Designation: D2559 – 12a$^{\varepsilon 1}$

Standard Specification for Adhesives for Bonded Structural Wood Products for Use Under Exterior Exposure Conditions[1]

This standard is issued under the fixed designation D2559; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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

ε[1] NOTE—Paragraph 1.4 was corrected editorially in February 2016.

INTRODUCTION

This specification, which was initially approved in 1966, was developed to ensure that adhesives developed and used in structural glued laminated timber (glulam) are considered suitable for the intended application. This would include, as a maximum level of severity in the case of moisture effects, full and continuous exposure to the weather.

The use of adhesives for structural wood products has expanded beyond Glulam to include products such as Structural Composite Lumber, wood I-Joists and various composites adhesively bonded using a variety of materials. Although most structural glued wood products have traditionally specified an adhesive suitable for exterior exposure, the actual exposure of glued wood products to exterior conditions may range from exposure to the weather for brief periods of time, to continuous exposure to a marine environment.

A distinction between adhesive certification and product performance requirements is necessary to ensure the broadest possible acceptance of adhesive systems.

1. Scope*

1.1 This specification covers adhesives suitable for the bonding of wood, including treated wood, into structural wood products for general construction or other uses where a high-strength, durable adhesive bond is required.

1.2 This specification includes test methods that may be referenced by specific product standards for the evaluation and approval of structural wood adhesives. Methods are included to evaluate adhesives intended for use in exterior exposure.

NOTE 1—Consult the Commentary in Appendix X1 regarding the intent and limitations of each test method contained in this specification.

1.3 *Description of Bondline Performance*—It is recognized that structural wood adhesives are used in various applications and levels of severity in terms of moisture content, loading, cyclic and seasonal weather conditions, heat exposure and other use conditions. It is the intent of this standard to determine the suitability of an adhesive for use under various levels of severity and conditions with specific and appropriate test methods and requirements.

NOTE 2—This specification does not contain specific tests outlined for different chemical types of adhesives.

1.4 Strength and durability requirements of the adhesive are based on the performance of the adhesive in laminated wood as measured by:

1.4.1 Resistance to shear by compression loading after conditioning to the target moisture content indicated in 14.2.3 and meeting requirements in 14.4.

1.4.2 Resistance to delamination during exposure to three cycles of vacuum pressure wetting followed by drying at elevated temperature as indicated in 15.3 and meeting requirements in 15.4.

1.4.3 Resistance to creep under static load by subjecting test specimens to a specified shear stress and exposing one set of test specimens to an environment of elevated temperature and ambient humidity and another set to an environment of high humidity and meeting requirements set forth in 16.3.

1.4.4 For applications involving chemical treatment, the adhesive shall be evaluated using representative samples of treated wood.

NOTE 3—When using chemically treated wood, compatibility between the treatment, adhesive, and wood is to be considered and agreed upon between the chemical manufacture and the user.

[1] This specification is under the jurisdiction of ASTM Committee D14 on Adhesives and is the direct responsibility of Subcommittee D14.30 on Wood Adhesives.

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

NOTE 4—Additional durability testing may also be required as specified by individual product standards. Consult the Commentary in Appendix X1 for additional information and guidance as to the type of durability testing that may be appropriate to supplement this specification when characterizing the adhesive for suitability with specific wood products.

1.5 The evaluation of adhesives for use in ground contact and marine exposures are beyond the scope of this specification.

1.6 The evaluation of binder adhesives is beyond the scope of this specification.

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

1.8 The text of this specification references notes, footnotes and a commentary which provide explanatory material. These notes, footnotes and commentary (excluding those in tables and figures) shall not be considered as requirements of the specification.

1.9 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D9 Terminology Relating to Wood and Wood-Based Products
D143 Test Methods for Small Clear Specimens of Timber
D905 Test Method for Strength Properties of Adhesive Bonds in Shear by Compression Loading
D907 Terminology of Adhesives
D1165 Nomenclature of Commercial Hardwoods and Softwoods
D1583 Test Method for Hydrogen Ion Concentration of Dry Adhesive Films
D2555 Practice for Establishing Clear Wood Strength Values
D3535 Test Method for Resistance to Creep Under Static Loading for Structural Wood Laminating Adhesives Used Under Exterior Exposure Conditions
D4442 Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials
D4300 Test Methods for Ability of Adhesive Films to Support or Resist the Growth of Fungi
D5055 Specification for Establishing and Monitoring Structural Capacities of Prefabricated Wood I-Joists
D5266 Practice for Estimating the Percentage of Wood Failure in Adhesive Bonded Joints
D5456 Specification for Evaluation of Structural Composite Lumber Products
E6 Terminology Relating to Methods of Mechanical Testing
E41 Terminology Relating To Conditioning
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

[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. Terminology

3.1 *Definitions*—Many terms in this specification are defined in Terminologies D9 and D907.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *delamination, n*—the separation of layers in a laminate because of failure of the adhesive, either in the adhesive itself or at the interface between the adhesive and the adherend.

3.2.2 *engineered wood product, n*—a product consisting of a combination of smaller wood-based components bonded together using a structural adhesive and designed using engineering methods; an alternative to traditional sawn lumber.[3]

NOTE 5—The following ASTM standards may be referred to for other terms used in this specification: Nomenclature D1165, and Terminologies D9, E6, and E41.

3.2.3 *exterior exposure, n*—service environment that cause physical and chemical changes similar to that observed from weathering in which a wood product, including any adhesive bondlines, is subjected to weathering, including but not limited to: rain, snow, heat, cold and ultraviolet radiation and their cyclic or seasonal effects.

3.2.4 *glulam, n*—synonym for *structural-glued-laminated timber*.

3.2.5 *structural-glued-laminated timber, n*—an engineered stress-rated product of a timber laminating plant comprising assemblies of specially selected and prepared wood laminations securely bonded together with adhesives, with the following characteristics: (*1*) the grain of all laminations is approximately parallel longitudinally; and (*2*) the laminations may be comprised of pieces end-joined to form any length, of pieces placed or glued edge-to-edge to make wider ones or of pieces bent to curved form during gluing. (Synonym: *glulam*) ANSI/AITC A190.1–2007. American National Standard for Wood Products–Structural Glued Laminated Timber (edited to conform with ASTM format).

3.2.6 *weathering, n*—a complex series of physical and chemical changes occurring in wood products, including but not limited to, checking, dimension stability and chemical decomposition as well as a change in adhesive bondline integrity related to the natural swelling and shrinking stresses when exposing to the natural elements such as air, water, light and man-made pollutants.

4. Significance and Use

4.1 Structural design based on strength of material principles of the structural components, including the adhesive and the adhesive's potential durability, requires that the suitability for structural exterior exposure be predicted.

4.2 Performance of the adhesive for resistance to shear by compression loading, resistance to delamination during accelerated aging, exposure to wetting and drying, and resistance to creep under load data developed by this test aid in determining if the adhesive is suitable for use in structural wood products under conditions of exterior exposure.

[3] American Forest and Paper Association, American Wood Council, *Engineered Wood Products – At a Glance*, http://www.woodaware.info/guideewp.html.

4.3 Test methods specified in the scope of this specification are intended to provide the minimum basis for determining the suitability of an adhesive for use in exterior exposure conditions.

NOTE 6—Product-specific standards should be consulted for test methods applicable to desired service conditions, and appropriate criteria in context with anticipated in-service product performance requirements.

4.4 Test methods indicated for approval and certification of adhesives can be useful to adhesive manufacturers, testing laboratories, quality control agencies, architects, specifiers, other professionals and the general public.

4.5 The suitability of adhesive systems for use in the manufacture of engineered wood products for exterior applications is dependent on both the adhesive certification test requirements specified in this specification, and performance requirements provided in specific product standards.

4.6 This specification does not purport to address all test criteria required to fully identify the suitability of the adhesive in a structural wood product.

5. Classification

5.1 The manufacturer shall classify the adhesive as to general type. Typical classifications include, but are not limited to: resorcinol, phenol-resorcinol, phenol, melamine, structural polyurethane, emulsion polymer isocyanate, etc.

