology D 883 and Guide D 5033.

3.1.1 *plastic lumber*, *n*—a manufactured product composed of more than 50 weight percent resin, and in which the product generally is rectangular in cross-section and typically supplied in board and dimensional lumber sizes, may be filled or unfilled, and may be composed of single or multiple resin blends.

3.1.2 *plastic shape*, *n*—a manufactured product composed of more than 50 weight percent resin, and in which the product generally is not rectangular in cross-section, may be filled or unfilled, and may be composed of single or multiple resin blends.

3.1.3 *resin*, *n*—solid or pseudosolid organic material often of high molecular weight, that exhibits a tendency to flow when subjected to stress, usually has a softening or melting range, and usually fractures conchoidally. (See Terminology D 883.)

3.1.3.1 *Discussion*—In a broad sense, the term is used to designate any polymer that is a basic material for plastics.

4. Summary of Test Method

4.1 A specimen of rectangular cross section is tested in flexure as a beam as follows:

4.1.1 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-third of the support span (see Fig. 1).

4.1.2 The specimen is deflected until rupture occurs in the outer fibers or until a maximum outer fiber strain of 3 % is reached, whichever occurs first.

5. Significance and Use

5.1 Flexural properties determined by this test method are especially useful for research and development, quality control, acceptance or rejection under specifications, and special purposes.

5.2 For many materials, there may be a specification that requires the use of this test method, but with some procedural modifications that take precedence when adhering to the specification. It is therefore advisable to refer to that material specification before using these test methods. Table 1 in Classification D 4000 lists the ASTM materials standards that currently exist.

5.3 Flexural properties may vary with specimen depth, temperature, atmospheric conditions, and the difference in rate of straining specified in Test Methods A and B.

6. Apparatus

6.1 *Testing Machine*— A properly calibrated testing machine that is capable of operation at a constant rate of motion of the movable head and has the accuracy of ±1 % of maximum load expected to be measured. It shall be equipped with a deflection

[2] *Annual Book of ASTM Standards*, Vol 04.10.
[3] *Annual Book of ASTM Standards*, Vol 08.01.
[4] *Annual Book of ASTM Standards*, Vol 08.02.
[5] *Annual Book of ASTM Standards*, Vol 08.03.
[6] *Annual Book of ASTM Standards*, Vol 03.01.
[7] *Annual Book of ASTM Standards*, Vol 14.02.

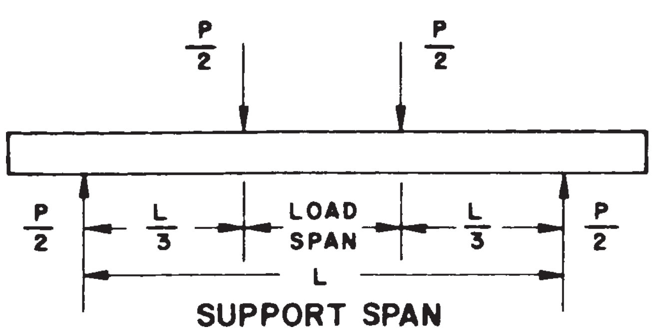


FIG. 1 Loading Diagram

measuring device. 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. The load indication mechanism shall be essentially free from inertial lag at the crosshead rate used. The accuracy of the testing machine shall be verified in accordance with Practice E 4.

6.2 *Loading Noses and Supports* —The loading noses and supports shall have cylindrical surfaces. In order to avoid excessive indentation, of the failure due to stress concentration directly under the loading noses, the radius or noses and supports shall be at least 0.5 in. ~~(~~ [12.7 mm~~)~~] for all specimens. If significant indentation or compressive failure occurs or is observed at the point where the loading noses contact the specimen, then the radius of the loading noses should be increased up to 1.5 times the specimen depth. 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 noses (see Fig. 2).

NOTE 2—Test data have shown that the loading noses and support dimensions can influence the flexural modulus values. Dimensions of loading noses and supports must be specified in the test report.

6.3 *Lateral Supports*— Specimens tested in the edgewise or "joist" position having a depth-to-width ratio greater than two are subject to lateral instability during loading, especially if the specimen breaks. For safety, lateral supports are needed while testing such specimens. Lateral support apparatus shall be provided at least at points located about half-way between the reaction and the load point. Additional supports may be used as required. Each support shall allow vertical movement without frictional restraint but shall restrict lateral deflection (See Fig. 3). Test Method D 198 provides further examples of lateral support apparatus.

