**Designation: D5574 – 94 (Reapproved 2021)**

# Standard Test Methods for Establishing Allowable Mechanical Properties of Wood-Bonding Adhesives for Design of Structural Joints[1]

This standard is issued under the fixed designation D5574; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 These test methods cover the principles for establishing allowable mechanical properties for adhesives that can be used to design adhesive-bonded joints for structural components and assemblies of wood or wood with other materials. These test methods are modeled after Practice D245.

1.2 The properties determined are allowable shear stress, allowable tensile stress, and allowable shear modulus.

1.3 In determination of allowable shear- and tensile-stress levels, these test methods are limited by the horizontal shear and tension perpendicular-to-the-grain capacity of the wood adherends (hard maple, *Acer saccharum*, Marsh.). The adhesives so tested may actually have shear or tensile allowable stresses exceeding the wood, but the determined allowable design stress levels are limited (upper bounded) by the wood in these test methods. If a wood other than hard maple is used for testing the adhesive, then the allowable strengths are upper bounded by the properties of that particular wood.

1.4 The strength properties are determined by standard ASTM test methods. As a result, only procedural variations from the standards and special directions for applying the results are given in these test methods.

1.5 Time-to-failure data derived from creep-rupture testing (see Test Method D4680) provide a measure of the ultimate strength of an adhesive bond as a function of time at various levels of temperature and moisture.

1.5.1 With proper caution, useful service life at a given shear stress level may be extrapolated from relatively short loading periods.

1.6 The resistance of the adhesive to permanent loss of properties due to aging (permanence) is assessed by means of strength tests after constant elevated-temperature and moisture aging of test specimens.

1.6.1 If the subject adhesives will be used to bond wood that has been treated with a preservative, fire retardant, or any other chemical to modify its properties, then the permanence of the adhesive shall be tested using wood adherends treated in the same manner.

1.7 Factors for durability, permanence, and creep derived by shear tests and analysis, are assumed to apply to tension (normal-to-the-bond) strength as well.

1.8 Requirements for production, inspection, and certification of adhesives evaluated under these test methods are not included.

1.9 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*



## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

D245 Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber
D897 Test Method for Tensile Properties of Adhesive Bonds
D905 Test Method for Strength Properties of Adhesive Bonds in Shear by Compression Loading
D907 Terminology of Adhesives
D1101 Test Methods for Integrity of Adhesive Joints in Structural Laminated Wood Products for Exterior Use
D1151 Practice for Effect of Moisture and Temperature on Adhesive Bonds
D2555 Practice for Establishing Clear Wood Strength Values
D2559 Specification for Adhesives for Bonded Structural

[1] These test methods are under the jurisdiction of ASTM Committee D14 on Adhesives and are the direct responsibility of Subcommittee D14.70 on Construction Adhesives.

Current edition approved March 1, 2021. Published March 2021. Originally approved in 1994. Last previous edition approved in 2012 as D5574 – 94 (2012). DOI: 10.1520/D5574-94R21.

[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.

Wood Products for Use Under Exterior Exposure Conditions
D2915 Practice for Sampling and Data-Analysis for Structural Wood and Wood-Based Products
D3931 Test Method for Determining Strength of Gap-Filling Adhesive Bonds in Shear by Compression Loading
D3983 Test Method for Measuring Strength and Shear Modulus of Nonrigid Adhesives by the Thick-Adherend Tensile-Lap Specimen
D4027 Test Method for Measuring Shear Properties of Structural Adhesives by the Modified-Rail Test
D4502 Test Method for Heat and Moisture Resistance of Wood-Adhesive Joints
D4680 Test Method for Creep and Time to Failure of Adhesives in Static Shear by Compression Loading (Wood-to-Wood)
D4896 Guide for Use of Adhesive-Bonded Single Lap-Joint Specimen Test Results
IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI): The Modern Metric System

## 3. Terminology

3.1 *Definitions:*

3.1.1 *allowable design stress, n*—a stress to which a material can be subjected under stated service conditions with low probability of mechanical failure within the design lifetime. **(D4896)**

3.1.1.1 *Discussion*—Allowable design stress is obtained by multiplying the basic stress by a safety factor and possibly one or more modification factors as required by the intended service environment.

3.1.2 *allowable shear stress, n*—in an adhesive-bonded joint, the allowable design stress for structural joints subjected to shear force.

3.1.3 *allowable tensile stress, n*—in an adhesive-bonded joint, the allowable design stress for structural joints subjected to tension force.

3.1.4 *creep rupture, n*—the fracture of a material resulting from a sustained stress (or sum of stresses) above the creep rupture limit.

