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# Standard Practice for
# Calculating Bending Strength Design Adjustment Factors for Fire-Retardant-Treated Plywood Roof Sheathing[1]

This standard is issued under the fixed designation D6305; 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.

ε[1] NOTE—Editorial corrections were made to Appendix X1 in October 2015.

## 1. Scope

1.1 This practice covers procedures for calculating bending strength design adjustment factors for fire-retardant-treated plywood roof sheathing. The methods utilize the results of strength testing after exposure at elevated temperatures and computer-generated thermal load profiles reflective of exposures encountered in normal service conditions in a wide variety of continental United States climates.

1.2 Necessarily, common laboratory practices were used to develop the methods herein. It is assumed that the procedures will be used for fire-retardant-treated plywood installed using appropriate construction practices recommended by the fire retardant chemical manufacturers, which include avoiding exposure to precipitation, direct wetting, or regular condensation.

1.3 The heat gains, solar loads, roof slopes, ventilation rates, and other parameters used in this practice were chosen to reflect common sloped roof designs. This practice is applicable to roofs of 3 in 12 or steeper slopes, to roofs designed with vent areas and vent locations conforming to national standards of practice, and to designs in which the bottom side of the sheathing is exposed to ventilation air. These conditions may not apply to significantly different designs and therefore this practice may not apply to such designs.

1.4 Information and a brief discussion supporting the provisions of this practice are in the Commentary in the appendix. A large, more detailed, separate Commentary is also available from ASTM.[2]

1.5 The methodology in this practice is not meant to account for all reported instances of fire-retardant plywood undergoing premature heat degradation.

1.6 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.

1.7 *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:*[3]

D9 Terminology Relating to Wood and Wood-Based Products

D5516 Test Method for Evaluating the Flexural Properties of Fire-Retardant Treated Softwood Plywood Exposed to Elevated Temperatures

## 3. Terminology

3.1 *Definitions:*

3.1.1 Definitions used in this practice are in accordance with Terminology D9.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bin mean temperature*—10°F (5.5°C) temperature ranges having mean temperatures of 105 (41), 115 (46), 125 (52), 135 (57), 145 (63), 155 (68), 165 (74), 175 (79), 185 (85), 195 (91), and >200°F (93°C).

## 4. Summary of Practice

4.1 The test data determined by Test Method D5516 are used to develop adjustment factors for fire-retardant treatments to apply to untreated-plywood design values. The test data are used in conjunction with climate models and other factors and the practice thus extends laboratory strength data measured after accelerated aging to design value recommendations.

[1] This practice is under the jurisdiction of ASTM Committee D07 on Wood and is the direct responsibility of Subcommittee D07.07 on Fire Performance of Wood.

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[2] Commentary on this practice is available from ASTM Headquarters. Request File No. D07–1004.

[3] 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.

## 5. Significance and Use

5.1 This practice develops treatment factors that shall be used by fire retardant chemical manufacturers to adjust bending strength design values for untreated plywood to account for the fire-retardant treatment effects. This practice uses data from reference thermal-load cycles designed to simulate temperatures in sloped roofs of common design to evaluate products for 50 iterations.

5.2 This practice applies to material installed using construction practices recommended by the fire retardant chemical manufacturers that include avoiding exposure to precipitation, direct wetting, or regular condensation. This practice is not meant to apply to buildings with significantly different designs than those described in 1.3.

5.3 Test Method D5516 caused thermally induced strength losses 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. This assumption is the fundamental basis of this practice.

## 6. Procedure to Calculate Strength Loss Rate

6.1 The procedure is a multistep calculation where first an initial strength loss is determined, then the rates of strength loss at various temperatures are calculated, and finally the initial loss and rates are combined into the overall treatment adjustment factor.

6.2 Use the load-carrying capacity in bending, referred to as maximum moment ($M$), as the controlling property for purposes of determining allowable spans.

