Designation: D7247 – 16

Standard Test Method for Evaluating the Shear Strength of Adhesive Bonds in Laminated Wood Products at Elevated Temperatures[1]

This standard is issued under the fixed designation D7247; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This standard describes a test method for evaluating the comparative shear strength of a planar adhesive bond at both ambient and elevated temperatures relative to the performance of solid wood under the same conditions. The test method is based on the breaking load after the specimen is exposed to either ambient or a constant elevated temperature for a specified duration as described in Section 7. This standard does not preclude the development and implementation of other methods that provide equivalent performance meeting the intent of this method.

1.2 This test method is intended for the evaluation of adhesives that can be used to assemble test specimens in accordance with Test Method D905. The evaluation of other types of adhesives, such as the binder systems used for strand-based products, is beyond the scope of this test method.

1.3 This test method is intended for the evaluation of adhesives as a component of laminated wood products at elevated temperatures. The evaluation of fire performance on fire-rated laminated wood products or assemblies is beyond the scope of this test method.

1.4 This test method may be used for the evaluation of heat durability for binder adhesives used in strand-based structural wood composites, such as oriented strand lumber (OSL) and laminated strand lumber (LSL), by substituting strand-based composite specimens for the bonded specimens.

1.5 The exact formulation of adhesive supplied to the manufacturer of laminated wood products shall be evaluated. Modifications to the adhesive formulation require a separate evaluation unless approved by the manufacturer of the laminated wood product, qualified agency, and code evaluation agency.

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

1.7 *This standard does not purport to address all of the safety concerns, such as the fire hazard, 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]

D905 Test Method for Strength Properties of Adhesive Bonds in Shear by Compression Loading
D907 Terminology of Adhesives
D2395 Test Methods for Density and Specific Gravity (Relative Density) of Wood and Wood-Based Materials
D2915 Practice for Sampling and Data-Analysis for Structural Wood and Wood-Based Products
D4933 Guide for Moisture Conditioning of Wood and Wood-Based Materials
D5266 Practice for Estimating the Percentage of Wood Failure in Adhesive Bonded Joints
D5456 Specification for Evaluation of Structural Composite Lumber Products

2.2 *Other Documents:*

ANSI A190.1 American National Standard for Wood Products — Structural Glued Laminated Timber[3]
ANSI/AWC NDS-2015 National Design — Specification for Wood Construction (NDS)[3]
Wood Handbook Wood as an Engineering Material[4]

3. Terminology

3.1 *Definitions:*

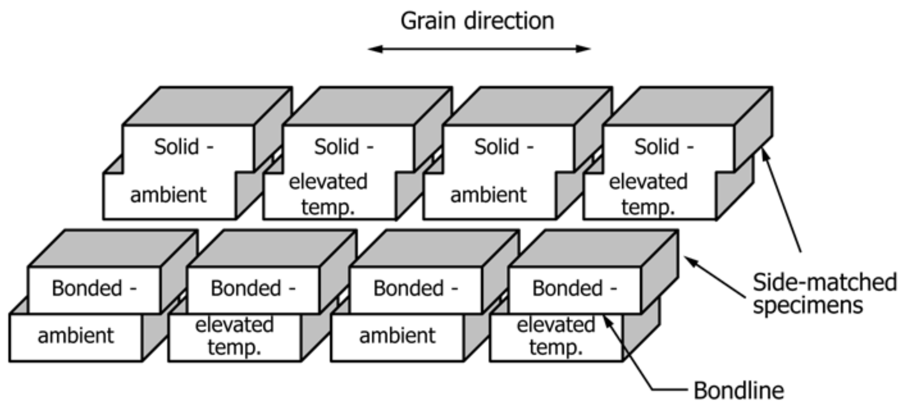
[1] This test method is under the jurisdiction of ASTM Committee D14 on Adhesives and is the direct responsibility of Subcommittee D14.30 on Wood Adhesives.

