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

This standard is issued under the fixed designation D6109; 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 These test methods are suitable for determining the flexural properties for any solid or hollow manufactured plastic lumber product of square, rectangular, round, or other geometric cross section that shows viscoelastic behavior. 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 products in the edgewise or "joist" position.

1.4 Plastic lumber currently is produced using several different plastic manufacturing processes. These processes utilize a number of diverse plastic resin material systems that include fillers, fiber reinforcements, and other chemical additives. The test methods are applicable to plastic lumber products where the plastic resin is the continuous phase, regardless of its manufacturing process, type or weight percentage of plastic resin utilized, type or weight percentage of fillers utilized, type or weight percentage of reinforcements utilized, and type or weight percentage of other chemical additives.

1.4.1 Alternative to a single resin material system, diverse and multiple combinations of both virgin and recycled thermoplastic material systems are permitted in the manufacture of plastic lumber products.

1.4.2 Diverse types and combinations of inorganic and organic filler systems are permitted in the manufacturing of plastic lumber products. Inorganic fillers include such materials as talc, mica, silica, wollastonite, calcium carbonate, and so forth. Organic fillers include lignocellulosic materials made or derived from wood, wood flour, flax shive, rice hulls, wheat straw, and combinations thereof.

1.4.3 Fiber reinforcements used in plastic lumber include manufactured materials such as fiberglass (chopped or continuous), carbon, aramid and other polymerics; or lignocellulosic-based fibers such as flax, jute, kenaf, and hemp.

1.4.4 A wide variety of chemical additives are added to plastic lumber formulations to serve numerous different purposes. Examples include colorants, chemical foaming agents, ultraviolet stabilizers, flame retardants, lubricants, anti-static products, biocides, heat stabilizers, and coupling agents

1.5 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.

1.6 *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 known ISO equivalent to this standard.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing

D883 Terminology Relating to Plastics

D2915 Practice for Sampling and Data-Analysis for Structural Wood and Wood-Based Products

D5033 Guide for Development of ASTM Standards Relating to Recycling and Use of Recycled Plastics (Withdrawn 2007)[3]

D5947 Test Methods for Physical Dimensions of Solid Plastics Specimens

E4 Practices for Force Verification of Testing Machines

E691 Practice for Conducting an Interlaboratory Study to

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

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

[3] The last approved version of this historical standard is referenced on www.astm.org.

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

Determine the Precision of a Test Method

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions of terms applying to these test methods appear in Terminology D883 and Guide D5033.

3.1.2 *plastic lumber, n*—a manufactured product made primarily from plastic materials (filled or unfilled), typically used as a building material for purposes similar to those of traditional lumber, which is usually rectangular in cross-section. (Terminology D883)

3.1.2.1 *Discussion*—Plastic lumber is typically supplied in sizes similar to those of traditional lumber board, timber and dimension lumber; however the tolerances for plastic lumber and for traditional lumber are not necessarily the same. (Terminology D883)

3.1.3 *plastic lumber shape, n*—plastic lumber, which generally is not rectangular in cross section

3.1.4 *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. (Terminology D883)

3.1.4.1 *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 either in a flat, or "plank," mode (Method A) or edgewise, or "joist," mode (Method B) as follows:

4.1.1 The beam 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; use of other distances for the load spans are addressed in Appendix X1).

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 these test methods are especially useful for research and development, quality control, acceptance or rejection under specifications, and special purposes.

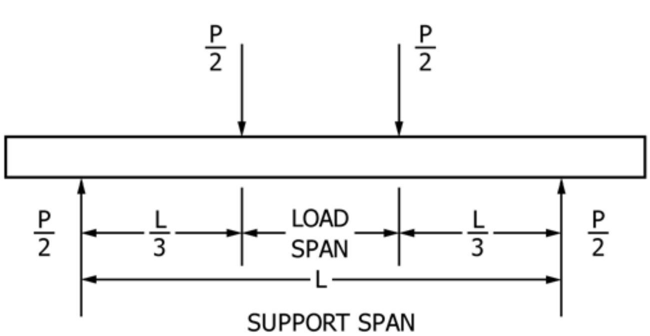


FIG. 1 Loading Diagram

5.2 Specimen depth, temperature, atmospheric conditions, and the difference in rate of straining specified in Test Methods A and B are capable of influencing flexural property results.