5.2 The manufacturer may be considered to be the testing facility certifying the adhesive.

6. Ordering Information

6.1 The manufacturer will furnish the adhesive in any suitable form agreeable to the purchaser.

7. Fillers and Extenders

7.1 If amylaceous or protein fillers and extenders are used, the adhesive must not only pass requirements of this specification, but in addition, possess sufficient antifungal properties to inhibit the growth of selected fungal species when tested in accordance with Test Methods D4300. The adhesive manufacturer shall state in his bulletin whether such materials are present.

8. Chemical Requirements

8.1 The cured adhesive film shall develop a pH value of not less than 2.5 when tested in accordance with Test Method D1583.

9. Physical Requirements

9.1 The adhesive manufacturer shall furnish written instructions stating the general chemical type of adhesive, its storage and mixing procedure, the method of wood preparation, and any other data which is pertinent to the use of the adhesive in the manufacture of laminated wood products.

9.2 The adhesive must pass the tests required by this specification for all limiting conditions recommended in the manufacturer's bulletin. The information furnished by the manufacturer should include each of the following for each species of wood included in his recommendations:

9.2.1 Limits of working life,

9.2.2 Minimum and maximum open and closed assembly times as dictated by temperature, moisture content of the wood, mix age, etc.,

9.2.3 Minimum spread rates for assembly times and use conditions as indicated in 9.2.2,

9.2.4 Minimum cure time and temperature of bondline for complete cure,

9.2.5 Minimum pressure, and

9.2.6 Maximum and minimum allowable moisture content of the wood.

10. Selection and Preparation of Wood for Testing of Adhesives

10.1 Test the adhesive on the species of wood to be bonded or for which it is recommended including chemically treated wood (see Note 7). The wood shall have a maximum slope of grain of 1 in 15 on any face or any edge. The wood shall contain no knots larger than 3 mm (⅛ in.) in diameter and shall be free from decay, machining defects (such as chipped grain, dubbed ends, feed roll polish, coarse knife marks, and feed roll compression), and any drying defects such as case hardening, collapse, splits, or checks. Use only flat-grained wood.

NOTE 7—Grouping of species is not permitted.

10.2 *Wood Moisture Content:*

10.2.1 *Ambient Curing Adhesives*—Condition the wood at 23 ± 2°C (73.4 ± 3.6°F) and a relative humidity of 50 to 70 % (preferably 65 %) until a moisture content of 8 to 14 % or, preferably 9 to 12 %, has been attained.

10.2.2 *Hot Press Curing Adhesives*—Condition the wood at 23 ± 2°C (73.4 ± 3.6°F) and a relative humidity of less than 50 % until a moisture content of 3 to 8 % has been attained.

10.3 Freshly surface each lamination before bonding with the adhesive to be tested. Remove at least 0.4 mm (1/64 in.) from each face within 24 h of bonding. The machining tolerances for each lamination used in preparing the test samples shall be no greater than ±0.25 mm (0.01 in.) between laminations and ±0.20 mm (0.008 in.) within laminations.

11. Preparation of Laminated Wood Test Members

11.1 *Ambient-Curing Adhesives:*

11.1.1 Prepare six pieces of wood of the same species for each laminated wood member. Each of the six pieces shall have a specific gravity equal to or exceeding the minimum requirement of Table 1. Each piece of wood shall be 19-mm (0.75-in.) thick lumber (see Note 8) at least 140 mm (5½ in.) in width and 1 m (40 in.) long. Orient the direction of the annular growth rings when viewed on the end of the laminations in the laminated wood test member so that they are alternated.

NOTE 8—This thickness would normally come from "nominal 1-in. lumber."

11.1.1.1 As an alternative to the preparation of laminated wood test members 1 m (40 in.) in length, prepare duplicate 610-mm (24-in.) laminated wood members to obtain at least an equivalent number of test specimens. This alternative includes the preparation of separate two-ply assemblies for evaluation in

TABLE 1 Required Shear Strength for Structural Laminated Wood Products

NOTE 1—For species other than those given, strength values shall be based on 90 % of the value for shear parallel to grain at 12 % moisture content. The use of 90 % of shear parallel to grain at 12 % moisture content takes into account the various subspecies of a particular wood species. The values for shear parallel to grain may be found in Tables 4-3a through 4–4b of the Wood Handbook, Forest Products Society (1999 edition). Base the minimum allowable specific gravity on volume for wood at 12 % moisture content. For species not listed see Note 3. Adjustments for changes in moisture content shall be made in accordance with formula 4–3 (page 4–34) found in the 1999 Wood Handbook.

NOTE 2—It has been documented that bonded shear specimens (Test Method D905 type specimen) on the average provide higher shear strength values than solid wood specimens (Test Methods D143 type specimen). It may appear to be inconsistent to compare shear strength data of bonded specimens to data based on 90 % of the solid wood shear strength found in the Wood Handbook. However, the goal of evaluating shear strength of adhesives in Specification D2559 is to demonstrate the shear strength in a laminated product (tested using Test Method D905 type specimens) meets or exceeds the strength of a solid wood beam when tested by standard procedures for solid wood (Test Methods D143 type specimen).

NOTE 3—For species not found in the 1999 Wood Handbook, values for shear parallel to grain at 12 % moisture content using solid wood are to be obtained on clear, straight-grained specimens following specific ASTM test methods and procedures. These include Test Methods D143 and Practice D2555. Test Methods D143 testing is to be performed on a minimum of 28 shear strength specimens.

Species	Required Shear Strength, KPa (psi)[A]			Minimum Allowable Specific Gravity of Solid Wood Used for Each Lamination[B]
	Moisture Content of Wood at Test			
	8 %	12 %	16 %	
Douglas fir	7 600 (1 110)	7 000 (1 020)	6 500 (940)	0.43
Hemlock, western	8 900 (1 290)	8 000 (1 160)	7 200 (1 050)	0.41
Larch, western	9 400 (1 370)	8 400 (1 220)	7 600 (1 100)	0.55
Oak, white	14 300 (2 080)	12 400 (1 800)	11 000 (1 560)	0.68
Pine, southern	10 400 (1 510)	8 600 (1 250)	7 100 (1 040)	0.51
Redwood	6 300 (910)	5 800 (850)	5 400 (790)	0.40

[A] Based on 90 % of the shear strength parallel to grain at 12 % moisture content from Table 4–3 of the 1999 Wood Handbook. Use the same shear strength values for a specific species when chemically treated wood is used.
[B] Based on weight when oven dry and volume at 12 % moisture content.

accordance with 1.4.1 using Test Method D905 block shear specimens that may be used as an alternate to stair-step specimens.

11.1.2 Apply the adhesive uniformly to the contacting faces of each lamination in accordance with the manufacturer's instructions.

11.1.3 Place the laminated wood members under pressure for a period of time and at the bondline temperature specified by the manufacturer of the adhesive.

11.1.4 *Conditioning*—Condition the laminated wood members at 23 ± 2°C (73.4 ± 3.6°F) and a relative humidity of 50 to 70 % (preferably 65 %) for the minimum time recommended by the manufacturer for each curing temperature used during the pressure period, and test immediately.

11.2 *Hot-Press Curing Adhesives:*

11.2.1 Prepare six pieces of wood of the same species for each laminated test member. Each of the six pieces shall have a specific gravity equal to or exceeding the minimum requirement of Table 1. Each piece of wood shall be 19 mm (0.75 in.) thick lumber (see Note 9) at least 140 mm (5½ in.) in width and 1 m (40 in.) long as allowed in 11.1.1.1. Orient the direction of the annular growth rings when viewed on the end of the laminations in the laminated wood test member so that they are alternated.

NOTE 9—This thickness would normally come from "nominal 1 in. lumber."

11.2.1.1 As an alternative to the preparation of laminated wood test members 1 m (40 in.) in length, prepare duplicate 610-mm (24-in.) laminated wood members to obtain at least an equivalent number of test specimens. This alternative includes the preparation of separate two-ply assemblies for evaluation in accordance with 1.4.1 using Test Method D905 block shear specimens that may be used as an alternate to stair-step specimens.

11.2.2 Apply the adhesive uniformly to the contacting faces of each lamination in accordance with the manufacturer's instructions.

