



Standard Specification for Polyethylene-Based Structural-Grade Plastic Lumber for Outdoor Applications¹

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1. Scope

1.1 This specification covers a type of plastic lumber product, defined as polyethylene-based structural-grade plastic lumber (SGPL), for use as main framing members, including joists, stringers, beams, columns; and secondary framing members, including planking, posts and bracing; in outdoor structures such as decks, boardwalks, docks, and platforms.

1.2 This specification is applicable to solid, rectangular SGPL products where polyethylene resin (non cross-linked) is the continuous phase and is at least 50 % of the product (by weight).

1.3 This specification is not applicable to plastic lumber products containing cellulosic materials as additives, fillers or fiber reinforcements.

1.4 SGPL products covered by this specification shall not be used as tensile members.

1.5 SGPL products are produced using several different manufacturing processes. These processes utilize a number of polyethylene resin material systems that include varying proportions of fillers, fiber reinforcements, and other chemical additives.

1.6 Due to thermodynamic effects that result in outer-surface densification during manufacture, SGPL products are typically non-homogeneous in the cross-section. This standard does not address materials that have been modified from their original cross-section.

1.6.1 The cross-section non-homogeneity is addressed in the material property assessments in this document only for applications in which the product cross-section is not modified by cutting, notching, or drilling. For products modified in this manner, additional engineering considerations are required and they are beyond the scope of this document.

1.7 For purposes of this standard, an SGPL product is a specific combination of polyethylene resin, together with

fillers, reinforcements, and additives. Each formulation is to be identified as a distinct and different product, to be tested and evaluated separately.

1.8 Diverse and multiple combinations of both virgin and recycled polyethylene material systems are permitted in the manufacture of SGPL products.

1.9 Fiber reinforcements used in SGPL include manufactured materials such as fiberglass (chopped or continuous), carbon, aramid and other polymeric materials.

1.10 A wide variety of chemical additives are typically added to SGPL formulations. Examples include colorants, chemical foaming agents, ultraviolet stabilizers, fire retardants, lubricants, anti-static products, heat stabilizers, and coupling agents.

1.11 Diverse types and combinations of filler systems are permitted in the manufacturing of SGPL products. Fillers that cause the product to fail the requirements of 6.13 are not permitted in the manufacturing of SGPL products.

1.12 In order for a product to be classified as SGPL, it must meet the minimum stress and modulus criteria consistent with the specific product as marked, and additionally the properties specified in Section 6 of this specification.

1.13 This specification pertains to SGPL where any reinforcement is uniformly distributed within the product. When reinforcement is not uniformly distributed, the engineering issues become substantially more complex. For this reason, such products are not covered in this document.

1.14 Products that fail at strains of less than 0.02 (2 %) when tested in flexure in accordance with 6.6 are not compatible with the underlying assumptions of Annex A1 and are beyond the scope of this standard (see Note 1).

NOTE 1—Calculation of time-dependent properties in Annex A1 is based on the assumption that the product does not fail in a brittle manner. The 2 % strain limit was selected based on the judgment of the task group members that created Annex A1.

1.15 This specification addresses issues relevant to a buyer's requirements for SGPL products and has therefore been developed in the format of a procurement specification.

1.16 Criteria for design are included as part of this specification for SGPL products.

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1.17 Use of SGPL members in application will typically require the design of structural connections. Connection design between SGPL members falls outside the scope of this standard.

1.18 The values are stated in inch-pound units, as these are currently the most common units used by the US construction industry. Equivalent SI units are indicated in parentheses.

1.19 *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 2—There is no known ISO equivalent to this Standard.

2. Referenced Documents

2.1 The following documents of the issue in effect on the date of product purchase form a part of this specification to the extent referenced herein:

2.2 ASTM Standards:²

D883 Terminology Relating to Plastics

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

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

D6108 Test Method for Compressive Properties of Plastic Lumber and Shapes

D6109 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastic Lumber and Related Products

D6112 Test Methods for Compressive and Flexural Creep and Creep-Rupture of Plastic Lumber and Shapes

D6341 Test Method for Determination of the Linear Coefficient of Thermal Expansion of Plastic Lumber and Plastic Lumber Shapes Between –30 and 140°F (–34.4 and 60°C)

D6662 Specification for Polyolefin-Based Plastic Lumber Decking Boards

D7032 Specification for Establishing Performance Ratings for Wood-Plastic Composite Deck Boards and Guardrail Systems (Guards or Handrails)

E84 Test Method for Surface Burning Characteristics of Building Materials

2.3 Other Documents:

ASCE 7 Minimum Design Loads for Buildings and Other Structures³

3. Terminology

3.1 *Definitions of Terms*—For definitions of terms used in this specification associated with plastics issues refer to the terminology contained in Terminology **D883**.

3.2 Definitions:

3.2.1 *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**)

3.2.1.1 *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**)

3.2.2 *resin, n*—a solid or pseudo solid organic material often of high molecular weight, which exhibits a tendency to flow when subjected to stress, usually has a softening or melting range, and usually fractures conchoidally (Terminology **D883**).

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

3.3 Definitions of Terms Specific to This Standard:

3.3.1 *bulge, n*—convex distortion (away from the center of the cross-section) of the face of the product from a straight line drawn from edge to edge across the width.

3.3.2 *crook, n*—distortion of the product in which there is a deviation in a direction perpendicular to the edge from a straight line from end to end along the length.

3.3.3 *cup, n*—concave distortion (towards the center of the cross-section) of the face of the product from a straight line drawn from edge to edge across the width.

3.3.4 *edge, n*—the side of a rectangular-shaped product corresponding to the thickness.

3.3.5 *face, n*—the side of a product corresponding to the width.

3.3.6 *reinforcement, n*—a material added to the thermoplastic resin to improve its mechanical properties.

3.3.7 *self-supporting specimen, n*—a specimen that remains in place by its own structural characteristics both before and during a fire test.

3.3.8 *structural grade plastic lumber, n*—a solid, rectangular reinforced thermoplastic composite lumber product manufactured for load-bearing applications such as joists, beams, or columns in outdoor structures.

3.3.9 *test set, n*—a full complement of test specimens required for a specific assessment.

3.3.9.1 *Discussion*—As an example, a test set for flexural properties (see 6.6.3) requires 28 test specimens.

3.3.10 *thickness, n*—the lesser dimension of the cross-sectional profile of a rectangular-shaped product.

3.3.11 *width, n*—the greater dimension of the cross-sectional profile of a rectangular-shaped product, or the dimension of the cross-sectional profile of a square product.

4. Ordering Information

4.1 The information contained in this specification is intended to be helpful to producers, distributors, regulatory agencies and users including designers, architects, and engineers. The information will also promote understanding between purchasers and sellers. The purchaser shall state whether

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 Available from American Society of Civil Engineers (ASCE), 1801 Alexander Bell Dr., Reston, VA 20191, <http://www.asce.org>.

this specification is to be used, select the preferred options permitted herein, and include the allowable design information in the invitation to bid and purchase order from the following:

- 4.1.1 Title, number and date of this specification,
- 4.1.2 Minimum allowable bending stress and apparent bending stiffness,
- 4.1.3 Percent recycled content (if requested),
- 4.1.4 Flame spread index,
- 4.1.5 Color,
- 4.1.6 Quantity in lineal feet,
- 4.1.7 Cut length,
- 4.1.8 Cross-sectional dimensions,
- 4.1.9 Packing requirements,
- 4.1.10 Palletization, if required,
- 4.1.11 Marking, if other than specified.

5. Dimensions and Permissible Variations

5.1 It is permissible to produce SGPL either in sizes that are similar to the standard dimensions of the wood industry, or to other dimensions designated by manufacturers or buyers. This specification does not limit the dimensional range of production.

5.2 Use of a licensed Professional Engineer is recommended for designing and selecting SGPL products in accordance with this specification.

5.3 **Thickness**—Unless otherwise specified in 4.1.8, product thickness tolerance shall be:

For members less than 2 in. in nominal thickness the tolerance on thickness shall be $+3/16$ / $-1/16$.

Nominal (in.)	Actual (in.)	Tolerance (in.)
2	1½	$+3/16$ / $-1/16$
3	2½	$+3/16$ / $-1/16$
4	3½	$+3/16$ / $-3/32$
5	4½	$+3/16$ / $-3/32$
6	5½	$+3/16$ / $-1/8$

For members greater than 6 in. in nominal thickness the tolerance on thickness shall be $+3/16$ / $-1/8$ inch.

5.4 **Width**—Unless otherwise specified in 4.1.8, product width shall be:

For members less than 3 in. in nominal width the tolerance on width shall be $+3/16$ / $-1/16$ inch.

Nominal (in.)	Actual (in.)	Tolerance (in.)
3	2½	$+3/16$ / $-1/16$
4	3½	$+3/16$ / $-3/32$
6	5½	$+3/16$ / $-3/32$
8	7¼	$+3/16$ / $-1/8$
10	9¼	$+3/16$ / $-1/8$
12	11¼	$+1/4$ / $-5/32$

For members greater than 12 in. in nominal width the tolerance on width shall be $+1/4$ / $-5/32$ inch.

5.5 **Length**—Unless otherwise specified in 4.1.7, products up to 20 ft shall have tolerances of $\pm 1/2$ inch. Over 20 feet the tolerances shall be $\pm 1/2$ -in. per 20-ft of length or fraction thereof. Measurement of lengths shall be made at $23 \pm 2^\circ\text{C}$ ($73.4 \pm 4^\circ\text{F}$) and relative humidity of $50 \pm 5\%$.

5.6 **Flatness Tolerance**—Products shall be flat with a maximum cup or bulge in the face limited to the tolerances in Table 1 and Table 2. Linear interpolation of the values is acceptable for dimensions other than listed.

TABLE 1 Cup or Bulge Tolerances Relative to Nominal Width (2x)

Face Width, in.	≤ 4 in.	6 in.	8 in.	10 in.	12 in.
Tolerance ($\pm$)	$1/16$ in.	$3/32$ in.	$1/8$ in.	$3/16$ in.	$1/4$ in.

TABLE 2 Cup or Bulge Tolerances Relative to Nominal Size (square)

Size, in.	≤ 4 in.	6 in.	8 in.	10 in.	> 12 in.
Tolerance ($\pm$)	$3/32$ in.	$1/8$ in.	$3/16$ in.	$1/4$ in.	$1/4$ in.

5.7 **Squareness**—Unless a specially shaped member is specified, the cross-section of all structural-grade plastic lumber products shall be perpendicular (that is, 90 degree angle from face to edge of a square or rectangular shape and suited for the intended purpose).

5.8 **Crook**—Crook shall conform to the tolerances in Table 3. Linear interpolation of the values is acceptable for dimensions other than listed.

6. Performance Requirements

6.1 Load Combinations: Plastic members subject to multiple load types shall be checked for all applicable load combinations. Load factors and load reductions shall be determined in accordance with the applicable code or ASCE 7. All applicable load combinations shall be evaluated to determine the critical load combination to be used in design.

NOTE 3—Application of load duration factors to load combinations in which each load has a different associated duration is a complex process and varies depending on whether the design engineer is using allowable stress design (ASD) or load and resistance factor design (LRFD) methodology. A conservative design approach applies the load duration factor equal to the longest duration in the applicable load combination. More refined approaches for specific applications can be found in the technical literature.

