Designation: D 5516 – 00

An American National Standard

Standard Test Method for
Evaluating the Flexural Properties of Fire-Retardant Treated Softwood Plywood Exposed to Elevated Temperatures[1]

This standard is issued under the fixed designation D 5516; 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 test method is designed to determine the effect of exposure to high temperatures and humidities on the flexure properties of fire-retardant treated softwood plywood. In this test method, plywood is exposed to a temperature of 77°C (170°F).

1.2 The purpose of the test method is to compare the flexural properties of fire-retardant treated plywood relative to untreated plywood. The results of tests conducted in accordance with this test method provide a reference point for estimating strength temperature relationships. This test method is intended to provide an accelerated test at elevated temperatures and controlled humidities of plywood sheathing treated with the same chemical formulation(s) and processing conditions as plywood used commercially.

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

1.4 *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:*

D 9 Terminology Relating to Wood[2]

D 1165 Nomenclature of Domestic Hardwoods and Softwoods[2]

D 2915 Practice for Evaluating Allowable Properties for Grades of Structural Lumber[2]

D 3043 Methods of Testing Structural Panels in Flexure[2]

D 3201 Test Method for Hygroscopic Properties of Fire-Retardant Wood and Wood-Base Products[2]

E 84 Test Method for Surface Burning Characteristics of Building Materials[3]

E 176 Terminology of Fire Standards[3]

2.2 *American Wood Preservers' Association Standard:*

AWPA C–27 Plywood-Fire Retardant Treatment by Pressure Processes[4]

2.3 *Federal Standard:*

U.S. Product Standard PS1 for Construction and Industrial Plywood[5]

3. Terminology

3.1 *Definitions*—Definitions used in this test method are in accordance with Terminologies D 9 and E 176, and Nomenclature D 1165.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *depth of beam*—that dimension of the beam which is perpendicular to the span and parallel to the direction in which the load is applied.

3.2.2 *span*—the total distance between the centerline of supports providing the reactions on which a beam is supported to accommodate a transverse load.

3.2.3 *span-depth ratio*—the numerical ratio of span divided by beam depth.

4. Summary of Test Method

4.1 After preconditioning (see 6.5), matched specimens of treated and untreated plywood will be exposed to 77°C (170°F) temperature and relative humidity equal to or greater than 50 %.

4.2 Flexural strength tests are conducted on exposed specimens removed after various time periods. Flexural strength results shall include maximum moment, bending stiffness, and work to maximum load. Adjust the test results to 67 % relative humidity. (See X1.2.)

4.3 The purpose of this test method is to determine the ratio of the treated mean to the untreated mean for the plywood and plot the accelerated exposure strength data against exposure time.

5. Significance and Use

5.1 The flexural properties evaluated by this test method are intended to provide any one or all of the following:

5.1.1 Data on the comparative effects of fire-retardant chemical formulations and environmental conditions on the flexural properties of plywood.

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[1] This test method is under the jurisdiction of ASTM Committee D-7 on Wood and is the direct responsibility of Subcommittee D07.07 on Fire Performance of Wood.

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[2] *Annual Book of ASTM Standards*, Vol 04.10.

[3] *Annual Book of ASTM Standards*, Vol 04.07.

[4] Available from American Wood-Preservers' Assoc., P.O. Box 5690, Granbury, TX 76049–0690.

[5] Available from U.S. Department of Commerce, Washington, DC.

5.1.2 Data for use in developing modification factors for the allowable design properties of treated plywood when exposed to elevated temperatures and humidities.

5.1.3 Data comparing variables, such as other plywood species and dimensions.

5.2 Results obtained from tests conducted and analyzed in accordance with the procedures of this test method may be used with other information to establish recommended roof sheathing spans for fire-retardant treated plywood.

NOTE 1—Temperatures lower than the test temperature specified in this test method and the cumulative effects of the elevated temperatures and humidity exposures expected to be encountered in service should be taken into account when recommended roof sheathing spans are established.