11.2.3 Hot press three-layer assemblies at the pressure, press temperature, and to the bondline temperature specified by the manufacturer of the adhesive. These three-layer assemblies, after conditioning in accordance with 11.1.4, are assembled into six laminated wood test members using a Specification D2559 approved ambient-curing adhesive for the center bondline in accordance with 11.1.3.

11.2.4 *Conditioning*—Condition the laminated wood members at 23 ± 2°C (73.4 ± 3.6°F) and a relative humidity of 50 to 70 % (preferably 65 %) for the minimum time recommended by the manufacturer for each curing temperature used during the pressure period, and test immediately.

12. Number of Tests

12.1 Prepare six laminate wood members for tests, one at each of the limiting conditions listed, but all other factors, as itemized in 9.1 and 9.2, shall be in accordance with the manufacturer's instructions.

12.1.1 Liquid adhesives:

12.1.1.1 Minimum open assembly time with minimum closed assembly time,

12.1.1.2 Maximum open assembly time with maximum closed assembly time, and

12.1.1.3 Minimum open assembly time with maximum closed assembly time.

12.1.2 Film adhesives:

12.1.2.1 Minimum cure time,
12.1.2.2 Minimum cure temperature, and
12.1.2.3 Minimum pressure.

13. Preparation of Test Specimens

13.1 Dress the laminated wood members, prepared in accordance with Sections 11 and 12, on the sides to a uniform width of 127 mm (5 in.) at the completion of the conditioning period. Trim 76 mm (3 in.) off one end of each of these members and discard it. Cut the remaining trimmed members into five sections as shown in Fig. 1. Use the 102-mm (4-in.) sections labeled "A" for conducting tests in resistance to shear by compression loading in accordance with Section 14, and use the 254-mm (10-in.) sections labeled "B" for conducting resistance to delamination tests in accordance with Section 15. Discard the remaining waste trim portion.

13.1.1 If duplicate laminated wood members are made in accordance with 11.1.1.1 or 11.2.1.1 to obtain at least an equivalent number of test specimens, then trim 51 mm (2 in.) off each end. Utilize the remaining trimmed member, 508 mm (20 in.) in length by cutting two 254-mm (10-in.) sections labeled "B" or one 254-mm section "B" and two 102-mm (4-in.) sections "A" as shown in Fig. 1. If two "B" sections are prepared then make separate specimens for shear testing by preparing two-layer laminated wood members and specimens in accordance with Test Method D905 and 11.1.1.1 and 11.2.1.1. Make and test these specimens from the same species of wood, at exactly the same time, and under the same conditions as required for other test samples in this specification.

TEST METHODS

14. Resistance to Shear by Compression Loading

14.1 *Apparatus*—The testing machine capacity is to be of about 66900 N (15 000 lb) in compression or of sufficient capacity to test the species of wood in use. Equip the testing machine with a shearing tool containing a self-aligning seat to ensure uniform lateral distribution of the load. The machine shall be capable of maintaining a uniform rate of loading such that the load is applied with a continuous motion of the movable head to a maximum rate load not to exceed 13-mm (0.50-in.)/min. The shearing tool shown in Fig. 1 of Test Method D905 has been found satisfactory. Locate the testing machine in an atmosphere such that the moisture content of the test pieces developed in accordance with 11.1.4 is not noticeably altered during testing.

14.2 *Samples:*

14.2.1 Prepare at least six samples for testing in shear by compression loading. When stair-step shear samples are used, cut two from each of the 102-mm (4-in.) sections labeled "A" in Fig. 1. When separate two-ply laminated wood samples are made in accordance with 11.1.1.1 or 11.2.1.1 make at least six test samples and cut at least five test specimens from each as specified by the dimensions of Figs. 2 and 3 of Test Method D905.

14.2.2 The stair-step shear specimens shall conform to the form and dimensions shown in Fig. 2. Take care in preparing the test specimens to assure that the grain direction in the wood is parallel to the direction of loading during test. The loaded surfaces shall be smooth and parallel to each other and perpendicular to the height. When sawing the bonded assembly, exercise care to ensure that the saw cuts to, but not beyond, the adhesive line. Measure the width and height of the specimen at the adhesive line to the nearest 0.25 mm (0.01 in.) to determine the shear area. All requirements above shall apply when individual test specimens are cut from the separately laminated test members of Test Method D905.

14.2.3 Condition the individual test specimens in the conditioning environment described in 11.1.4 and 11.2.4 to a target moisture content of 8, 12, or 16 % for species listed in Table 1. For all other species condition to a target moisture content of 12 %. The allowable variation in the target moisture content before testing is ±1 %. Moisture content is to be determined using Test Methods D4442.

14.3 Test the test specimens cut from the test samples described in 14.2 to failure. Report the shear strength calculated in kilopascals (kPa) (pounds per square inch (psi)) based on the bonded area between two laminations rounded to the nearest 0.0645 mm^2 (0.01 in.^{2}), for each test specimen together with the estimated percentage wood failure. Practice D5266 has been found useful in estimating the percentage of wood failure in adhesive bonded joints.

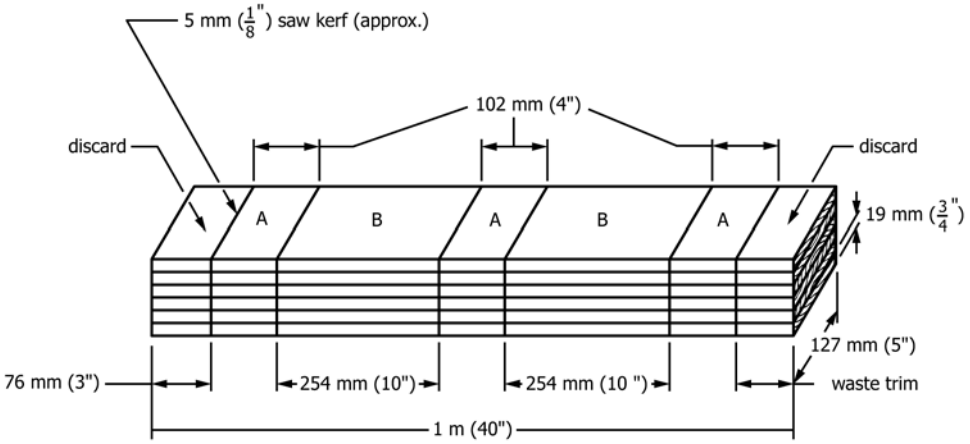

FIG. 1 Laminated Test Beam

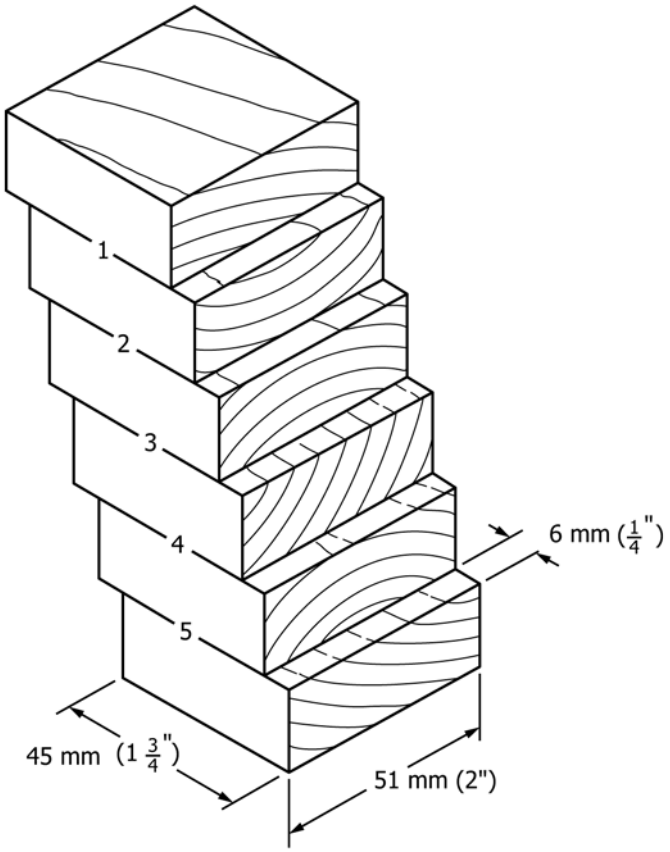

FIG. 2 Stair-Step Shear Specimen

14.4 *Requirements:*

14.4.1 The average shear strength for each group of laminated wood members made at one manufacturing condition as specified in Section 12, and tested as described above shall be not less than the values specified in Table 1 at the appropriate moisture content of the wood.