6.2 Design Properties:

6.2.1 All members shall be designed such that for all load combinations:

$$f_a \leq F_n' \times C_D \quad (1)$$

where:

- f_a = total applied stress in each combination (psi)
- F_n' = allowable stress as calculated in 6.6.3.2, 6.7.2, 6.8.2.1, 6.8.3.1, or 6.9.3.2 (psi)
- C_D = Load Duration Factor for the material and considered load duration. Derivation of C_D is explained in Annex A2.

6.3 Interpolation of Properties:

6.3.1 Interpolation of mechanical properties of a SGPL product from test data from the same product at other width dimensions is permitted if the test results verify a logical progression of properties and the following conditions are met:

6.3.1.1 All specimens have the same thickness and material composition.

TABLE 3 Crook Tolerances Relative to Nominal Length and Width

Length in Feet	≤ 4 in. Width	6 in. Width	8 in. Width	10 in. Width	12 in. Width
4-6	$3/8$ in.	$1/4$ in.	$3/16$ in.	$3/16$ in.	$3/16$ in.
8	$1/2$ in.	$1/2$ in.	$3/8$ in.	$3/8$ in.	$3/8$ in.
10	$3/4$ in.	$3/8$ in.	$1/2$ in.	$1/2$ in.	$1/2$ in.
12	1 in.	$7/8$ in.	$13/16$ in.	$13/16$ in.	$13/16$ in.
14	1-1/4 in.	1-1/8 in.	1 in.	1 in.	1 in.
16	1-1/2 in.	1-3/8 in.	1-1/8 in.	1-1/8 in.	1-1/8 in.

6.3.1.2 Three or more test sets are performed on specimens with varying width.

6.3.1.3 At least one test set is performed on specimens with a width greater than that of the product whose properties are being interpolated.

6.3.1.4 At least one test set is performed on specimens with a width less than that of the product whose properties are being interpolated.

6.4 Creep Rupture:

6.4.1 Creep Rupture tests shall be performed for the intended use (that is, flexural test for a flexural member, compression test for a compression member) in accordance with the procedures outlined in Test Methods **D6112**.

6.4.2 F_{cr} shall be the stress required to cause creep rupture in ten years determined from the creep rupture curve calculated in Test Methods **D6112**.

6.4.3 E_{cr} shall be the effective ten-year modulus determined from the creep rupture curve calculated in Test Methods **D6112**.

6.4.4 The combined effect of time (that is, creep rupture) and temperature determined by Test Methods **D6112** shall be compared against the product of C_{TF} and β . The more conservative result shall form the basis of design.

6.5 Serviceability:

6.5.1 Deflection shall be calculated using the apparent modulus of elasticity determined in **6.6.3.3**. Calculated deflection shall not exceed applicable code or project specific deflection limits.

6.5.2 The maximum ten-year strain in any member shall not exceed 0.03 (3 %).

NOTE 4—It is possible that some applicable codes or project specific requirements will require deflection limits that result in a maximum strain of less than 0.03.

6.6 Flexural Members:

6.6.1 The test procedure shall be in accordance with Test Methods **D6109** with the following modifications:

6.6.1.1 The specimens for flexural members shall be tested in the joist configuration (Method B in Test Methods **D6109**) unless it is shown that the minimum properties in the plank configuration also hold for the joists and that there is no size effect for the product.

6.6.2 *SGPL Requirements*—SGPL shall meet or exceed the following criteria:

6.6.2.1 The mean value of the secant flexural modulus minus one standard deviation of the value at 1 % outer fiber strain shall equal or exceed 200,000 psi at $23 \pm 2^\circ\text{C}$ ($73.4 \pm 4^\circ\text{F}$) and $50 \pm 10\%$ RH.

6.6.2.2 The mean, minus two standard deviations, value of the flexural stress F_{bt} at 3 % outer fiber strain shall equal or exceed 2,000 psi at $23 \pm 2^\circ\text{C}$ ($73.4 \pm 4^\circ\text{F}$). If any SGPL product fails prior to reaching 3 % strain, then the mean, minus two standard deviations, of the flexural stress at failure for that product shall equal or exceed 2,000 psi.

NOTE 5—The typical mode of failure for SGPL members results from flexure by excessive strain rather than by rupture. Thus, the requirement in the standard flexural test is to define the failure stress as the stress at 3 % strain, if rupture has not occurred before that point.

6.6.3 Allowable Flexural Properties:

6.6.3.1 *Specimens Tested*—A minimum of 28 specimens shall be tested at $23 \pm 2^\circ\text{C}$ ($73.4 \pm 4^\circ\text{F}$). Specimens selected for testing shall be representative of typical production and shall be selected to include sources of potential variability.

6.6.3.2 *Allowable Flexural Stress*—The allowable flexural stress, F_b' , of a product is given as follows (see temperature tolerances in **6.6.3.1**):

$$F_b' = (F_b/FS) * C_{TF} * C_L \quad (2)$$

where:

F_b = the base flexural stress value at 23°C (73.4°F) for normal duration loading (10 yr. duration), (psi), which is defined as follows:

$$F_b = F_{bt} * \beta \leq F_{cr} \quad (3)$$

where:

F_{bt} = the non-parametric 5 % lower tolerance limit at 75 % confidence of the flexural stress at 3 % outer fiber strain (or failure if 3 % strain cannot be reached) determined from flexure tests conducted in accordance with Section **6.6.1** (psi). Statistical calculations shall be in accordance with Practice **D2915**. F_{bt} shall meet the requirements of **6.6.2**

F_{cr} = ultimate creep rupture stress for flexure calculated in accordance with **6.4**, (psi)

β = Stress-time factor to convert the test value, F_{bt} , to a ten-year normal duration value. This value shall be determined in accordance with **Annex A1**.

FS = factor of safety = 2.5,

C_{TF} = temperature factor for flexure determined in accordance with **Annex A3**

C_L = beam stability factor determined using principles of engineering mechanics.

NOTE 6—Discussion of beam stability is provided in **X1.2**.

6.6.3.3 *Apparent Modulus of Elasticity and Adjustment for Creep*—The apparent modulus of elasticity, E' , shall be determined as follows:

$$E' = E * C_{TE} / \alpha \leq E_{cr} \quad (4)$$

where:

E = modulus as determined from Test Methods **D6109**, except that it represents the chord modulus values between 0.1 F_{bt} and 0.4 F_{bt} , (psi)

E_{cr} = the effective ten-year stiffness determined in accordance with **6.4**, (psi)

C_{TE} = temperature factor for modulus determined in accordance with **Annex A3**

α = creep adjustment factor determined in accordance with **Annex A1**.

NOTE 7—An example problem for the case of uniform loading on a single span joist is described in **Appendix X4**.

6.6.3.4 For uniform loading at an average ambient temperature of 90°F the maximum total deflection of the structural-grade plastic lumber product including the effect of creep shall not exceed $L/180$ or as otherwise specified by the applicable code.

6.7 Shear Properties:

6.7.1 *Test Procedure*—Test Method **D2344/D2344M** incorporating the following criteria and modifications:

6.7.1.1 *Specimen Size for Testing*—Specimens for test shall not be machined to reduce the cross-sectional thickness—only full-size cross sections shall be used. Also, in accordance with subsection 5.3 of Test Method **D2344/D2344M**, span length-to-specimen thickness ratio of 4 shall be used for the specimen size.

6.7.1.2 *Specimens Tested*—A minimum of 28 specimens shall be tested. Specimens selected for testing shall be representative of typical production and shall be selected to include sources of potential variability.

6.7.1.3 An extension indicator shall be affixed to the specimen to record the displacement (strain) of the specimen below the upper loading nose as a function of applied stress. The recorded stress-strain data shall also be reported.

6.7.1.4 Use the short beam stress, F_{sbs} , as calculated in Equation (1) of Test Method **D2344/D2344M** as the shear stress value F_v in Equation (9) below.

6.7.2 *Allowable Shear Stress*—The allowable shear stress of a product is given as follows:

$$F_v' = (F_v/FS) * C_{TF} \quad (5)$$

where:

F_v = the base shear stress value at 23°C (73.4°F) for normal duration loading (10-year duration), (psi) defined below,

FS = factor of safety = 2.5,

C_{TF} = temperature factor for flexure, determined in accordance with Annex A3

F_v , the base shear stress value for the product is determined as follows:

$$F_v = F_{vt} * \beta \leq F_{cr} \quad (6)$$

where:

F_{vt} = the non-parametric 5 % lower tolerance limit at 75 % confidence of the shear stress at 3 % fiber strain (or failure if 3 % strain cannot be reached) determined from shear tests conducted in accordance with 6.7.1 (psi). Statistical calculations shall be in accordance with Practice **D2915**.

F_{cr} = ultimate creep rupture stress for shear calculated in accordance with 6.4, (psi)

β = stress-time factor to convert the test value, F_v , to a ten year normal duration value. This value shall be determined in accordance with Annex A1.

6.8 Bearing:

6.8.1 Tests shall be performed in accordance with Test Method **D6108** with the following modifications:

6.8.1.1 *Specimens Tested*—A minimum of 28 specimens shall be tested at $23 \pm 2^\circ\text{C}$ ($73.4 \pm 4^\circ\text{F}$). Specimens selected for testing shall be representative of typical production and shall be selected to include sources of potential variability.

6.8.1.2 *Bearing Perpendicular to the Direction of Extrusion*:

(1) *Test Method **D6108**, Subsection 6.2*: The standard test specimen shall take the form of the actual manufactured product cross-section with a length equal to half its width.

(2) *Test Method **D6108**, Subsection 10.2*: Place the test specimen between the surfaces of the compression platens, taking care to align the center line of the surface perpendicular to the extrusion with the center line of the platens to ensure that the ends of the specimen are parallel with the surface of the platens. The proper positioning of a member with dimensions $b \times d$ is shown in Fig. 1. Adjust the crosshead of the testing machine until it just contacts the top of the compression platen.

6.8.1.3 *Bearing Parallel to the Direction of Extrusion*:

(1) *Test Method **D6108**, Subsection 6.2*: The standard test specimen shall take the form of the actual manufactured product cross-section with a width equal to twice its length.

(2) *Test Method **D6108**, Subsection 10.2*: Place the test specimen between the surfaces of the compression platens, taking care to align the center line of the surface parallel to the extrusion with the center line of the platens to ensure that the ends of the specimen are parallel with the surface of the platens. The proper positioning of a member with dimensions $b \times d$ is shown in Fig. 2. Adjust the crosshead of the testing machine until it just contacts the top of the compression platen.

