Designation: D 6305 – 98$^{\epsilon 1}$

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 D 6305; 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—Eq 18 was corrected in April 2000.

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 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 This practice is written in inch-pound units with SI units provided in parentheses for information only.

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:*

D 9 Terminology Relating to Wood[3]

D 5516 Test Method for Evaluating the Mechanical Properties of Fire-Retardant Treated Softwood Plywood Exposed to Elevated Temperatures[3]

3. Terminology

3.1 *Definitions*:

3.1.1 Definitions used in this practice are in accordance with Terminology D 9.

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), and 175°F (79°C).

4. Summary of Practice

4.1 The test data determined by Test Method D 5516 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 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 fore 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 D 5516 caused thermally induced strength losses in laboratory simulations within a reasonably short

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

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

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

6.1.1 *Test Results Based on Randomized Block Sampling*—Analyze average maximum moment (M) data for treated and untreated plywood developed in accordance with Test Method D 5516 using randomized block sampling as in the following sections:

6.1.1.1 Linear regressions of the form:

$$M = a(D) + b \tag{1}$$

where:
M = average maximum moment,
D = number of days of elevated temperature exposure, and
a,b = constants.

shall be fitted to the maximum moment and exposure time data for each elevated temperature exposure for both treated and untreated specimens. Average moments for 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.

6.1.1.2 The intercept, or estimated maximum moment at zero days, of the regression for the treated specimens shall be taken as the unexposed average for treated specimens. For the untreated specimens, if a significant negative slope term (a) at the 95 % confidence level is obtained, the intercept of the untreated regression shall be designated the unexposed average. If a negative slope of the untreated specimen regression is not significant at the 95 % level or if the slope is positive, the average of the mean maximum moments at each exposure period, including zero, shall be considered the unexposed average moment for untreated specimens.

6.1.1.3 The ratio of the unexposed average maximum moment (M) for treated specimens to the unexposed average moment for untreated specimens shall be designated the immediate treatment effect, R_o associated with the room temperature conditioning exposure of T_o. The ratio of the maximum moments estimated from the regression for treated specimens at 60 days[4] to the unexposed average for untreated specimens shall be designated the 60 day treatment ratio R_{ti} at exposure temperature T_i:

$$R_o = M_{TRT,UNEX}/M_{UNTRT,UNEX} \text{ at Temperature, } T_o \tag{2}$$

$$R_{ti} = M_{TRT,60}/M_{UNTRT,UNEX} \text{ at Temperature, } T_i \tag{3}$$

6.2 *Test Results Using End-Matched Treated and Untreated Samples*—When end-matching of treated and untreated specimens is employed to reduce variability in accordance with Test Method D 5516 and each conditioning temperature used is represented by at least one paired specimen set from each plywood panel providing test material, the analysis shall be as in the following sections.

6.2.1 The average maximum moment (M) of the treated and untreated specimens from each panel conditioned at the same temperature for the same period of time shall be computed and the ratio of these moments determined. The average of these panel ratios shall be designated the test treatment ratio, R_t:

$$R_t = M_{TRT,EX}/M_{UNTRT,EX} \tag{4}$$

6.2.2 The slope and intercept of the linear relationship between the mean average maximum moment for untreated specimens and days of exposure for all elevated temperatures evaluated using the specimens from the same panels shall be determined in accordance with 6.1.1.2. Averages 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. If the slope of this relationship is negative and is significant at the 95 % confidence level, the test treatment ratio determined in 6.2.1 shall be adjusted by the ratio of the average untreated test maximum moment for all specimens at the same temperature and exposure period and the intercept or zero day average maximum moment for untreated specimens.