Current edition approved April 1, 2016. Published April 2016. Originally approved in 2006. Last previous edition approved in 2007 as D7247 – 07a$^{\varepsilon 1}$ which was withdrawn January 2016 and reinstated in April 2016 as D7247 – 16. DOI: 10.1520/D7247-16.

[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] APA — The Engineered Wood Association, 7011 S. 19th St., Tacoma, WA 98466, www.apaword.org.

[4] Available from U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, One Gifford Pinchot Drive Madison, WI 53726, www.fpl.fs.fed.us.



Note–See Fig. 2 for specimen dimension.

FIG. 1 Example of Side-Matched Specimen Fabrication (Using Nominal 2 by 6 in. Lumber with Bonded Specimens and Side-Matched Solid Wood Control Specimens)

3.1.1 Many terms in this test method are defined in Terminology D907.

4. Significance and Use

4.1 A discussion of the issues and limitations associated with the measurement of strength properties of adhesive bonds in shear by compression loading is found in Test Method D905.

4.2 While various combinations of test temperature and heat exposure duration can be used, the provisions specified in 7.2.4 shall be based on the understanding that the objective of this test method is to evaluate adhesive bond performance just before wood begins to burn and the elevated temperature is selected to be slightly below the unpiloted ignition temperature for wood when taken into account the specific product and its end-use applications.

4.3 When using this test method, consideration shall be given to the unique production conditions, such as wood moisture content, applied spread rate, press pressure, and curing temperature of the adhesive.

5. Apparatus

5.1 The testing machine and shearing tool described in Test Method D905 have been found to be satisfactory for the test method described herein.

5.2 An oven capable of maintaining the targeted test temperature to within ±1 % and with sufficient air circulation to provide constant temperature conditions within the oven interior is required for heating the specimens.

5.3 Thermometers/thermocouples capable of measuring the temperature of the test specimen and air are required.

NOTE 1—Type "K" 24 gauge thermocouples are recommended.

5.4 *Dessicator,* capable of maintaining the dry condition of the dried specimen sets until exposure and testing.

NOTE 2—Fresh or freshly regenerated desiccant is recommended for each test.

6. Test Specimen

6.1 The wood species used for the tests shall be the wood species used in commercial production. Wood species with similar bonding characteristics in accordance with ANSI A190.1 shall be permitted to be grouped for the purpose of this test method. Nominal 2-in. thick lumber shall be used to manufacture the test specimens. The lumber shall have the annual growth rings oriented 45 to 90°, as measured from the wide face (vertical grain), and be free of defects and at the equilibrium moisture content recommended by the manufacturer of the adhesive. If no such recommendation exists, the moisture content shall be between 10 and 12 % prior to bonding following the moisture conditioning procedures described in Guide D4933. Each piece of lumber used as part of this test method shall have a specific gravity equal to or exceeding the value specified in the National Design Specification for Wood Construction (NDS) for the wood species, as determined in accordance with Test Methods D2395 based on oven-dry weight and volume. The specific gravity determination for each piece of lumber shall be permitted to be conducted on the ends trimmed from the lumber during the preparation of the bonded and solid wood test specimens. The side-matched components from which the bonded and solid wood control specimens are prepared shall have a specific gravity within 0.02 of each other (for example, if the solid wood control specimens have a specific gravity of 0.50, the bonded specimens shall have a specific gravity between 0.48 and 0.52).

6.2 Specimens shall be prepared in accordance with the general principle of Test Method D905. To ensure that pieces with a mean specific gravity are bonded together, a single piece of the nominal 2 in. thick lumber shall provide, at a minimum, the two pieces (lumber) necessary for each bonded specimen and a side-matched solid wood (control) specimen. An example of the shear specimen-cutting pattern is shown in Fig. 1. Care shall be exercised to ensure the same annual ring orientation when bonding the lumber together into a bonded assembly.