7. Test Specimens

7.1 The specimens shall be full size as manufactured, then cut to length for testing. The original outside surfaces shall be unaltered. The support span to depth ratio shall be nominally 16:1.

7.2 For Test Method A, flatwise or "plank" tests, the depth of the specimen shall be the thickness, or smaller dimension, of the material. For Test Method B, edgewise or "joist" tests the width becomes the smaller dimension and depth the larger. For all tests, the support span shall be 16 (tolerance +4 and −2) times the depth of the beam. The specimen shall be long enough to allow for overhanging on each end of at least 10 % of the support span. Overhang shall be sufficient to prevent the specimen from slipping through the supports.

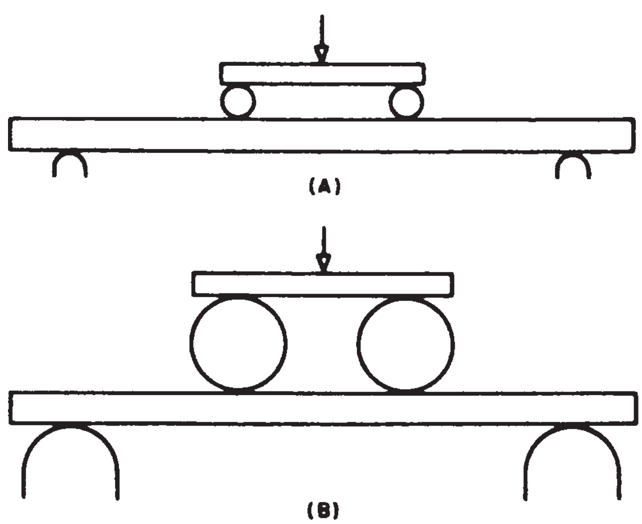
8. Number of Test Specimens

8.1 Five specimens shall be tested for each sample.

9. Conditioning

9.1 *Specimen Conditioning*—Condition the test specimens at 73.4 ± 3.6°F ~~(23~~ [23 ± 2°C~~)~~] and 50 ± 5 % relative humidity for not less than 40 h prior to testing in accordance with Procedure A of Practice D 618 for those tests where conditioning is required. In cases of disagreement, the tolerances shall be ±1.8°F ~~(±1°C)~~ [±1°C] and ±2 % relative humidity.

9.2 *Test Conditions*— Conduct the tests in the Standard Laboratory Atmosphere of 73.4 ± 3.6°F ~~(23~~ [23 ± 2°C~~)~~] and 50 ± 5 % relative humidity, unless otherwise specified in the test methods or in this specification. In cases of disagreement, the tolerances shall be ±1.8°F ~~(±1°C)~~ [±1°C] and ±2 % relative humidity.



NOTE 1—(*A*) = minimum radius = 12.7 mm; (*B*) = maximum radius = 1.5 times the specimen depth.