6.8.2 *Bearing Perpendicular to Extrusion*:

6.8.2.1 *Allowable Bearing Stress*—The allowable bearing stress, $F_{C\perp}'$, of a product loaded in compression perpendicular to the extrusion direction is given as follows (see temperature tolerances in 6.8.1.1):

$$F_{C\perp}' = (F_{C\perp}/FS) * C_{TC} \quad (7)$$

$F_{C\perp}$ = the base bearing stress value at 23°C (73.4°F), (psi) defined below,

FS = factor of safety = 2.5,

C_{TC} = temperature factor for compression, determined in accordance with Annex A3,

$F_{C\perp}$, the base bearing stress value for the product is determined as follows:

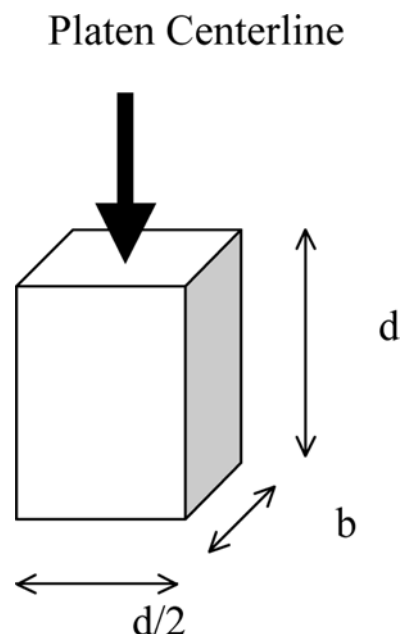


FIG. 1 Bearing Perpendicular to the Direction of Extrusion Platen Centerline

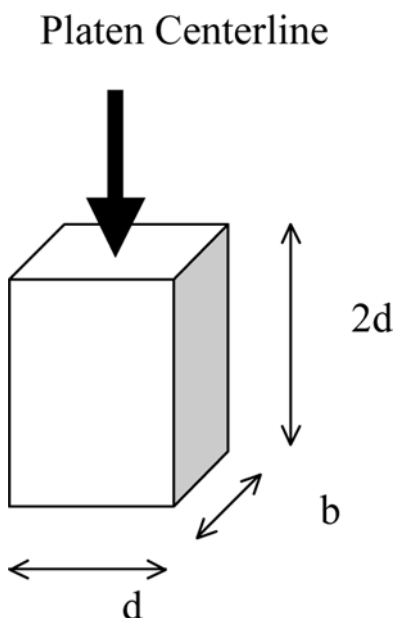


FIG. 2 Bearing Parallel to the Direction of Extrusion Platen Centerline

$$F_{C\perp} = F_{C\perp_i} * \beta \leq F_{cr} \quad (8)$$

where:

$F_{C\perp_i}$ = the non-parametric 5 % lower tolerance limit at 75 % confidence of the bearing stress perpendicular to the extrusion direction at 3 % fiber strain (or failure if 3 % strain cannot be reached) determined from bearing tests conducted in accordance with 6.8.1 (psi). Statistical calculations shall be in accordance with Practice D2915.

F_{cr} = the ultimate creep rupture stress for bearing perpendicular to the direction of extrusion calculated in accordance with 6.4, (psi)

β = stress-time factor to convert the test value, $F_{C\perp_i}$, to a ten year normal duration value. This value shall be determined in accordance with Annex A1.

6.8.3 Bearing Parallel to Extrusion:

6.8.3.1 Allowable Bearing Stress—The allowable bearing stress, $F_{C\parallel}'$, of a product loaded in compression parallel to the extrusion direction is given as follows:

$$F_{C\parallel}' = (F_{C\parallel}/FS) * C_{TC} \quad (9)$$

where:

$F_{C\parallel}$ = the base bearing stress value at 23°C (73.4°F), (psi) defined below

FS = factor of safety = 2.5,

C_{TC} = temperature factor for compression, determined in accordance with Annex A3,

$F_{C\parallel}$, the base bearing stress value for the product is determined as follows:

$$F_{C\parallel} = F_{C\parallel_i} * \beta \leq F_{cr} \quad (10)$$

where:

$F_{C\parallel_i}$ = the nonparametric 5 % lower tolerance limit at 75 % confidence of the bearing stress parallel to the extrusion direction at 3 % fiber strain (or failure if 3 % strain cannot be reached) determined from bearing tests conducted in accordance with 6.8.1 (psi). Statistical calculations shall be in accordance with Practice D2915.

F_{cr} = ultimate creep rupture stress for compression parallel to the direction of extrusion calculated in accordance with 6.4, (psi)

β = stress-time factor to convert the test value, $F_{C\parallel_i}$, to a ten year normal duration value. This value shall be determined in accordance with Annex A1.

6.9 Compression Members:

6.9.1 Test Procedure—Test Method D6108.

6.9.1.1 Specimens Tested—A minimum of 28 specimens shall be tested at 23 ± 2°C (73.4 ± 4°F). Specimens selected for testing shall be representative of typical production and shall be selected to include sources of potential variability.

6.9.2 SGPL Requirements—SGPL shall meet or exceed the following criteria:

6.9.2.1 The mean minus one standard deviation value of the secant compression modulus at 1 % strain shall equal or exceed 120,000 psi at 23 ± 2°C (73.4 ± 4°F) and 50 ± 10 % RH.

6.9.2.2 The mean, minus two standard deviations, value of the compressive stress F_{ct} at 3 % strain shall equal or exceed 1,500 psi at 23 ± 2°C (73.4 ± 4°F) and 50 ± 10 % RH. If any SGPL product fails prior to reaching 3 % strain, then the mean, minus two standard deviations, of the stress at failure for that product shall equal or exceed 1,500 psi.

NOTE 8—Often the compression modulus and stress values of SGPL are significantly lower than the flexural modulus and stress values.

6.9.3 Design of Compression Members:

6.9.3.1 SGPL compression members shall meet the following slenderness ratio limitation:

$$S_r = K L_u / r < 28 \quad (11)$$

where:

S_r = slenderness ratio,

K = buckling length coefficient (greater than or equal to 1.0) that depends on the end constraint for the column.

L_u = unbraced length of the member, (in.)

r = radius of gyration (in.)

The above slenderness ratio shall be checked for both principle bending axes of the member.

NOTE 9—This slenderness ratio limitation has been used by SGPL manufacturers in the past. Due to the broad range of products covered by this standard, designers are cautioned to check all compression members for potential buckling using the properties of the product being used. Discussion of column stability is provided in Appendix X1.2. Specific discussion of column slenderness ratio is provided in X1.2.7.4

6.9.3.2 The allowable compressive stress, F_c' , of a product is given as follows:

$$F'_c = (F_c/FS) * C_{TC} * C_p \quad (12)$$

where:

F_c = the base compressive stress value at 23°C (73.4°F) for normal duration loading (10 yr. duration), (psi) as defined below,

$$F_c = \beta * F_{ct} \leq F_{cr} \quad (13)$$

where:

F_{ct} = the non-parametric 5 % lower tolerance limit at 75 % confidence of the compressive stress at 3 % fiber strain determined from compression tests conducted in accordance with 6.9.1 (psi). Statistical calculations shall be in accordance with Practice D2915. F_{bc} shall meet the requirements of 6.9.2.

F_{cr} = ultimate creep rupture stress for compression calculated in accordance with 6.4, (psi)

β = stress-time factor to convert the test value, F_{ct} , to a ten year normal duration value. This value shall be determined in accordance with Annex A1,

FS = factor of safety = 2.5,

C_{TC} = temperature factor for compression, determined in accordance with Annex A3,

C_p = column stability factor determined using principles of engineering mechanics

NOTE 10—Discussion of column stability is provided in X1.2.

6.10 Combined Stresses:

6.10.1 *Bending and Compression*—Plastic members subject to both axial compression and flexure shall be proportioned using principles of engineering mechanics.

NOTE 11—Discussion of combined stresses is provided in X1.2.

6.10.2 Structures expected to experience significant side sway shall not be used unless appropriate engineering procedures or tests are employed in the design of such members to ensure that all applied loads will be safely carried by the members.

6.11 Dimensional Stability—Thermal Expansion:

6.11.1 The value of the coefficient of thermal expansion shall be calculated in accordance with the test procedure outlined in Test Method D6341 with the following modifications:

6.11.1.1 *Specimens Tested*—A minimum of 15 specimens shall be tested to establish an average value. Report the measured coefficient of thermal expansion in the longitudinal or the transverse direction to two significant figures for use in design calculations.

6.11.2 Thermal expansion shall be considered for the design of expansion slots or any other case where movement due to thermal effects will cause structural or serviceability concerns. Specimens selected for testing shall be representative of typical production and shall be selected to include sources of potential variability.

6.12 Weatherability:

6.12.1 SGPL products that are exposed to solar radiation shall meet the requirements of subsection 6.3.2 of Specification D6662.

NOTE 12—The testing requirements of subsection 6.3 of Specification

D6662 can only identify products with the potential to deteriorate in less than two years under outdoor conditions. However, the results from testing of plastic lumber decking boards after eleven years of outdoor exposure have shown that the boards had discolored and faded, but that both strength and stiffness were basically unchanged. Similar results are expected with SGPL. Further details of this testing and results are given in Appendix X3 in Specification D6662

6.13 Hygrothermal Cycling:

6.13.1 *Test Procedure*—Specimens shall also be prepared as described in Test Methods D6109. Each specimen shall then be weighed to the nearest 0.00022 lb (0.1 g). Specimens shall then be totally submerged underwater (using weights to hold down, if necessary) for a period of 24 hours. After removal from water, each specimen shall then be dried with a dry cloth on the outside surfaces and weighed again within 20 minutes. The specimens shall then be frozen to $-20 (\pm 5)^\circ\text{F}$ ($-29 (\pm 2)^\circ\text{C}$) for 24 hours, then returned to room temperature. The above process completes one hygrothermal cycle.

6.13.2 The procedure in 6.13.1 shall be repeated two more times, for a total of three cycles of water submersion, moisture absorption equilibrium, and freezing. After completion of these steps, the specimens shall be returned to room temperature and tested as described in Test Methods D6109.

6.13.3 *Specimens Tested*—A minimum of 15 specimens shall be prepared in accordance with Test Methods D6109 and tested. Specimens selected for testing shall be representative of typical production and shall be selected to include sources of potential variability.

6.13.4 *Criteria*—Any obvious physical changes that occur as a result of the hygrothermal cycling shall be noted. The flexural modulus and the greater of the stress level at 3% strain or the stress at fracture as defined in Test Methods D6109 shall retain 90 % of the mean value when tested without hygrothermal cycling in accordance with 6.6.3.2.

6.14 Flame Spread Index:

6.14.1 The flame spread index of SGPL products shall be determined by testing in accordance with Test Method E84.

6.14.2 A minimum of five test specimens shall be tested.

6.14.3 The test specimens shall either be self-supporting by their own structural characteristics or held in place by added supports along the test specimen surface. The test specimen shall remain in place throughout the test duration, without such severe sagging that it interferes with the effect of the gas flame on the test specimen. Test results are invalid if the bulk of the test specimen melts or drops to the furnace floor.

6.14.4 Appendix X1 of Test Method E84 provides guidance on mounting methods.

6.14.5 Products shall have a flame spread index no greater than 200 when tested in accordance with Test Method E84.

NOTE 13—For combustible construction, codes often require fire performance at least equivalent to that of wood. A maximum flame spread index of 200 when tested in accordance with Test Method E84 is considered to be equivalent to that of wood. For outdoor applications, there is no requirement specified for smoke developed index.

NOTE 14—Fire retardants are available to increase the resistance to ignitability and flame spread of SGPL and shall be incorporated as needed.

