TREATMENT AND REDRYING OF WESTERN HEMLOCK PLYWOOD

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ABSTRACT

This study investigated the mechanical properties of western hemlock plywood after treatment with waterborne preservatives and redrying. Unlike previously reported results for southern pine plywood, western hemlock plywood was more sensitive to redrying temperature than to preservative treatment. Generally, western hemlock plywood was affected by temperature and other variables. Losses in mechanical properties were generally higher compared to similarly treated and redried southern pine plywood. Treatment of the plywood with either acidic (CCA-type C) or alkaline (ACZA) solutions resulted in adequate preservative gradients. Western hemlock tended to be affected more by acidic solutions than by alkaline solutions. Based on this research, treated western hemlock plywood should not be redried at temperatures in excess of 140°F without applying some design stress reduction factor.

Extensive research has been done on the effect of redrying temperature on the mechanical properties of preservative-treated solid wood (3-6,11,14-21). It has been shown that, while treatments may reduce the strength of wood to some extent, the strength loss is exaggerated upon redrying at elevated temperatures.

Redrying wood and plywood after treatment is necessary to maintain lower handling and transportation costs, better workability, and better dimensional stability in use. Prior to the present work, MacKay (13) presented the only known work on the effect of kiln-drying on preservative-treated plywood. However, no mechanical testing was done, the discussion was mainly qualitative, and he concluded that higher commercial drying temperatures could be used to reduce drying times as long as minor degrade increases were acceptable. In a companion paper to this research (10), the authors showed that when southern pine plywood treated with chromated copper arsenate (CCA) was redried at temperatures in excess of 180°F, most property values were reduced. Effects were inconsequential at a redrying temperature of 140°F.

There is common agreement that treatment alone does not have a significant negative effect on the strength of wood and plywood. However, both acidic (24) and alkaline solutions may cause strength losses by altering the basic chemical composition of wood. Alkaline solutions have different degrading effects, but Winandy et al. (23) and Bendtsen et al. (7) showed that while ammoniacal copper arsenate (ACA) was less damaging to wood than CCA, the differences between the two systems were not significant. Krzyewski et al. (12) reported that ammoniacal copper zinc arsenate (ACZA) and ACA solutions had negligible effects on stiffness and strength. The gluebond durability was excellent in the 2-hour boiling test.

MATERIALS AND METHODS

SPECIES

Thirty-two 0.5-inch western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) 4-ply plywood panels were furnished by a commercial plant in Washington. All panels were C-C plugged and bonded with exterior glue (1).

PRESERVATIVES

Sixteen panels were treated with CCA-type C (CCA-C) preservative. Treating solutions were prepared by dilution of a 48 percent commercial oxide concentrate. Solutions conformed to the American Wood Preservers' Association (AWPA) standard P5 (2) (CrO_3:CuO:As_2O_5 = 47.5%:18.5%:34.0%). An additional 16 panels were treated with ACZA prepared from an 18 percent commercial oxide concentrate. Solution composition conformed to AWPA P5 standard (2) (CuO:ZnO:As_2O_5 = 50.0%:25.0%:25.0%). The required treating solution strength was deter-

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TABLE 1. — Drying schedules used to redry treated plywood.

Operating parameters	Drying schedule		
	Low temperature	Medium temperature	High temperature
Dry-bulb (°F)			
Initial	140	180	220
Final	150	180	220
Wet-bulb (°F)			
Initial	135	175	195
Final	125	165	190
Drying time (hr.)	36	36	12
Fan reversal (hr.)	6	3	3