6. Test Specimens

6.1 *Material Selection*:

6.1.1 Test 3, 4, or 5-ply commercially available panels.

NOTE 2—Southern pine is suggested as the test material because it requires higher fire-retardant chemical retentions to obtain the same flame spread rating compared to other softwood plywood species. Because the bending strength of treated plywood correlates to the chemical retention levels, Southern pine plywood is believed to represent a worst case scenario for the same chemical formulation and treating/redrying procedures. Thus, evaluation of other species of plywood by testing of that species, rather than by application of southern pine test results, are considered to be indicative of that species only.

6.1.2 Thickness shall not be less than 0.012 ± 0.001 m ($\frac{15}{32} \pm \frac{1}{32}$-in.) nor greater than 0.016 ± 0.0005 m ($\frac{5}{8} \pm \frac{1}{64}$-in.).

6.1.3 Select as source materials panels that provide bending strength specimens after cutting with clear essentially straight-grained faces free of scoring or other manufacturing defects. The inner plies shall be free of voids, core gaps, and core laps. Panels shall have generally uniform grain orientation and percent latewood along and across the panel faces. A minimum of six sheets of plywood meeting this description is required. Alternate 1.22-m (4-ft) wide sections to be treated and adjacent untreated 1.22–m (4-ft) sections shall have visually similar wood quality. Sample sections may be specially fabricated or selected from production.

6.1.3.1 Specimens shall be inspected and the culling of specimens done as necessary in accordance with the criteria in 7.3.4.

NOTE 3—A special 5-ply, 0.0158-m ($\frac{5}{8}$-in.), unsanded N-grade Southern pine plywood has been used for this test. This type of plywood minimizes voids in the laminates and the veneers are specially selected to minimize knots and other natural defects.

NOTE 4—A minimum of six sheets of plywood is required but culling of specimens may require more sheets.

6.1.4 The specimen cutting pattern and numbering sequence is shown in Fig. 1. Each panel of plywood is to be labeled with a number from 1 to 6. Cut each sheet crosswise to provide 0.61 by 1.22-m (2 by 4-ft) sections. Each section is labeled with the sheet number and letter A, B, C, or D. The A and C sections of each of the six panels is to be treated, while the B and D sections of the six panels are to remain untreated.

6.2 *Treatment*:

6.2.1 Pressure treat the A and C section of each of the six plywood panels with the fire-retardant formulation being tested. The gage retention level of each charge shall not be less than the value midway between the middle of the retention range and the maximum retention as specified by the agency certifying the flame spread index of the treated plywood. The retention range specified by the certifying agency shall provide a flame-spread index of 25 or less when tested in accordance with Test Method E 84 extended to 30 min, when the flame spread progresses no more than 10.5 ft (3.2 m) beyond the center line of the burners during the extended test and shows no more evidence of significant progressive combustion.

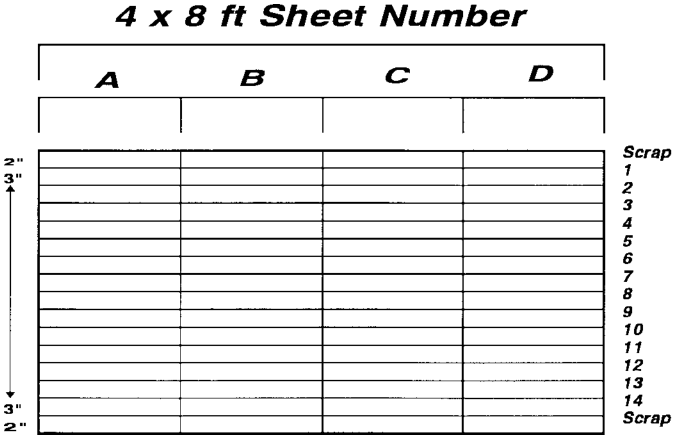


FIG. 1 Plywood Cutting Pattern

6.2.2 Weigh all plywood sections before and immediately after treatment to determine the chemical retention based on the solution retained and the concentration of chemicals in the solution. Complete a treating report for each charge of material to ducument the treating cycle, times, pressures and plywood retentions.