7. Specimen Conditioning

7.1 *Conditioning of Specimens for Tests*—Unless specifically stated otherwise, all specimens shall be conditioned and tested in accordance with the appropriate test method.

8. Workmanship

8.1 The structural-grade plastic lumber products furnished in accordance with this specification shall be an acceptable match to approved samples in pattern, color, and surface appearance. The products shall be free of defects that adversely affect performance or appearance. Such defects include blemishes, spots, indentations, cracks, blisters, and breaks in corners or edges.

9. Product Technical Data Sheet

9.1 The manufacturer shall provide the following information for each product:

- 9.1.1 Flexural properties as determined in 6.6.
- 9.1.2 Shear properties as determined in 6.7.
- 9.1.3 Bearing properties as determined in 6.8.
- 9.1.4 Compression properties as determined in 6.9.
- 9.1.5 Temperature adjustment factors for flexural stress and modulus in accordance with Annex A3.

9.1.6 Temperature adjustment factor for compression in accordance with Annex A3.

9.1.7 Stress-time adjustment factor, β , for flexure in accordance with Annex A1.

9.1.8 Creep adjustment factor, α , for flexure in accordance with Annex A1.

9.1.9 Ten-year modulus in accordance with 6.4.3.

9.1.10 Load duration factors for range of time periods in accordance with Annex A2.

9.1.11 Creep rupture value for stress, F_{cr} in accordance with 6.4.2.

10. Quality Assurance

10.1 A quality assurance program shall be employed to verify compliance with specific portions of this specification.

11. Packaging and Packing

11.1 The products shall be packaged in accordance with normal commercial practice and packed to assure acceptance by common carrier and to provide protection against damage during normal shipping, handling, and storage.

12. Keywords

12.1 plastic lumber; polyethylene; recycled plastics; reinforced; structural grade composite lumber

ANNEXES

(Mandatory Information)

A1. DERIVATION OF ALPHA AND BETA FACTORS AND CREEP CURVES

A1.1 The procedures in this annex were developed based on testing of a specific formulation of structural grade plastic lumber. They provide one method for determination of adjustment factors for time-dependent properties. These procedures have been used successfully to support designs of several demonstration bridges and railroad tie applications. However, during development of this standard, committee members expressed the need to expand the experimental backup data to include a wider range of formulations. This process is currently underway.

A1.2 The following method shall be used to calculate α , β , and development of creep curves based on short-term experimental data. This procedure is based on a Rutgers University thesis titled “Time Dependence of the Mechanical Properties of an Immiscible Polymer Blend” by Jennifer Lynch dated October 2002. For use in design, these values shall be compared against the creep-rupture factors determined in accordance with Test Methods D6112 and the more conservative shall apply.

A1.2.1 Perform five constant strain rate tests at $\dot{\epsilon} = 3 \text{ \%}/\text{min}$ in accordance Test Methods D6109. Continue the test until 5 % strain or until rupture. Record all data at the same time interval for all tests. Determine the average values of load, deflection, stress, strain, and strain energy density ($SED = \sigma \epsilon$) for each

time interval recorded. If the coefficient of variation at any time interval is greater than 8 % increase the number of specimens in accordance with subsection 3.4.2 of Practice D2915 until the coefficient of variation is less than 8 %. Fit fifth order polynomial regression curves for stress versus time and SED versus strain.

$$\sigma 3 \text{ \%}(t) = A_5 t^5 + A_4 t^4 + A_3 t^3 + A_2 t^2 + A_1 t \quad (\text{A1.1})$$

$$SED_3 \text{ \%}(\epsilon) = B_5 \epsilon^5 + B_4 \epsilon^4 + B_3 \epsilon^3 + B_2 \epsilon^2 + B_1 \epsilon \quad (\text{A1.2})$$

where:

A_x and B_x = regression constants for each curve.

A1.2.2 Repeat the procedure outlined in A1.2.1 for a strain rate of $\dot{\epsilon}' = 0.03 \text{ \%}/\text{min}$. Provide all test data and regression curves required by A1.2.1.

Discussion—It is permitted to use strain rates other than those recommended in A1.2.1 and A1.2.2 provided that the strain rate of A1.2.1 is approximately 100 times the strain rate of A1.2.2. For the remainder of this procedure $\dot{\epsilon} 3 \text{ \%}$ and $\dot{\epsilon} 0.03 \text{ \%}$ are left as variables to allow the use of alternate strain rates.

A1.2.3 Procedure for determining the rate relation exponent function m ($\sigma \epsilon_{0.03 \text{ \%}}$):

A1.2.3.1 Select 30 SED values such that the interval between values is equal and the largest value is equal to the

largest SED from the 0.03 %/min strain rate test. Each SED value shall be calculated using the following equation:

$$SED_i = (SED_{max,0.03\%}) * i/30 \quad (A1.3)$$

where:

$i = 1$ through 30.

A1.2.3.2 For both the 0.03 %/min test and the 3 %/min test determine the strain for each SED value calculated in A1.2.3.1 using Eq A1.3. Calculate stress ($\sigma = SED/\epsilon$) and time ($t = \epsilon/\dot{\epsilon}$) for each SED value.

A1.2.3.3 For each SED value, determine a value of m , as given by the following equation:

$$m = \frac{\log\left(\frac{\epsilon_{0.035\%}}{\epsilon_{3\%}}\right)}{\log\left(\frac{\epsilon_{3\%}}{\epsilon_{0.035\%}}\right)} \quad (A1.4)$$

A1.2.3.4 From the 30 calculated m values, fit a fifth order polynomial regression curve:

$$m(\sigma\epsilon_{0.03\%}) = C_{5\epsilon_{0.03\%}} \epsilon_{0.03\%}^5 + C_{4\epsilon_{0.03\%}} \epsilon_{0.03\%}^4 + C_{3\epsilon_{0.03\%}} \epsilon_{0.03\%}^3 + C_{2\epsilon_{0.03\%}} \epsilon_{0.03\%}^2 + C_{1\epsilon_{0.03\%}} \epsilon_{0.03\%} \quad (A1.5)$$

A1.2.4 Procedure for determining ten-year failure stress and for predicting creep - The steps outlined in A1.2.4.2 through A1.2.4.4 for determining stress, together with the steps outlined in A1.2.4.5 through A1.2.4.9 for predicting creep are iterative processes. These steps shall be performed using mathematical computer software capable of performing numerical iterations.

A1.2.4.1 Procedure for determining ten-year failure stress

A1.2.4.2 For each of the 30 SED values calculated in A1.2.3.1 calculate the predicted stress at ten years with the equation:

$$\sigma_{10} = \sigma_{0.03\%}/min * (\epsilon_{10}/\epsilon_{0.03\%})^{m(\sigma\epsilon)} \quad (A1.6)$$

where:

$\sigma_{0.03\%}/min$ = stress from 0.03 %/min test for a particular SED value.

ϵ_{10} = $\epsilon_f/(5,256,000 \text{ min})$

$m(\sigma\epsilon)$ = m as a function of SED calculated in A1.2.3.4, and

ϵ_f = the lesser of 0.03 or the strain corresponding to the creep rupture strain, F_{cr} calculated in 6.4.

A1.2.4.3 For the 30 predicted stress values fit a fifth order polynomial regression curve for stress versus strain:

$$\sigma_{10}(\epsilon) = D_5 \epsilon^5 + D_4 \epsilon^4 + D_3 \epsilon^3 + D_2 \epsilon^2 + D_1 \epsilon \quad (A1.7)$$

where:

D_x = regression constants, and

ϵ = SED/σ_{10}

A1.2.4.4 Calculate the failure stress at ten years by substituting ϵ_f into Eq A1.7:

$$\sigma_{f,10} = \sigma_{10}(\epsilon_f) \quad (A1.8)$$

where:

ϵ_f = the initial failure strain estimate,

ϵ_{fi} = defined below for the first iteration, and

$\epsilon_{f,c}$ = defined in A1.2.4.9 for all subsequent iterations.

$$\epsilon_{fi} = (\epsilon_f/2) * (1 + n_c) \quad (A1.9)$$

where:

ϵ_f = the lesser of 0.03 or the strain corresponding to the creep rupture strain, F_{cr} , calculated in 6.4,

n_c = an initial estimate of the creep exponent = 0.05

A1.2.4.5 Procedure for predicting creep:

A1.2.4.6 Equate the average stress of the 3%/min test with $\sigma_{f,10}$ calculated in A1.2.4.4 and solve for t_{r1} as follows:

$$\sigma_{3\%}(t_{r1})_{ave} = \frac{\int_0^{t_{r1}} \sigma_{3\%}(t) dt}{\int_0^{t_{r1}} dt} = \sigma_{f,10} \quad (A1.10)$$

where:

$\sigma_{3\%}(t)$ is as calculated in A1.2.1.

A1.2.4.7 Equate the average stress of the 0.03%/min test with $\sigma_{f,10}$ calculated in A1.2.4.4 and solve for t_{r2} as follows:

$$\sigma_{0.03\%}(t_{r2})_{ave} = \frac{\int_0^{t_{r2}} \sigma_{0.03\%}(t) dt}{\int_0^{t_{r2}} dt} = \sigma_{f,10} \quad (A1.11)$$

where:

$\sigma_{0.03\%}(t)$ is as calculated in A1.2.2.

A1.2.4.8 Solve for the creep exponent n_c as follows:

$$n_c = \frac{\log\left(\frac{\epsilon_{0.03\%}}{\epsilon_{3\%}}\right)}{\log\left(\frac{t_{r1}}{t_{r2}}\right)} \quad (A1.12)$$

where:

$\epsilon_{3\%} = \epsilon_{3\%} * t_{r1}$

$\epsilon_{0.03\%} = \epsilon_{0.03\%} * t_{r2}$

A1.2.4.9 Recalculate γ_f to incorporate creep:

$$\epsilon_{f,c} = (\epsilon_f/2) * (1 + n_c) \quad (A1.13)$$

A1.2.4.10 Repeat A1.2.4.2 through A1.2.4.4 and A1.2.4.5 through A1.2.4.9 using $\epsilon_{f,c}$ for ϵ_f until there is less than 1 % variation in $\epsilon_{f,10}$ between iterations.

A1.2.5 Perform five creep tests in accordance with Test Methods D6112, at a constant stress equal to the final iterated value of $\sigma_{f,10}$ calculated above. Record all data at the same time interval for all creep tests. If the coefficient of variation at any time interval is greater than 8 %, increase the number of specimens in accordance subsection 3.4.2 of Practice D2915 until the coefficient of variation is less than 8 %. Plot average strain versus time and perform a power regression to determine n_c :

$$\epsilon(t) = K t^{n_c} \quad (A1.14)$$

where:

$n_{c,test}$ shall be within 5 % of $n_{c,predicted}$ calculated in A1.2.4.8. If the difference is greater than 5 %, recalculate $\epsilon_{f,c}$ in A1.2.4.9 using $n_{c,test}$ and $\sigma_{f,10}$ in A1.2.4 with the recalculated $\epsilon_{f,c}$. Repeat the creep test at a constant stress equal to the recalculated $\sigma_{f,10}$. This shall be repeated until $n_{c,test}$ is within 5 % of $n_{c,predicted}$.