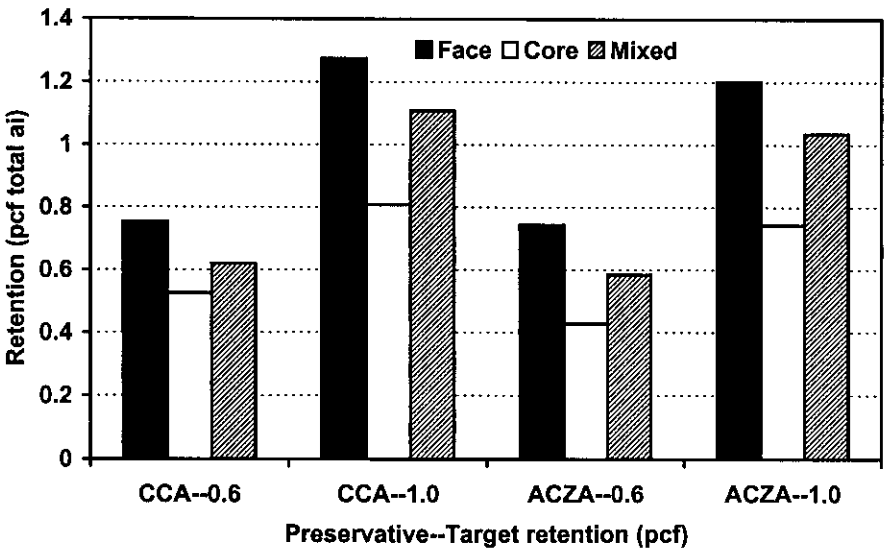

Figure 1. — Distribution of preservatives in western hemlock plywood.

mined after evaluation of the water uptake of the samples treated with water, in the case of CCA treatments, or an ammonium hydroxide solution adjusted to 10 to 11 pH, in the case of ACZA treatments. These treatments served as the 0.0 pcf retentions for the experiments.

Treatments

Panels were randomly assigned to treatment and drying temperature combinations as described later. Each plywood panel was cut into 16 samples measuring 12 by 24 inches. Twenty-five samples per combination were treated. Untreated control samples were cut and stored in the conditioning room until tested. The rest of the samples were treated using the full-cell process at room temperature. A vacuum (28 in. Hg) was held for 45 minutes followed by filling the cylinder with preservative under vacuum. When the cylinder was completely filled with preservative solution, a pressure of 150 psig was applied and held for 3 hours before venting to atmospheric pressure. The preservative was removed and each sample was weighed, wrapped in polyethylene, and stored in a cold room at 4°C. Retention was calculated from the weight gain of treating solution and the treating solution concentration.

Redrying of Treated Plywood

Drying schedules and conditions are shown in **Table 1**. The moisture content (MC) changes were followed by periodically weighing five water-treated moisture samples placed in the stack at random. Drying was continued until an average 10 percent MC was reached. Samples were stored in a conditioning room maintained at 24°C and 12 percent equilibrium MC (EMC) until tested.

Static Bending

All panels were tested as simply supported beams on a Tinius Olsen universal testing machine using third-point loading as described by Winandy and Morrell (20). The purpose of using third-point loading was to subject the portion of the panel between load points to a uniform bending moment, free of shear, and to a uniform load distribution. The testing span was 22 inches and the crosshead speed was 0.22 in./min. For testing consistency between treatments, knots were located on the compression side of the bending test specimen for all samples tested. Center-line deflection was measured with an electromagnetic deflectometer directly attached to the sample. The load-deflection curve was recorded on a rotating cylinder. Area under the load-deflection was determined with a computerized digitizing tablet. At the completion of the test, two 1- by 2-inch MC samples were cut from each panel, ovendried at 104°C for 24 hours, and the MC was calculated.

Rolling Shear

These tests were performed following the procedure described by Winandy (16). After being conditioned for at least 2 weeks, the samples were tested on the Tinius Olsen machine. Each sample was simply supported and centrally loaded. The crosshead speed was 0.01 in./min. The load-to-proportional limit and the corresponding deflection were determined using the recorded load-deflection curve. Rolling shear was calculated following the Biblis and Chiu (8) method. Failure mode was recorded for each sample. The modulus of elasticity was taken from the static bending test results for each panel. This testing method is a short-span bending test resulting mainly in horizontal shear failure of the plies. The American Society for Testing and Materials standards suggest a different testing procedure leading to a true rolling shear failure; however, that method was not compatible with this study because of the large number of samples. The method used does not require any special preparation such as gluing each sample between metallic plates.