6.3 The mating surfaces of the lumber used to prepare the bonded specimens shall be surfaced no more than 24 h prior to bonding. The adhesive preparation, spread rate, clamping

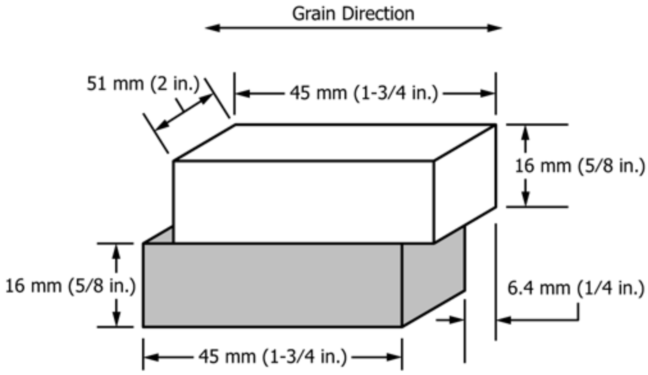


FIG. 2 Form and Dimensions of a Bonded Specimen

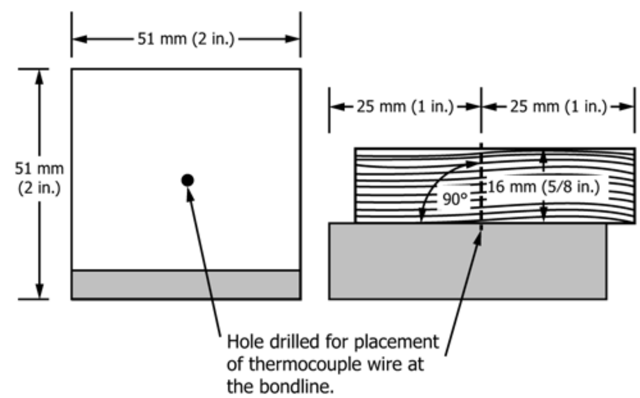


FIG. 3 Top View (Left) and Side View (Right) of Drilled Hole for Thermocouple Placement

pressure and clamping time shall follow the adhesive manufacturer's recommendations. The production conditions for the end-use products shall also be considered (see 4.3).

6.4 A minimum of 20 bonded specimens shall be prepared in accordance with Fig. 2. The bonded specimens will have a thickness less than the specified 38 mm (1.5 in.) as described in Test Method D905 due to surfacing from nominal 2-in lumber. In addition, a minimum of 20 solid wood (without the bondline) control specimens side-matched with the bonded specimens shall be prepared as shown in Fig. 1. The side-matched solid wood specimens shall be surfaced to the same thickness as the bonded specimens. The bonded and matched solid wood control specimens shall be prepared as 20 pairs.

6.5 A total of 10 pairs of bonded and matched solid wood control specimens shall be tested at ambient temperature and the remaining 10 pairs of bonded and matched solid wood control specimens shall be tested at the targeted elevated temperature.

6.6 For specimens tested at the elevated temperature, a hole shall be drilled through one lamination at a 90° angle to the bondline and extending 0.6 mm (1⁄32 in.) past the bondline. The drilled hole shall allow the thermocouple wire casing to fit snugly inside the hole (see Fig. 3), with the exposed portion of the thermocouple wire touching the bondline of the bonded specimen or the geometric center (shear plane) of the matched solid wood control specimen. The tip of the thermocouple wire shall have a maximum of 1 mm (0.040 in.) of insulation removed.

NOTE 3—Experience has shown that stripping the wire insulation approximately 12.7 mm (0.5 in.), twisting the wires together, and cutting the exposed wire back to 1 mm (0.040 in.) gives consistent results. Damage-to or improper-removal-of thermocouple wire insulation increases the possibility of inaccurate temperature readings in the oven. Prior to re-using thermocouple wire, it is to be re-tested to ensure that accurate temperature readings are being provided.

