Designation: D6305 – 21

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.

1. Scope

1.1 This practice covers procedures for calculating adjustment factors that account for the effects of fire-retardant treatment on bending strength of plywood roof sheathing. The adjustment factors calculated in accordance with this practice are to be applied to design values for untreated plywood in order to determine design values for fire-retardant-treated plywood used as sheathing in roof systems. The methods establish the effect of treatment based upon matched bending strength testing of materials with and without treatment after exposure at elevated temperatures.

NOTE 1—This analysis focuses on the relative performance of treated and untreated materials tested after equilibrating to ambient conditions following a controlled exposure to specified conditions of high temperature and humidity. Elevated temperature, moisture, load duration, and other factors typically accounted for in the design of untreated plywood must also be considered in the design of fire-retardant-treated plywood roof sheathing, but are outside the scope of the treatment adjustments developed under this practice.

1.2 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 This practice uses thermal load profiles reflective of exposures encountered in normal service conditions in a wide variety of continental United States climates. 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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *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:*[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.

[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.

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.

5. Significance and Use

5.1 This practice establishes the procedure to determine adjustment factors that account for the isolated effects of fire-retardant treatment on plywood roof sheathing. These effects are established relative to performance of untreated plywood. 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 for unexposed treated specimens ($M_{TRT,\ UNEX}$) to the average maximum moment for unexposed untreated specimens ($M_{UNTRT,\ UNEX}$) shall be designated the initial treatment ratio, 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 of the treated specimens conditioned at the same temperature for the same period of time ($M_{TRT,\ EX}$) shall be computed. The ratio of this moment to the average maximum moment of the untreated, unexposed specimens ($M_{UNTRT,\ UNEX}$) as obtained in 6.3.1 and 6.3.2 shall be designated as the test treatment ratio, R_t. Include the ratio for specimens conditioned at room temperature but not exposed to elevated temperature prior to testing.

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

(per 6.3.2)

NOTE 2—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 in the form of Eq 3 shall be fitted to the maximum moment and exposure time data for each elevated temperature exposure. Maximum 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.

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

where:

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

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 3—The intercept value obtained in 6.3.2 may be different from the value of $M_{UNTRT,\ UNEX}$ used in 6.2.1 for determining R_o.

6.4 The relationship between the ratios and days of exposure for all elevated temperatures shall be determined by linear regressions in the form of Eq 4. The ratio for treated 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.

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

where:

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

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 = relative humidity in elevated temperature test.

6.5 If Test Method D5516 protocol testing was only done at one elevated temperature, the rates, k_2, at other temperatures shall be estimated by the use of Arrhenius equation (Eq 6), 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 4—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 to $k_{50,i}$ by Eq 6.

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

where:

E_a = 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 Using Eq 6, calculate capacity loss rates per day as the negative values of the rate constants (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 5—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 6—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:*

TABLE 1 Reference Thermal Load Profiles

Sheathing Mean Bin Temperature, °F(°C)	Cumulative Average Days/Year 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)

6.8.1 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 given in Table 1, 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.

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 Table 1 for each mean bin temperature.

7. Treatment Adjustment 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,

[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**).

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

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.

NOTE 7—Information on how treatment factors are to be used to determine allowable roof sheathing loads is given in Annex A1.

8. Example Calculations

8.1 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.

8.1.1 *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

8.1.1.1 *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,

$$k_{50} = k_t\,(50/RH_i) = (-0.00784)(50/79) = -0.00496 \quad (9)$$

8.1.2 *Example 2—Arrhenius Estimations:*

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

[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 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.

Temperature	K	1/T	$k50$	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:

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

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

$$\ln \frac{k_{50},\,adj}{k_2} = \frac{E_a\,(T_1 - T_2)}{R\,(T_1)\,(T_2)} \quad (11)$$

$$k_2 = -0.00217 \quad (12)$$

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