Glueline Shear

The four 1- by 3-inch samples cut from the panel remnants were tested for glueline shear following the American Plywood Association (APA) US-PS 1-83 Standard (1). Two of the samples were boiled in water for 4 hours and then dried for 20 hours at a temperature of 65°C to an MC of 8 percent or less. The samples were boiled again for a period of 4 hours, cooled in water, and then tested to failure while wet on a Globe shear machine. The other two samples were conditioned at 24°C and 12 percent EMC for at least 2 weeks and then tested in shear. The failure load was recorded and percent wood failure was read. The wood failure reading was checked on 40 samples by the APA and their readings were compared to the values obtained locally.

Determination of penetration and retention

From each bending sample remnant, one 1- by 4-inch sample was cut for analysis. The core was separated from the face and the back for two-thirds of the length, yielding three separate parts: the core veneers, the face veneers, and the mixed face-core. These fragments were ground to 20 mesh on a Wiley mill prior to analysis. X-ray fluorescence (XRF), using an Asoma Model 8620 x-ray analyzer, was used for analysis of the CCA-treated material. For the ACZA-treated material, the arsenic was determined using XRF. Since this Asoma model can not differentiate between copper and zinc, these elements were analyzed by atomic absorption (AA) on an Instrumentation Laboratories Model S-11 Spectrometer with an acetylene-air flame. For AA analysis, approximately 0.2 g of 20 mesh ground wood was combined with 50 mL of 70 percent nitric acid and boiled on a hot plate for 30 minutes. Water was added to the resultant solution to attain the appropriate dilution for analysis.

Results and discussion

Western hemlock was more sensitive to redrying temperature than was southern pine. Some surface checking and slight surface darkening were observed as the drying temperature increased. A detailed qualitative study was not possible because of the micro-fractures and surface checking that already existed prior to treatment and drying. Ammonia treatment caused a slight surface darkening. The surfaces of the samples treated with ACZA were strongly colored blue-green (9).

Preservative distribution

As found in an earlier study with southern pine (*10*), the core of western hemlock plywood had a lower retention than that of the face. The core of the plywood was less well treated with AZCA than with CCA (**Fig. 1**). Core loadings for CCA averaged 71 and 64 percent of the face plies for the 0.6-pcf and 1.0-pcf

TABLE 2. — Mean comparisons for bending properties of treated western hemlock plywood.

Property value		Comparisons[a]
MOE	Retention (pcf) × Temperature (°F)	(psi)
	Controls	1,275,875 A
	1.0 × 140	1,252,062 A
	0.0 × 140	1,177,583 AB
	0.6 × 180	1,170,166 AB
	0.6 × 220	1,165,354 AB
	0.6 × 140	1,158,895 B
	1.0 × 180	1,150,854 BC
	0.0 × 180	1,122,125 BC
	0.0 × 220	1,065,229 C
	1.0 × 220	1,047,291 C
Bending stiffness	Temperature (°F)	(lb./ft.-in.^{2})
	Controls	124,427 A
	140	120,920 A
	180	117,327 A
	220	110,262 B
MOR	Retention (pcf)	(psi)
	Controls	6,389 A
	0.0	5,388 B
	0.6	5,339 B
	1.0	5,295 B
	Temperature (°F)	
	Controls	6,389 A
	140	5,712 A
	180	5,278 B
	220	5,032 B
S_{pl}	Retention (pcf)	(psi)
	Controls	5,129 A
	1.0	4,000 B
	0.6	3,967 B
	0.0	3,933 B
	Temperature (°F)	
	Controls	5,129 A
	140	4,453 B
	180	3,850 C
	220	3,595 C
W_{pl}	Retention (pcf)	(in.-lb./ft.)
	Controls	320 A
	0.0	230 B
	1.0	225 B
	0.6	220 B
	Temperature (°F)	
	Controls	320 A
	140	270 A
	180	210 B
	220	194 B
W_{max}	Retention (pcf)	(in.-lb./ft.)
	Controls	731 A
	0.0	621 AB
	0.6	572 ABC
	1.0	532 C

[a] Means not followed by the same capital letter differ one from another at $\alpha = 0.05$.

target retentions, respectively. The corresponding ratios for ACZA-treated samples were 58 and 62 percent. For both preservatives, the composite face/core samples met the desired target retention. The data indicate that adequate treatment of western hemlock can be achieved with either preservative.