6.7 All specimens shall be oven dried for 48 h at 60 ± 2°C (140 ± 4°F) and placed in an atmosphere, such as a desiccator, to allow for cooling in dry conditions.

NOTE 4—The intent of the oven drying is to remove the moisture from the wood adherend so that the specimen weight reduction during testing in accordance with Section 7 is primarily due to thermal degradation.

6.8 After cooling, the specimen weight shall be determined. The width and length of the test specimen shall be measured and recorded, at the bondline, to the nearest 0.25 mm (0.010 in.) to determine the shear area. Test specimens are to be kept in the desiccator until just prior to testing in accordance with Section 7.

7. Test Procedures

7.1 *Specimens at Ambient Temperature Condition:*

7.1.1 A sample set consisting of 10 solid wood control specimens and 10 bonded specimens shall be tested at ambient laboratory conditions in accordance with the procedures outlined in Test Method D905. Loads shall be applied with a continuous motion of the movable head at a rate of 5 mm (0.20 in.)/min until failure. The ultimate load shall be recorded along with an estimation of wood failure (to the nearest 5 %) in accordance with Practice D5266.

7.2 *Specimens at Elevated Temperature Condition:*

7.2.1 The oven shall be preheated to the targeted temperature using a thermocouple to monitor the interior oven temperature (see Note 5 for additional information). The oven air temperature shall be held at the desired level for a sufficient amount of time to heat all of the components of the oven to the targeted temperature.

7.2.2 Only one specimen, either one solid wood control specimen or one side-matched bonded specimen, shall be placed in the oven at a time. A thermocouple wire shall be placed into the specimen as described in 6.6 and shown in Fig. 3. The drilled hole shall be backfilled, if necessary, with glass insulation, high temperature silicon, or a similar protective barrier. The backfill materials shall be allowed to cure according to the manufacturer's recommendations prior to testing. The starting time and specimen oven-dry weight, after the backfill materials are cured, as applicable, shall be recorded.

7.2.3 The bondline temperature of the bonded specimen or the temperature at the shear plane of the matched solid wood control specimen shall be monitored. Because of the insulating nature of wood, the bondline temperature may be different from the oven air temperature and thus the targeted temperature. Therefore, as the specimen approaches the targeted temperature, the rate of heating shall be slowed to a rate that can be easily controlled either manually or by using a proportional temperature controller with an integral and derivative (PID) control algorithm. The amount of time for the specimen to reach the targeted temperature shall not be less than 30 min. nor more than 90 min.

NOTE 5—When a manually controlled oven is used, previous studies have shown that for a targeted temperature of 232°C (450°F), the heat should be turned down when the interior temperatures of the specimens reach approximately 210°C (410°F). The bondline temperature will continue to rise, but the rate of increase will decrease. As the rate of temperature rise decreases, heat can be re-introduced, if necessary, to attain the targeted bondline temperature. Practice runs with "dummy" specimens are recommended before the collection of actual data. The use of a PID device may help the temperature control.

7.2.4 The time when the bondline temperature of the bonded specimen or the temperature at the shear plane of the matched solid wood control specimen reaches the targeted temperature shall be recorded. The bondline temperature of the bonded specimen or the shear plane of the solid wood control specimen shall be maintained at the targeted temperature, within the tolerance stated in 5.2, for at least 10 min. The exposure duration shall be pre-selected based on the specific product, its end-use applications and shall be consistently used for both solid wood control and bonded specimens. A range of shear strength retentions for solid wood control specimens shall be permitted to be specified in lieu of an exposure duration.

NOTE 6—The product standard, manufacturer of the laminated wood product, qualified agency, or code evaluation agency, or combinations thereof, may specify the targeted temperature and exposure duration when adopting this test method.

7.2.5 The bondline temperature of the bonded specimen or the temperature at the shear plane of the matched solid wood control specimen shall be monitored and any deviations from the targeted temperature shall be recorded. After the targeted temperature is reached, the lowest recorded and average bondline temperature shall not deviate from the target temperature by more than 5°C (9°F) and 2°C (4°F), respectively. The actual exposure duration shall not deviate from the pre-selected exposure duration by more than 30 seconds.