3.1.4.1 *Discussion*—The material may experience creep through the primary, secondary, and tertiary stages of rupture.

3.1.5 *creep-rupture limit, n*—the stress level below which creep rupture will not occur within a given time in a specified environment. See *creep rupture*.

3.1.6 *durability, n*—as related to adhesive joints, the endurance of joint strength relative to the required service conditions. **(D907)**

3.1.6.1 *Discussion*—Service conditions may include water and other chemicals, temperature, stress, radiation, microorganisms, and other environmental factors.

3.1.7 *permanence, n*—the resistance of an adhesive bond to deteriorating influences. **(D907)**

3.1.8 *structural adhesive, n*—a bonding agent used for transferring required loads between adherends exposed to service environments typical for the structure involved. **(D907)**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *allowable shear modulus, n*—the modulus calculated in accordance with Section 14, that is used for the design of a structural joint.

3.2.2 *basic shear modulus, n*—the average shear modulus of 30 specimens fabricated and tested in accordance with 13.1.

3.2.3 *basic shear strength, n*—a near minimum value of the shear strength distribution determined as the one-sided lower confidence interval on the fifth percentile as determined in accordance with 7.1. (See lower 5 % tolerance limit.)

3.2.4 *basic tensile strength, n*—a near minimum value of the tensile strength distribution determined as the one-sided lower confidence interval on the fifth percentile as determined in accordance with 9.1. (See lower 5 % tolerance limit.)

3.2.5 *creep factor, n*—for modulus, the monotonic modulus as a function of loading rate expressed as the decimal fraction of the basic modulus.

3.2.6 *creep factor, n*—for strength, the estimated 30 year creep rupture limit as a decimal fraction of the basic strength.

3.2.7 *delamination factor, n*—a pass/fail factor based on the percentage of delamination on the end grain of a laminate after cyclic delamination treatment.

3.2.7.1 *Discussion*—The factor is 0 or 1: 0 if end-grain delamination is greater than 10 % of total end-grain bondline; 1 if less than 10 % after cyclic soak-dry treatment.

3.2.8 *durability factor, n*—the average strength under elevated test conditions expressed as a decimal fraction of the strength at standard condition.

3.2.8.1 *Discussion*—Increases in temperature and moisture level usually lower strength temporarily, as long as the specimen is not so weakened that fracture occurs. Decreases in temperature and moisture level usually increase strength. Exceptions occur when increasing the temperature raises the level of adhesive cure and strength, or decreasing the temperature or moisture induces brittleness and stress concentrations.

3.2.9 *lower 5 % nonparametric tolerance limit [NTL], n*—an estimate of the one-sided lower confidence bond on the fifth percentile of the strength distribution determined as the lowest ranked value (fast order statistic) of sample of specimens from a population.

3.2.10 *lower 5 % parametric tolerance limit [PTL], n*—an estimate of the lower confidence bound on the fifth percentile of the strength distribution calculated as the mean of a sample minus the sample standard deviation multiplied by a confidence level factor.

3.2.11 *lower 5 % tolerance limit, n*— an estimate of the one-sided lower confidence bound on the fifth percentile of the strength distribution of a population of specimens.

3.2.12 *modification factor, n*—any external or internal factor of the service environment that temporarily or permanently alters the strength or stiffness of an adhesive.

3.2.13 *multiaxial stress, n*—stress in two or three perpendicular directions, bi- or triaxial stress.

3.2.13.1 *Discussion*—In most wood structures bonded with structural adhesives, multiaxial stress consists of a shear stress in the plane of, and tension stress normal to the plane of the adhesive layer.

3.2.14 *permanence factor, n*—the estimated residual strength at 30 years expressed as a decimal fraction of the original strength at standard conditions.

3.2.14.1 *Discussion*—This factor accounts for permanent, usually long-term, changes in strength or modulus due to the effects of factors such as heat, moisture, chemicals, ultraviolet light, and biological agents.

3.2.15 *safety factor, n*—a reduction factor to account for uncertainty in establishing an allowable design stress.

3.2.15.1 *Discussion*—The safety factor accounts for possible differences between laboratory and end-use conditions, differences in adhesive production lots, bonding variables, and the assumption that there is no interaction between modification factors.

## 4. Summary of Test Methods

4.1 These test methods are based on a conservative estimate of the near minimum value of the distribution of adhesive strengths measured by a standard test method. The basic strength of the adhesive is the lower 5 % nonparametric tolerance limit obtained by a sample of 59 specimens. The allowable design stress is the basic strength reduced by a safety factor as a minimum:

$$\text{allowable design stress} = \text{basic strength} \times \text{safety factor}$$

The allowable shear modulus is the mean modulus of a group of specimens measured by a standard test method and adjusted by modification factors similar to those for strength as required by the service environment.