Bending properties

The choice of treating chemical (CCA or ACZA) was not a significant factor in any of the analyses; therefore, data for both chemicals were combined for subsequent analyses. Comparisons for the mechanical test values for treated western hemlock are shown in **Table 2**. Drying temperature was the predominant factor affecting the various values obtained, with a few exceptions that are described later. This trend is consistent with the general body of knowledge on western coniferous species, which holds that most western species are much more temperature sensitive than southern pine.

Compared to untreated controls, nonsignificant reductions in MOE of 9 and 12 percent were obtained for the CCA and the ACZA, respectively. This is somewhat contrary to the data reported by Winandy (16), which showed a greater reduction for CCA-treated material than for the ACA-treated specimens.

Unlike previous results with southern pine (10), the MOE for western hemlock was significantly affected by the interaction of retention and redrying temperature (**Table 2**). Average reductions from control values were as high as 18 percent for the 1.0 pcf/220°F combination. For drying temperatures of 180°F or higher, MOE was strongly reduced as compared to controls (**Fig. 2**). For samples treated with water or to 1.0 pcf and subsequently redried at 220°F, analysis of the cumulative frequency distributions showed a strong reduction relative to the controls throughout the distribution. The samples redried at 180°F shifted to lower MOE values at approximately the 40th percentile. Bending stiffness (EI) was significantly affected only by high-temperature redrying (**Table 2**).

No temperature and retention interaction existed for MOR, hence their effects can be discussed separately. All treatments significantly reduced MOR averages, as much as 17 percent for the 1.0 pcf retention (**Fig. 3**). Redrying at 180°F or higher significantly reduced

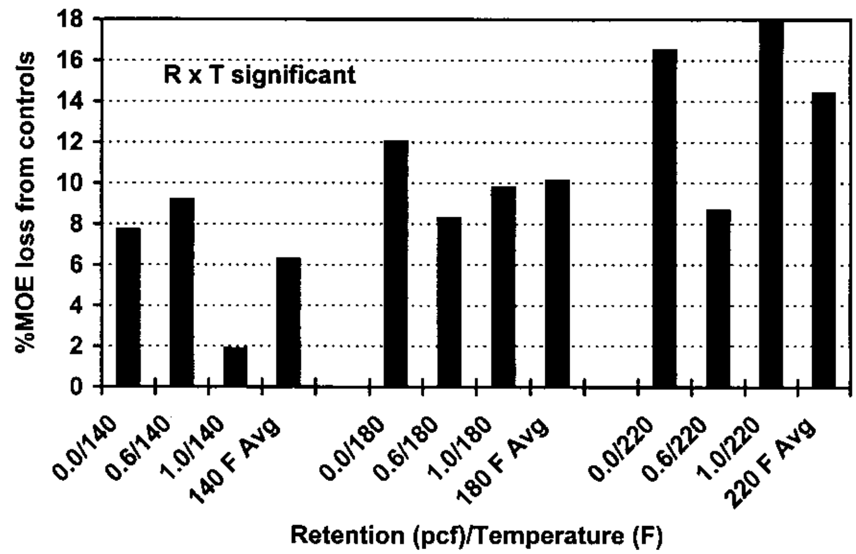

Figure 2. — Percent loss in MOE by retention/redrying temperature.

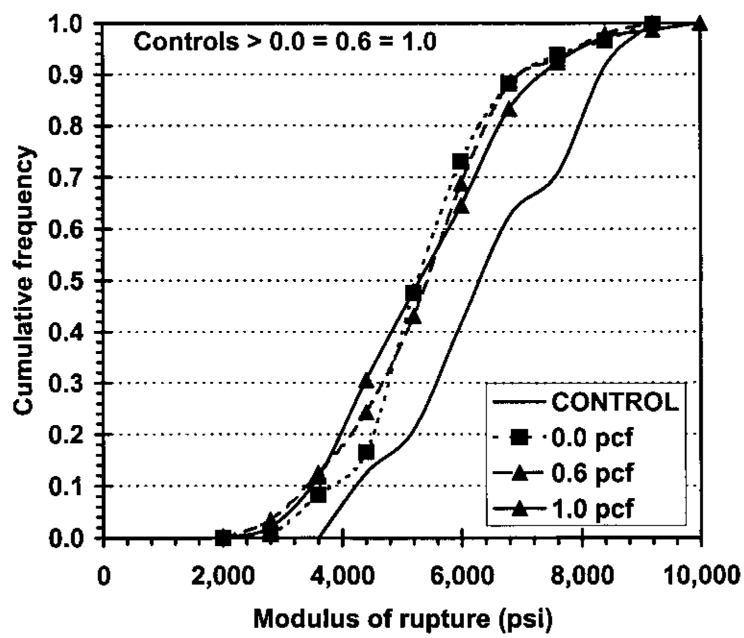

Figure 3. — Effect of retention on modulus of rupture distributions.