7.2.6 After the bondline temperature of the bonded specimen or the temperature at the shear plane of the matched solid wood control specimen has been exposed to the targeted temperature for the pre-selected exposure duration, the specimen shall be tested immediately in accordance with 7.1. The ultimate load shall be recorded along with an estimation of wood failure (to the nearest 5 %) in accordance with Practice D5266. The specimen weight after testing shall be recorded. (**Warning—**The specimen is hot. Handle the specimen with insulated gloves to avoid burns.)

NOTE 7—Experience has shown the estimation of wood failure on high temperature specimens to be difficult due to charring of the specimens. Wood failure results may not accurately portray minor differences of failure mode between testing at room and elevated temperature.

7.2.7 The procedure shall be repeated for the remaining specimens in accordance with 7.2.

8. Calculations

8.1 The shear strength in MPa (or psi) shall be calculated based on the shear area of the specimen, measured to the nearest 0.06 cm^2 (0.01 in.^{2}) in accordance with Eq 1.

$$f_v = P/A \tag{1}$$

where*:*

f_v = shear strength, MPa (or psi),
P = load at failure, N (or lbf), and
A = shear area of the specimen, mm^2 (or in.^{2}).

8.2 The shear strength of each specimen shall be reported.

8.3 The specimen weight loss ratio, which is the specimen weight after testing divided by the specimen oven-dry weight prior to Section 7 test procedures, shall be calculated and reported.

8.4 The residual shear strength ratio for the bonded and solid wood control specimens shall be calculated separately in accordance with Eq 2.

$$R = \frac{f_{v,e}}{f_{v,a}} \tag{2}$$

where:

R = residual shear strength ratio,
$f_{v,e}$ = mean shear strength at the elevated temperature (MPa or psi), and
$f_{v,a}$ = mean shear strength at the ambient temperature (MPa or psi).

8.5 The lower 95 % confidence interval on the mean residual shear strength ratio for the solid wood specimens shall be calculated in accordance with Eq 3.

$$R_{LC} = R\left(1 - \frac{tV}{\sqrt{N}}\right) \tag{3}$$

where:

R_{LC} = lower 95 % confidence interval on the mean residual shear strength ratio,
R = residual shear strength ratio calculated from Eq 2,
t = student t statistic with 95 % confidence (see table titled Values of the t Statistics Used in Calculating Confidence Intervals of Practice D2915) = 2.262 for 10 specimens (9 degrees of freedom),
V = coefficient of variation for the shear strength of the solid wood control specimens at the targeted elevated temperature; V ≤ 0.3 (when V is greater than 0.3, use 0.3 in the calculation), and
N = sample size for the solid wood control specimens at the elevated temperature.

NOTE 8—The acceptance criteria for adhesive performance at elevated temperatures is to be established by the manufacturer of the laminated wood product, qualified agency, and code evaluation agency. The mean residual shear strength ratio for the bonded specimens is recommended to be equal to or higher than the lower 95 % confidence interval on the mean residual shear strength ratio for the solid wood control specimens, R_{LC}, as calculated in accordance with Eq 3.

9. Report

9.1 The report shall include the following:

9.1.1 Identification of the adhesive tested.

9.1.2 Identification of the wood species used.

9.1.3 Application and bonding conditions used in fabricating the specimens.

9.1.4 Conditioning procedure used for the specimens.

9.1.5 Temperature and relative humidity in the test room.

9.1.6 Time elapsed before the elevated temperature specimen reached the targeted temperature after being placed in the oven.

9.1.7 One plot of specimen temperature versus time in oven, at a minimum of 5 intervals.

9.1.8 One plot of oven temperature versus time, at a minimum of 5 intervals.

9.1.9 Amount of time the elevated temperature specimen was held at the targeted temperature.

9.1.10 Specimen weight and specific gravity prior to and after Section 7 test procedures. Average weight loss ratio for each test condition.