14.4.2 The average wood failure for each group of laminated wood members made at one condition and tested as prescribed in Section 14 shall be not less than 75 % for all species listed in Table 1.

14.5 *Retest:*

14.5.1 If the strength requirements of 14.4 are not satisfied, but the wood failure value is 95 % or more, retest the adhesive.

15. Resistance to Delamination During Accelerated Exposure

15.1 *Apparatus:*

15.1.1 An autoclave or similar pressure vessel capable of withstanding at least 550 kPa (80 psi) is required for impregnating the specimens with water. Equip the vessel with a vacuum pump or similar device capable of drawing vacuum of at least 85 kPa (25 in.) Hg (sea level) in the vessel and provide a method for obtaining pressures to 517 kPa (75 psig). Equip the vessel with a steam inlet capable of providing steam at 100°C (212°F) for 1½ h.

15.1.2 An oven capable of maintaining 65.5 ± 2°C (150 ± 3.6°F) with sufficient circulation to remove moisture from the chamber is required for drying the specimens.

15.1.3 Circular fluorescent desk lamp with 5× viewing magnifier in the center of the lamp. Equivalent light sources and magnifier may be substituted for the above.

15.1.4 Machinist's scale graduated in 0.01 and 0.10 divisions.

15.2 *Samples:*

15.2.1 For ambient-curing adhesives prepare six delamination specimens representing three from each 254-mm (10-in.) section labeled "B" in Fig. 1. Cut each 254-mm section into three 76-mm (3-in.) specimens with the 76-mm dimension parallel to the grain direction in the wood. The total length of bondlines on each end grain face is 635 mm (25 in.). On six specimens this equals 7620 mm (300 in.). Test eighteen specimens (six from each of three laminated wood test members prepared in accordance with Sections 11, 12, and 13 to certify each adhesive on each species of wood to be laminated.

15.2.2 For hot-press curing adhesives prepare eight delamination specimens (four from each 610 mm (24 in.) laminated wood member as allowed in 13.1.1) with dimensions as specified in 15.2.1. In order to achieve the required 7620 mm (300 in.) of test bondlines (as specified in 15.2.1) with hot-pressed laminated wood members, the end grain faces of 7.5 specimens are required. Thus for hot-press curing adhesives, four test bondlines 508 mm (20 in.) on each end grain face of 8 specimens will be examined for a total of 8128 mm (320 in.). Test twenty four specimens (four from each of six laminated wood test members prepared in accordance with Sections 11 – 13) to certify each adhesive on each species of wood to be laminated.

15.3 *Procedure:*

15.3.1 Weigh and record to the nearest 1 g (0.035 oz) the weight of each test specimen. Place the eighteen 76-mm (3-in.) test specimens in the pressure vessel described in 15.1.1, weigh down, and admit water at a temperature of 18 to 27°C (65 to 80°F) in sufficient quantity so that the specimens are completely submerged throughout the test. Separate the test specimens by stickers, wire screens, or other means in such a manner that all end grain surfaces are freely exposed to the water. Draw a vacuum of at least 85 kPa (25 in.) Hg (sea level) and hold for 5 min. Release the vacuum and apply pressure of 517 ± 14 kPa (75± 2 psi) for 1 h. Repeat the vacuum-pressure cycle with the test specimens remaining submerged, making a two-cycle impregnating period requiring a total of approximately 2⅙ h (Note 10). Dry the test specimens in the oven described in 15.1.2 at 65.5 ± 2°C (150 ± 3.6°F) for a period of between 21 and 22 h, with sufficient air circulation to lower their weight to within 15 % of the original test specimen weight. During drying, place the test specimens at least 51 mm (2 in.) apart with the end-grain surfaces parallel to the stream of air. This completes the first cycle.

NOTE 10—This should increase the weight of the test specimens by at least 50 %. If the weight is not increased by this amount, continue this cycle until the weight has increased at least 50 %.

15.3.2 Return the specimens to the pressure vessel and admit steam at 100°C (212°F) for 1½ h, with drains open so the wet condensate is removed as formed, after which admit water at 18 to 27°C (65 to 80°F) and apply a pressure of 517

± 14 kPa (75 ± 2 psi) for 40 min. Dry the specimens in the oven as above. This completes the second cycle.

15.3.3 Repeat the first cycle, making a total test period of 3 days. Record the data as outlined in 15.4.1.

15.4 *Requirements:*

15.4.1 At the end of the final drying period specified in Section 15, visually examine each specimen. Immediately measure, to the nearest 1.27 mm (0.05 in.), the total length of open joints (delamination) on each end-grain surface of each specimen and record in Table 2. Do not record as delamination any failure in the wood due to checking or small isolated knots. Do not record any delamination that is less than 2.54 mm (0.10 in.) in length and more than 5 mm (0.20 in.) away from any recordable delamination. Record as delamination, any failure where shallow wood failure is noted and no other factors related to the wood, such as grain angle and growth-ring structure, are influencing the delamination. Do not include as delamination, any failure where a significant amount of wood failure is noted and which is influenced by factors such as grain angle or growth-ring structure. Measure and record in Table 2 the total length of end grain bond line for each of the specimens. For total delamination length, add together the recorded delamination for each bond line on the two end-grain surfaces of all the specimens. Report as percent delamination, the total delamination length in each bond line of all the specimens divided by the total length of all the bond lines of all specimens multiplied by 100 and record in Table 2 (see Note 12). The delamination for each manufacturing condition (see Section 12) shall not exceed 1 % for any bond line in the laminated test member for softwoods or 1.6 % for hardwoods. Table 2 is provided to record all measurements and calculate percent delamination.

NOTE 11—In order to ensure that the core moisture content will exceed the shell moisture content and thus hold the delamination open and visible, the laminated wood test specimens shall be removed from the final drying cycle in the oven, as prescribed in 15.3.1, when the final weight of each specimen is not less than 1.15 nor more than 1.25 times the weight before original treatment.

NOTE 12—For hot-pressed adhesives the center bondline is evaluated as well as the test bondlines to ensure that the Specification D2559 ambient-curing adhesive performs as expected.

15.5 *Retest*—If the requirements of 15.4.1 are not satisfied in any one laminated wood member, including the center bondline of a hot-pressed laminated test member, then test one additional member. If all the requirements are met in retest, disregard the results of the original test.

16. Resistance to Creep Under Static Loading

16.1 Considerations regarding adhesive creep resistance:

16.1.1 Creep data obtained in this specification is based on observing standard test specimens laminated with a test adhesive, loaded to a specific shear stress, subjected to a specific environment of temperature and humidity and monitored for any deformation over a short period of time. Test results from the evaluation of adhesive creep, under designated environmental conditions of the test, provide a measure of the adhesive to withstand constant loading over a relatively long period of time. Adhesive creep testing in this specification is intended to evaluate creep properties of an adhesive over a relatively short period of time and is not intended as a measure of creep resistance of a structural wood product. Long term creep testing related to the adhesive in a structural wood product and exposed to specific service environments or classes is to be conducted in accordance with appropriate product standards. (Note 4.)

NOTE 13—Evaluation of creep in a structural wood product has several components. Creep of an adhesive, as measured by this specification, is intended to only address the adhesive component and not other factors such as design of the wood product, wood components, and any interacting factors such as those related to shear stresses and service environment. Consult the Commentary in Appendix X1 for additional information and guidance related to evaluation of creep.

16.2 *Procedure*—Test the adhesive in accordance with Test Method D3535 using four multijoint specimens, each loaded to 218-kg (480-lb) total load or 1655 kPa (240 psi). Expose two specimens to an environment of 71°C (160°F) at ambient humidity and the other two at 27°C (80°F) at 90 % relative humidity. The exposure period shall be 7 days in both cases.