6.2.3 For each temperature exposure, linear regressions of the form:

$$R_t = a(D) + b \tag{5}$$

where:
D,a,b = as previously defined.

shall be fitted to the test treatment ratio, or adjusted test treatment ratio, and number of days of elevated temperature exposure. The intercept or zero day ratio estimated from this regression shall be designated the immediate treatment effect, R_o, associated with the room temperature conditioning exposure of T_o. The treatment ratio estimated from the regression for 60 day exposure shall be designated the 60 day treatment ratio, R_{ti}, at exposure temperature T_i:

$$R_o = b_{TRT,UNEX} \text{ at Temperature, } T_o \tag{6}$$

$$R_{ti} = R_{TRT,60} \text{ at Temperature, } T_i \tag{7}$$

6.3 The ratio R_{ti} from 6.1.1.3 or 6.2.3 shall be adjusted to a 50 % relative humidity (RH) basis by the following equation:

$$R_i = R_o - [R_o - R_{ti}][50/RH_i] \tag{8}$$

where:
R_i = 60 day treatment ratio at 50 % RH,
RH_i = elevated temperature test RH, and
R_o,R_{ti} = as previously defined.

6.4 If Test Method D 5516 protocol testing was only done at one elevated temperature, rates at other temperatures shall be estimated by the use of an Arrhenius equation that states that the rate of a chemical reaction is approximately halved for each 18°F (10°C) the temperature is reduced. (Conversely, the rate approximately doubles for each 18°F (10°C) that the temperature is increased.)

6.4.1 To accomplish this, the rate constant, k_1, for the loss of maximum moment (M) at the temperature, T_1, shall be first determined as:

[4] The 60 day period was selected as a reference level for calculation purposes. See Test Method D 5516.

$$Rate = D(maximum\ moment\ (M)) = k_1 * D \tag{9}$$

$$k_1 = \frac{D(Maximum\ moment\ (M))}{D} \tag{10}$$

where:
D = days, as previously defined.

Then, from the Arrhenius equation, the rate constant, k_2, at temperature, T_2, is related by:

$$\ln \frac{k_1}{k_2} = \frac{E_a (T_1 - T_2)}{RT_1T_2} \tag{11}$$

where: **(1)**[5,6]
E_a = 21 810 cal/mole (91 253 J/mole),
R = 1.987 cal./mole-°K = (8.314 J/mole-°K) = gas constant, and T_1 and T_2 are in °K.

The rate constants, k_2, shall be used to calculate estimated maximum moments at 60 days by:

$$M_{est,T_2} = k_2\ (60) \tag{12}$$

The estimated maximum moments at the different temperatures shall be reduced by 10 % to allow for the uncertainty in only one measurement of the ratio and then used to calculate R_t in accordance with 6.1.1.3 or 6.2.3.

6.5 Compute estimated treatment ratios, R_{ei}, for T_o and for bin mean temperatures of 105 (41), 115 (46), 125 (52), 135 (57), 145 (63), 155 (68), 165 (74) and 175°F (79°C). Determine capacity loss per day rates associated with each bin mean temperature as:

$$CL = (R_{e0} - R_{ei})/60 \tag{13}$$

where:
CL = capacity loss per day, dimensionless,
R_{e0} = estimated treatment ratio at T_o, and
R_{ei} = estimated treatment ratio at bin mean temperature T_i

6.6 If Test Method D 5516 testing was done at two elevated temperature exposures, the rate constants shall be calculated using the procedures of 6.4 for each temperature. The resulting moments are reduced by 5 % and the average of the reduced moments used in further calculations in accordance with 6.1.1.3 or 6.2.3.

6.7 If Test Method D 5516 testing was done at three or more elevated temperature exposures, capacity losses shall be established by fitting a linear regression to $ln\ (R_o\text{-}R_i)$ and $1/T_i$, where: T_i is in °K.

NOTE 1—This constructs an Arrhenius plot using classical chemical kinetics techniques. Other modeling techniques are available but require a different procedure for calculating strength loss rates.[7]

6.8 *Reference Thermal Load Profiles*—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) and 175°F(79°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 content 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 **(3)**. The specific model inputs used were 0.65 shingle absorptivity and a ventilation rate of 8 ach[8]. 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 6.5 and the cumulative average days per year from 6.8 for each mean bin temperature.

7. Treatment Factor

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

$$TF = [1 - IT - n(CF)(CLT)] \tag{14}$$

where:
TF = treatment factor ≤1.00 - IT,
IT = initial treatment effect = 1-R_{e0},
n = number of iterations = 50,
CF = Cyclic factor[9]= 0.6, and
CLT = total annual capacity loss.