4.2 The allowable design stress (or modulus) can be modified by one or more modification factors that are appropriate for the intended-service exposure of the adhesive.

4.3 The modification factors used in these test methods are durability, permanence, delamination, and creep.

4.3.1 Temperature and moisture are the principal variables of both the durability and permanence factors. Chemicals, such as preservatives or fire retardants, may constitute a third element of the durability and permanence factors. These factors are shown in Appendix X1. Stress level and time, in addition to temperature and moisture, are important elements of the creep favor. Chemicals may be important to the creep factor if they plasticize or otherwise soften the adhesive. Cyclic gradients of moisture and temperature are principal elements of the delamination factor.

4.3.2 Modification factors are derived from standard test methods and specimens under critical-use conditions such as extreme temperature, moisture, chemical, or stress levels expected in service.

4.4 Flow charts showing tests and calculations required to establish allowable shear stress, allowable tensile stress perpendicular to bond, and allowable shear modulus for a given adhesive are shown in Appendix X2.

NOTE 1—The sequence described in the procedure sections of these test methods are not absolute. The delamination factor sets a pass/fail criteria for a given adhesive for exterior wet-use applications. If there is any doubt that the adhesive will pass the delamination requirement, the user can conduct this test before all others in order to save the expense of conducting the other tests needlessly.

## 5. Significance and Use

5.1 Safe and reliable mechanical properties for adhesives are necessary to achieve the full structural benefit of adhesives in bonded structural components and assemblies.

5.2 An adhesive's properties exhibit a natural variation or distribution of values. The allowable design stress for an adhesive must be adjusted to allow for variability and environmental effects to ensure human safety and prevent premature failure of costly structures.

5.3 Modification factors can be applied to the allowable design stress by the design engineer as deemed appropriate for the expected service conditions of the adhesive, or in accordance with the requirements of a building code.

5.4 The allowable properties developed under these methods apply only to the actual adhesive formulation tested and analyzed.

5.5 The allowable properties developed for a given adhesive shall apply only to adhesive bondlines with thicknesses in the range for which data is available.



## 6. Adhesive and Wood Preparation

6.1 Obtain a representative sample from each lot of adhesive to be tested.

6.1.1 For liquid or paste adhesives, take a sample from each lot of at least 1 qt (446 mL).

6.1.2 For adhesives consisting of more than one part, take a sufficient sample of each part to prepare at least 2 lb (908 g) of adhesive at the time of test-specimen fabrication.

6.1.3 For dry adhesives, take a sample from each lot weighing at least 1 kg (1.1 lb).

6.2 Follow the adhesive manufacturer's specifications for proper packing, mixing, and handling of the sample.

6.3 Follow the adhesive manufacturer's instructions for proper use of the adhesive. The information needed will vary for different types of adhesive. Important information may include:

6.3.1 The acceptable moisture-content range for the wood.

6.3.2 Complete mixing directions for the adhesive.

6.3.3 The acceptable range of conditions for adhesive application, such as rate of spread, thickness of wet film, bead size, number of coats to be applied, minimum temperature for application, single or double spread, and conditions for drying where more than one coat is required.

6.3.4 The acceptable range of open- and closed-assembly time over the ambient temperature and humidity range specified.

6.3.5 The acceptable range of curing conditions, including the pressure to be applied, if any; whether this pressure may be provided by nails or staples, or both, or by other means; the minimum time under pressure and the minimum temperature of the assembly when under pressure. It should be stated whether this temperature is that of the bondline, or of the atmosphere in which the assembly is to be maintained.

6.3.6 The acceptable storage conditions and storage time prior to use.

6.4 Hard maple (*Acer saccharum*, Marsh.) is the standard material for all test adherends. Other species may be selected by mutual consent of the parties requesting these tests. This could occur, for example, if it is thought that the wood species might have an adverse interaction with the aging behavior of an adhesive. Regardless of the species used, select and prepare the wood in accordance with the guidelines given in Test Method D905.

## TEST METHOD FOR ALLOWABLE SHEAR STRESS

## 7. Procedure

NOTE 2—Refer to the testing and analysis path for determining allowable shear stress in Appendix X2.

7.1 *Determination of the Basic Shear Strength ($S_{0.5}$):*

7.1.1 Fabricate 60 standard block-shear specimens representing at least twelve bonded assemblies. Use Test Method D905 for bondlines less than 1⁄32-in. (0.8 mm) thick, and Test Method D3931 for bond lines exceeding this thickness.