6.3 *Post-Treatment Drying*:

6.3.1 After pressure treatment, kiln dry the 12 treated plywood sections to a moisture content of 10 to 12 % using the manufacturer's recommended procedures but in no case exceeding the temperature limits specified in AWPA C-27. Sticker all plywood sections to obtain proper air flow across the panels and to provide even drying.

6.3.2 Monitor the moisture content of the plywood sections during the drying cycle by individually weighing the sections. The sections shall not be damaged or warped during the drying process. Keep a well-documented kiln charge report and kiln recorder chart showing temperatures and humidities on the dried material.

6.4 *Specimen Preparation*:

6.4.1 After drying, cut the treated and untreated 0.61 by 1.22-m (2 by 4-ft) sections into nominal 0.076 by 0.61-m (3 by 24-in.) test specimens as shown on Fig. 1. Alternatively, specimen sizes in accordance with Methods D 3043 shall be used instead of this size. Number these specimens consecutively from 1 to 14, creating 168 treated and 168 untreated specimens. Randomly select 20 of the 168 untreated and treated specimens as unexposed controls. The remaining 148 treated and 148 untreated specimens shall be randomly assigned to 7 sets of 20 specimens for both the treated and untreated material. These are subjected to exposure followed by strength testing. This results in 8 treated and 8 untreated specimens not assigned to any set for testing (see Note 5).

Note 5—The 168 treated and 168 untreated specimens (6.4.1) are 48 more specimens than are needed to be tested. The resulting two extra sets of 20 can be saved as replacement sets if the number of specimens in a set drops below the minimum of 18 (7.3.4). Alternatively, the extra 48 specimens can be used to increase the number of specimens in each set. A sample size of 28 allows one to estimate a 75 % confidence interval for the 5 % nonparametric tolerance limit (see Practice D 2915).

6.4.1.1 Alternatively, the variation in the mean response can be reduced by a blocked specimen selection where each treated specimen is end-matched to an untreated specimen from the same original panel. If blocking is used and a specimen is eliminated either before or after testing, then its mate shall also be eliminated.[6]

6.5 *Preconditioning*—Equilibrate all sets of treated and untreated specimens at an ambient temperature and relative humidity to achieve an equilibrium moisture content in the untreated specimens of 10 ± 2 %. Specimens are considered to be at equilibrium moisture content when a constant weight has been achieved. A constant weight is assumed when two consecutive weighings at a 24-h interval differ by no more than ±0.2 %.

7. Procedure

7.1 *Specimen Exposure*:

7.1.1 After preconditioning, test the unexposed controls (see 6.4.1) as described in 7.1.2 and 7.1.3 for initial, unexposed bending strength properties.

7.1.2 Expose all the remaining treated and untreated specimen sets in a chamber controlled to 77 ± 1°C (170 ± 2°F) and a minimum of 50 % relative humidity. The control of the relative humidity in the chamber shall be ±4 % and average ±1 % around the set point.

7.1.3 The first set of 20 untreated and 20 treated specimens shall be subjected to flexural test after 14 days exposure in the 77°C (170°F) chamber. Remove 4 additional sets of 20 treated and 20 untreated specimens at well-spaced, appropriate intervals to establish the slope of the line when the strength properties are plotted versus time. Experience has shown that removals at 2 to 3-week intervals for an exposure period of >75 days are normally sufficient (Fig. 2 illustrates modulus of rupture (MOR) response with time).