6. Apparatus

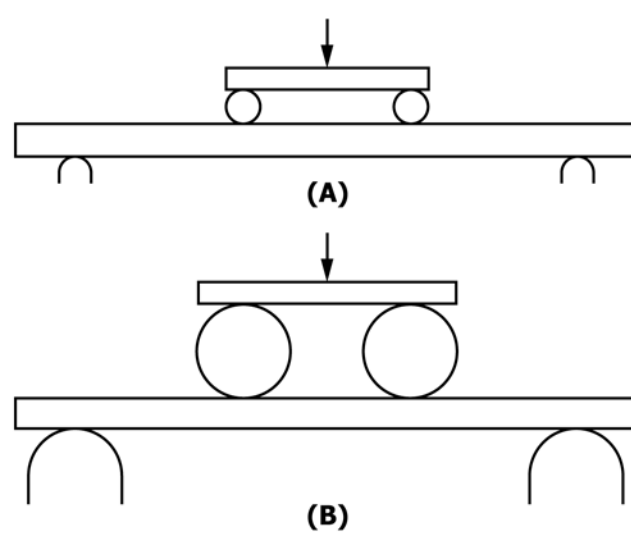
6.1 *Testing Machine*—A properly calibrated testing machine that is capable of operation at a constant rate of motion of the movable head and has the accuracy of ±1 % of maximum load expected to be measured. It shall be equipped with a deflection measuring device. The stiffness of the testing machine 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 E4.

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 shall be increased up to 1.5 times the specimen depth (see Fig. 2).

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

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.



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

7.2 For Test Method A, flatwise or "plank" tests, the depth of the specimen shall be the thickness, or smaller dimension, of the product. 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 ± 2°C) and 50 ± 5 % relative humidity for not less than 40 h prior to testing in accordance with Procedure A of Practice D618 for those tests where conditioning is required. In cases of disagreement, the tolerances shall be ±1.8°F (±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 ± 2°C) and 50 ± 5 % relative humidity, unless otherwise specified in the referenced test methods or in these test methods. In cases of disagreement, the tolerances shall be ±1.8°F (±1°C) and ±2 % relative humidity.

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 D5947 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),
d = depth of the beam, in. (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 ±10 %.

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. Check parallelism 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. Perform the necessary toe compensation (see Annex A1) to correct for seating and indentation of the specimen and deflections in the machine. Stress-strain curves shall 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 shall be calculated by letting r equal 0.03 in./in. (mm/mm) as follows for a load span of one-third of the support span:

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

where:

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

NOTE 3—For some products the increase in strain rate provided under Test Method B is capable of inducing the specimen to yield or rupture, or both, within the required 3 % strain limit.

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

10.2 *Test Method B:*

10.2.1 *Edgewise or "Joist" Testing:*

10.2.2 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).

10.2.3 *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 stability and safety during the test, 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 shall be used as required to provide necessary stability and safety during the test. Each support shall allow vertical movement without frictional restraint but shall restrict lateral deflection (See Fig. 3).

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). For rectangular cross-sections, this stress is 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:

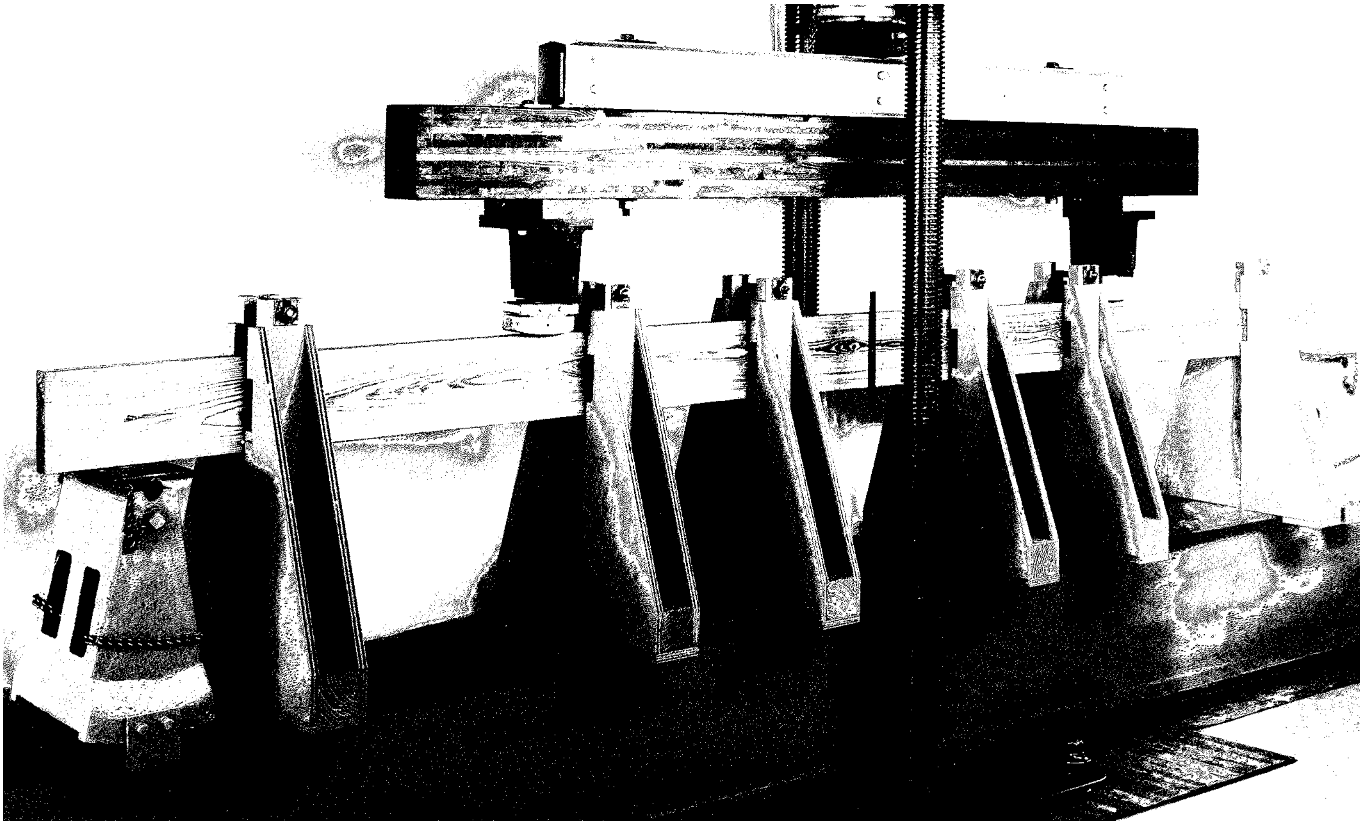


FIG. 3 Example of Lateral Support

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

where:

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

NOTE 5—Eq 3 applies strictly to products 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.

11.2 *Flexural Strength (Modulus of Rupture)*—The flexural strength is equal to the maximum stress in the outer fibers at the maximum load, load at rupture, or when the strain reaches 3 %, whichever occurs first. It is calculated in accordance with Eq 3 by letting P equal the maximum load, the load at rupture, or the load corresponding to a deflection at 3 % strain, whichever occurs first.

11.3 *Stress at a Given Strain*—Some products will neither break nor show a true yield point at outer fiber strains up to 3 %. In these cases the maximum fiber stress at any given strain shall 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.

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

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

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

11.5 *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 psi (MPa) and report to three significant figures (see Annex A1).

11.6 *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 psi (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.

$$E_B = S_B/r_B \quad (5)$$

where:

E_B = Secant Modulus of elasticity in flexure, psi (MPa),

r_B = strain at which Secant Modulus of elasticity is to be determined, in./in. (mm/mm); for example, 0.01 in./in., and.

S_B = value of stress on the strain-strain curve that corresponds to r_B, the specified strain level, psi.

NOTE 6—Appendix X1 provides the equations corresponding to Eq 1 through Eq 4 for non-rectangular cross-sections, that are also applicable to hollow profiles and for loading spans that are other than a one-third of the support span as required in 10.1.4.

11.7 *Chord Modulus*—For some applications, calculating a chord modulus is required. The chord modulus is the slope of a straight line connecting the points on the load-deflection curve that represent 10 % and 40 % of the maximum stress, or stress at 3 % maximum outer fiber strain, whichever occurs first.

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:

$$S = \sqrt{\left(\left(\sum X^2 - n\bar{X}^2\right)/(n-1)\right)} \quad (6)$$

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 product 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, average value, and standard deviation,

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

12.1.15 Modulus of elasticity (tangent) or chord modulus or both, as applicable, 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 Tables 1 and 2 are based on a round-robin test conducted in 2001, in accordance with Practice E691, involving two products tested by five laboratories. For each product, 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 product. Flexural Secant Modulus values at 1 % Strain (Table 1) were reported by all five laboratories while Flexural Stress values 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 shall not be applied rigorously to the acceptance or rejection of materials, as those data are specific to the round robin and are not necessarily representative of other lots, conditions, products, or laboratories. Users of these test methods shall apply the principles outlined in Practice E691 to generate data specific to their laboratory and products, or between specific laboratories. The principles of 13.2 – 13.2.3 would then be valid for such data.)