7.1.2 Assign 59 specimens to test. Save the extra specimen for a replacement.

7.1.3 Condition the test specimens to equilibrium moisture content at 23°C (73.4°F) and 65 % relative humidity before testing.

7.1.4 Test the specimens by the appropriate method (either Test Method D905 or Test Method D3931).

7.1.5 Calculate the mean shear strength ($\bar{S}$).

7.1.6 Determine the lower 5 % nonparametric tolerance limit [NTL] for shear strength.

7.1.7 The lower 5 % [NTL] is the basic shear strength ($S_{0.05}$).

NOTE 3—A lower one-sided 95 % confidence bound on the fifth percentile of a strength distribution has the following property: if a series of such confidence bounds are determined for a series of samples from the population, then 95 % of these confidence bounds will lie below the true fifth percentile of the population. In other words, less than 5 % of the strength values of the population will fall below the lower 5 % NTL in 5 out of 100 samples of the population. The nonparametric estimate of the lower tolerance limit is preferred over the parametric estimate because it requires no assumption about the type or shape of the distribution (for example, Normal, Weibull, Lognormal, ...). If the type and shape of the distribution is known then the lower confidence interval can be calculated using parametric techniques. Tolerance limits and their determination are described in more detail in Test Method D2915.

7.2 *Determination of the Durability Factor ($C_d$):*

7.2.1 Fabricate 30 specimens in accordance with 7.1.1 for each critical end-use condition. If there is more than one critical end-use condition, for example, high temperature-high humidity at one extreme and low temperature at the other extreme, a durability factor must be determined for each condition.

7.2.2 Select critical end-use conditions for testing from the standard test conditions in accordance with Practice D1151. Test exposures numbered two through twelve represent the broader range of service conditions possible for wood-bonding adhesives. Choose the standard test condition that equals, or most closely approaches, the critical end-use conditions of the adhesive application.

7.2.3 Condition 30 specimens to equilibrium at each required temperature and moisture (critical end-use) condition.

7.2.4 Determine the shear strength of specimens at equilibrium with the selected conditions, using either Test Method D905 or Test Method D3931.

7.2.5 Calculate the durability factor ($C_d$) as the mean shear strength at the conditions of test, expressed as a percentage of the mean shear strength ($\bar{S}$) determined in accordance with 7.1.5. Since only one durability factor can be operable at a given time, use only the smallest durability factor of those determined in the subsequent calculation of the allowable design stress.

7.3 *Determination of the Delamination Factor ($C_{del}$):*

7.3.1 Fabricate three bonded assemblies, in accordance with Sections 10 and 11 of Specification D2559, and cut three specimens from each assembly, as described in Section 13.

7.3.2 Subject the specimens to the accelerated exposure in accordance with Section 15 of Specification D2559.

7.3.3 Evaluate the percentage of delamination in accordance with Section 15 of Specification D2559.

7.3.4 Calculate delamination as the percentage of total end-grain bondline delaminated:

$$\textit{length of endgrain bondline that is delaminated} / \textit{total length of endgrain bondline} \times 100$$

7.3.5 If delamination is less than 10 %, the delamination factor is 1. If delamination is greater than 10 %, or if more than 20 % of the total delamination (2 % actual) occurs within a single bondline, the delamination factor is 0.

7.4 *Determination of the Creep Factor ($C_c$):*

7.4.1 Fabricate ten block-shear specimens in accordance with Test Method D4680 for each intended test condition.

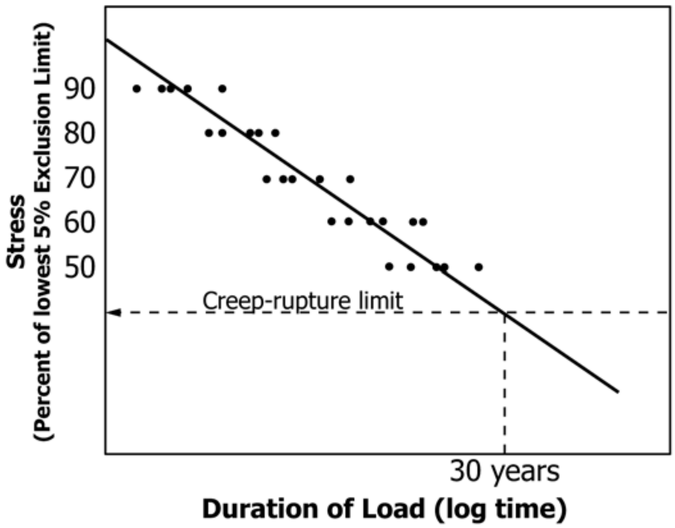
7.4.2 Compare the lower 5 % tolerance limit value determined for dry, bonded specimens ($S_{0.5}$) determined in 7.1.6 to the lower 5 % tolerance limit values for dry and wet solid wood ($S_{0.5\ wood}$). The lower 5 % parametric tolerance limit values for dry and wet hard maple shear strengths are 1600 and 1000 psi (11.0 and 6.9 MPa) respectively. Guidelines for computing the lower 5 % parametric tolerance limit values for other wood species are given in Test Method D2915 with input from Note 9 in Test Method D2555.