A1.2.6 Calculate β :

$$\beta = \sigma_{f,10}/F_{bt} \quad (\text{A1.15})$$

where:

F_{bt} = experimental flexural stress as described in 6.6.3.2, (psi)

$\sigma_{f,10}$ = the failure stress determined after sufficient iterations performed in accordance with A1.2.5.

A1.2.7 Calculate α :

$$\alpha = E/E_{10} \quad (\text{A1.16})$$

where:

E = the modulus of elasticity as described in 6.6.3.3 (psi)

E_{10} = the failure modulus calculated as follows:

$$E_{10} = \sigma_{f,10}/\epsilon_{f,c} \quad (\text{A1.17})$$

where:

$\sigma_{f,10}$ = the failure stress determined after sufficient iterations performed in accordance with A1.2.5

$\epsilon_{f,c}$ = the final iterated ten-year failure strain as determined in A1.2.5.

NOTE A1.1—Commercial software is available for the conversion of laboratory data to the α and β factors.

A1.2.8 In addition to calculation of α and β , these procedures shall be used to generate creep curves (strain versus time) to assist design engineers to determine expected deformations for various design conditions.

A2. DETERMINATION OF LOAD DURATION FACTOR C_D

A2.1 The following procedure shall be used to determine the load duration factor C_D . This procedure is only valid for load durations greater than or equal to three times the duration (from start to failure or 3 % strain) of the slow test described in A1.1. This procedure does not apply when creep does not have a significant impact on the failure of the member, which is the case in rapid loading. For durations less than 3 times the duration of the slow test, the value of C_D corresponding to the load duration of three times the slow test duration shall be used.

NOTE A2.1—The following procedure is an extension of the procedure presented in Annex A1. Completion of the Annex A1 procedure is required to determine C_D using the procedure presented below.

A2.1.1 Determine the duration of loading, recommended durations for typical load types are presented in Table X5.1.

A2.1.2 Determine the strain rate for the duration of loading:

$$\epsilon_t = \epsilon_{f,c}/t \quad (\text{A2.1})$$

where:

$\epsilon_{f,c}$ = final iterated ten-year failure strain determined in A1.2.5,

t = duration of loading.

A2.1.3 Procedure for determining t-year failure stress:

A2.1.3.1 For each of the 30 SED values calculated in A1.2.3.1 calculate the predicted stress at t years with the equation:

$$\sigma_t = \sigma_{0.03\%/min} * (\epsilon_t/\epsilon_{0.03\%})^{m(\sigma\epsilon)} \quad (\text{A2.2})$$

where:

$\sigma_{0.03\%/min}$ = stress from 0.03%/min test for a particular SED value,

ϵ_t = $\epsilon_{f,c}/(t \text{ min})$,

$m(\sigma\epsilon)$ = m as a function of SED calculated in A1.2.3.4, and

ϵ_f = final iterated ten-year failure strain determined in A1.2.4.9

A2.1.3.2 For the 30 predicted stress values, fit a fifth order polynomial regression curve for stress versus strain:

$$\sigma_t(\gamma) = D_5 \epsilon^5 + D_4 \epsilon^4 + D_3 \epsilon^3 + D_2 \epsilon^2 + D_1 \epsilon \quad (\text{A2.3})$$

where:

D_x = regression constants, and

ϵ = SED/ σ_t

A2.1.3.3 Calculate the failure stress at t years by substituting $\epsilon_{f,c}$ into Eq A2.3:

$$\sigma_{f,t} = \sigma_t(\epsilon_{f,c}) \quad (\text{A2.4})$$

where:

$\epsilon_{f,c}$ is as defined in A2.1.3.1.

A2.1.4 Determine C_D for the load duration t:

$$C_D = \sigma_{f,t}/\sigma_{f,10} \quad (\text{A2.5})$$

where:

$\sigma_{f,10}$ is the final iterated value determined in A1.2.7.

A3. DETERMINATION OF TEMPERATURE ADJUSTMENT FACTOR C_T

A3.1 The following procedure shall be performed to determine the Temperature Adjustment Factor for compressive stress (C_{TC}), flexural stress (C_{TF}), and flexural modulus (C_{TE}). This procedure shall be performed for all intended uses of the product, but need not be performed for both uses (that is, it is permitted to only perform the flexural tests if only the flexural temperature factors are required for the intended use). All specimens selected for testing shall be representative of typical production and shall be selected to include sources of potential variability. Interpolation of temperature dependent properties is permissible provided that the interpolation is performed in accordance with 6.3.

A3.2 *Control Group*—Conduct tests on a control group comprised of a minimum of 28 specimens at $23 \pm 2^\circ\text{C}$ ($73.4 \pm 4^\circ\text{F}$). The average stress at 3 % strain or failure stress of each specimen of the control group shall be computed. Additionally, for flexure only, the modulus of each specimen of the control group shall be computed.

A3.3 *Temperature Groups*—Conduct tests on experimental groups comprised of a minimum of five specimens at $-10 \pm 2^\circ\text{C}$ ($14 \pm 4^\circ\text{F}$), and $50 \pm 2^\circ\text{C}$ ($122 \pm 4^\circ\text{F}$) in accordance with A3.2.

A3.4 If the coefficient of variation for any of the groups (A3.2 or A3.3) is greater than 8 %, then additional tests shall be performed to increase the sample size of that group to that of a nonparametric approach for a 5 % lower tolerance limit with 75 % confidence in accordance with Practice D2915.

A3.5 Calculation of Temperature Adjustment Factor for Stress

A3.5.1 Determine an experimental temperature adjustment factor for stress, C_{Ti} , for each tested specimen such that:

$$C_{Ti} = F_i / F_{CTL} \quad (\text{A3.1})$$

where:

F_i = stress at 3 % strain or failure for a specimen,

F_{CTL} = average stress at 3 % strain or failure of the control group.

A3.5.2 Average the experimental temperature adjustment factors calculated in A3.5.1 for each temperature. Plot the average temperature adjustment factor, C_T , versus temperature.

A3.5.3 Determine the best-fit polynomial equation for C_T versus temperature. The order of the polynomial shall be sufficiently high to characterize the C_T versus temperature curve.

A3.5.4 A separate temperature adjustment factor curve is required for each property being considered (C_{TC} for compression and/or C_{TF} for flexure).

A3.6 Calculation of Temperature Adjustment Factor for Stiffness (Modulus)

A3.6.1 Determine an experimental temperature adjustment factor for modulus, C_{Ti} , for each tested specimen such that:

$$C_{Ti} = E_i / E_{CTL} \quad (\text{A3.2})$$

where:

E_i = modulus for a specimen,

E_{CTL} = average modulus of the control group.

A3.6.2 Average the experimental temperature adjustment factors calculated in A3.6.1 for each temperature. Plot the average temperature adjustment factor, C_{TE} , versus temperature.

A3.6.3 Determine the best-fit polynomial equation for C_{TE} versus temperature. The order of the polynomial shall be sufficiently high to characterize the C_{TE} versus temperature curve.

A3.7 For general application to outdoor building applications, a design temperature of 125°F is recommended.

NOTE A3.1—The design temperature of 125°F has been accepted within Specification D7032 and by various building code jurisdictions.

A3.8 For specific applications or for a specific project, the design engineer is permitted to select an alternative design temperature as approved by the authority having jurisdiction.

APPENDIXES

(Nonmandatory Information)

X1. RATIONALE (COMMENTARY) REGARDING SECTION 6

X1.1 Figure X1.1 shows sample flexural stress-strain curves for two plastic products as they relate to the minimum performance requirements of decking boards and SGPL. Products that fall above the Specification D6662 line would be classified as Specification D6662 decking. Products that fall above the SGPL line would be classified as SGPL as defined in this specification.

X1.2 Discussion of Engineering Mechanics Issues

X1.2.1 Design engineers are generally familiar with engineering formulae for beam stability, column stability, and combined stress effects. However, these formulae are typically based on underlying assumptions such as linear elastic material properties. Due to the broad range of formulations within the

Minimum and Example Plastic Properties

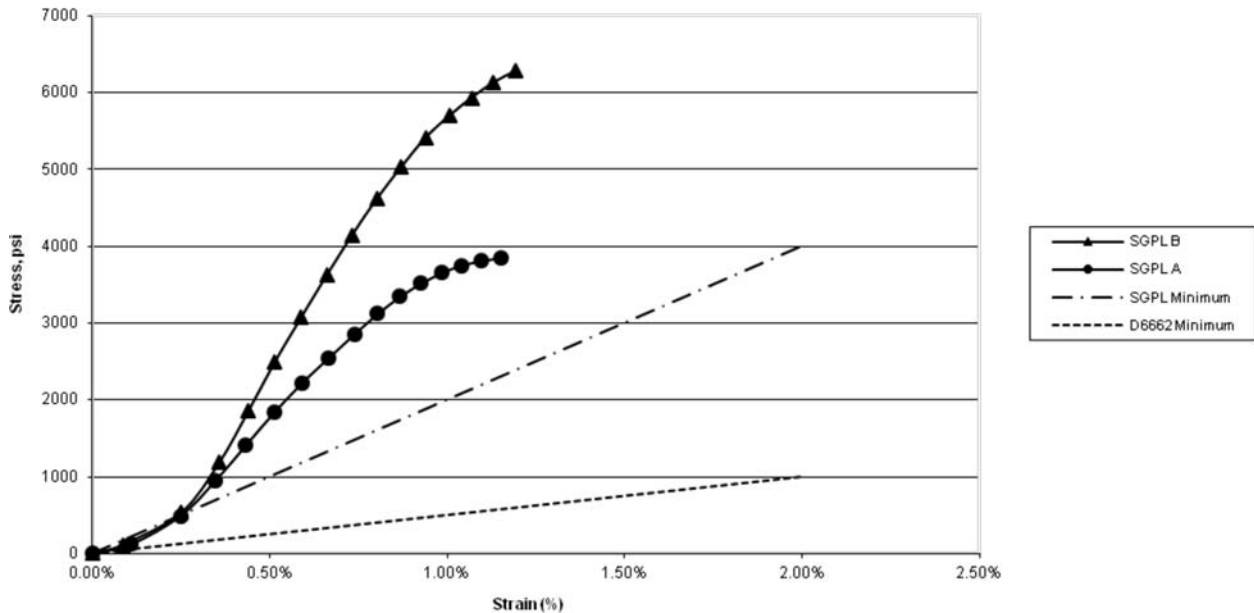


FIG. X1.1 Flexural Stress Strain Curves for Example Plastic Products in Accordance with Test Methods D6109 at 23°C (73.4°F)

scope of this standard, there will be a correspondingly broad range in the amount of nonlinear or viscoelastic behavior. As with any material, the final design will need to consider the potential of the material to behave in a nonlinear fashion depending upon its inherent properties and its slenderness in application.

X1.2.2 Products complying with this standard will have developed creep curves and other data that can be used by design engineers to judge the applicability of linear elastic stability and combined stress equations to specific product formulations.

X1.2.3 For the convenience of design engineers, examples of typical linear elastic stability equations are provided in this appendix, along with limited discussion regarding some of the additional considerations that may be required in design. These equations non-conservatively neglect consideration of non-linear elastic behavior.