NOTE 7—Practice E691 for developing Precision and Bias Statement calls for using six products and six laboratories. While only two products and five laboratories were used in the 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 product. *r* is the interval representing the critical difference between two test results for the same product, obtained by the same operator using 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 product. *R* is the interval representing the critical difference between two test results for the same product, obtained by different operators using different equipment in different laboratories.

13.2.3 The judgments in 13.2.1 and 13.2.2 will have an approximately 95 % (0.95) probability of being correct.

13.3 *Bias*—No statement is made about the bias of these test methods, as there is no standard reference product or reference test methods that are applicable.

TABLE 1 Flexural Secant Modulus at 1 % Strain

Product	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

Product	Mean	Values as a Percent of the Mean			
	psi	V_r	V_R	I_r	I_R
Product 1	3568.8	7.27 %	12.95 %	20.58 %	36.65 %
Product 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

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 product. 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.

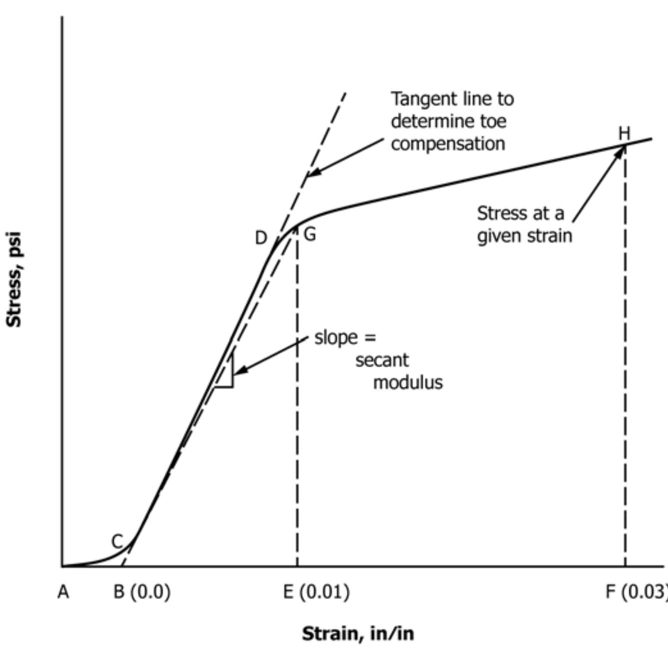


FIG. A1.1 Typical Stress-Strain Curve for Plastic Lumber Under Flexural Loading With a Hookean Region

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 is 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) 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) for plastic lumber), that is, the stress at point *H*.

APPENDIX

(Nonmandatory Information)

X1. EQUATIONS FOR NON-RECTANGULAR CROSS-SECTIONS AND OTHER LOAD SPANS

X1.1 Equations Eq X1.1 through Eq X1.4 below correspond to Eq 1 through Eq 4 in these test methods and are applicable for any general cross-section, including hollow-profiles and are also applicable for load spans not equal to one-third of the support span.

$$R = (3aL - 4a^2)(ZS_m)/(6I) \quad (X1.1)$$

$$D = (3L^2 - 4a^2)(rS_m)/(24I) \quad (X1.2)$$

$$S = (Pa)/(2S_m) \quad (X1.3)$$

$$r = (24DI)/(S_m(3L^2 - 4a^2)) \quad (X1.4)$$

where:

I = Moment of Inertia, and
S_m = Section Modulus, for the cross-section

For test configurations where the span to depth ratio is less than 16:1, 4.3 of Practice D2915 provides guidance on calculation of a flexural modulus using the shear modulus (modulus of rigidity) of the product.

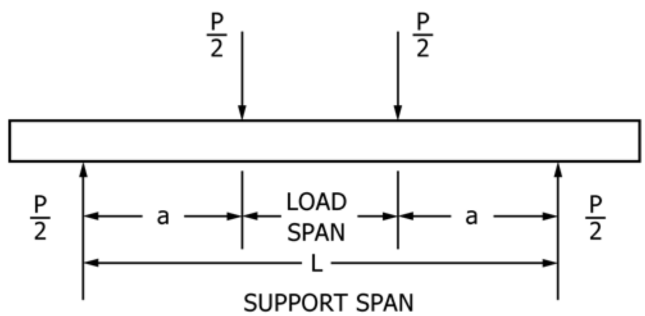


FIG. X1.1 Loading Diagram for Load Span Not Equal to One-Third of Support Span

SUMMARY OF CHANGES

Committee D20 has identified the location of selected changes to this standard since the last issue (D6109 – 10) that may impact the use of this standard. (June 1, 2013)

(1) Revised the term *plastic lumber* in 3.1.2.