6.2.1 The ratio of the average maximum moment ($M$) for unexposed treated specimens to the average moment for unexposed untreated specimens shall be designated the Initial treatment effect, $R_o$, associated with the room temperature conditioning exposure of $T_o$.

$$R_o = M_{TRT,\ UNEX}/M_{UNTRT,UNEX} \quad (1)$$

6.2.2 If testing is done at more than one temperature, $R_{oi}$ shall be determined at each temperature and used in subsequent rate calculations for that specific temperature. The average of these values, $R_{o,avg}$ shall be used in initial treatment effect calculations (see 7.1).

6.3 The average maximum moment ( $M$) of the treated specimens conditioned at the same temperature for the same period of time shall be computed. The ratio of these moments to the moment of the untreated, unexposed specimens as obtained in 6.3.1 and 6.3.2 shall be designated the test treatment ratio, $R_t$. Include the ratio for specimens conditioned at room temperature but not exposed to elevated temperature prior to testing.

$$R_t = R_{test} = M_{TRT,(UNEX,\ EX)}/M_{UNTRT,UNEX} \quad (2)$$

(per 6.3.2)

NOTE 1—When end matching of treated and untreated specimens is employed to reduce variability in accordance with Test Method D5516, use the ratio of the matched pairs from each panel to calculate the panel mean. The average of the panel means shall be used to calculate $R_t$.

6.3.1 For untreated specimens, linear regressions of the form:

$$M = a(D)+b \quad (3)$$

where:

$M$ = average maximum moment,
$D$ = number of days of elevated temperature exposure,
$a$ = constant, and
$b$ = intercept.

shall be fitted to the maximum moment and exposure time data for each elevated temperature exposure. Average moments for untreated specimens conditioned at room temperature but not exposed to elevated temperature prior to testing shall be included as zero day data in the regression analysis.

6.3.2 The intercept of the regression obtained in 6.3.1 for the untreated specimens shall be designated the unexposed average. If a negative slope of the untreated specimen regression is not obtained, the average of the mean maximum moments at each exposure period, including zero, shall be considered the unexposed average moment for untreated specimens.

NOTE 2—The intercept value obtained in 6.3.2 may be different from the unexposed, untreated value used in 6.2.1 for determining $R_o$.

6.4 The slope and intercept of the linear relationship between the ratios and days of exposure for all elevated temperatures shall be determined by linear regressions of the form:

$$R_{t,i} = k_t(D)+c \quad (4)$$

where:

$R_{t,i}$ = test ratios of average maximum moments,
$D$ = number of days of elevated temperature exposure,
$k_t$ = slope, and
$c$ = intercept.

Include the ratio for treated specimens conditioned at room temperature but not exposed to elevated temperature prior to testing as zero day data in the regression analysis.

6.4.1 If a negative slope is not obtained in 6.4, there was no apparent strength loss at the exposure temperature and alternate procedures described in 7.2 are required.

6.4.2 The slope $k_t$ from 6.4 shall be adjusted to a 50 % relative humidity ($RH$) basis by the following equation:

$$k_{50,i} = k_t(50/RH_i) \quad (5)$$

where:

$k_{50,i}$ = slope at 50 % $RH$ at temperature $i$, and
$RH_i$ = elevated temperature test $RH$.

6.5 If Test Method D5516 protocol testing was only done at one elevated temperature, rates at other temperatures shall be estimated by the use of Arrhenius equation, which states that the rate of a chemical reaction is approximately halved for each 10°C the temperature is reduced. (Conversely, the rate approximately doubles for each 10°C that the temperature is increased.)

6.5.1 If testing was done at only one temperature, then to allow for the uncertainty in only one measurement of the ratio, the rate $k_{50,i}$ shall be increased by 10 % prior to the Arrhenius calculations. If testing was done at two temperatures, then the rate at each temperature shall be increased by 5 % prior to the Arrhenius calculations.