TABLE 2 ASTM D2559 Test Results

Adhesive: _____
Assembly time: _____
Species: _____
Softwood: _____
Hardwood: _____

	Measured Delamination Length By Specimen Number, in.[A]								Bond Line Delamination, in.[B]	Bond Line Length, in.[C]	Calculated Delamination, %[D]	Allowable Delamination Softwood, %	Allowable Delamination Hardwood, %
Bond Line	1	2	3	4	5	6	7[E]	8[E]					
A												1	1.6
B												1	1.6
C												1	1.6
D												1	1.6
E												1	1.6

[A] Sum of both end grain surfaces for each bond line.
[B] Sum of delamination for both end grain surfaces of all specimens for each bond line.
[C] Sum of end grain bond line length of all the specimens.
[D] Bond line delamination (total delamination length in the bond line of all specimens) divided by bond line length (total length of all the bond lines of all specimens) multiplied by 100.
[E] Used only for hot pressing adhesives.

16.3 *Measurement*—At the end of the exposure period, measure the total length of slippage (creep) to the nearest 0.127 mm (0.005 in.). Add the total creep for both test specimens of each variable combination and report in milimetres (inches).

16.4 *Requirement*—The total creep shall not exceed 3.63 mm (0.139 in.) for the two specimens combined from each variable combination. If either variable combination exceeds the allowable limit, the adhesive has failed.

16.5 *Retest*—If the creep requirements of 16.4 are not satisfied, but the wood failure is 95 % or more, retest the adhesive.

17. Report

17.1 The report shall include the following:

17.1.1 Identification of the adhesive used by class, number, or manufacturer's mark.

17.1.2 Application and bonding conditions used for the specimens.

17.1.3 Wood species evaluated and if not listed in Table 1 the adjusted (90 %) shear strength parallel to grain at 12 % moisture content. Report whether from the Wood Handbook or from testing following guidance in Note 3 in Table 1.

17.1.4 Wood preparation and conditioning including specific gravity and moisture content at time of bonding.

17.1.5 Temperature and relative humidity at time of bonding.

17.1.6 Number of specimens tested.

17.1.7 Number of laminated wood members represented.

17.1.8 Maximum and minimum values obtained. Include the standard deviation or all individual test values, or both, in the report at the option of either the purchaser or the manufacturer of the adhesive.

17.1.9 The average value for each test and the average percentage wood failure for shear and creep resistance.

18. Precision and Bias

18.1 A round robin test was conducted on the test method for Resistance to Shear. The precision of shear strength testing has two components: within-laboratory (repeatability) and between-laboratory (reproducibility). The data from the round robin test was analyzed using Practice E691. The precision of the test method is affected by many factors including, but not limited to: (*1*) the wood species, (*2*) grain direction, (*3*) growth ring orientation, (*4*) the quality of the bonded joint, (*5*) precision of the testing machine, and (*6*) the operator.

TABLE 3 Shear Strength and Wood Failure Precision

	s_r[A]	s_R[B]	r[C]	R[D]
Shear Strength	159.8	175.6	447.4	491.7
Wood Failure	11.2	13.4	31.4	37.5

[A] Standard Deviation Within-Laboratory (repeatability).
[B] Standard Deviation Between-Laboratories (reproducibility).
[C] 95 % Repeatability Limit (within a laboratory).
[D] 95 % Reproducibility Limit (between laboratories).

TABLE 4 Cyclic Delamination Precision

	s_r[A]	s_R[B]	r[C]	R[D]
SPF	3.97	4.25	11.12	11.76
SYP	1.54	2.68	4.31	7.50
Hem Fir	5.01	9.18	14.02	25.70

[A] Standard Deviation Within-Laboratory (repeatability).
[B] Standard Deviation Between-Laboratories (reproducibility).
[C] 95 % Repeatability Limit (within a laboratory).
[D] 95 % Reproducibility Limit (between laboratories).

18.1.1 The round robin was done using southern yellow pine lumber. Table 3 gives the results of the round robin. The results are expressed as precision statistics within a laboratory (repeatability) and between-laboratories (reproducibility). Both standard deviation (s_r and S_R) and 95 % repeatability and reproducibility limits (r and R) were selected as precision statistics. The data generated by this round robin is available.

18.1.2 The 95 % repeatability and reproducibility limits were similar for both shear strength and estimated wood failure. This may indicate that the largest source of variability may be affecting all laboratories such as properties of the wood.

18.2 A round robin was conducted on the test method for Resistance to Delamination using three different species of wood (SPF, SYP, and Hem Fir). The results of the round robin were analyzed using Practice E691.

18.2.1 Table 4 gives the results of the round robin. Both standard deviation (s_r and s_R) and 95 % repeatability and reproducibility limits (r and R) were selected as precision statistics. Since the reproducibility standard deviation (between laboratories) was not much larger than the repeatability standard deviation (within a laboratory), it may indicate that the largest variability was due to a factor which would affect all laboratories such as drying of the specimens or measuring the amount of observable delamination.

18.2.2 The precision of this test method is affected by many factors such as: wood species, grain direction, growth ring orientation, specific gravity of the wood, quality of the bonded joint, oven drying rate, and the operator (including reading of delamination). The data generated by this round robin is available.

18.3 The test methods have no bias because the shear strength, wood failure, and percent delamination are defined by the testing methods.

19. Keywords

19.1 adhesive; delamination; durability; exterior exposure; glulam; laminated wood; shear strength; structural-glued-laminated timber

APPENDIX

(Nonmandatory Information)

X1. COMMENTARY

X1.1 Introduction to the Standard

X1.1.1 This revision of Specification D2559 for Adhesives for Structural Wood Products for Use Under Exterior Exposure Conditions has been underway for some time. The goals of this revision were many including, but not limited to:

a. Structural wood adhesives development has expanded to incorporate new chemistries and technologies;

b. Laminated structural wood products are no longer limited to assessing adhesives for structural glued-laminated-timber (glulam) but may also be applicable to other structural wood products, some of which are now referred to as Engineered Wood;

c. Structural wood products containing these adhesives are used in various applications that differ in severity as to the demands on the wood product and the adhesive bonds;

d. Additional durability requirements and test methods may be needed to address the various demands in severity on the adhesive bonds depending upon the wood product and service environments;

e. Harmonization with the ASTM Committee D07 on Wood, Canadian Standards Association (CSA) and International Organization of Standards (ISO) results in parallel mechanisms to evaluate structural wood adhesives.

Specification D2559 had its beginnings in 1966 as a mechanism to evaluate and certify adhesives for use in the manufacture of Glued Laminated Lumber. The specification became recognized as the premier method to evaluate structural wood adhesives. It was selected for reference in many product standards within ASTM, in the wood industry and internationally both as an adhesive evaluation tool and to specify adhesives in selected structural wood products.

This specification is considered the classic standard specification for evaluating structural wood adhesives. These adhesives are intended for use in the manufacture of wood products exposed to a wide spectrum of environmental conditions or severity of exterior exposure. This spectrum of environmental conditions range from an adhesive intended for use in a protected service environment expected to withstand occasional short duration wetting and drying during transport and building construction, to continuous exterior exposure under wet conditions.

A shortcoming that became evident when Engineered Wood began to be used in place of glulam, in some instances, was that Specification D2559 made no allowances for preparation or testing of heat-cured test specimens. This was addressed with changes to the specification, which was issued in 2004.

Exterior Exposure—The specification was primarily developed as an evaluation mechanism to determine the suitability of structural adhesives for use in glulam. This specification has evolved to include a significant number of additional uses for adhesives in structural wood products. Due to the nature of building construction and the consequences of product failure, almost all structural wood products manufactured using these adhesives, including those intended for interior applications, are expected to withstand exterior exposure. In addition, there are exceptions where use of the adhesive in interior applications would be subjected to similar environmental conditions as a fully exterior environment, especially in terms of moisture.

X1.2 Application of the Standard Specification

X1.2.1 This standard is applicable to structural wood products that are adhesively bonded with a variety of adhesive chemistries. Specification D2559 has remained the evaluation standard of choice for the traditional structural wood adhesives as well as the newer adhesives for these products. These newer adhesively bonded wood products that have been developed are commonly referred to as Engineered Wood. Engineered wood products include glulam but also products such as laminated veneer lumber (LVL), I-joists, structural finger joints and other structural composite lumber (SCL) products. Specification D2559 is referenced in many of the appropriate product standards such as Specification D5456 for Evaluation of Structural Composite Lumber Products and Specification D5055 for Establishing and Monitoring Structural Capacities of Prefabricated Wood I-Joists.