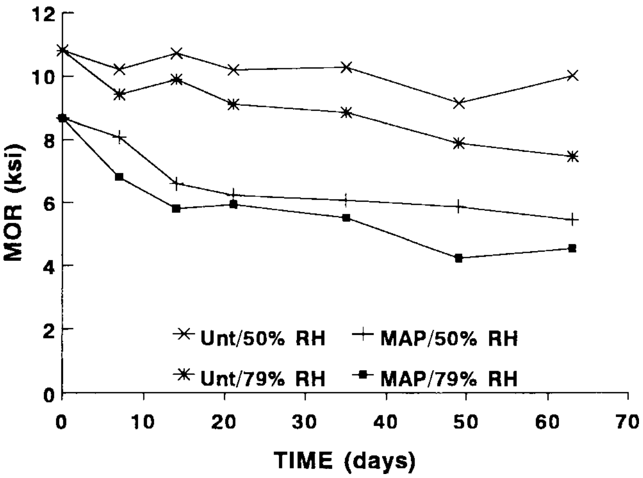
7.2 *Postconditioning*—After exposure to elevated temperatures, postcondition all sets of treated and untreated specimens at an ambient temperature and relative humidity that allow the untreated specimens to equilibrate to a moisture content of 10 ± 2 %, using the same general procedure as for preconditioning described earlier. Then equilibrate the treated specimens to whatever equilibrium moisture content these conditions produce.

7.3 *Strength Testing—Flexural Properties*:

7.3.1 Test untreated and treated specimens for flexural stiffness and strength using the general procedures specified in Methods D 3043, Method A.

7.3.2 Deviations from Methods D 3043, Method A (see Ref **((2))**) are required as follows:

7.3.2.1 Nominal specimen size of 0.076 by 0.61 m (3 by 24 in.).



Note 1—UNT = Untreated and MAP = Monoammonium phosphate treated.

FIG. 2 SYP Plywood Exposed at 170°F (77°C)

7.3.2.2 Test span of 0.56 m (22 in.).

7.3.2.3 Rotational end plates and lateral rotation of end supports are optional. However, the end supports shall be rounded if rotational end plates are not provided.

7.3.2.4 Loading rate of 0.305 m/s (0.20 in./min).

7.3.3 Load and deflection data shall be collected up to the maximum bending load and continued until the specimen can no longer withstand 50 % of the maximum load.

7.3.4 After testing, if a specimen has one or more of the following characteristics at the location of failure measure and report these characteristics:

7.3.4.1 Average short grain steeper than 1:16 in the tension ply or steeper than 1:8 in the compression ply;

7.3.4.2 Core lap of any width;

7.3.4.3 Core gap wider than 3.2 mm (⅛) in.

7.3.4.4 These characteristics may be listed as reasons for elimination of specimens from subsequent calculations. However, the minimum sample size is 18 specimens. Report strength data both with and without results from specimens containing these characteristics.

8. Report

8.1 Report the following information:

8.1.1 The average relative humidity and temperature for each conditioning environment.

8.1.2 Thickness, specific gravity (oven-dry mass/volume at test), test moisture content, modulus of elasticity, and modulus of rupture for each specimen; as well as maximum moment, stiffness, and work-to-maximum-load from the strength tests.

8.1.3 If one or more of the characteristics listed in 7.3.4 exists at the location of failure on a specimen after testing.

8.1.4 Determine the average strength, stiffness and physical property data for each set of treated and untreated specimen sets at each exposure condition and based on all matched specimens tested.

8.1.5 Report the following strength properties as the ratio of the means of the treated to untreated values after adjustment to 67 % relative humidity: (See Appendix X1.)

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[6] Cochran, W. G., and Cos, G. M., *Experimental Designs*, J. Wiley and Sons, Inc., New York, NY, 1957.

Flexural stiffness (EI) (lb.·in.^{2}/ft of width or N·m^2/m of width),

Maximum Moment (MM) (in.·lb/ft of width or N·m/m of width), and

Work to Maximum Load (WML) (in.·lb/in^3 or kJ/m^3).

8.1.6 In addition to the means of the groups, the medians, standard deviations, and coefficients of variation for each group.

8.1.7 If the data includes specimens with one or more of the characteristics listed in 7.3.4, report the results of 8.1.4, 8.1.5, and 8.1.6, with and without results from specimens containing these characteristics.

8.1.8 Report the equilibrium moisture content (oven dry basis). No adjustment of strength or stiffness properties of untreated controls to the moisture content of the treated specimens should be made when establishing treatment design value factors.