NOTE 3—Increasing the rate of $k_{50,i}$ has the effect of increasing the apparent strength loss.

6.5.2 The Arrhenius equation is used to estimate rates at other temperatures. The rate constant, $k_2$, at temperature, $T_2$, is related by

$$\ln \frac{k_{50,i}}{k_2} = \frac{Ea\,(T_1 - T_2)}{R\,T_1\,T_2} \quad (6)$$

where:

$Ea$ = 21 810 cal/mol (91 253 J/mol) (**1**),[4,5]
$R$ = 1.987 cal/mol-°K = (8.314 J/mol-°K) = gas constant, and
$T_1$ and $T_2$ are in °K.

6.6 Compute capacity loss as the negative value of the rates ($k_2$) for bin mean temperatures of 105 (41), 115 (46), 125 (52), 135 (57), 145 (63), 155 (68), 165 (74), 175 (79), 185 (85), 195 (91), and >200°F (93°C).

NOTE 4—Use the negative values of the rates ($k_2$) for *CLT* since *CLT* is expressed as a loss.

6.7 If Test Method D5516 testing was done at three or more elevated temperature exposures, capacity losses shall be established by fitting a linear regression to the natural logarithm of the negative of the slopes of the regressions obtained in 6.4 at each exposure temperature and $1/T_i$ where $T_i$ is in °K.

NOTE 5—This constructs an Arrhenius plot using classical chemical kinetics techniques, which is the simplest modeling approach. Other more sophisticated modeling techniques are available but require a different procedure for calculating strength loss rates.[6]

6.7.1 If Test Method D5516 testing was done at two temperatures, the two rate constants ($k_2$) calculated from Eq 6 shall be averaged for each bin mean temperature.

6.8 *Reference Thermal Load Profiles:*

6.8.1 The cumulative days per year the average sheathing temperature falls within 10°F (5.6°C) bins having mean temperatures of 105 (41), 115 (46), 125 (52), 135 (57), 145 (63), 155 (68), 165 (74), 175 (79), 185 (85), 195 (91), and >200°F (93°C) represent a thermal load profile. The profiles tabulated below, based on reference year weather tape information for various locations, an indexed attic temperature and moisture model developed by the Forest Products Laboratory, and a south-facing roof system ventilated as required by the applicable code having dark-colored shingle roofing, shall be considered the standard thermal environments fire-retardant-treated plywood roof sheathing is exposed to in different snow load zones (**4**). The specific model inputs used were 0.65 shingle absorptivity and a ventilation rate of 8 air changes per hour (ach).[7] See Table 1.

**TABLE 1 Reference Thermal Load Profiles**

| Sheathing Mean | Cumulative Average Days/Year | | |
|---|---|---|---|
| Bin Temperature, °F(°C) | Zone 1A[A] | Zone 1B[A] | Zone 2[A] |
| 105(41) | 10.960 | 34.281 | 10.970 |
| 115(46) | 8.053 | 24.911 | 8.308 |
| 125(52) | 8.597 | 13.529 | 5.041 |
| 135(57) | 7.865 | 6.856 | 1.532 |
| 145(63) | 6.798 | 0.960 | 0.283 |
| 155(68) | 5.083 | ... | ... |
| 165(74) | 0.586 | ... | ... |
| 175(79) | ... | ... | ... |
| 185(85) | 0.021 | ... | ... |
| 195(91) | 0.021 | ... | ... |
| ≥200(93) | 0.021 | ... | ... |

[A] *Zone Definition:*

(*1*) Minimum roof live load or maximum ground snow load ≤20 psf (≤958 Pa)
  A. Southwest Arizona and Southeast Nevada (Area bound by Las Vegas, Yuma, Phoenix, Tucson)
  B. All other qualifying areas
(*2*) Maximum ground snow load >20 psf (>958 Pa)

6.9 *Annual Capacity Loss*—Total annual capacity loss (CLT) due to elevated temperature exposure shall be determined for locations within each zone as the summation of the product of the capacity loss per day (CL) rate from 6.6 and the cumulative average days per year from 6.9 for each mean bin temperature.