FIG. 2 Four Point Loading and Support Noses at Minimum and Maximum Radius

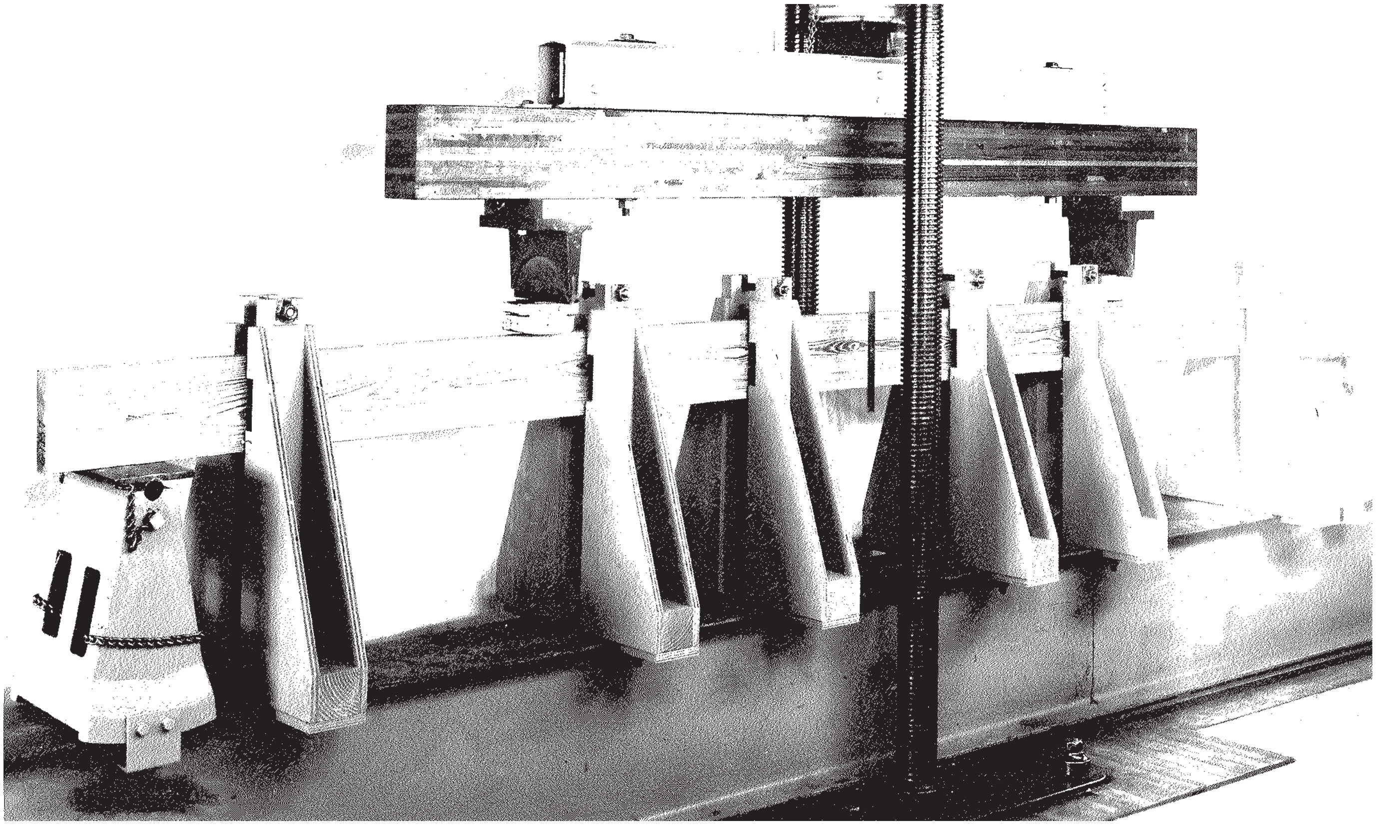


FIG. 3 Example of Lateral Support

10. Procedure

10.1 *Test Method A*:

10.1.1 *Flatwise or "plank" Testing*:

10.1.2 Use an untested specimen for each measurement. Measure the width of the specimen to a precision of 1 % of the measured dimensions at several points along the product's length and record the average value. Measure the depth of the specimen at several points and record the average value (see Test Methods D 5947 for additional information).

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

10.1.4 Calculate the rate of crosshead motion as follows, and set the machine as near as possible to that calculated rate for a load span of one-third of the support span:

$$R = 0.185ZL^2/d \quad (1)$$

where:

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

In no case shall the actual crosshead rate differ from that calculated from Eq 1, by more than ±50 %.

10.1.5 Align the loading noses and supports so that the axes of the cylindrical surfaces are parallel and the load span is one-third of the support span. This parallelism may be checked by means of a plate containing parallel grooves into which the loading noses 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. The loading nose assembly shall be of the type which will not rotate.

10.1.6 Apply the load to the specimen at the specified crosshead rate, and take simultaneous load-deflection data. Measure deflection at the common center of the spans. Make appropriate corrections for indentation in the specimens and deflections in the weighing system of the machine. Stress-strain curves may be plotted to determine the flexural yield strength, modulus of elasticity and secant modulus at 1 % strain.