7.4.3 For a given test condition, wet or dry, select the *lowest* of the three lower limits from 7.4.2.

7.4.4 Conduct wet- and dry-creep tests in accordance with Test Method D4680 at stress levels equivalent to 90, 80, 70, and 60 % of the selected lower 5 % tolerance limit stress value.

7.4.5 Graph or plot the results as shown in Fig. 1 and calculate a straight-line regression through the data points.

7.4.6 Determine the creep-rupture limit as the estimated stress that would cause creep-rupture in 30 years (263 000 h) or other time, as appropriate for the intended structure. Do not extrapolate the straight-line regression relationship beyond the experimental data by more than one decade on the log-time scale.




NOTE 1—Also shown is the stress or creep-rupture limit that does not cause failure with 30 years used to calculate the creep factor.

**FIG. 1 Plot of Applied Stress Versus the Time to Failure or Creep**

7.4.7 Calculate the creep factor ($C_c$) as the creep-rupture limit stress value (or the stress level equivalent to the longest permissible extrapolation) expressed as a decimal fraction of the appropriate (see 7.4.2) lower 5 % tolerance limit shear stress for bonded specimens ($S_{0.5}$ ) or for wood ($S_{0.5\ wood}$).

7.5 *Determination of the Permanence Factor ($C_p$):*

7.5.1 Fabricate specimens in accordance with the procedures for estimating service life in Test Method D4502.

7.5.2 Conduct dry- and wet-accelerated aging tests in accordance with the procedures for estimating service life in 10.2 of Test Method D4502, but with the following differences:

7.5.2.1 Determine the degradation rate at each temperature (see Fig. 2, top) and moisture level instead of the failure time (estimated time to 75 % residual strength), in accordance with Test Method D4502.

7.5.2.2 Next, determine the temperature dependence of the degradation rate instead of the temperature dependence of the failure time, in accordance with Test Method D4502, and from this equation, calculate the estimated degradation rate at 23°C (73.4°F) (see Fig. 2, middle).

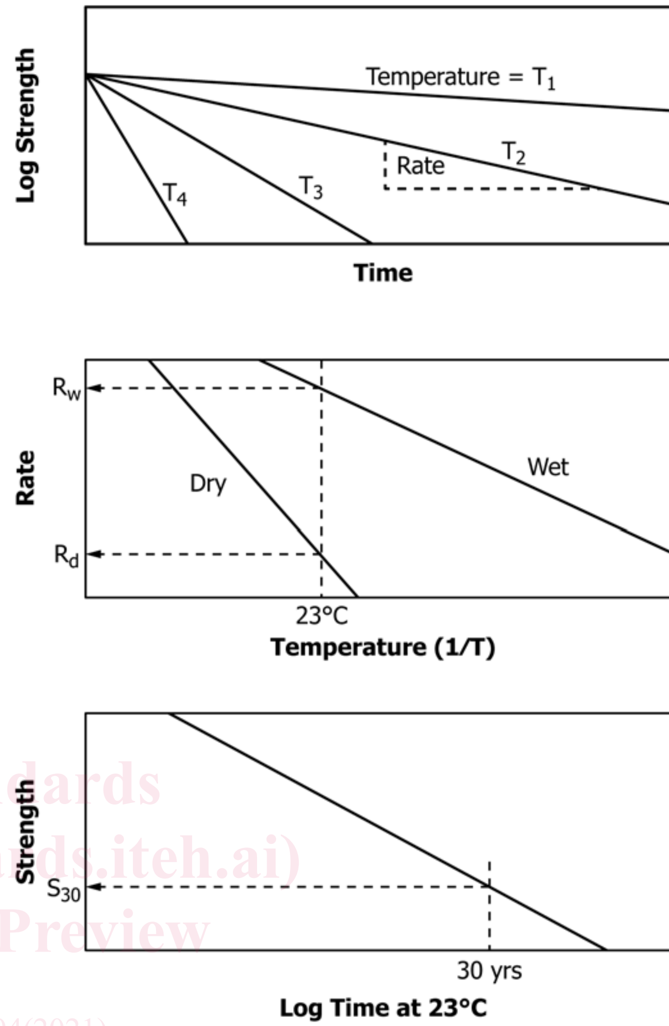
7.5.2.3 Using the estimated degradation rate at 23°C (73.4°F), calculate the estimated residual strength after 30 years (263 000 h) at 23°C for the dry and wet conditions (see Fig. 2, bottom).