## 7. Treatment Factor

7.1 For each zone, a treatment adjustment factor (TF) shall be calculated as:

$$TF = [1 - IT - n(CF)(CLT)] \quad (7)$$

where:

$TF$ = treatment adjustment factor ≤1.00 - IT,
$IT$ = initial treatment effect = 1-$R_0$,
$n$ = number of iterations = 50,
$CF$ = Cyclic factor[8] = 0.6, and
$CLT$ = total annual capacity loss.

7.2 If testing was only done at one exposure temperature that was 168°F (76°C) or greater and a negative slope was not obtained in 6.4, there was no apparent strength loss and hence no annual capacity loss can be calculated. In this case, the treatment adjustment factor will be the lesser of the initial treatment effect (1-$R_o$) or 0.90, which reflects the 10 % allowance for uncertainty in only measuring at one temperature.

$$TF = \text{lesser of } (1 - R_o) \text{ or } 0.90 \quad (8)$$

7.2.1 If the exposure temperature was less than 168°F (76°C) and a negative slope was not obtained in 6.4, then the exposure testing must be repeated at a higher temperature that either exceeds 168°F (76°C) or causes a negative slope in 6.4.

[4] The boldface numbers in parentheses refer to a list of references at the end of the text.

[5] Pasek and McIntyre (**1**) have shown that the Arrhenius parameter, $E_a$, for phosphate-based fire retardants for wood averages 21 810 cal/mol (91 253 J/mol). Other values are appropriate for fire retardants that are not phosphate based.

[6] A description of other models is available in Refs (**2**) and (**3**).

[7] Based on reported data given in Ref (**5**).

[8] This factor was derived by comparing the mechanical property data obtained from plywood exposed to continuous elevated temperatures to data obtained from cyclic exposures that peaked at the same elevated temperature as the continuous exposure. The respective publications are Refs (**6**) and (**7**).

**TABLE 2 Ratios for Relative Humidity Adjustment**

| Exposure Temperature °F (°C) | RH percent | Exposure, days | Ratio at Test ($R_{ti}$) |
|---|---|---|---|
| 80(27) | 65 | 0 | 0.926 |
| 170(77)-B | 79 | 7 | 0.844 |
| 170(77)-B | 79 | 14 | 0.741 |
| 170(77)-B | 79 | 21 | 0.696 |
| 170(77)-B | 79 | 35 | 0.570 |
| 170(77)-B | 79 | 49 | 0.489 |
| 170(77)-B | 79 | 63 | 0.430 |

## 8. Allowable Roof Sheathing Loads

8.1 Maximum allowable roof live plus dead uniform loads for a particular plywood thickness and roof sheathing span shall be determined as:

$$w = (TF)(C)(F_bKS)(DOL)/L^2 \tag{9}$$

where:

$w$ = allowable total uniform load based on bending strength, (lb/ft$^2$ ($Pa$)),
$TF$ = zone treatment factor ≤ (100 - IT),
$C$ = 120 in./ft (3.05 m/m) for panels continuous over three or more spans,
= 96 in./ft (2.44 m/m) for panels on single span or continuous over two spans,
$F_bKS$ = published design maximum moment or bending strength for untreated plywood of the grade and thickness being used (in-lb/ft (kNm/m)),

NOTE 6—Such design values for $F_bKS$ are published by panel agencies and associations.

$DOL$ = duration of load adjustment,
= 1.15 for Zones 1B, and 2, 1.25 for Zone 1A, and
$L$ = span (center of supports, (in. (mm)).