10.1.7 If no break has occurred in a specimen by the time the maximum strain in the outer fibers has reached 0.03 in./in.~~(~~ [mm/mm~~)~~], discontinue the test (see Note 3 and Note 4). The deflection at which this strain occurs may be calculated by letting r equal 0.03 in./in./min~~(~~ [mm/mm/min~~)~~] as follows for a load span of one-third of the support span:

$$D = 0.21\ rL^2/d \qquad (2)$$

where:

D = midspan deflection, in. ~~(mm),~~ [mm],
r = strain, in./in./min ~~(~~ [mm/mm/min~~)~~], and
d = depth of the beam, in. ~~(mm).~~ [mm].

NOTE 3—For some materials the increase in strain rate provided under Test Method B may induce the specimen to yield or rupture, or both, within the required 3 % strain limit.

NOTE 4—If the product does not fracture at 3 % strain, these test methods do not reveal product strength.

10.2 *Test Method B*:

10.2.1 *Edgewise or "Joist" Testing*:

10.2.2 Specimens that have a depth-to-width ratio of two or greater will have some additional considerations when testing in the edgewise position.

10.2.3 Follow procedures of Test Method A, except that Z, the rate of strain of the outer fibers, shall nominally be in the range of 0.002 and 0.003 in./in./min ~~(~~ [mm/mm/min~~)~~].

10.2.4 *Lateral Supports*— Specimens tested in the edgewise or "joist" position having a depth-to-width ratio greater than two are subject to lateral instability during loading, especially if the specimen breaks. For safety, lateral supports are needed while testing such specimens. Lateral support apparatus shall be provided at least at points located about half-way between the reaction and the load point. Additional supports may be used as required. Each support shall allow vertical movement without frictional restraint but shall restrict lateral deflection (See Fig. 3). Test Method D 198 provides further examples of lateral support apparatus.

NOTE 5—See Test Method D 198 for examples of lateral support apparatus.

11. Calculation

11.1 *Maximum Fiber Stress*—When a beam is loaded in flexure at two central points and supported at two outer points, the maximum stress in the outer fibers occurs between the two central loading points that define the load span (See Fig. 1). This stress may be calculated for any point on the load-deflection curve for relatively small deflections by the following equation for a load span of one-third of the support span:

$$S = PL/bd^2 \qquad (3)$$

where:

S = stress in outer fiber throughout load span, psi ~~(MPa),~~ [MPa],
P = load at a given point on load-deflection curve, lb ~~(N),~~ [N],
L = support span, in. ~~(mm),~~ [mm],
b = width of beam, in. ~~(mm),~~ [mm], and
d = depth of beam, in. ~~(mm).~~ [mm].

NOTE 6—Eq 3 applies strictly to materials for which the stress is linearly proportional to the 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 3 % for specimens tested by the procedure herein described.

NOTE 7—The above calculation is not valid if the specimen is slipping excessively between the supports.

11.2 *Flexural Strength (Modulus of Rupture)*—The flexural strength is equal to the maximum stress in the outer fibers at the moment of break. It is calculated in accordance with Eq 3 by letting P equal the load at the moment of break. If the material does not break, this part of the test is not applicable. In this case, it is suggested that yield strength, if applicable, be calculated and that the corresponding strain be reported also.

11.3 *Flexural Yield Strength*—Some materials that do not break at outer fiber strains up to 3 % may give load-deflection curves that show a point Y, at which the load does not increase with an increase in deflection. In such cases, the flexural yield strength may be calculated in accordance with Eq 3 by letting P equal the load at point Y.

11.4 *Stress at a Given Strain*—The maximum fiber stress at any given strain may be calculated in accordance with Eq 3 by letting P equal the load read from the load-deflection curve at the deflection corresponding to the desired strain.

11.5 *Maximum Strain*— The maximum strain in the outer fibers also occurs at the midspan, and it may be calculated as follows for a load span of one-third of the support span:

$$r = 4.70Dd/L^2 \qquad (4)$$

where: D, d, L, and r are the same as for Eq 2.

11.6 *Modulus of Elasticity*—When a Hookean region (proportional area) exists, calculate the modulus of elasticity by drawing a tangent to the initial linear portion of the load deformation curve, selecting any point on this straight line portion, and dividing the flexural stress represented by this point by the corresponding strain, measure from the point where the extended tangent line intersects the strain-axis. Express the results in megapascals and report to three significant figures (see Annex A1).