the strength compared to the average value of the controls and the samples dried at 140°F (**Table 2**). At 220°F, the reduction was 21 percent compared to the controls. Cumulative probability distribution analysis showed this trend more clearly than did the averages (**Fig. 4**). Any combination of treatment and redrying caused a reduction in MOR. Drying in excess of 140°F had a greater significant effect on MOR.

As with MOR, fiber stress at proportional limit (S_{pl}) was independently affected by retention and drying temperature, but the interaction of temperature was not significant. All treatments significantly reduced S_{pl} up to 23 percent from that of the controls, but were not different among themselves. The effect of temperature was greater than that of treatment with a reduction of 30 percent for a redrying temperature of 220°F.

Work-to-proportional limit (W_{pl}) was also reduced by temperature. The data suggest that the treatment (i.e., retention) effect is due to a rewetting phe-

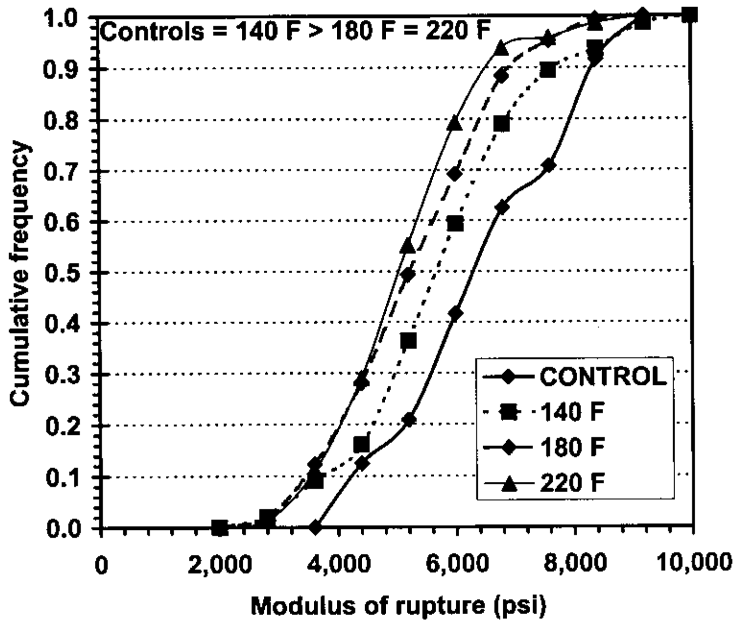

Figure 4. — Effect of temperature on modulus of rupture distributions.

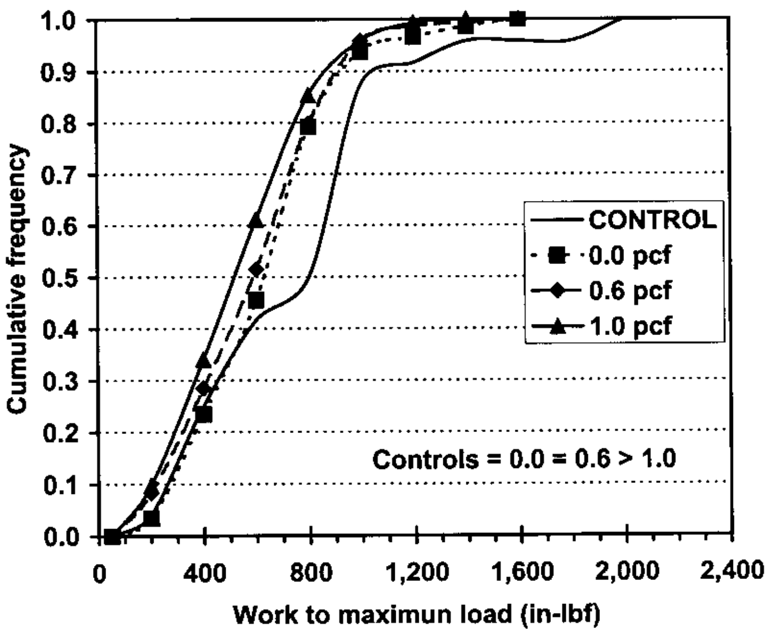

Figure 5. — Cumulative probability distributions for work to maximum load.