9.1.11 Shear strength and percentages of wood failure for each specimen. Note the presence and extent of charring of adhesive or wood, or both.

9.1.12 The average shear strength, average percent wood failure, and mean residual strength (if applicable) for each test condition.

9.1.13 The calculated residual shear strength ratios (R) for the bonded and solid wood control specimens, and the calculated lower 95 % confidence interval on the mean residual shear strength ratio (R_{LC}) for the solid wood control specimens.

10. Precision and Bias

10.1 The precision and bias of the procedure in this test method for measuring the shear strength of adhesives at elevated temperature is being determined and it is expected that results will be available by January 2008.

11. Keywords

11.1 bonded; bondline; laminated; residual shear strength ratio

APPENDIX

(Nonmandatory Information)

X1. COMMENTARY

X1.1 The objective of any structural adhesive is to transfer loads between substrates when exposed to specific service environments and to provide an adhesive bond equal to or stronger than the cohesive strength of the substrates bonded together. Many different factors influence the determination of the shear strength of an adhesive bond, especially at elevated temperatures. For example, the strength of the wood, the shear tool design, the rate of loading, and the rate of temperature gain of an individual specimen may all bias the results to a certain extent. Therefore, it cannot be assumed that this test method measures the true shear strength of the adhesive. Instead, the small-scale shear test method is used as a relative measure of adhesive bond strength relative to the longitudinal shear strength of solid wood. Solid wood has code-recognized fire performance and is commonly used as a benchmark by fire fighters.

X1.2 The shear strength of structural wood members is affected by the temperature of the wood in service. Shear strength is increased as the temperature cools below the normal temperature range found in most buildings. Conversely, the shear strength decreases as temperature increases. For example, the NDS calls for a 30 % reduction in the tabulated shear strength when the temperature of a structural member is sustained at 65°C (150°F). Based on the Wood Handbook, the thermal degradation of wood occurs in three phases; *(a)* dehydration or loss of water vapor (up to 150°C or 302°F), *(b)* noncombustible degradation where gaseous vapors are slowly given off and char begins to form (100 to 250°C or 212 to 482°F), and *(c)* combustible degradation where volatile organic compounds are emitted, which may or may not flame, depending on oven conditions (270 to 470°C or 518 to 878°F). This test method can be used to evaluate the condition at the upper end of the second phase of wood degradation, above the hot press temperatures typically used in production of wood composites (149 to 204°C or 300 to 400°F), yet below the unpiloted ignition temperature of the wood adherend (270 to 470°C or 518 to 878°F). Wood ignition is the decomposition (pyrolysis) of material into volatiles and a char residue. After pyrolysis, the char may disintegrate by glowing or smoldering; the volatiles mix with oxygen in the air and may undergo flaming combustion. The temperature at which the wood ignites is a function of the wood moisture content and species, the temperature and heat flow within the oven, and the time of exposure at an elevated temperature. This test method does not evaluate a number of factors pertaining to a flashover fire on a full-scale assembly, such as size and shape of the floor joist, joist depth and spacing, piloted versus unpiloted ignition temperature, and assembly protection, etc.

X1.3 It is the prerogative of the product standard, manufacturer of the laminated wood product, qualified agency, and/or code evaluation agency, when adopting this test method, to select a combination of test temperature and exposure duration (or a range of shear strength reductions) for a specific product and its end-use applications. The minimum exposure of 10 min. is specified to ensure the temperature uniformity at the bondline of the bonded specimen. Limited test data used for the development of this standard is documented.[5]

[5] Yeh, B. and Brooks, R. "Evaluation of Adhesive Performance at Elevated Temperatures for Engineered Wood Products," *Proceedings: World Conference on Timber Engineering*, August 6–10, 2006. Portland, OR.