It is noted and recognized that this specification is first and foremost an adhesive standard to evaluate an adhesive before considering it suitable for specific products or applications, and is not intended as the sole mechanism for determining the suitability of an adhesive for adhesively bonded wood products. However, although product standards such as those within ASTM Committee D07 on Wood are specifically intended for that purpose, it is recognized the line between evaluating an adhesive and an end product may not be distinct. As a result, a significant amount of the evaluation of the adhesive is necessary to provide assurance that it and the resulting adhesive bonds will perform as expected in structural wood products in their intended environment, but without addressing a specific end product.

X1.3 Scope

X1.3.1 The specification recognizes the adhesive performance, and thus, the requirements of an adhesive in a structural wood product are dependent on the severity, especially the moisture content and swelling and shrinking stresses, to which a bonded wood product may be subjected.

X1.3.2 *Considerations of Adhesive Bond Exposures*—Structural wood adhesives are used in many adhesively bonded wood products. This specification and specified test methods take into condensation the wide range of environmental conditions to which the adhesive bonds may be subjected. These products can be exposed to service environments in which the adhesive bonds may be subjected to various levels of severity in terms of amount of moisture, swelling and shrinking stress

created in the wood product by alternately wetting or soaking and drying, exposure to elevated temperatures and in the most severe cases bonding to chemically altered or preservative treated wood.

X1.4 Treated Wood

X1.4.1 When the adhesive is to be evaluated for use in bonded wood products requiring the use of preservative treated wood, such as defined by the applicable building codes and/or provided as a recommendation by EWP manufacturers, the specific species of wood and the preservative treatment should be taken as the "test species" to be subjected to the testing as indicated in X1.19 – X1.21. This includes Resistance to Shear, Cyclic Delamination, and Creep. It is recommended that the adhesive manufacturer, preservative manufacturer and treater, and manufacturer of the wood product as well as those specifying the use of the preservative treated wood consider the potential interaction of the chemicals, treatment conditions and in-service conditions which may result in conditions that are either detrimental to the bond line or the wood adjacent to the bond line over time. As this may involve the exchange of proprietary information in order to develop a suitable evaluation protocol, it is beyond the scope of this specification.

X1.5 Considerations of Preservative Treated Wood

X1.5.1 The specification recognizes the need to provide minimum performance level testing on chemically treated wood as is required for different wood species. In addition, it's recognized interaction with chemicals present in treated wood may affect or inhibit adhesion or exterior performance of the wood product containing the adhesive. There may also be longer-term interactions that will need to be considered under specialized test conditions that are beyond the scope of this specification. As such the wood treatment chemical manufacturer and processor, adhesive manufacturer, and user are to confirm from the aspect of their individual concerns the final bonded structural wood product will perform as expected.

X1.6 Additional Durability Testing

X1.6.1 In this specification, evaluation of structural adhesives as to their suitability for use in marine, or ground contact exposures are beyond the scope of this specification.

X1.6.2 Specific wood products may require durability testing that is unique to the use of the product and the adhesive. As such, a wood product standard may specify a durability test that is considered essential to confirm suitability of the adhesive under specific conditions of use and exposure. Such procedures and requirements may not be restricted to ASTM, CSA, ISO or EN methods but may include industry standards from organizations such as the American Institute of Timber Construction (AITC), APA–The Engineered Wood Association or others.

X1.7 Use of Binder Adhesives

X1.7.1 Structural adhesives as described in this specification are used in structural wood products involving applications consisting of solid wood, such as glulam as well as with those of various forms of composite lumber, such as wood I-Joists. Certain binder adhesives are found in various wood products that are components in structural wood products. These components may also be used in combination with structural adhesives that have been evaluated by this specification using solid wood.

Although binder adhesives are used in specific structural wood applications by way of being a component of a composite product, evaluation of these adhesives is beyond the scope of this specification.

X1.8 Terminology

X1.8.1 *exterior exposure, n*—"Exterior" exposure is not intended to be limited to outdoor applications or an "exterior" environment. Interior environments that cause physical and chemical changes similar to that observed from weathering, do exist. An example of one such environment is an enclosed or indoor swimming pool. Consideration of exterior exposure in large part relates to inherent moisture content and temperature of the specific environmental condition. These considerations can vary from wood contained within the interior of dry, heated or unheated buildings which has generally been found to have a MC between 6 and 14 % according to season and location of adhesive bondlines in structural wood products which are subjected to full and repeated or continuous exposure to the weather including high moisture content conditions, that traditionally are considered those in which the moisture content of solid wood exceeds 16 %.

X1.8.2 *engineered wood product, n*—The expansion of the specification to be inclusive of all adhesively bonded structural wood products including but not limited to glulam, laminated veneer lumber (LVL), parallel strand lumber (PSL), and structural finger joints as well as Wood I-Joists has yielded a new industry term intended to encompass all structural wood products. The committee on wood (D07) is actively working to develop a definition for engineered wood products. Once their work is complete, the definition will be reviewed by D14.30 to determine if it can be used in place of the definition recently approved by D14 Committee on Adhesives.

X1.9 Significance and Use

X1.9.1 Suitability for structural exterior exposure predictability is required because most wood products are exposed to either limited moisture during the building cycle or are used in continuous exterior exposure environments. In order to provide a reliable adhesive for a structural wood product, the adhesive is required to meet the minimum requirements of Specification D2559.

X1.10 ASTM Standards [2]

X1.10.1 Specification D2559 is not intended to cover all the test standards needed to evaluate adhesives used in structural wood products. At a minimum, the specific wood product standards should be referenced to determine what additional tests may need to be conducted. Several ASTM standards are listed below that may be of use in evaluating wood products manufactured with structural wood adhesives:

D1151 Practice for Effect of Moisture and Temperature on Adhesive

D1183 Practice for Resistance of Adhesives to Cyclic Laboratory Aging Conditions

D1184 Test Method for Flexural Strength of Adhesive Bonded Laminated Assemblies

D4680 Test Method for Creep and Time to Failure of Adhesives in Static Shear by Compression Loading (Wood-to-Wood)

D4688 Test Method for Evaluating Structural Adhesives for Finger Jointing Lumber

D6007 Test Method for Determining Formaldehyde Concentrations in Air from Wood Products Using a Small-Scale Chamber

D6815 Specification for Evaluation of Duration of Load and Creep Effects of Wood and Wood-Based Products

D7247 Test Method for Evaluating the Shear Strength of Adhesive Bonds in Laminated Wood Products at Elevated Temperatures

E1333 Test Method for Determining Formaldehyde Concentrations in Air and Emission Rates from Wood Products Using a Large Chamber

X1.11 Fillers and Extenders

X1.11.1 The use of fillers and/or extenders in an adhesive is sometimes desirable to improve the adhesive's working properties and reduce its cost. However, it is important to regulate the amount and type of fillers and extenders because if the amount used is excessive, the strength and durability of the adhesive can suffer. If amylaceous or protein-based materials are used, the adhesive can become susceptible to fungal attack. Fungal attack may affect the working properties of the adhesive as well as the durability and the strength properties of the bonded structural wood product. This standard permits fillers and extenders to be used, but relies on adhesive manufacturers to know the types and amounts that can be added without compromising performance and intent of this standard.[4]

X1.12 Chemical Requirements

X1.12.1 It is important to regulate the pH of the adhesive used for the bonding of wood. The strength of the wood layer adjacent to the adhesive layer can be affected by the pH of the adhesive. pH of adhesives that are subjected to repeated wetting and drying, which is simulated in the vacuum pressure, boiling and drying cycles specified in the standard, may affect the strength of the wood adjacent to the bond line. Thus, compared to an adhesive with a neutral pH, adhesives with extreme pH values can show a more pronounced reduction in shear strength, but are expected to show no corresponding reduction in percent wood failure.[4] The pH limit is an important criteria in order to avoid adhesives that would cause degradation of the wood which may be accompanied by higher wood failure.

