EFFECTS OF TWO FIBER TREATMENTS ON PROPERTIES OF HEMLOCK HARDBOARD

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ABSTRACT

The effects of fiber treatments (steam and acetylation), resin content, and wax content on mechanical and physical properties of dry-process hardboard made from hemlock were investigated. Sixty 10-inch by 10-inch by 0.125-inch boards were tested. Various board properties such as modulus of rupture, modulus of elasticity, tensile strength parallel to the surface, internal bond, water absorption, thickness swelling, and linear expansion were studied. Test results showed that both acetylation and steam pretreatment improved board dimensional stability. This demonstrates that both treatments reduce the hygroscopicity of the hemlock fibers. Water absorption, thickness swelling, and linear expansion were reduced greatly by acetylation. Increasing resin content significantly improved board mechanical and physical properties. However, some mechanical properties of the boards were somewhat decreased by the fiber treatment of acetylation.

Many research projects have been conducted to investigate the effects of the most common factors (parameters) such as moisture content (MC), binders, additives, different kinds of fiber treatment, etc., on board physical and mechanical properties (3-7,9, 10). Efforts had been made primarily for enhancing the board strength properties or improving the board dimensional stability and durability under environmental variations.

Hsu (5) and Youngquist et al. (11) studied the effects of steam and acetylated fiber treatment, resin content, and wax content on hardboard properties and indicated that both steam treatment and acetylation improved dimensional stability after a 2-hour water boiling test. Bending properties were greatly reduced by the acetylation treatment compared to no treatment. Hsu et al. (5,6) pointed out that the excessive thickness swelling (TS) of wood-based composites was mainly due to the springback of compressed wood. They suggested that the most efficient way of reducing this springback effect is to minimize the build-up of internal stress in the board by steam pretreatment, which, in turn, will reduce the springback of the compressed wood and thus minimize the TS. Hsu also indicated that a proper steam pretreatment not only improved dimensional stability, but also improved mechanical properties of hardboard. Rowell (7-9) reported that treatment of acetylation on wood fibers, flakes, and strands can greatly improve the dimensional stability properties of boards. Suzuki and others (10) investigated the water absorption (WA) of dry process fiberboard. They reported that WA and TS decreased with increasing addition of resin and paraffin wax and with its apparent density. Addition of both resin and paraffin wax resulted in lower WA than that due to paraffin wax alone. At longer periods of immersion in water, the effect of paraffin wax gradually decreased. It is evident that some measures and methods are frequently adapted to enhance the mechanical and physical properties of hardboard: 1) controlling the resin content and wax content at a best level to reach a satisfactory range of modulus of rupture (MOR), modulus of elasticity (MOE), tensile strength, internal bond (IB), WA, and TS; 2) using chemical treatment (modification) on fibers (acetylation) to obtain ideal dimensional stability; and 3) using steam pretreatment to soften and plasticize wood fibers, thus the internal compressive stress will be eased and, as a result, WA and TS will be reduced.

The objectives of this study were to: 1) determine the effects of steam and acetylated treatments of wood fibers on

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mechanical and physical properties of dry-process hardboard made from western hemlock; and 2) determine the effect of two levels of both wax and phenolic resin content on various board properties.

MATERIALS AND METHODS

A total of 12 groups of hardboard with a nominal dimension of 10 inches by 10 inches by 0.125 inch were involved in this study. Five pieces of sample boards of the same treatment were in each group, serving as replicates. The hemlock fibers were either pretreated at a 225-psi steam pressure (396°F) for 10 minutes, pretreated by acetylation to an acetyl weight gain of about 23 percent, or not treated (control). Then wax and resin were sprayed on the fibers as they tumbled in a rotating drum. Tumbling was continued for 5 minutes after the addition of wax and resin in order to obtain an even dispersion of the adhesives on the fibers. The blended furnish was then transferred to an atmospheric single-disk refiner to break up the fiber clumps and to spread the resin and wax over a larger fiber surface area. Mats were formed on a lo-inch by 10-inch vacuum-forming box where the fibers were passed through a 0.05-inch screen and onto a 0.06-inch screen, then flipped over the mat onto a caul plate. The average MC of mats prior to press was controlled to a level of less than 10 percent. The boards were pressed on a manually controlled, steam-heated press. The press temperature was 375°F. The pressing time was 8 minutes; for the steam-pretreated and control boards, the maximum pressure of 1,100 psi was exerted, and for the acetylated boards, the maximum pressure was 1,500 psi because of high latency, which is defined as fiber curls and kinks. After pressing, all boards were trimmed to 10 inches by 10 inches.