7.5.3 The permanence factor is the estimated residual strength (dry or wet) remaining after 30 years, expressed as a decimal fraction of the corresponding initial strength of unaged wet or dry specimens ($S_{unaged\ dry}$ or $S_{unaged\ wet}$) tested in accordance with 10.1 of Test Method D4502.

7.6 *Determination of the Safety Factor (Q)*—The safety factor shall be 0.625, that is the same as the safety factor for wood.

## 8. Calculation of Allowable Shear Stress

8.1 Multiplicatively combine the basic shear strength for the wet or dry conditions with the appropriate modification factors and the safety factor, for example:




NOTE 1—(*Top*)—Logarithm of strength as a function of time used to determine strength degradation rate at specific aging temperatures $T_1$, $T_2$, $T_3$, and $T_4$ with the rate at temperature $T_2$ illustrated. (*Middle*)—Strength degradation rate as a function of the reciprocal of aging temperature in wet and dry conditions indicating the estimated rates ($R_w$ and $R_d$) at 23°C, (*Bottom*)—Estimated strength (dry or wet) as a function of time in service at 23°C showing the estimate at 30 years ($S_{30}$).

**FIG. 2 Plots Showing the Determination of the Estimated Strength at 30 years ($S_{30}$) Based on Aging Effects Used to Calculate the Permanence Factor**

$$\begin{aligned} \textit{allowable shear stress}\ (F_v) &= \textit{basic shear strength}\ (S_{0.5}) \\ &\times \textit{safety factor}\ (Q) \times \textit{durability factor}\ (C_d) \\ &\times \textit{delamination factor}\ (C_{del}) \\ &\times \textit{creep factor}\ (C_c) \\ &\times \textit{permanence factor}\ (C_p) \end{aligned}$$

The result is the allowable shear stress ($F_v$) for the dry or wet condition.

## TEST METHOD FOR ALLOWABLE TENSILE STRESS PERPENDICULAR TO THE GRAIN

## 9. Procedure

NOTE 4—Refer to the testing and analysis path for determining allowable tensile stress in Appendix X2.

9.1 *Determination of the Basic Tensile Strength Perpendicular to the Grain ($T_{0.5}$):*

9.1.1 Fabricate twelve bonded assemblies, in accordance with Test Method D897 and cut five standard tensile-button specimens from each assembly for a total of 60 specimens.

9.1.2 Randomly assign 59 specimens to test and one replacement specimen.

9.1.3 Condition the specimens to equilibrium moisture content at 23°C (73.4°F) and 65 % relative humidity before testing.

9.1.4 Test the specimens under ramp load in conformance with Test Method D897.

9.1.5 Calculate the mean tensile strength ($\bar{T}$).

9.1.6 Determine the lower 5 % nonparametric tolerance limit [NTL] for tensile strength perpendicular to the grain ($T_{0.05}$).

9.1.7 The lower 5 % NTL is the basic tensile strength ($T_{0.05}$).

9.2 *Determination of the Durability Factor ($C_d$)*—This test method assumes that the durability factor for tensile stress perpendicular to the grain is the same as the factor determined for shear stress.

9.3 *Determination of the Delamination Factor ($C_{del}$)*— This test method assumes that the delamination factor for tensile stress perpendicular to the grain is the same as the factor determined for shear stress. Use the delamination factor for shear.

9.4 *Determination of the Creep Factor ($C_c$)*—This test method assumes that the creep factor for tensile stress perpendicular to the grain is the same as the factor determined for shear stress. Use the creep factor determined for shear.

9.5 *Determination of the Permanence Factor ($C_p$)*—This test method assumes that the permanence factor for tensile stress perpendicular to the grain is the same as the factor determined for shear stress. Use the permanence factor for shear.

9.6 *Determination of the Safety Factor (Q)*—The safety factor shall be 0.625, that is the safety factor for wood.