8.1.9 Note any deviations from the procedure.

8.2 *Other Items That Can Be Reported*:

8.2.1 Graphical reports may be used to indicate trends but a full tabular report must also be given.

8.2.2 Any curve-fitting techniques and correlation coefficients.

9. Precision and Bias

9.1 The precision of this test method has not yet been determined. Initial test data obtained during the development of this test method are contained in Winandy, et al.[7] When further data are available, a precision statement will be included.

9.2 Since there is no accepted reference material suitable for determining the bias of the procedure in this test method, bias has not been determined.

10. Keywords

10.1 bending properties; fire retardant; flexural properties; plywood; roof sheathing; strength effects; temperature; thermal effects; treatment

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[7] Winandy, J. E., LeVan, S. L., Ross, R. J., Hoffman, S. P., and McIntyre, C. R., *Thermal Degradation of Fire-Retardant Treated Plywood: Development and Evaluation of a Test Protocol*, USDA Forest Service, Forest Products Laboratory Research Paper FPL-501, 1991.

APPENDIXES

(Nonmandatory Information)

X1. CALCULATIONS

X1.1 After the data are obtained, the natural logarithm of the bending modulus of rupture (MOR) is plotted versus days of exposure for the treated specimens. This will yield a linear plot and the slope is equal to the unadjusted first order rate constant, k'(Fig. X1.1).

X1.2 If the data were obtained at a humidity other than 67 %, then the rate constant (k') needs to be adjusted to 67 % relative humidity (see Eq 2 of Winandy, et al (1991b)). The appropriate factor is listed in Table X1.1.

X1.2.1 Intermediate values can be interpolated from Table X1.1.

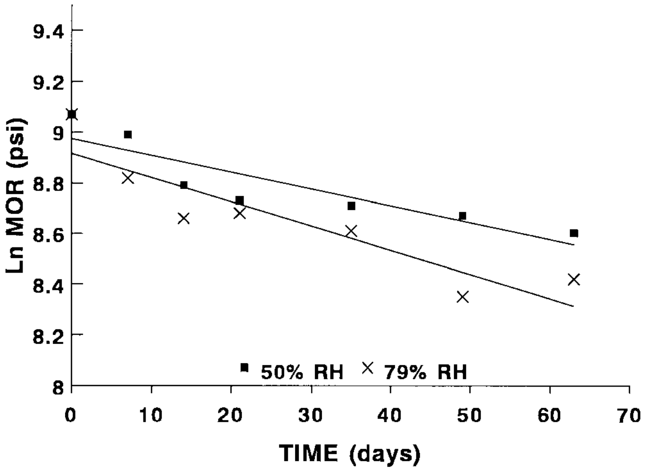

FIG. X1.1 MAP-Treated SYP Plywood Exposed at 170°F (77°C)

TABLE X1.1 Factors to Adjust Rate Constant, k′, at Relative Humidities Other than 67 %

Test RH, %	50	55	60	65	70	75	80	85
Factor	1.34	1.22	1.12	1.03	0.96	0.89	0.84	0.79

X1.3 *Examples:*

X1.3.1 The test was run at 77°C (170°F) and 79 % relative humidity. From Table X1.1, the appropriate factor can be interpolated as 0.85, so the adjusted k'' is k'* (0.85) or (0.85)* (−0.0095) or −0.00808.

X1.3.2 The test was run at 77°C (170°F) and 50 % relative humidity. From Table X1.1 , the appropriate factor is 1.34, so the adjusted k'' is k'* (1.34) or (1.34)* (−0.0067) or −0.00898.

X1.3.3 Note that the two estimates of k'', −0.00808 and −0.00898 compare quite favorably to each other; ideally, they would be the same.

X1.4 The adjusted k'' can then be used to estimate the strength loss by multiplying the exposure time by k''. That is, to calculate the strength loss at 60 days at 77°C (170°F) and 67 % RH, multiply −0.00808 times 60 to obtain −0.485 for Example 1. Example 2 yields −0.00898 times 60 = 0.539. In this adjustment, the two estimates of the strength loss at 170°F and 67 % RH then are 48.5 % and 53.9 %. Again the estimated values compare favorably.