## 9. Example Calculations

9.1 Example calculations illustrating relative humidity adjustment, Arrhenius estimations relating treatment ratio and temperature and calculation of capacity loss rates, annual total capacity loss, and treatment factor are given in this section. The test data are from Ref **(6)** and it is assumed that all the test specimens were randomized for purposes of these examples.

9.1.1 *Example 1*—Test Data are listed below to facilitate the example calculations:

| Exposure Temperature | *RH* | $M_{o,TRT}$ | $M_{o,UNT}$ | $R_o$ |
|---|---|---|---|---|
| 130 (54) | 73 | 1410 | 1650 | 0.855 |
| 150 (66) | 76 | 1250 | 1420 | 0.861 |
| 170 (77)-A | 79 | 1410 | 1650 | 0.855 |
| 170 (77)-B | 79 | 1250 | 1420 | 0.861 |
| 170 (77)-C | 50 | 1410 | 1650 | 0.855 |
| | | | $R_{o,avg}$ | =0.857 |

9.1.1.1 *Example 1.1*—Relative Humidity Adjustment: Testing at one elevated temperature (based on 170-B data). See Table 2 for ratios. Regression of Table 2 data (ratio versus days) yields $k_t$ of −0.00784. Then,

$$k_{50} = k_t\,(50/RH_i) = (-0.00784)(50/79) = -0.00496 \tag{10}$$

9.1.2 *Example 2—Arrhenius Estimations:*

9.1.2.1 *Example 2.1*—From Example 1, know that $Ro$ = 0.861 and from Example 1.1, know that $k_{50}$ = 0.00496.

| Temperature | K | 1/*T* | *k*50 | $R_o$ |
|---|---|---|---|---|
| 170 (77)-B | 350 | 0.002857 | -0.00496 | 0.861 |

Since testing was done at only one temperature, $k_{50}$ is increased by 10 % and the adjusted $k_{50}$ is used in subsequent calculations:

$$k_{50,adj} = k_{50} + 10\,\%\,k_{50} = -0.00496 + (-0.000496) = -0.00546 \tag{11}$$

The factor for an 18°F (10°C) decrease to 152°F (67°C) can be calculated by:

$$\ln \frac{k_{50},\,adj}{k_2} = \frac{Ea\,(T_1 - T_2)}{R\,(T_1)\,(T_2)} \tag{12}$$

$$k_2 = -0.00217 \tag{13}$$

9.1.2.2 *Example 2.2*—Estimate from test data from one elevated temperature. See Table 3.

**TABLE 3 Rate Estimate from Test Data from One Elevated Temperature**[A]

| °F(°C) | *K* | $k_2$ | Capacity Loss |
|---|---|---|---|
| 170(77) | 350 | −0.00546 = $k_{50,adj}$ | 0.00546 |
| 105(41) | 313 | −0.000134 | 0.000134 |
| 115(46) | 319 | −0.000259 | 0.000259 |
| 125(52) | 325 | −0.000489 | 0.000489 |
| 135(57) | 330 | −0.000816 | 0.000816 |
| 145(63) | 336 | −0.001478 | 0.001478 |
| 155(68) | 341 | -0.002386 | 0.002386 |
| 165(74) | 347 | −0.004163 | 0.004163 |
| 175(79) | 352 | −0.006525 | 0.006525 |

[A] Calculations based on 170 (77)-B data.