nomenon. Treated material was reduced an average of 30 percent when compared to the controls. Drying at temperatures greater than 140°F led to a reduction of up to 40 percent for redrying at 220°F. Redrying at 140°F produced changes not statistically different from the controls, but redrying at higher temperatures caused a significant decrease in W_{pl}.

Work-to-maximum load (W_{max}) was only affected by preservative retention and the concurrent rewetting effect. Samples treated to a retention of 1.0 pcf showed a 27 percent loss in W_{max}. Lower retentions were not different from the controls. Frequency distributions for W_{max} are shown in **Figure 5**.

As expected, drying temperatures had a clear effect on the strength properties of western hemlock plywood. Failure modes for western hemlock plywood generally followed the trends found in previous research for southern pine (10). The presence of plugs in the tension side or the voids in the core heavily influenced the type of failure. However, most of the failures were in the tension side combined with shear in the core.

ROLLING SHEAR

Rolling shear values were affected by both retention and temperature, but no interaction was found (**Table 3**). All temperature levels significantly lowered the shear strength by 27 percent, but temperature values were not different among themselves. All treatments were significantly different from the controls, and treatment reduced shear strength as much as 21 percent. Most of the failures in the rolling shear test were in the neutral axis with failure propagation toward the tension side.

GLUELINE SHEAR

Wood failure and glueline shear values are presented in **Table 4**. Although significant interactions were found for the test variables (**Table 5**), least square mean comparisons for glueline shear strength for samples tested in the dry condition indicated no deleterious strength loss from that of untreated controls. The 1.0 pcf/220°F/ACZA combination exhibited the lowest shear strength and averaged 91 percent of the control value. No significant effects on glueline shear strength were found for samples tested wet.

With respect to wood failure, retention was a significant factor for samples tested wet, while the temperature and chemical interaction was significant for samples tested dry. In both cases, no negative effect was found when compared to the controls. For samples tested wet, the wood failure of CCA-treated samples was significantly higher than that for ACZA-treated samples. Any reduction in wood strength should favor greater wood failure. The present result would indicate that CCA treatment is more severe than treatment with ACZA.

SUMMARY AND CONCLUSIONS

Four-ply western hemlock plywood, treated at 0.0, 0.6, and 1.0 pcf CCA-type C or ACZA and redried at temperatures of 140°F, 180°F, and 220°F, was tested in static bending. In general, western hemlock plywood was affected by temperature and/or its interactions with other variables to a greater extent than was southern pine (9). A comparison of significant effects for the two species is shown in **Table 6**.

Unlike southern pine, western hemlock was more sensitive to temperature than to retention. Bending stiffness was affected only by temperature, while MOR and S_{pl} were reduced independently by retention and drying temperature. Similar to southern pine, the energy-related properties of western hemlock were more sensitive to drying and treatment effects than were other properties. The type of preservative was not a factor in any of the analyses. Taken together, the data in this study suggest that the drying effect is largely a consequence of the rewetting of plywood during treatment.

The research work done in this study suggests other fruitful areas for investigation. Two possibilities include:

1. Conducting a detailed study on the residual carbohydrate fractions as a function of treatment and redrying with an eye to clearly establishing the causal mechanism for strength loss;

2. Determining final drying schedules for different types of plywood variables such as species, thickness, and grade.

Coupled with previous work with solid wood, the recommendation arising from the present work is that CCA-treated or ACZA-treated western hemlock plywood should not be redried at temperatures in excess of 140°F without some adjustment in design values.

TABLE 3. — Western hemlock mean comparisons for rolling shear.