11.7 *Secant Modulus of Elasticity* —The secant modulus of elasticity is the slope of the straight line that joins the origin (corrected for toe effect) and a selected point on the stress strain curve. It shall be expressed in MPa. The selected point is generally chosen at a specified stress or strain. It is calculated in accordance with Eq 5 by letting *m* equal the slope of the secant to the load-deflection curve.

$$E_B = 0.21\ L^3 m/bd^3 \quad (5)$$

where:

E_B = secant modulus of elasticity in flexure, psi (MPa), [MPa],
m = slope of the secant to the initial straight-line portion of the load-deflection curve, N/mm, and *L*, *b*, and *d* are the same as for Eq 3.

11.8 *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.

11.9 *Standard Deviation*—the standard deviation shall be calculated as follows and reported in two significant figures:

$$S = \sqrt{[(\Sigma X^2 - n\bar{X}^2)/(n-1)]} \quad (6)$$

where:

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

11.10 See Annex A1 for information on toe compensation.

12. Report

12.1 Report the following information:

12.1.1 Complete identification of the material tested, including type, source, manufacturer's code number, form, principal dimensions, and previous history,

12.1.2 Laboratory name,

12.1.3 Date of test,

12.1.4 Direction of loading,

12.1.5 Conditioning procedure,

12.1.6 Depth and width of specimen,

12.1.7 Test Method used, A or B,

12.1.8 Support span length,

12.1.9 Support span-to-depth ratio,

12.1.10 Radius of supports and loading noses,

12.1.11 Rate of crosshead motion,

12.1.12 Maximum strain in the outer fibers of the specimen.

12.1.13 Flexural strength (if applicable), average value, and standard deviation,

12.1.14 Secant modulus of elasticity in bending, average value and standard deviation of 1 % strain,

12.1.15 Flexural yield strength (if desired), with strain used, average value, and standard deviation, and

12.1.16 Stress at any given strain up to and including 3 % (if desired), with strain used, average value, and standard deviation.

13. Precision and Bias

13.1 Thiables i 1 and 2 are based on a round-robin test conducted in 2001, in accordance with Practice E 691, involving two materials tested by five laboratories. For each material, all the specimens were prepared at one source. Each "test result" was the average of five individual determinations. Each laboratory obtained one test results for each material. Flexural Secant Modulus at 1 % Strain (Table 1) were reported by all five laboratories while Flexural Stress at 3 % Strain (Table 2) were reported by four laboratories. (**Warning—**The following explanations of *r* and *R* (13.2-13.2.3) are intended only to present a meaningful way of considering the approximate precision of these test methods. The data given in Table 1 should not be applied rigorously to the acceptance or rejection of materials, as those data are specific to the round robin and bias have may not been determined.

TABLE 1 Flexural Secant Modulus at 1 % Strain

Material	Mean	Values as a Percent of the Mean			
	ksi	V_r	V_R	I_r	I_R
Plastic Lumber 1	230.8	9.7 %	16.4 %	27.3 %	46.5 %
Plastic Lumber 2	120.2	5.0 %	8.5 %	14.3 %	24.2 %

V_r= Repeatability
I_r= 2.83 V_r
V_R= Reproducibility
I_R= 2.83 V_R

TABLE 2 Flexural Stress at 3 % Strain

Material	Mean	Values as a Percent of the Mean			
	psi	V_r	V_R	I_r	I_R
Material 1	3568.8	7.27 %	12.95 %	20.58 %	36.65 %
Material 2	2388.1	3.26 %	6.06 %	9.21 %	17.15 %

V_r= Repeatability
I_r= 2.83 V_r
V_R= Reproducibility
I_R= 2.83 V_R

Interlaboratory studies will be representative of other lots, conditions, materials, or laboratories. Users of these test methods should apply the principles outlined in Practice E 691 to generate data specific to their laboratory and materials, or between specific laboratories. The principles of 13.2-13.2.3 would then be valid for such data.)

NOTE 8—Practice E 691 for developing Precision and Bias Statement calls for using six materials and six laboratories. While only two materials and five laboratories were used in the reproducibility round robin effort, the data have been analyzed and presented for use by future laboratories.

13.2 *Concept of "r" and "R" in Table 1*—If S_r and S_R have been calculated from a large enough body of data, and for test results that were averages from testing five specimens for each test result, then:

13.2.1 *Repeatability*—Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the *r* value for that material. *r* is the interval representing the critical difference between two test results for the same material, obtained by the same operator using this practice.