## 10. Calculation of Allowable Tensile Stress ($F_t$)

10.1 Use the modification factors determined for shear in accordance with 7.2 – 7.5.

10.2 Multiplicatively combine basic tensile strength for the dry or wet condition with the appropriate modification factors and the safety factor to calculate the allowable tensile stress ($F_t$), for example:

$$\begin{aligned} \textit{tensile stress}\,(F_t) &= \textit{basic tensile strength}\,(T_{0.5}) \times \textit{safety factor}\,(Q) \\ &\times \textit{durability factor}\,(C_d) \times \textit{delamination factor}\,(C_{del}) \\ &\times \textit{creep factor}\,(C_c) \times \textit{permanence factor}\,(C_p) \end{aligned}$$

## TEST METHOD FOR MULTIAXIAL STRESS

## 11. Procedure

11.1 Use the allowable shear and tensile stresses calculated in accordance with Sections 8 and 10 to calculate the allowable design stress under multiaxial loading.

## 12. Calculation

12.1 Calculate the design stress for multiaxial or combined stress loading by the linear interaction equation:

$$f_v/F_v + f_t/F_t \geq 1$$

where:

$f_v$ = applied shear stress ($S_{xy}$) in the presence of some tensile stress,
$f_t$ = applied tensile stress ($T_y$) in the presence of some shear stress,
$F_v$ = allowable shear stress in the absence of tensile stress, and
$F_t$ = allowable tensile stress in the absence of shear stress.

## TEST METHOD FOR ALLOWABLE SHEAR MODULUS

## 13. Procedure

NOTE 5—Refer to the testing and analysis path for determining allowable shear modulus in Appendix X2.

13.1 *Determination of the Basic Shear Modulus (G):*

13.1.1 Chose either Test Method D3983 or Test Method D4027 for measuring the shear modulus of adhesives. See Section 1 (Scope) of each test method for its adaptability to various types of adhesive and adherend.

13.1.2 Fabricate ten bonded assemblies for dry tests at 27°C and 65 % relative humidity and for each intended temperature and moisture condition to be evaluated.

13.1.3 Cut three specimens from each bonded assembly for a total of 30 specimens for each temperature and moisture condition.

13.1.4 Condition 25 specimens for the dry test to equilibrium moisture content at 23°C (73.4°F) and 65 % relative humidity before testing.

13.1.5 Test specimens in accordance with the selected test method (Test Method D3893 or Test Method D4027) at a strain rate equivalent to 1.0 mm/mm/min based on the adhesive layer thickness. (See 12.4 of Test Method D3983 for additional guidance).

13.1.6 Load each specimen to failure while recording the load and the adherend slip or displacement as required by Test Method D3983 or Test Method D4027.

13.1.7 Determine the initial tangent modulus if the load-slip curve is linear. Determine the secant modulus if the curve is non-linear. Determine the secant modulus by a straight line drawn from the origin of the load-slip diagram to a point on the load-slip curve equal to the allowable shear stress determined previously (see 13.2.1 and Fig. 9 of Method D3983 for further guidance).

13.1.8 The basic shear modulus (*G*) is the mean shear modulus of the 25 specimens tested at 23°C (73.4°F) and 65 % relative humidity and determined in accordance with 13.1.7.

13.2 *Determination of the Durability Factor for Modulus ($C_{dm}$):*

13.2.1 It cannot be presumed that the durability determined for shear strength will be the same for shear modulus.

13.2.2 Fabricate specimens for the test method chosen in accordance with 13.1.2.

13.2.3 Condition 25 specimens in accordance with 7.2.2 and 7.2.3.

13.2.4 Test the specimens in accordance with 13.1.5 and 13.1.6.

13.2.5 Determine the modulus in accordance with 13.1.7.

13.2.6 The durability factor for modulus is the modulus determined in 13.2.5 expressed as a percentage of the basic shear modulus.

13.3 *Determination of the Permanence Factor for Modulus* ($C_{pm}$):

13.3.1 It cannot be presumed that the permanence factor for shear stress will be the same for shear modulus. For example, hardening of an adhesive due to thermal aging may raise the shear modulus, but lower the shear strength, through embrittlement.

13.3.2 Fabricate sufficient specimens (of the type required by the chosen shear modulus test method) to satisfy the requirements of Test Method D4502 for estimating service life at one moisture condition.

13.3.3 Choose the most severe moisture condition the adhesive will encounter in service (moist or wet) and follow the aging procedures outlined in Test Method D4502.

13.3.4 After each group of specimens have been aged for the required time period, recondition them to equilibrium at 23°C (73.4°F) and 65 % relative humidity.