**TABLE 4 Estimate from Test Data from Test Data at Three Elevated Temperatures**

| Temperature | K | 1/*T* | Negative of $k_t$ (Slope) | ln $k_t$ | |
|---|---|---|---|---|---|
| 130 (54) | 327 | 0.003058 | 0.000524 | −7.553 | |
| 150 (66) | 339 | 0.002950 | 0.001804 | −6.318 | |
| 170 (77)-A | 350 | 0.002857 | 0.003622 | −5.621 | |
| 170 (77)-B | 350 | 0.002857 | 0.004961 | −5.306 | |
| 170 (77)-C | 350 | 0.002857 | 0.004647 | −5.372 | |
| Temperature | *K* | 1/*T* | ln $k_2$ | $k_2$ | Capacity Loss |
| 105 (41) | 313 | 0.003195 | −8.950 | −0.000130 | 0.000130 |
| 115 (46) | 319 | 0.003135 | −8.322 | −0.000243 | 0.000243 |
| 125 (52) | 325 | 0.003077 | −7.717 | −0.000445 | 0.000445 |
| 135 (57) | 330 | 0.003030 | −7.230 | −0.000725 | 0.000725 |
| 145 (63) | 336 | 0.002976 | −6.664 | −0.001276 | 0.001276 |
| 155 (68) | 341 | 0.002933 | −6.208 | −0.002013 | 0.002013 |
| 165 (74) | 347 | 0.002882 | −5.678 | −0.003420 | 0.003420 |
| 175 (79) | 352 | 0.002841 | −5.250 | −0.005247 | 0.005247 |

**TABLE 5 CLT for Zone 1B Using Data from One Exposure Temperature**

| Temperature °F(°C) | Sheathing Average Days/Year | Loss/Day (*CL*)[A] | Loss/Year |
|---|---|---|---|
| 105(41) | 34.281 | 0.000134 | 0.00459 |
| 115(46) | 24.911 | 0.000259 | 0.00646 |
| 125(52) | 13.529 | 0.000489 | 0.00662 |
| 135(57) | 6.856 | 0.000816 | 0.00560 |
| 145(63) | 0.96 | 0.001478 | 0.00142 |
| | | | CLT = 0.0247 |

[A] From Table 3.

9.1.2.3 *Example 2.3*—Estimate from test data from three elevated temperatures. See Table 4.

9.1.3 *Example 3*—Capacity loss rate. See Table 3.

9.1.4 *Example 4*—Capacity Loss Total (CLT) for Zone 1B. See Table 5.

9.1.5 *Example 5*—Treatment factor (from test data from one elevated temperature in Table 5):

$$\text{Zone 1B} \tag{14}$$

$$TF = 1.00 - IT - 50(0.6)(CLT)$$

$$IT = 1.00 - Ro = 0.139$$

$$CLT = 0.0247$$

$$TF = 0.12$$

9.1.6 *Example 6*—Treatment factor (from test data from three elevated temperatures in Table 6):

$$\text{Zone 1B} \tag{15}$$

$$TF = 1.00 - IT - 50(0.6)(CLT)$$

$$IT = 1.00 - Ro_{o,avg} = 0.143$$

$$CLT = 0.0227$$

$$TF = 0.18$$

## 10. Precision and Bias

**TABLE 6 CLT for Zone 1B Using Data from Three Exposure Temperatures**

| Temperature °F(°C) | Sheating Average Days/Year | Loss/Day (CL)$^A$ | Loss/Year |
|---|---|---|---|
| 105(41) | 34.281 | 0.000130 | 0.00446 |
| 115(46) | 24.911 | 0.000243 | 0.00605 |
| 125(52) | 13.529 | 0.000445 | 0.00602 |
| 135(57) | 6.856 | 0.000725 | 0.00497 |
| 145(63) | 0.960 | 0.001276 | 0.00123 |
| | | | CLT = 0.0227 |

$^A$ From Table 4.

10.1 It is not possible to determine the precision and bias of this practice since no testing is done. Committee D07 is pursuing the precision and bias of the underlying Test Method D5516. The Scope and Significance and Use Sections herein spell out the limitations and assumptions of this practice.

## 11. Keywords

11.1 design load values; fire retardant treatment; plywood; strength test

# APPENDIX

### (Nonmandatory Information)

## X1. COMMENTARY

X1.1 A large, more detailed commentary documenting the rationale used in the development of the practice is available from ASTM.[2]

X1.2 The strength test data used are those developed in accordance with "Protocol for Testing Fire Retardant Treated Plywood After Exposure to Elevated Temperatures," developed under the auspices of a special Task Group composed of plywood producer, fire-retardant chemical manufacturer, treater, and association (APA, FPL) members. The protocol was submitted to Committee D07 and published as an emergency standard, ES-20 (1992). The protocol is now standardized as Test Method D5516 and the data was published (**6**).