X1.5 If data are available at two or more relative humidity conditions at the same temperature, then the adjusted rates, k'', for each condition should be calculated and then the average of the calculated rates used in further calculations. In the examples in X1.3, the −0.00808 and −0.00898 would be averaged to −0.00853 and then −0.00853 times 60 yields −0.512 or 51.2 %.

X1.6 Similarly, if data are available at three or more different temperatures, an Arrhenius plot can be developed to ascertain the Arrhenius parameters.[8] The Arrhenius plot is obtained by plotting the logarithm of the rate constants against the reciprocal of the absolute temperatures (Fig. X1.2).

X1.7 The manufacturers of fire-retardant formulations are developing a uniform methodology for interpreting cumulative exposures. For this purpose, the cumulative effects of exposure temperature and humidity may be determined using average year data developed from field measurements, or computer simulations based on verified models and official weather information, or both. Where information on long-term performance of roof systems made with fire-retardant-treated plywood is available, the results of tests conducted in accordance with this test method on plywood treated with the same chemical formulation or formulations used in such roof systems provide a reference point for validating methodology used to relate strength retention-temperature relationships based on accelerated testing with estimated cumulative thermal loads on roof sheathing.

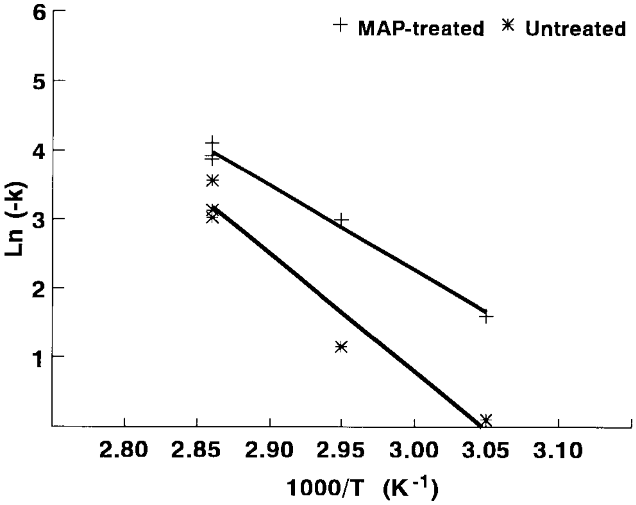

FIG. X1.2 Arrhenius Plot

X2. COMMENTARY

X2.1 Fire retardants have been used to treat plywood and lumber for many decades in the United States. Fire-retardant treatment can reduce the flame spread of the treated material to such an extent as to be considered an alternative to noncombustible materials in specific instances by building codes.

X2.2 In the early 1960s, two of the model building codes were changed to allow the use of fire retardant treated (FRT) plywood and lumber as structural members in roofs of certain noncombustible types of construction. Subsequently in the early 1980s, most of the model building codes were changed to allow for the use of FRT plywood roof sheathing as an alternative to a parapet on a fire-resistance rated wall between multi-family dwelling units. During the mid-1980s, a number of failures of FRT roof sheathing were reported. These failures were characterized by a darkening of the FRT plywood, which crumbled very easily. Also, the roof sheathing became very brash and brittle. In some of the more extreme instances, severe out-of-plane buckling occurred.

X2.3 These strength failures did not occur in all the fire retardant formulations used commercially, nor did every use of a particular formulation result in a failure (Winandy, et al, 1991a). It appeared that the strength failures were a result of the specific chemical formulation used, the temperatures that the roof sheathing was exposed to, and moisture content of the treated plywood. A more comprehensive background of this subject can be found in Still, et al, 1991.

X2.4 In general, fire retardants work by lowering the temperature at which wood pyrolyses. By lowering this pyrolysis temperature, fire retardants can cause an increase in the amount of char formed and a reduction in the amount of flammable volatiles released (LeVan and Collet, 1989). This serves to reduce the flame spread. However, this same mechanism of fire retardancy seemed to be responsible for the strength loss observed in FRT roof sheathing. The elevated temperatures that the FRT plywood was exposed to in roof decks appeared to be triggering the fire retardant mechanism prematurely, resulting in strength failures (LeVan, et al, 1990).