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:

$$w = (TF)(C)(F_bKS)(DOL)/L^2 \tag{15}$$

TABLE 1 Reference Thermal Load Profiles

Sheathing Mean Bin Temperature, °F(°C)	Cumulative 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)	7.885	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, southeast Nevada (Las Vegas, Yuma, Phoenix, Tucson triangle)
B. All other qualifying areas
(*2*) Maximum ground snow load > 20 psf (> 958 Pa)

[5] Pasek and McIntyre have shown that the Arrhenius parameter, E_a, for phosphate-based fire retardants for wood averages 21 810 cal/mole (91 253 J/mole).

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

[7] A description of their models is available in Ref **(2)**.

[8] Based on reported data given in Ref **(4)**.

[9] 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 given in Ref **(5)**.

where:

w = allowable total uniform load based on bending strength, (lb/ft^2 (Pa)),

TF = zone treatment factor ≤ (1-IT),

C = 120 in./ft (10 m/m) for panels continuous over three or more spans, and,
= 96 in./ft (8 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 2—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, (inches (mm)).

9. Sample 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 **(5)** and it is assumed that all the test specimens were randomized for purposes of these examples.

9.1.1 *Example 1—Test Data and Relative Humidity Adjustment*:

9.1.1.1 *Example 1.1*— See Test Method D 5516. Testing at one elevated temperature. See Table 2.

9.1.1.2 *Example 1.2*— See Test Method D 5516. Testing at three elevated temperatures. See Table 3.

9.1.2 *Example 2—Arrhenius Estimations*:

9.1.2.1 *Example 2.1*— From test data at 170 (77°C) and 79 % RH, know:

$$Moment\ (M)_{TRT,UNEX} = 1191 \text{ lb. in } (135\ N{*}m)$$

$$Moment\ (M)_{TRT,170} \text{ @ 60 days} = 555 \text{ lb. in } (63\ N{*}m)$$

Therefore:

$$k_1 = \frac{M_{TRT,EX} - M_{TRT,UNEXP}}{D} = \frac{555–1191}{60} \quad (16)$$

$$k_1 = –10.6 \quad (17)$$

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

$$ln\frac{k_1}{k_2} = \frac{Ea\,(T_1 - T_2)}{R\,(T_1)\,(T_2)} \quad (18)$$

$$k_2 = –4.17 \quad (19)$$

Therefore:

$$k_2 = –4.17 = \frac{M_{152} - 1191}{60} \quad (20)$$

TABLE 2 Testing at One Elevated Temperature

Exposure		Treatment Ratio, 60 days	
Temperature °F(°C)	RH percent	Test	Adjusted to 50 % RH
80 (27)	65	0.8822	—
170(77)	79	0.411	0.58[A]

[A]0.88-[0.88–0.41][50/79] = 0.58 from Eq 8.

TABLE 3 Testing at Three Elevated Temperatures

Exposure		Treatment Ratio, 60 days	
Temperature °F(°C)	RH percent	Test	Adjusted to 50 % RH
80 (27)	65	0.88	—
130 (54)	73	0.84	0.85[A]
150 (66)	76	0.70	0.76[B]
170 (77)	79	0.41	0.58

[A]0.88-[0.88–0.84][50/73] = 0.85 from Eq 8.
[B]0.88-[0.88–0.70][50/76] = 0.76 from Eq 8.

$$M_{152} = 941 \text{ lb in.}$$

To allow for experimental error, reduce by 10 %:

$$\text{Moment } (M)_{152} = 941 - 94 = 847 \quad (21)$$

Then:

$$R_{152} = \frac{847}{1191} = 0.71 \quad (22)$$

Adjust to 50 % RH:

$$R_{152} = 0.88 - (0.88 - 0.71)\ 50/79 = 0.77 \quad (23)$$

9.1.2.2 *Example 2.1*— Estimate from test data from one elevated temperature: See Table 4.