X1.2.4 Equations for Linear Elastic Beam Stability (C_L)

$$C_L = \left(\frac{c * C_b * \pi}{I_x * F_b * L_u} \right) * \sqrt{\frac{E'_{min} I_y G'_{min} J}{(1 - I_y/I_x)}} \leq 1.0 \quad (X1.1)$$

where:

- c = distance from outer compression fiber to the neutral axis, (in.)
- C_b = equivalent moment factor determined as follows:

$$C_b = \frac{12.5}{3 \left(\frac{M_1}{M_{MAX}} \right) + 4 \left(\frac{M_2}{M_{MAX}} \right) + 3 \left(\frac{M_3}{M_{MAX}} \right) + 2.5} \quad (X1.2)$$

where:

- M_1 = absolute value of moment at the quarter point (in.-lb)

- M_2 = absolute value of moment at the half point (in.-lb)
- M_3 = absolute value of moment at the three quarter point (in.-lb)
- M_{MAX} = maximum moment (in.-lb)

As an alternate, C_b is often set as 1.0 as a conservative value.

E'_{min} = reference modulus of elasticity for stability defined as: (psi)

$$E'_{min} = \frac{E'(1 - 1.645 * COV_E)}{2.0} \quad (X1.3)$$

where:

- E' = apparent modulus of elasticity from 6.6.3.3 (psi)
- COV_E = coefficient of variation for the modulus of elasticity measured in 6.6.2
- G'_{min} = reference torsional shear moduli for stability defined as (psi):

$$G'_{min} = \frac{G(1 - 1.645 * COV_G) C_{TE}}{2.0 * \alpha} \quad (X1.4)$$

where:

- G = torsional shear modulus (psi)
- COV_G = coefficient of variation for the torsional shear modulus
- α = creep adjustment factor determined in accordance with Annex A1 (Values for α shall be provided by manufacturers for their specific products based on methodology presented in Annex A1.)
- C_{TE} = temperature factor for modulus determined in accordance with A3.1
- I_y = moment of inertia about the weak axis (in.⁴)
- I_x = moment of inertia about the strong axis (in.⁴)
- J = torsional constant, polar moment of inertia (in.⁴)

F_b^* = allowable flexural stress $\hat{F}_b$ of 6.6.3.2 modified by all factors except C_L , (psi)
 L_u = effective unbraced length, (in.)

X1.2.5 Discussion of Equations for Linear Elastic Beam Stability (C_L)

X1.2.5.1 As with any manufactured product, it is the actual dimensions that apply in Eq X1.1, and tolerances are already considered within the factors of safety allowed and the tolerances are defined in Section 5.

X1.2.5.2 The ratios of M_1 / M_{Max} , M_2 / M_{Max} and M_3 / M_{Max} in Eq X1.2 must be computed as absolute values in order to compute a correct value for the equivalent moment factor.

X1.2.5.3 Eq X1.1 and Eq X1.2 are based on assumed linear elastic materials. Some products covered by this standard might be acceptably close to this assumption while others will exhibit high levels of nonlinearity/inelasticity. It is the responsibility of the manufacturer to provide users with adequate data upon which design engineers can base their judgment regarding the applicability of these equations to beam stability design. In the absence of such data, designers are advised to provide continuous lateral support for beam elements.

X1.2.5.4 Eq X1.1 non-conservatively neglects consideration of non-linear elastic behavior and the reduction due to interaction of compression edge strain and beam buckling. It is the responsibility of the manufacturer to provide users with adequate data to address this assumption.

X1.2.5.5 Assignment of appropriate values for G and J for use in the torsional rigidity calculation are not easily accomplished for materials that are not isotropic and homogeneous. Further information on this topic is available in the technical literature.

X1.2.6 Equations for Linear Elastic Column Stability (C_P)

$C_P = 1.0$ for a column with lateral support throughout its length. For all other columns:

$$C_P = \frac{\pi^2 E_{min}' I_y}{(KL_u)^2 A F_c'} \leq 1.0 \quad (X1.5)$$

where:

E_{min}' = reference modulus of elasticity for stability defined in X1.2.4,
 I_y = moment of inertia about the weak axis,
 K = effective length factor determined by the condition of the end restraint,
 L_u = unbraced member length,
 F_c^* = allowable flexural stress F_c' of 6.9.3.2 modified by all factors except C_P (psi),
 A = cross sectional area.

X1.2.7 Discussion of Equations for Linear Elastic Column Stability (C_P)

X1.2.7.1 Eq X1.5 is based on assumed linear elastic materials. Some products covered by this standard might be acceptably close to this assumption while others will exhibit high levels of nonlinearity/inelasticity. It is the responsibility of the manufacturer to provide users with adequate data upon which design engineers can base their judgment regarding the applicability of these equations to beam stability design. In the absence of such data, designers are advised to provide continuous lateral support for column elements.

X1.2.7.2 Eq X1.5 non-conservatively neglects consideration of non-linear elastic behavior and the reduction due to interaction of compressive strain and column buckling. It is the responsibility of the manufacturer to provide users with adequate data to address this assumption.

X1.2.7.3 Eq X1.5 is also based on assumptions of concentric loading and perfect initial column straightness. Product design specifications for most materials assume some small amount of load eccentricity and/or deviation from straightness in this calculation. Further information on this topic is available in the technical literature.

X1.2.7.4 Because this standard permits a broad range of material property combinations, it is potentially not conservative to compute an overall limiting slenderness ratio for all SGPL products simply based on the minimum requirements for SGPL stated in the text. Equation 11 proposes a value of KL/r of 28 based on previous experience with SGPL products

X1.2.8 Equations for Linear Elastic Combined Bending and Compression Interaction

X1.2.8.1 Provided that f_c is less than F_{ex}' , the combined compression and bending interaction about a single axis can be evaluated with the following interaction equation:

$$\frac{f_c}{C_D F_c'} + \frac{f_{bx}}{C_D F_{bx}' (1 - f_c / F_{ex}')} \leq 1.0 \quad (X1.6)$$

where:

C_D = load duration factor for applicable design condition
 f_c = P/A = actual compressive stress (psi)
 F_c' = allowable compressive stress under axial compression only (psi), in accordance with 6.9.3.2
 f_{bx} = flexural stress about a single axis at service load due to bending (psi)
 F_{bx}' = allowable flexural stress about the loaded axis in bending in accordance with 6.6.3.2
 F_{ex}' = critical elastic buckling stress about the axis loaded in bending (psi), calculated as follows:

$$F_{ex}' = \frac{\pi^2 E_{min}' I_x}{(KL_u)^2 A} \leq 1.0 \quad (X1.7)$$

where:

E_{min}' = reference modulus of elasticity for stability defined in X1.2.4
 I_x = moment of inertia about the axis loaded in bending (in.⁴)
 K = effective length factor determined by the condition of the end restraint
 L_u = unbraced member length (in.)
 A = cross sectional area (in.²)

X1.2.9 Discussion of Equations for Combined Stress Interactions

X1.2.9.1 Eq X1.6 and Eq X1.7 are based on assumed linear elastic materials. Some products covered by this standard might be acceptably close to this assumption while others will exhibit high levels of nonlinearity/inelasticity. It is the responsibility of the manufacturer to provide users with adequate data upon which design engineers can base their judgment regarding the applicability of these equations to beam stability

design. In the absence of such data, designers are advised to provide continuous lateral support for column elements.

X1.2.9.2 **Eq X1.6** non-conservatively neglects consideration of non-linear elastic behavior and the reduction due to interaction of compressive strain and beam and column buckling. It is the responsibility of the manufacturer to provide users with adequate data to address this assumption.

X1.2.9.3 **Eq X1.6** and **Eq X1.7** are also based on an assumption that a compressive load is concentrically to an

initially straight column. Simultaneous bending stress is assumed to be applied about only one axis. Some product design specifications recommend that designers assume some small amount of load eccentricity and/or deviation from straightness in this calculation. There are also design situations that may induce bending about both axes or required consideration of combined tension and bending loads. Further information on these topics is available in the technical literature.

X2. SAMPLE CALCULATION OF CREEP RELATED FACTORS

INTRODUCTION

Determine the creep factor, α , the stress time factor, β , and the load duration factor, C_D , for a two-month load duration based on the following data:

Five tests performed at the constant strain rate of 0.8 %/min yield the average curves:

$$\sigma(t) = -2,921.37 t^5 + 13,073.0 t^4 - 21,836.1 t^3 + 14,693.3 t^2 + 316.746 t$$

$$SED(\epsilon) = 0 \epsilon^5 + 0 \epsilon^4 + 0 \epsilon^3 + 326805 \epsilon^2 - 319.319 \epsilon,$$

where SED is strain energy density and equals $\sigma\epsilon$.
The minimum failure strain at this rate was 1.04 %.

Five tests performed at the constant strain rate of .008 %/min yield the average curves:

$$\sigma(t) = -2.14493E - 8 t^5 + 1.3225E - 5 t^4 - 0.002584 t^3 + 0.062839 t^2 + 34.4802 t$$

$$SED(\epsilon) = 0 \epsilon^5 + 0 \epsilon^4 - 18463500 \epsilon^3 + 494488 \epsilon^2 - 323.140 \epsilon$$

The minimum failure strain at this rate was 1.42 % and the failure stress was 3080.36 psi.

Five creep tests performed at a constant stress of 2200 lbs yield the average curve:

$$\epsilon = 0.0031 t^{0.078618}$$

NOTE X2.1—The numbers presented in this and following examples are shown with six significant figures. The analysis on which this data is based was conducted using computer software that calculated values and curve formulas with more than six significant figures. Therefore, users of this guide need to note that it is possible that some variation will exist, due to round off, between values they calculate while trying to follow the example and values presented here.

X2.1 Determine the rate relation exponent function: m ($\sigma\epsilon$)

X2.1.1 Thirty (30) SED values, equally spaced between zero and the maximum measured SED value of 43.8662, are determined. Calculate the strain, stress, and time for each SED value for both strain rates as shown in **Table X2.1**.

For example, the first set of slow strain rate data is calculated as follows:

$$SED(\epsilon) = 0 \epsilon^5 + 0 \epsilon^4 - 18463500 \epsilon^3 + 494488 \epsilon^2 - 323.140 \epsilon$$

$$1.46221 = 0 \epsilon^5 + 0 \epsilon^4 - 18463500 \epsilon^3 + 494488 \epsilon^2 - 323.140 \epsilon$$

where:

$$\begin{aligned} \epsilon &= 0.002073 \text{ in./in.} \\ \sigma &= SED / \epsilon \\ \sigma &= 1.46221 / 0.002073 \\ \sigma &= 705.421 \text{ psi} \\ t &= \epsilon / \dot{\epsilon} \\ t &= 0.002073 / 0.00008 \\ t &= 25.9102 \text{ min} \end{aligned}$$

X2.1.2 For each SED value determined above, calculate the rate relaxation exponent, m , according to equation A1.4.