X2.5 In late 1987, Section D07.06.04 formed a task group to develop a protocol for evaluating the long-term effect of fire-retardant treatments on the mechanical properties of plywood. This task group included members of the wood industry, fire-retardant manufacturers, and researchers from the USDA Forest Products Laboratory. The final protocol evolved over a two-year period, which addressed key questions about the scope, design, and accuracy of the proposed test method. A more thorough discussion of the development of this protocol can be found in Winandy, et al (1991b). The more important criteria the task group identified were as follows: wood species, plywood quality, and specimen size; mechanical properties; simulation of field conditions in the laboratory; exposure temperature, humidity, and duration; experimental design considerations.

X2.6 Southern Pine plywood was selected as the material most appropriate for the test protocol. Southern Pine is the wood species most often used for fire-retardant treatment, due to its low cost and excellent treatability. Also, Southern Pine is the most readily available species for use in the Eastern United States, where FRT plywood finds the most widespread use.

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[8] Hill, C. P., Jr., *Chemical Engineering Kinetics*, McGraw-Hill, New York, NY, 1982.

Additionally, Southern Pine requires a higher dry chemical retention than other species, making it most susceptible to the effects of fire-retardant chemicals.

X2.7 N-grade plywood was initially included in the test protocol because the objective was to develop a comparative procedure, rather than establish design values. N-grade plywood is free of defects and voids, and therefore, could be used to establish relative thermal effects without the uncontrollable influence of plywood grade defects.

X2.8 In order to have specimens that were large enough to have significant measurable mechanical properties, but small enough to be practically used, the task group decided that 75- by 610-mm (3- by 24-in.) (face veneer parallel to long axis) bending specimens were sufficient based on work of McNatt and coworkers (1984, 1990).

X2.9 Bending properties, specifically modulus of elasticity, stiffness, modulus of rupture, maximum bending moment, and work to maximum load, were evaluated because bending loads were considered critical for plywood roof sheathing.

X2.10 Plywood roof sheathing is exposed to both cyclic temperature and humidity conditions on a daily basis, as well as seasonal temperature and humidity cycles. Because recreating laboratory conditions that mimic actual field conditions would be both extraordinarily time-consuming and cost-prohibitive, the laboratory exposure technique chosen was a steady-state, elevated temperature and humidity exposure. This exposure is fast, more extreme than cyclic exposure, and indicates whether particular chemicals are activated at the tested temperature.

X2.11 The task group originally chose three temperatures for exposure conditions: 54, 65, and 77°C (130, 150, and 170°F). These three temperatures were selected because they respectively represent: a daily temperature commonly achieved in plywood roof sheathing; a critical temperature limit for long-term exposure of wood products; and a periodically obtained daily maximum temperature.

X2.11.1 It had been thought that there existed a temperature threshold, below which thermally induced strength degradation does not occur, and above which permanent degradation does occur. Because of evidence that strength losses occurred at all three temperatures, with greater losses occurring at higher temperatures, it was decided that running the thermal exposures at 77°C, 67 % relative humidity over an extended period of at least 75 days is sufficient to yield a referenced thermal cycle to provide information for other standards under development.

X2.12 Humidity that varied between 50 and 79 % relative humidity was considered as two realistic extremes. Eventually, 67 % relative humidity was selected in order to maximize the degradative mechanism, while minimizing corrosion of test equipment and problems of accurate moisture control.

X2.13 Blocked and random experimental designs were both evaluated. It was found that a blocked design could minimize the error due to panel to panel variability, and so a blocked experimental design was preferred (see 6.4.1.1 or Winandy, et al, 1991b).

X2.14 Using the final test protocol, thermally induced strength losses were evidenced in laboratory simulations within a reasonably short period. The environmental conditions used in the laboratory-activated chemical reactions that are considered to be similar to those occurring in the field. Results from this protocol can be used to compare relative performance for new or existing FR treatments before they are used in service conditions with periodic or sustained exposure to elevated temperatures.

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