9.1.2.3 *Example 2.2*— Estimate from test data at three elevated temperatures. See Table 5.

9.1.3 *Example 3*—Capacity loss rate, see Table 6.

9.1.4 *Example 4*—CLT for Zone 1B, See Table 7.

9.1.5 *Example 5*—Treatment factor:

$$\text{Zone 1B} \quad (24)$$

$$TF = 1 - \text{IT} - 50(0.6)(CLT)$$

$$IT = 1 - R_{e0} = 0.1178$$

$$CLT = 0.0232$$

$$TF = 0.19$$

10. Precision and Bias

10.1 It is not possible to determine the precision and bias of the practice since no testing is done. Committee D-7 is pursuing the precision and bias of the underlying Test Method D 5516. 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

TABLE 4 Estimate from Test Data from One Elevated Temperature

°F(°C)	°K	k_2	(M)	$(M)_{red}$	$R_{t,70\,\%}$	$R_{t,50\,\%}$
170(77)	350	—	555	—	0.41	0.58
175(79)	352	–10.9	431	388	0.33	0.52
165(74)	347	–6.98	706	635	0.53	0.65
155(68)	341	–3.99	913	822	0.69	0.75
145(63)	336	–2.48	1018	920	0.77	0.80
135(57)	330	–1.37	1095	986	0.83	0.84
125(52)	325	–0.82	1134	1021	0.86	0.85
115(46)	319	–0.43	1161	1045	0.88	0.87
105(41)	313	–0.22	1175	1058	0.89	0.87

TABLE 5 Estimate from Test Data at Three Elevated Temperatures

Temperature			Treatment Ratio		
°F(°C)	°K	1/T	Test	R_o-R_i	$ln(R_o$-$R_i)$
170(77)	350	0.002857	0.58	0.88-0.58 = 0.30	–1.204
150(66)	339	0.002950	0.76	0.88-0.76 = 0.12	–2.120
130(54)	327	0.003058	0.85	0.88-0.85 = 0.03	–3.507
80 (27)	300	0.003333	0.88	. . .	. . .

°F(°C)	°K	1/T	$ln(R_o$-$R_i)$	R_i
170(77)	350	0.002857	–1.15	0.56
175(79)	352	0.002841	–.966	0.50
165(74)	347	0.002882	–1.436	0.64
155(68)	341	0.002933	–2.019	0.75
145(63)	336	0.002976	–2.521	0.80
135(57)	330	0.003030	–3.143	0.84
125(52)	325	0.003077	–3.678	0.85
115(46)	319	0.003135	–4.344	0.87
105(41)	313	0.003195	–5.034	0.87

TABLE 6 Capacity Loss Rate

T_i	R_i	Loss/Day $CL = (R_{e0}-R_{ei})/60$
75	0.8822=R_{e0}	0.000000
105	0.8742	0.000134
115	0.8672	0.000250
125	0.8544	0.000463
135	0.8362	0.000767
145	0.7993	0.001382
155	0.7487	0.002225
165	0.6497	0.003875
175	0.5181	0.006069

TABLE 7 CLT for Zone 1B

Temperature °F(°C)	Sheathing Average Days/Year	Loss/Day (CL)	Loss/Year
105(41)	34.281	0.000134	0.0041
115(46)	24.911	0.000250	0.0062
125(52)	13.529	0.000463	0.0063
135(57)	6.856	0.000767	0.0053
145(63)	0.960	0.001382	0.0013
			CLT = 0.0232

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.

X1.2 The strength test data used and 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 D-7 and published as an emergency standard, ES-20 (1992). The protocol is now standardized as Test Method D 5516.

X1.3 Thermal roof sheathing loads are based on a new 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 **(6)**. 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 made with fire-retardant-treated plywood has been used to corroborate the procedures employed to relate accelerated test results to service performance **(6)**.

X1.5 The procedures in 6.1 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, and McIntyre, , *J. Fire Sci.*, 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 (28) 1*, 1996, pp. 39-52.

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

(**4**) 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.

(**5**) 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, and 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*, 46 (5), 1996, pp. 64-71.

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