For example:

$$m = \frac{\log\left(\frac{\epsilon_{0.08\%}}{\epsilon_{0.8\%}}\right)}{\log\left(\frac{\dot{\epsilon}_{0.8\%}}{\dot{\epsilon}_{0.008\%}}\right)} = \frac{\log\left(\frac{0.002073}{0.001557}\right)}{\log\left(\frac{0.008}{0.00008}\right)} = 0.062076$$

TABLE X2.1 Example SED, Strain, Stress, and Time Values

SED	Slow Strain Rate			Fast Strain Rate		
	Strain (in/in)	Stress (psi)	Time (min)	Strain (in/in)	Stress (psi)	Time (min)
1.46221	0.002073	705.421	25.9102	0.001557	938.858	0.194679
2.92441	0.002807	1041.84	35.0872	0.002363	1237.40	0.295420
4.38662	0.003391	1293.56	42.3889	0.002987	1468.34	0.373435
5.84882	0.003898	1500.41	48.7270	0.003515	1663.84	0.439406
7.31103	0.004356	1678.20	54.4557	0.003981	1836.42	0.497642
8.77324	0.004781	1834.94	59.7653	0.004403	1992.62	0.550358
10.2354	0.005181	1975.60	64.7617	0.004791	2136.39	0.598876
11.6976	0.005562	2103.32	69.5188	0.005153	2270.28	0.644064
13.1599	0.005927	2220.30	74.0881	0.005492	2396.17	0.686505
14.6221	0.006281	2328.17	78.5063	0.005814	2515.18	0.726691
16.0843	0.006624	2428.00	82.8060	0.006119	2628.42	0.764921
17.5465	0.006961	2520.82	87.0079	0.006412	2736.66	0.801456
19.0087	0.007291	2607.31	91.1316	0.006692	2840.49	0.836504
20.4709	0.007615	2688.06	95.1934	0.006962	2940.43	0.870233
21.9331	0.007937	2763.53	99.2078	0.007222	3036.87	0.902782
23.3953	0.008255	2834.05	103.18828	0.007474	3130.16	0.934268
24.8575	0.008572	2900.01	107.14387	0.007718	3220.59	0.964787
26.3197	0.008887	2961.58	111.08813	0.007955	3308.48	0.994402
27.7819	0.009202	3018.95	115.03119	0.008186	3393.87	1.02324
29.2441	0.009519	3072.29	118.98352	0.008411	3477.05	1.05133
30.7063	0.009837	3121.63	122.95802	0.008630	3558.19	1.07872
32.1685	0.010157	3167.13	126.96264	0.008844	3637.44	1.10547
33.6307	0.010481	3208.83	131.00868	0.009053	3714.91	1.13161
35.0929	0.010809	3246.60	135.11430	0.009258	3790.72	1.15720
36.5551	0.011143	3280.45	139.29187	0.009458	3864.97	1.18226
38.0174	0.011485	3310.07	143.56714	0.009655	3937.72	1.20683
39.4796	0.011836	3335.47	147.95333	0.009847	4009.15	1.23092
40.9418	0.012199	3356.29	152.48130	0.010037	4079.27	1.25457
42.4040	0.012575	3372.10	157.18659	0.010222	4148.11	1.27781
43.8662	0.012969	3382.30	162.11690	0.010405	4215.83	1.30064

X2.1.3 Perform regression analysis on the m and corresponding slow test strain values determined in X2.1.2 and X2.1.1, respectively. The resulting fifth order polynomial for the m versus strain curve is:

$$m(\sigma_{\epsilon_{0.008\%}}) = 10,735,400,000 \epsilon_{0.008\%}^5 - 397,781,000 \epsilon_{0.008\%}^4 + 5,396,680 \epsilon_{0.008\%}^3 - 31525.0 \epsilon_{0.008\%}^2 + 69.1211 \epsilon_{0.008\%}$$

X2.2 Procedure for determining ten-year failure stress:

X2.2.1 Using each of the 30 SED values shown in X2.1.1, determine the predicted corresponding stress at ten years according to Eq A1.6.

For example:

$$\sigma_{10} = \sigma_{0.008\%} * (\epsilon_{10}/\epsilon_{0.008\%})^m = 705.421 * (5.70776E - 9/0.00008)^{0.062076} = 389.980 \text{ psi}$$

X2.2.2 Determine the predicted strains corresponding to the stresses calculated in the last section by dividing each SED by the corresponding predicted stress.

For example:

$$\epsilon = SED/\sigma_{10} = 1.46221/389.980 = 0.003749 \text{ in./in.}$$

Plot the calculated stress-strain points and perform a regression analysis. The resulting fifth order polynomial to the curve is:

$$\sigma_{10}(\epsilon) = -2.22351E + 13 \epsilon^5 + 1.26983E + 12 \epsilon^4 - 25,804,100,000 \epsilon^3 + 206,094,000 \epsilon^2 - 292349 \epsilon$$

X2.2.3 The initial estimate of the failure stress at ten years can be determined from the above equation by substituting the appropriate strain. The initial estimate of the failure strain is calculated according to Eq A1.9 as follows:

$$\begin{aligned} \epsilon_{f,i} &= (\epsilon_f/2) * (1 + n_c) \\ \epsilon_{f,i} &= (\epsilon_f/2) * (1 + n_c) \\ \epsilon_{f,i} &= 0.01575 \text{ in./in.} \end{aligned}$$

Substitute this value into the stress-strain equation calculated in X2.2.2 according to Eq A1.8 as follows:

$$\begin{aligned} \sigma_{f,10} &= \sigma_{10}(\epsilon_{f,i}) \\ \sigma_{10}(0.01575) &= -2.22351E + 13 (0.01575)^5 + 1.26983 E \\ &\quad + 12 (0.01575)^4 - 25,804,100,000 (0.01575)^3 \\ &\quad + 206,094,000 (0.01575)^2 - 292349 (0.01575) \\ \sigma_{f,10} &= 2234.37 \text{ psi} \end{aligned}$$

X2.3 Procedure for Predicting Creep:

X2.3.1 Equate the average stress of the fast test with the initial estimation of the 10-year failure stress, $\sigma_{f,10}$, calculated above as follows:

$$\begin{aligned} \sigma_{f,10} &= \frac{\int_0^{t_{r1}} \sigma_{0.8\%}(t) dt}{\int_0^{t_{r1}} dt} \\ 2234.37 &= \frac{\int_0^{t_{r1}} -2,921.37t^5 + 13,073.0t^4 - 21,836.1t^3 + 14,693.3t^2 + 316.746t}{\int_0^{t_{r1}} dt} \\ t_{r1} &= 1.37095 \text{ min.} \end{aligned}$$

Repeat this process for the slow test. The resulting time, t_{r2} , is 207.163 min.

X2.3.2 The strains corresponding to the times just calculated can be determined by multiplying the time by the strain rate.

For example:

$$\varepsilon^* t_{r2} = 0.00008 * 207.163 = 0.016573 \text{ in./in.}$$

Substitute the time and strain values calculated above into Eq A1.12 to solve for the creep exponent as follows:

$$n_c = \frac{\log\left(\frac{\varepsilon_{0.008\%}}{\varepsilon_{0.8\%}}\right)}{\log\left(\frac{t_{r1}}{t_{r2}}\right)} = \frac{\log\left(\frac{0.016573}{0.010968}\right)}{\log\left(\frac{207.163}{1.37095}\right)} = 0.082270$$

X2.3.3 Recalculate the expected failure strain in accordance with Eq A1.13:

$$\varepsilon_{fc} = \left(\frac{\varepsilon_f}{2}\right) * (1 + n_c) = \left(\frac{0.03}{2}\right) * (1 + 0.082270) = 0.016234 \text{ in./in.}$$

X2.4 Repeat the procedure outlined in A1.2.4 and A1.2.5 substituting ε_{fc} for ε_f . When the value of $\sigma_{f,10}$ has converged to a difference of less than 1% between iterations, the value of the failure strain is 0.016235, the expected stress to cause failure in ten years is 2234.83 psi, and the value of n_c is 0.082322.

X2.5 Compare the calculated n_c to the value determined from testing performed in accordance with A1.2.6 as follows:

$$\frac{|0.082322 - 0.078618|}{0.082322} = 4.5\% \leq 5.0\%$$

Therefore, no new test is required.

X2.6 The stress time factor, β , to convert a short term test at a constant strain rate of 0.008%/min to a long term value is calculated according to Eq A1.15 as follows:

$$\beta = \sigma_{f,10} / F_{bt} = 2234.83 / 3080.36 = 0.725509$$

X2.7 Procedure to calculate the creep factor, α :

X2.7.1 Determine the modulus of elasticity in accordance with 6.6.3.3 as follows:

The stress at failure for the slow test was 3080.36 psi. Therefore:

$$\begin{aligned} 0.1 F_{bt} &= 308.036 \text{ psi} \\ 0.4 F_{bt} &= 1232.144 \text{ psi} \end{aligned}$$

The corresponding strains, interpolated from measured data, are 0.1375% and 0.386% respectively.

By principles of mechanics:

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} = \frac{1232.144 - 308.036}{0.00386 - 0.001375} = 371,874 \text{ psi}$$

X2.7.2 Calculate E_{10} in accordance with A1.2.7:

$$E_{10} = \frac{\sigma_{f,10}}{\varepsilon_{fc}} = \frac{2234.83}{0.016235} = 137,655 \text{ psi}$$

X2.7.3 Determine α according to Eq A1.16:

$$\alpha = \frac{E}{E_{10}} = \frac{371,874}{137,655} = 2.70149$$

X2.8 Procedure to determine the load duration factor, C_D :

X2.8.1 Compute the strain rate according to Eq A2.1:

$$\dot{\varepsilon}_{,t} = \varepsilon_{,t} / t = 0.016235 / 86400 \text{ min} = 1.87905E - 7 \text{ in./in./min}$$

X2.8.2 For each of the 30 SED values determined in X2.1.1, calculate the predicted stress at the end of the duration of the load according to Eq A2.2.

For example:

$$\begin{aligned} \sigma_t &= \sigma_{0.03\%/min} * (\dot{\varepsilon}_t / \dot{\varepsilon}_{0.03\%})^{m(\sigma\varepsilon)} \\ \sigma_t &= 705.421 * (1.87905E - 7 / 0.00008)^{0.0062076} \\ \sigma_t &= 484.441 \text{ psi} \end{aligned}$$

X2.8.3 Determine the corresponding strains to the stresses calculated in the last section in the same manner as in X2.2.2. Plot the predicted stresses and strains at the end of the duration of the load. The fifth order polynomial regression curve for the plot is:

$$\begin{aligned} \sigma_{10}(\varepsilon) &= -3.33664E + 13 \varepsilon^5 + 1.66225E + 12 \varepsilon^4 - 29,795,700,000 \varepsilon^3 \\ &\quad + 210,686,000 \varepsilon^2 - 200861 \varepsilon \end{aligned} \quad (X2.1)$$

X2.8.4 Determine the failure stress at the end of the load duration by substituting the ten-year failure strain into the equation calculated in X2.8.3:

$$\sigma_{f,10} = \sigma_{10}(0.016235) \quad (X2.2)$$

$$\begin{aligned} \sigma_{10} &= -3.33664E + 13 (0.016235)^5 + 1.66225E + 12 (0.016235)^4 \\ &\quad - 29,795,700,000 (0.016235)^3 + 210,686,000 (0.016235)^2 \\ &\quad - 200861 (0.016235) \end{aligned}$$

$$\sigma_{f,10} = 2618.82 \text{ psi}$$

X2.8.5 Determine C_D for the duration according to equation A2.5:

$$C_D = \sigma_{f,t} / \sigma_{f,10} = 2618.82 / 2234.83 = 1.17093 \quad (X2.3)$$

X3. SAMPLE CALCULATION OF THE TEMPERATURE ADJUSTMENT FACTOR

X3.1 Calculation of temperature factor for flexural stress

X3.1.1 Determine the Temperature Adjustment Factors, C_{TF} and C_{TE} , for a flexural member given the following information:

The average stress at failure of 28 specimens tested at 23°C is 4811 psi and the modulus is 383,030 psi

The stresses at failure and flexural moduli of each of the five specimens tested at -10°C and 50°C are shown in **Table X3.1**.