X1.13 Physical Requirements General Considerations

X1.13.1 For proper use of the adhesive, the user needs to understand the recommended operating conditions for the adhesive so that they do not manufacture engineered wood products outside the acceptable operating condition or limits of the adhesive. The adhesive manufacturer needs to demonstrate that an acceptable bond is formed at the extremes of this operating window. This assures the adhesive user that the product should be acceptable if the adhesive is used within this operating window. To form a good bond, the adhesive needs to penetrate into the wood, but not over penetrate. Having sufficient spread rate, the proper open and closed assembly times, and correct pressing pressure are important in assuring proper penetration.

a. Too low of a spread rate will lead to a starved adhesive bond, especially under wet conditions.

b. The open time allows the adhesive to penetrate the wood and to lose the water solvent to evaporation. Some loss of water can lead to increased adhesive tack but too much water loss can lead to a dry surface.

c. The closed assembly time allows penetration into both surfaces and water migration into the wood, but there is little water loss to evaporation.

d. The pressing pressure not only brings the surfaces together but also forces the adhesive into lumens and other pores of the wood structure for better adhesive-wood contact. Other engineered wood products rely on a compression fit between components to provide suitable pressure for good contact.

e. The moisture content of the wood is important to obtain good penetration. If the wood is too dry the adhesive wets the wood slowly, and for polyurethane adhesives, for example, the adhesive may cure poorly due to insufficient moisture. Too much moisture inhibits adhesive penetration and can lead to slow setting of the adhesive.

The adhesive manufacturer must provide the adhesive user all the information that is needed to correctly use the adhesive so that the commercial assemblies and manufactured bonded wood product reflect the conditions under which the adhesive was approved.

X1.14 Selection and Preparation of Wood for Testing of Adhesives

X1.14.1 The intent of Specification D2559 is to evaluate the adhesive and adhesive bond, and not to evaluate the effect of wood defects on performance. Therefore the provisions in 10.1 are intended to eliminate or minimize the defects associated with wood that could detrimentally affect the properties of the adhesive bond line. The use of flat-grained wood is described as wood in which the growth rings make an angle of less than 45° with the wider face of the wood (see Fig. X1.1). Flat-grained wood laminations when oriented as described in the specification will produce stresses perpendicular to the bond

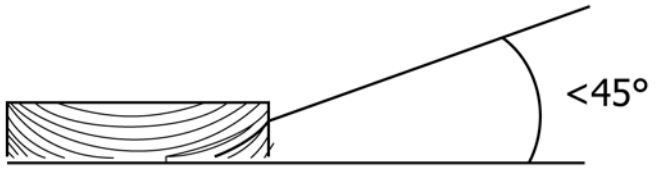

FIG. X1.1 Flat-Grained Wood

[4] CSA O112.9 Standard Specification for Evaluation of Adhesives for Structural Wood Products (Exterior Exposure), Commentary and Guidelines on Use of the Standard, p. 3, Canadian Standards Association, 2010.

line as the laminations expand and contract with moisture change. This is intended and will cause to show a separation where the bond line has failed.

Species

Table 1 lists a number of common species that are typically used to evaluate the adhesive for suitability of use. For species not listed refer to Tables 4-3a through 4-4b of the Wood Handbook, Forest Products Society (1999 edition or most current edition). For species not found in the Wood Handbook consult the notes in Table 1 for guidance. The adhesive is to be evaluated on each species for which recognition or suitability of use is required.

Minimum Allowable Specific Gravity

Table 1 provides the minimum allowable specific gravity of solid wood for each lamination in terms of the species listed. For those species not listed the minimum allowable specific gravity is to be based on volume of wood at 12 % moisture content. When evaluating chemically treated wood, conditioning should take place at 65 % relative humidity and 20°C (68°F) until equilibrium is attained.

X1.15 Wood Moisture Content

X1.15.1 The recommended moisture content of 8 to 14 % for ambient curing adhesives represents the equilibrium MC for solid wood products in "Dry Service" conditions. The recommended moisture content of 8 to 9 % for hot press curing adhesives represents the EMC for LVL products. Wood moisture content too low or too high can reduce the ability of the adhesive to wet and penetrate the wood, or inhibit the curing of the adhesive. In regards to wood that has been chemically treated, the properties at 65 % relative humidity and 20°C (68°F) should be used because the moisture content versus exposure condition may be changed.

X1.16 Wood Surfacing

X1.16.1 The use of freshly surfaced lumber is to minimize wood resin/sap as well as dust, debris or other foreign material from contaminating the bond line surface. Providing a fresh surface for bonding will ensure consistency in the quality of the lumber surface and that contamination is not interfering with the performance of the adhesive within the specific test specimens.

Although not expressly stated in the specification, it is implied the lumber is to be surfaced by knife planing. The use of sanding or abrasive planing, based on the literature, is not considered an acceptable method of preparing the surface of lumber prior to laminating. Sanding of the surface, in most cases, crushes the cells and provides a mechanically weak boundary layer resulting in reduced shear strength and increased wood failure of the adhesive bonds.

It has been well documented that the surface quality of some specific species, such as southern yellow pine (SYP), are time dependent related to wood resin contamination. It has also been documented that the relative humidity and temperature of the location where the surfaced lumber is stored can affect the tolerances of the laminations. The use of 24 hours as a maximum time for surfaced lumber to age prior to bonding is well accepted and proven to be an acceptable limit both in terms of extractives and moisture content. This time limit provides as much as possible a neutral surface and substrate for evaluating the performance of the adhesive bond line.

X1.17 Preparation of Structural Wood Test Members General Considerations

X1.17.1 In prior versions of this specification, it was not possible to test two- or three-layer assemblies in accordance with the Resistance to Cyclic Delamination test in which the assemblies had been laminated and cured by Hot Pressing. Thus, a method was added to convert two- or three-layer assemblies into the standard six ply assemblies.

In order to properly test the adhesive's strength, the wood has to be of good quality. The general assumption is that the adhesive has similar strength characteristics as the wood because the design standards are based upon wood strength. Table 1 defines the strength of the wood used in the test. Clear wood with a low slope of grain is needed because of the small specimen size and to control penetration.

X1.18 Number of Tests

X1.18.1 A minimum of six laminated test members as described in Section X1.17 provides assurance an adequate number of specimens will be from different samples and the test results will be an acceptable cross section of adhesive bond performance. Three combinations of assembly time are required to simulate preparation of a bonded wood product in a manufacturing facility. The three combinations of assembly time have historically been related to the use of adhesives in structural-glued-laminated-timber. However, the performance of the adhesive at both minimum and maximum assembly times is an important consideration for all structural wood products.

The reactive components of adhesives used in making structural assemblies chemically crosslink to develop creep resistance. The crosslinking process and solvent loss for the adhesive change the physical properties of the adhesive, which in turn alters its ability to penetrate the wood. The wood species influences both the penetration and the forces imparted onto the bondline. Thus, these tests need to be run with the same species that will be used commercially.

For liquid adhesives, the minimum open assembly time with minimum closed assembly time tests the case for low solvent (water) evaporation and minimum time to penetrate the wood. The maximum open assembly time with maximum closed assembly time tests a drier adhesive with the greatest allowable penetration. Minimum open assembly time with maximum closed assembly time gives the lowest amount of solvent evaporation with a long adhesive penetration time. For the film adhesives, the conditions for the least curing (minimum cure time and minimum cure temperature) are tested to be sure that sufficient curing takes place for the adhesive. For these adhesives, the minimum pressure confirms that the pressure is sufficient to give good penetration.

Many of the new fast curing adhesives which are being used in the production of structural wood products such as Wood I-Joists and Structural Finger Joints typically possess very short assembly times. Although these assembly times are very short, establishing confidence that the adhesive will perform as

expected at the designated assembly time limits, as recommended and documented by the adhesive manufacturer, is an important criterion in the evaluation and use of the adhesive.

X1.19 Resistance to Shear by Compression Loading General Considerations

X1.19.1 For structural applications, bonded wood products need to be almost the same in strength as the wood itself. Structures are designed based upon the measured strength of the wood species used in the construction. The bond needs to be close to the load carrying capacity of the wood. Given that wood properties are dependent upon moisture content, the samples need to be moisture equilibrated prior to testing.