13.3.5 Test the specimens in accordance with 13.1.5 and 13.1.6.

13.3.6 Determine the modulus of each specimen in accordance with 13.1.7.

13.3.7 Calculate degradation rates, temperature dependence, and estimated shear modulus after 30 years at 23°C in accordance with 7.5.2, substituting shear modulus for strength in the directions. For example, instead of determining the degradation rate of shear strength, in accordance with 7.5.2.2, determine the degradation rate of shear modulus.

13.3.8 The permanence factor for shear modulus is the estimated modulus after 30 years expressed as a percentage of the basic shear modulus.

13.4 *Determination of the Creep Factor for Modulus* ($C_{cm}$):

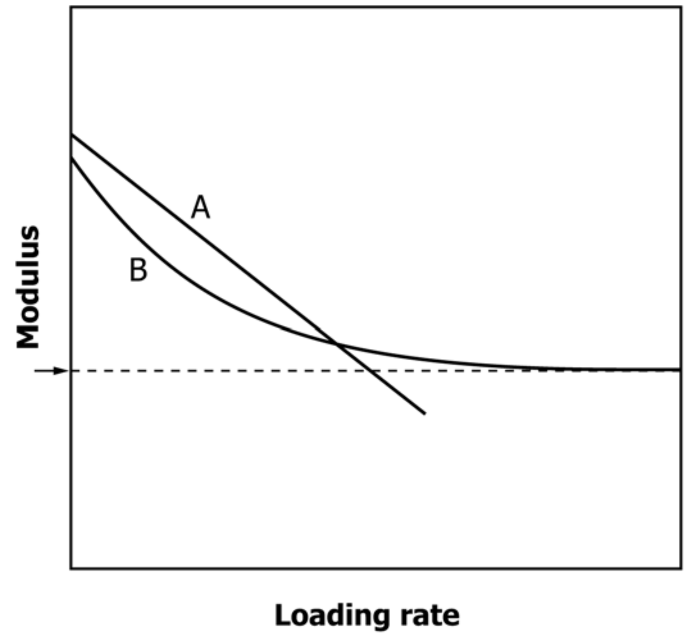
13.4.1 Fabricate specimens for the test method chosen in accordance with 13.1.2.

13.4.2 Condition the specimens to equilibrium at the critical end-use conditions expected in service.

13.4.3 Test groups of five specimens in accordance with the procedure for the chosen shear modulus method, except:

13.4.3.1 Test each group at a progressively slower rate, starting with the first group at a rate one decade slower than the rate used to determine the basic shear modulus. Continue testing groups of specimens in this manner until the curve for modulus versus rate of loading becomes flat or until it becomes evident that the curve will not flatten out, but instead reach zero modulus (see Fig. 3).

13.4.4 The creep factor is the asymptotic value of modulus expressed as a percentage of the basic shear modulus; or zero if there is no asymptote.




NOTE 1—With decreasing rate of loading until the joint either fails or approaches an asymptotic value for the applied stress level and the environmental conditions.

**FIG. 3 Change of Shear Modulus**



## 14. Calculation of the Allowable Shear Modulus ($G_v$)

14.1 Multiply the basic shear modulus by the permanence factor and the smallest of the durability and creep factors for modulus. For example, if the creep test causes greater reduction than the durability test:

$$\text{allowable shear modulus}\ (G_v) = \text{basic shear modulus}\ (G)$$
$$\times \text{permanence factor for modulus}\ (C_{pm}) \times \text{creep factor}\ (C_{cm})$$

The result is the allowable shear modulus ($G_v$) for the expected end-use conditions of the adhesive.

NOTE 6—If an adhesive has a creep-rupture limit, short-term tests at elevated temperature or moisture level will often produce the same modulus as that produced by creep testing at elevated conditions or even at normal conditions with sufficient duration of loading.

## 15. Report

15.1 Report the following information:

15.1.1 The adhesive type and manufacturer,

15.1.2 The bonding conditions including spread rate, open-assembly time, closed-assembly time, pressure, temperature, time under pressure, and conditioning time, and

15.1.3 *Allowable Shear Stress*—Including:

15.1.3.1 Standard shear test employed,

15.1.3.2 Mean adhesive layer thickness,

15.1.3.3 Mean shear stress at failure,

15.1.3.4 Basic shear strength,

15.1.3.5 Durability factor,

15.1.3.6 Permanence factor,

15.1.3.7 Creep factor, and

15.1.3.8 Allowable design stress for shear.

15.1.4 *Allowable Tension Stress Perpendicular to the Grain*—Including:

15.1.4.1 Mean adhesive layer thickness,