TABLE X3.1 Stresses at Failure and Flexural Moduli

Temperature (°C)	Stress at Failure (psi)				
-10	7949	7896	7678	7898	7919
50	2982	2982	3218	3102	3196
Temperature (°C)	Modulus of Elasticity (psi)				
-10	535499	459264	520624	613592	803248
50	191250	153088	179525	219140	321299

X3.2 Calculate Example Temperature Factors, C_{Ti} , in accordance with equations A3.1 and A3.2.

X3.2 For example:

$$C_{Ti} = \frac{F_i}{F_{CTL}} = \frac{7948}{4811} = 1.652 \quad (\text{X3.1})$$

The C_{Ti} values for both experimental groups are shown in **Table X3.2**.

TABLE X3.2 C_{Ti} Stress at Values for Experimental Groups

Temperature (°C)	C_{Ti} (Stress)				
-10	1.652	1.641	1.596	1.642	1.646
50	0.620	0.620	0.669	0.645	0.664
Temperature (°C)	C_{Ti} (Modulus)				
-10	1.398	1.199	1.359	1.602	2.097
50	0.499	0.400	0.467	0.572	0.839

X3.3 Calculate average C_{Ti} 's by temperature and plot Temperature Factor vs. Temperature. The results are shown in **Table X3.3** and **Fig. X3.1**.

TABLE X3.3 C_{Ti} Temperature Factor vs. Temperature

Temperature	Average C_{TF}
-10	1.6353
50	0.6435
Temperature	Average C_{TE}
-10	1.5311
50	0.5557

X3.4 Calculate the best-fit regression to the data (C_T vs. Temperature).

X3.5 For general building design, substitute the maximum expected in service temperature (125°F or 51.7°C) into the polynomial equations, yields $C_{TF} = 0.62$ and $C_{TE} = 0.56$.

X3.6 Example C_T 's for other temperatures for the same material are shown in **Table X3.4**.

TABLE X3.4 Temperature Factors for an Example SGPL Product

Temperature, °C (°F)	C_{TF}	C_{TE}
-10 (14)	1.64	1.53
0 (32)	1.42	1.37
15 (59)	1.13	1.13
23 (73.4)	1.00	1.00
50 (122)	0.64	0.59
60 (140)	0.54	0.43

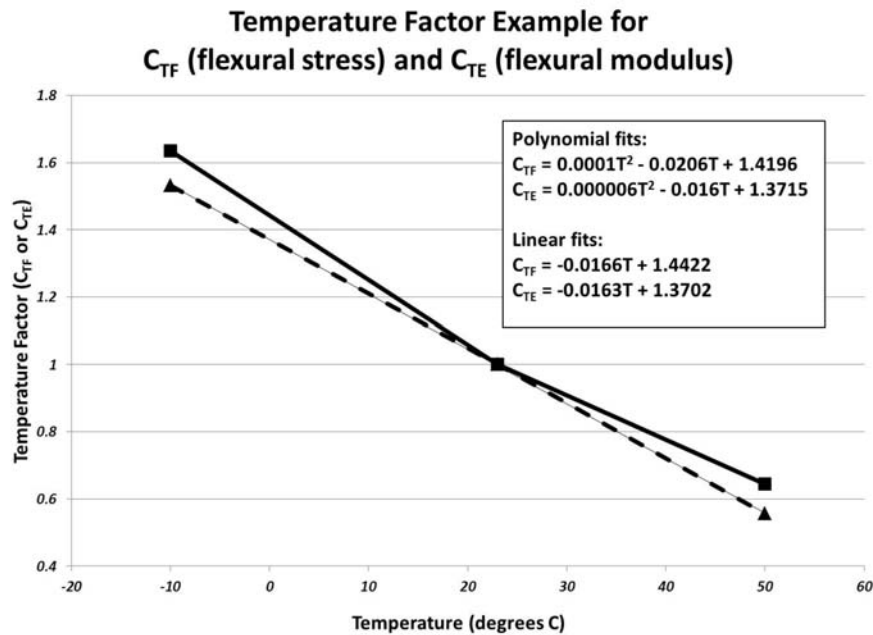


FIG. X3.1 Calculation of C_{TF} and C_{TE} as a Function of Temperature

X4. SAMPLE DESIGN CALCULATION

INTRODUCTION

Determine if a 3 by 8 plastic member can be used as a deck joist given the following information and the data presented in Table X4.1:

The beam is made of the same plastic material used in the creep adjustment factor example, temperature factor example, and Table X4.1.

TABLE X4.1 Data for an Example Plastic Product

Actual Width	2.5 in.
Actual Depth	9.25 in.
Span	8 feet simply supported
Spacing	2 feet O.C.
F_{bt} (unadjusted flexural stress)	3080 psi
E (unadjusted modulus of elasticity)	371 874 psi
Creep Rupture Stress (in accordance with Test Methods D6112)	2411 psi
Live Load	50 psf
Total Load	65 psf
Temperature Adjustment Factors	$C_{TF} = 0.62$; $C_{TE} = 0.56$
Time-related Adjustment Factors (ten-year basis)	$\alpha = 2.70$; $\beta = .726$

$$F_b = 3080 * 0.726 \leq 2411$$

$$F_b = 2235 \leq 2411$$

Therefore:

$$F_b = 2235 \text{ psi}$$

X4.2 Calculate F_b' X4.2 According to equation 2:

$$F_b' = C_T C_L F_b / (FS)$$

$$F_b' = 0.62 * 1.0 * 2235 / 2.0$$

$$F_b' = 693 \text{ psi}$$

X4.3 Calculate E' according to Eq 4:X4.3

$$E' = E * C_{TE} / \alpha$$

$$E' = 371874 * 0.56 / 2.70$$

$$E' = 77,087 \text{ psi}$$

X4.4 Procedure to calculate applied stresses and allowable flexural stress.X4.4 The applied stress from live load is calculated as follows:

$$w_{LL} = 50 \text{ psf} * 2 \text{ ft} * 12 \text{ in./ft} = 8.33 \text{ lb/in.} =$$

$$M_{LL} = w_{LL}^2 / 8 = 8.33 \text{ lb/in.} * (96 \text{ in.})^2 / 8 = 9600 \text{ lb*in.}$$

$$f_{LL} = M * y / I_x = 5760 \text{ lb.in.} * 4.625 \text{ in.} / 164.89 \text{ in.}^4 = 269.3 \text{ psi}$$

X4.1 Calculate F_b according to Eq 3:X4.1

$$F_b = F_{bt} * \beta \leq F_{cr}$$

$$F_{bt} = 3080 \text{ psi}$$

$$\beta = 0.726$$

(see subsection 13.6 for procedure to determine β)

$$F_{cr} = 2411 \text{ psi}$$

(see Test Methods D6112 for example calculations of the ultimate creep rupture stress)

Repeating the procedure for total load yields an applied stress of 350 psi.

Both of these are less than the allowable stress of 693 psi.

X4.5 Procedure to calculate allowable deflection. Assume a live load deflection limit of L/360

$$\text{Span} = 96 \text{ in.}; L/360 = 0.27''$$

$$D_{LL} = (5 * w_{LL} * L^4) / (384EI)$$

If the L/360 limit is interpreted to be a short term live load deflection, E would be taken as the short-term value. Thus, the appropriate modulus for this calculation would be 77087 * 2.70 = 208,250 psi

The computed deflection is 0.27'' – which meets the target of L/360.

X5. LOAD DURATION DATA FOR AN EXAMPLE SGPL PRODUCT (TABLE X5.1 AND FIGURE X5.1)

X5.1 See [Table X5.1](#) and [Fig. X5.1](#).

TABLE X5.1

Duration of Load	Load Duration Factor
Wind/Seismic Load - 10 minute	2.12
1 hour	1.28
Construction Load - 7 days	1.20
Snow Load - 2 months	1.17
1 year	1.10
Live Load - 10 years	1.00
Permanent/ Dead Load - 30 years	0.97

NOTE X5.1—The values shown in the table represent an example product, and will be different for other products.

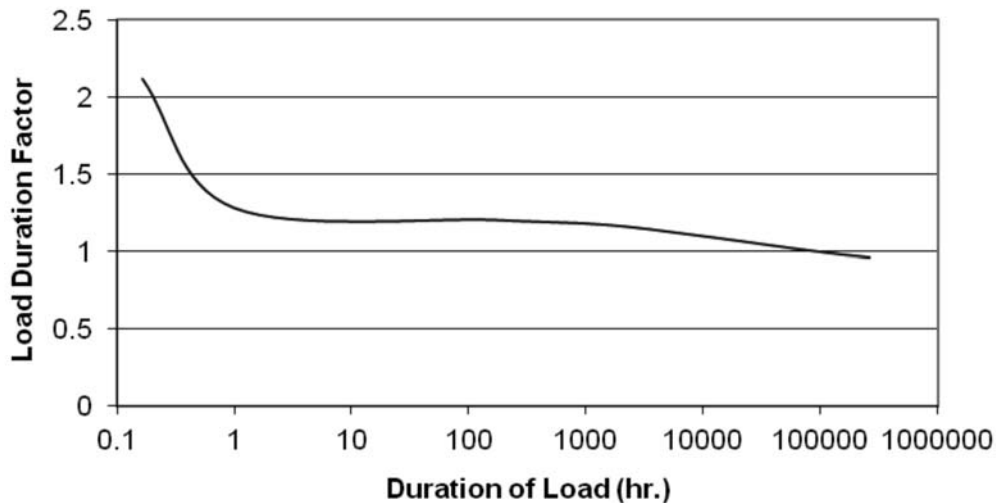


FIG. X5.1 Graph of Load Duration Factors for an Example SGPL Product

X6. TEST VERIFICATIONS OF ALLOWABLE STRESSES FOR SGPL PRODUCTS

X6.1 Test verifications of allowable stresses on full size members have been conducted for a number of practical commercial products, but most of the results are shown in proprietary reports.

X6.2 A set of examples includes studies conducted by scientists at the Georgia Institute of Technology, School of Civil and Environmental Engineering: Research Reports on Flexural Response of Proprietary Plastic Lumber Products Reinforced with E-Glass Bars, Dr. Abdul-Hamid Zureick and Dr. Yeonsoo S. Kim (2002-2004). The bases for these studies can be found in the following publications and presentations by Professor Zureick:

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