	Mean comparisons[a]
Temperature (°F)	(psi)
Controls	1,681 A
180	1,346 B
140	1,341 B
220	1,235 B
Retention (pcf)	(psi)
Controls	1,681 A
1.0	1,288 B
0.6	1,315 BC
0.0	1,328 C

[a] Means not followed by the same capital letter differ one from another at $\alpha = 0.05$.

TABLE 4. — Mean values and stanard deviations for glueline shear testing of treated western hemlock plywood treated with CCA or ACZA.[a]

		Samples tested wet		Samples tested dry	
Temperature	Retention	Wood failure	Shear strength	Wood failure	Shear strength
(°F)	(pcf)	(%)	(psi)	(%)	(psi)
Control	- -	76 (20)	33 (25)	77 (20)	68 (34)
CCA treatments					
140	0.0	88 (9)	33 (20)	83 (12)	69 (40)
	0.6	90 (11)	30 (26)	88 (12)	62 (29)
	1.0	83 (16)	21 (18)	83 (18)	68 (30)
180	0.0	87 (12)	29 (17)	84 (12)	63 (27)
	0.6	85 (19)	34 (25)	84 (20)	83 (28)
	1.0	87 (14)	27 (19)	82 (15)	62 (22)
220	0.0	81 (20)	34 (22)	83 (14)	69 (25)
	0.6	80 (20)	21 (14)	90 (13)	64 (26)
	1.0	89 (14)	25 (18)	91 (13)	63 (29)
ACZA treatments					
140	0.0	88 (14)	36 (26)	83 (15)	69 (27)
	0.6	83 (14)	29 (21)	86 (19)	66 (31)
	1.0	85 (18)	32 (21)	85 (15)	70 (31)
180	0.0	78 (12)	30 (16)	80 (16)	83 (27)
	0.6	85 (18)	31 (27)	81 (22)	64 (23)
	1.0	78 (21)	33 (35)	80 (18)	65 (28)
220	0.0	81 (21)	30 (16)	80 (16)	65 (25)
	0.6	80 (20)	29 (17)	83 (18)	79 (33)
	1.0	81 (17)	30 (25)	78 (21)	61 (28)

[a] Standard deviations are in parentheses.

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TABLE 5. — Mean comparisons for glueline shear values for western hemlock plywood treated with CCA and ACZA.

	Samples tested wet	
Wood failure	Retention (pcf)	(%)
	0.6	84.3 A
	0.0	84.1 A
	1.0	83.7 A
	Controls	76.0 B
	Chemical	
	CCA	86.6 A
	ACZA	81.5 B
	Samples tested dry	
Wood failure	Temperature (°F) × Chemical	(%)
	220 × CCA	87.6 A
	140 × CCA	84.7 AB
	140 × ACZA	84.4 AB
	180 × CCA	83.2 BC
	220 × ACZA	80.5 BC
	180 × ACZA	80.4 BC
	Controls	76.8 BC
Shear strength	Retention (pcf) × Temperature (°F) × Chemical	(psi)
	0.6 × 180 × CCA	83.5 A
	0.0 × 180 × NH_4	82.9 A
	0.6 × 220 × ACZA	79.2 AB
	1.0 × 140 × ACZA	69.8 BC
	0.0 × 140 × NH_4	69.3 BC
	0.0 × 220 × H_2O	68.7 BC
	1.0 × 140 × CCA	68.0 BC
	Controls	67.6 BC
	0.6 × 140 × ACZA	65.7 C
	0.6 × 220 × CCA	64.1 C
	0.6 × 180 × ACZA	64.0 C
	0.0 × 180 × H_2O	63.1 C
	1.0 × 220 × CCA	62.8 C
	1.0 × 180 × CCA	62.2 C
	0.6 × 140 × CCA	61.5 C
	1.0 × 220 × ACZA	61.4 C

TABLE 6. — Summary of significant effects for retention (R), temperature (T), or their interaction (R × T) obtained from mean comparison tests of the mechanical properties of southern pine[a] and western hemlock plywood.

Value	Southern pine	Western hemlock
MOE	None	R × T
EI	None	T
MOR	R × T	R, T
S_{pl}	R	R, T
W_{pl}	R	R, T
W_{max}	R	R
G_{TR}	R × T	R, T

[a] Taken from Khouadja et al. (10).

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