An important measure of the strength of the adhesive bond is to compare its compressive shear strength to the shear parallel to grain for the wood. The adhesive bond strength and shear strength of the wood parallel to grain are tested in a similar manner except for the following:

(1) In the Test Method D143 test, there is a single right-angle notch at one end of the specimen while the Test Method D905 specimen has notches at both ends;

(2) In the Test Method D143 specimen, the test forces shear failure to occur anywhere between the root of the notch at one end and the offset distance at the other end of the specimen, while the Test Method D905 test forces the shear failure between the root of the notches at both ends; and

(3) The Test Method D143 test uses a slower testing speed of 0.10 in./min. while Specification D2559 specifies a maximum testing speed of 0.5 in./min.

Table 1 gives the target for shear strength for select species. If data for the species tested is not in this Table, the text provides information on how to determine the strength for the wood. Treated or modified wood are considered separately from untreated or unmodified wood. Either a stair step from a six layer laminate or an equal number of bonds using two-ply specimens is permitted.

Wood failure is considered an important factor in addition to the shear strength. High wood failure, as specified in the specification, provides confirmation the bondline is not the weak link in the laminated product. This conservative measure is used to ensure that the short-term test will be an adequate measure of long-term performance.

X1.20 Resistance to Delamination During Accelerated Exposure General Considerations

X1.20.1 Dimensional changes in the wood can apply stresses on the bond line that test its ability to hold the bonded assembly together. The delamination test uses three cycles of maximum swelling and shrinking of the wood to correlate the fatigue behavior of the bond to the large number of more limited swelling and shrinking cycles that the bonded product needs to withstand during normal use in exterior applications. Because the wood will change dimensionally under normal use, the adhesive needs to accommodate these changes without compromising the structural capacity of the bond line. During the testing, in order to apply the maximum swelling and shrinking forces upon the adhesive, the wood pieces are cut flat-wise with a small slope of grain and are bonded in a pith-to-pith side and bark-to-bark side manner. This not only applies the maximum force parallel to the bond, but also applies the maximum force perpendicular to the bond line due to the cupping tendency of the wood. The ability of the wood to withstand these forces is determined by measuring the delamination of the bondline, with the lowest value being most desirable. Failure in the wood near the bond line is not considered to be an adhesive failure, as the intent is to ensure the bond line strength under swelling and shrinking exceeds that of the wood.

Table 2

Using Table 2 the amount of delamination in each of the test specimens is measured, recorded and reported for each bond line throughout the entire laminated assembly. In the case of ambient curing adhesives, six specimens are evaluated using a total of five bond lines (designated A-E in Table 2) providing a total exposed bond line of 50 in. per specimen or 300 in. total. With hot pressing adhesives, eight specimens are evaluated using a total of four bond lines (designated A, B, D and E) providing 40 in. of exposed bond line per specimen or 320 in. total. When evaluating hot pressing adhesives bond line C consists of an adhesive that is not under evaluation but is a Specification D2559 approved adhesive. This adhesive is used to prepare the six ply assemblies by laminating the two 3-ply samples, which were prepared with the hot pressing adhesive under evaluation. Bond line C must also pass the delamination test on each of the laminated wood members. However, as with other bond lines in a laminated wood member, if bond line C does not meet the test requirement, a retest is permitted using another laminated wood member.

The Bond Line Length of end grain bond line for the two end grain surfaces from all 6 (or 8) specimens combined is to be measured and recorded in Table 2, on the line allotted to each bond line. Add together the Bond Line Lengths of all bond lines and record at the bottom of that column and on each line of Table 2 under the heading Total Bond Line Length. Percent delamination is calculated and recorded in Table 2, reported by bond line number and for softwoods is not to exceed 1 % for any bond line. When using hardwoods delamination is not to exceed 1.6 % for any bond line.

X1.21 Resistance to Creep Under Static Loading General Considerations

X1.21.1 Resistance to creep is an important characteristic of a structural wood adhesive. Creep resistance is required to provide assurance that the adhesive maintains its ability to transfer loads without movement or slippage within the adhesive or between adherends under various exposure conditions of moisture and temperature and at designated applied shear stress. Creep (deformation with time) of the adhesive is not acceptable for structural products. In addition to causing the overall wood product to deform more than expected, creep deformation due to the adhesive may invalidate the engineering design assumptions of the wood product up to and including the structure by overstressing the components and possibly resulting in overall product failure.

It is the intent of this specification to evaluate and confirm the test adhesive does not exhibit creep beyond the limits indicated in 16.4 when evaluated under the conditions of the

test in terms of loading (applied shear stress), temperature or humidity. Confirmation of the creep resistance under conditions of the testing provide assurance of the capability of the adhesive to transfer required loads, maintain constant loading within the designated environment and over a relatively long period of time. It is not the intent of this standard to determine the limits of creep of the adhesive that would be acceptable, to determine the creep deformation of a structural wood product that may be experienced if manufactured with the test adhesive, or to make a determination of the creep components of a manufactured wood product.

Measurement of creep resistance in this specification provides a relative measure of adhesive suitability when used in the manufacture of wood products that are subjected to various stress levels; and interacting factors of wood product design, use environment, and creep characteristics of the wood components of the manufactured product. Creep resistance as measured by this specification provides guidance as to adhesive suitability but is not intended to be a substitute for long term creep evaluation of a bonded wood product when subjected to the exposure or environment. Structural wood adhesives currently used have had a long history of satisfactory performance. These adhesives exhibit very little or no creep when tested in accordance with the methods specified in this specification.

However, it is important that the minimum creep resistance of an adhesive be determined to ensure it is not a limiting factor in the design, development, or use of the adhesive in a bonded wood product. In addition, an evaluation of creep resistance of the adhesive is to be evaluated within specific exposure parameters in regards to moisture, temperature or additional environmental factors.

Creep resistance as measured in this specification is based on performance of the adhesive using a specific species, a standard multiple shear specimen, and test procedures developed for use to measure resistance to creep under conditions of the test. In this standard, and including Test Method D3535 which includes procedures for conducting the evaluation of creep, resistance to creep is evaluated independently under conditions of exposure to elevated temperature and increased humidity. Additional evaluations of creep or creep rupture of full sized products under additional conditions of exposure, use, and longer test durations are conducted by appropriate product standards, such as Specification D6815. These conditions of use include resistance to elevated temperature, humidity and applied stress. Test results based on creep resistance in this standard provide guidance for use by adhesive suppliers, wood product designers and manufacturers to assess the relative creep resistance of various adhesive formulations. Provided the impact of adhesive creep on the overall creep of the product is also known, the product performance can also be inferred when considering approved but nontraditional adhesive chemistries or technologies as alternatives to mainstream adhesive technologies.

SUMMARY OF CHANGES

Committee D14 has identified the location of selected changes to this standard since the last issue (D2559 – 10a) that may impact the use of this standard. (Approved June 1, 2012.)

(1) Section 1 Revision of Scope: Deletion of the use, description and requirements associated with designated Adhesive Service Classes.
(2) Section 3 Revision of Terminology: Deletion of definitions for Adhesive Service Class, Adhesive Service Class A and Adhesive Service Class B.
(3) Section 4 Revision of Significance and Use: Deletion of specific test requirements associated with a defined Adhesive Class.
(4) Deletion of Section 17 Supplemental Durability Testing for a specific adhesive class and its associated requirements.
(5) Changes in the non-mandatory Commentary in the Appendix of the standard including, but not limited to:

(a) X1.1 Introduction: Inclusion of Additional discussion.
(b) X1.3 Scope: Deletion of discussion related to description of Adhesive Service Classes.
(c) X1.4 and *X1.5:* Deletion of *Description of Specific Adhesive Service Classes A and B.*
(d) Addition of new *Sections: X1.4 Treated Wood* and *X1.5 Considerations of Preservative Treated Wood.*
(e) X1.7 Terminology: Additional discussion included on exterior exposure and deletion of discussion related to specific service classes.
(f) X1.14: Change in discussion on *Selection and Preparation of Wood for Testing of Adhesives.*
(g) X1.22: Removal of discussion related to *Supplemental Durability Testing and its References.*
(h) Deletion of *Table X1.1 Adhesive Service Classes.*