X1.3 Thermal roof sheathing loads are based on an attic temperature and moisture content model under continuing development at the U.S. Department of Agriculture's Forest Products Laboratory (**4**). The model has been indexed using field measured roof temperature data obtained in earlier studies by the Forest Products Laboratory (**8**) and in more recent data reported by Rose (**5**) . Other data have been published by Forest Products Laboratory researchers (**9, 10**) . A solar absorbance of 0.65 was used for the shingle roofing, which predicts the roof temperatures observed in test structures[2] and because higher absorbencies used with this model have been shown to predict unrealistic thermal loads.

X1.4 The performance of the roof systems on two nonresidential buildings over twenty years old, located in Thomson, GA, and made with fire-retardant-treated plywood, has been used to corroborate the procedures employed to relate accelerated test results to service performance.[2]

X1.5 The procedures in 6.2 are based on a linear relationship between maximum moment ($M$) and exposure time, in order to provide an additional safety factor. For other properties, a logarithmic relationship may be a more appropriate characterization.

## REFERENCES

**(1)** Pasek, E. A., and McIntyre, C. R., "Heat Effects on Fire-Retardant Treated Wood," *Journal of Fire Sciences*, Vol 8, Nov.–Dec., 1990, pp. 405–420.

**(2)** Winandy, J. E., and Lebow, P. K., "Kinetic Models for Thermal Degradation of Strength of Fire Retardant Treated Wood," *Wood and Fiber Science*, Vol 28, No. 1, 1996, pp. 39–52.

**(3)** Lebow, P. K., and Winandy, J. E., "Verification of the Kinetics-Based Model for Long-Term Effects of Fire Retardants on Bending Strength at Elevated Temperatures," *Wood and Fiber Science*, Vol 31, No. 1, 1999, pp. 49–61.

**(4)** Tenwolde, A., *The FPL Roof Temperature and Moisture Model: Description and Verification*, USDA Forest Service, Forest Products Laboratory, FPL-RP-561, Madison, WI.

**(5)** Rose, W. B., "Measured Values of Temperature and Sheathing Moisture Content in Residential Attic Assemblies," in: *Thermal Performance of the Exterior Envelopes of Building*, Geshwiler, M. (ed.), Proceedings of the ASHRAE/DOE/BTECC Conference, Clearwater Beach, FL, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Atlanta, GA, Dec. 1-10, 1992, pp. 379–390.

**(6)** Winandy, J. E., LeVan, S. L., Ross, R. J., Hoffman, S. P., and McIntyre, C. R., "Thermal Degredation of Fire Retardant Treated Plywood: Development and Evaluation of a Test Protocol," US Forest Products Laboratory, FPL-501, June 1991.

**(7)** LeVan, S. L., Kim, J. M., Nagel, R. J., and Evans, J. W., "Mechanical Properties of Fire Retardant Treated Plywood Exposed to Cyclic Temperature Exposure," *Forest Products Journal*, Vol 46, No. 5, 1996, pp. 64–71.

**(8)** Heyer, O. C., *Study of Temperature of Wood Parts of Houses Throughout the United States*, US Forest Products Laboratory, FPL-012, August 1963.

**(9)** Winandy, J. E., and Beaumont, R., "Roof Temperatures in Simulated Attics," U.S. Forest Products Laboratory, FPL-RP-543, 1995.

**(10)** Winandy, J. E., Barnes, H. M., and Hatfield, C., "Roof Temperature Histories in Matched Attics in Mississippi and Wisconsin," U.S. Forest Products Laboratory, FPL-RP-589, 2000.