13.2 It the same equipment on the same day in the same laboratory.

13.2.2 *Reproducibility*—Two test results obtained by different laboratories shall be judged not equivalent if they differ by more than the *R* value for that material. *R* is the intent of Subcommittee D 20.20 to publish this practice interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

13.2.3 The judgments in 13.2.1 and then begin 13.2.2 will have an investigation approximately 95 % (0.95) probability of its precision and bias. Anyone wishing to participate in this work being correct.

13.3 *Bias*—No statement may contact be made about the Chairman bias of Subcommittee D20.20 at ASTM Headquarters. these test methods, as there is no standard reference material or reference test method that is applicable.

14. Keywords

14.1 flexural properties; plastic lumber; recycled plastics; secant modulus; specimen; stiffness; strength; stress at a given strain

ANNEX

(Mandatory Information)

A1. TOE COMPENSATION

A1.1 In a typical stress-strain curve (See Fig. A1.1) there is a toe region, *AC*, that does not represent a property of the material. It is an artifact caused by the slack, and alignment or seating of the specimen during the test. In order to obtain correct values of such parameters as modulus of elasticity, secant modulus, strain and stress at a given strain this artifact must be compensated for to give the corrected zero point on the strain or extension axis.

A1.2 In the case of a plastic lumber product (See Fig. A1.1), a continuation of the initial linear region (*CD*) of the curve is constructed through the zero-stress axis. This intersection (*B*) is the corrected zero-strain point from which all extensions or strains must be measured, including the value of strain (*BE*) at which the secant modulus is measured and the strain value (*BF*) at which the stress at 3 % strain is measured, if needed. The elastic modulus can be determined by dividing the stress at any point along the line *CD* (or its extension) by the strain at the same point (measured from point *B*, defined as zero-strain). The secant modulus is determined using the slope of the straight line connecting *B* and the point on the stress-strain curve corresponding to the specified strain value (1 % or 0.01 in./in. (mm/mm) [mm/mm] for plastic lumber), that is the slope of the line *BG*. The stress at a given strain is the value of the stress corresponding to the specified value of strain at point *F* (3 % or 0.03 in./in. (mm/mm) [mm/mm] for plastic lumber), that is, the stress at point *H*.

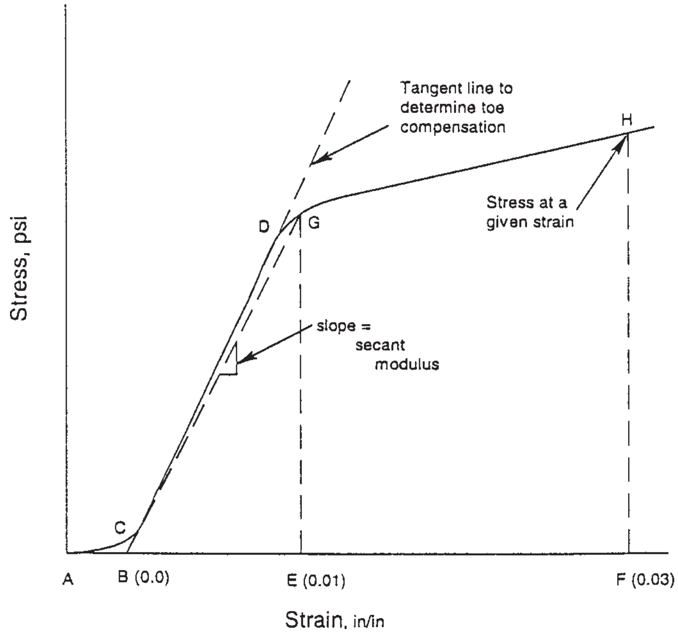


FIG. A1.1 Typical Stress-Strain Curve for Plastic Lumber Under Flexural Loading With a Hookean Region

SUMMARY OF CHANGES

This section identifies the location of selected changes to this test method. For the convenience of the user, Committee D20 has highlighted those changes that may impact the use of this test method. This section may also include descriptions of the changes, or reasons for the changes or both.

D 6109 - 03:
(*1*) Added Precision and Bias section.

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