EXPERIMENTAL DESIGN

The experiment was a factorial design (3 × 2 × 2) test with three levels of treatment (acetylation, steam-treatment, and control), two levels of resin content (3% and 7% based on ovendry wood weight), and two levels of wax content (0% and 0.5% based on ovendry wood weight). For each combination of independent variables, five sample boards were tested. A total of 60 boards were made in this study. A factorial analysis was conducted through the use of a randomized complete block to determine the effects of different combinations of treatments (independent variables) used on each dependent variable (testing result).

TESTING

All l/8-inch-thick samples had been put into a climate chamber for at least a week with a relative humidity (RH) of 50 percent ±2 percent and a temperature of 72°F± 2°F in a climate chamber with air circulation of high velocity. Then the weight and thickness measurements were made on each individual board. Specimens were cut into the required sizes and shapes in accordance with the ASTM D 1037 standards (2) for different tests, except that the size of the 24-hour water-soaking specimens was 4 inches by 5 inches instead of 6 inches by 6 inches. Test procedures of static bending (3 in. by 6 in.), tensile strength (2 in. by 10 in.), and internal bond (2 in. by 2 in.), WA and TS after a 24-hour water-soak (4 in. by 5 in.) all followed those outlined in ASTM D 1037 (2). The linear expansion (LE) of specimens was also determined by exposing 3-inch by 4-inch specimens from 30 to 90 percent RH at a temperature of 70°F ± 2°F.

RESULTS AND DISCUSSION

FACTORIAL ANALYSIS

Table 1 presents results of the experiment, and determined effects of three factors (A: treatment; B: resin content; and C: wax content) and their interactions on all properties of hemlock hardboards. The table shows that all factors significantly affected the MC of specimens. All main factors were also significant, except for the main effect A for the IB value, main effect B for the LE value, and main effect C for MOR, tensile strength, and TS (30% to 90% RH) values. The interactions A × C, B × C, and A × B × C did not have the significant effect on MOR and LE values.

BENDING PROPERTIES AND TENSILE PROPERTIES

Table 2 shows the average values of test results of MC, specific gravity, MOR, MOE, tensile strength, and IB in this study. As shown in the table, the control boards had the highest MOR values at both resin and wax levels as compared to acetylated boards and steam-pretreated boards. However, for MOE, the steam-pretreated boards had the highest average value, followed by control (untreated) boards and acetylated boards. Tensile strength had the same reducing order as did MOE. Steam pretreated boards exhibited higher average IB values than both acetylated and control boards. The test results indicated that, in general, the treatment of acetylation on wood fiber caused a reduction in board strength. Rowell and Banks (9) reported in an earlier study that IB, MOR, and MOE values were all reduced in flakeboards made from acetylated flakes. They interpreted this as probably due to the low nettability of the acetylated flakes and, therefore, the result was poor penetration of water-soluble phe-

TABLE 1. — Factorial analysis.[a]

Independent variable	MC	MOR	MOE	Tensile strength	IB	24-hour soak TS	24-hour soak WA	30% to 90% RH TS	30% to 90% RH LE
		Dependent variable[b]							
Treatment (A)	S	S	S	S	NS	S	S	S	S
Resin (B)	S	S	S	S	S	S	S	S	NS
Wax (C)	S	NS[b]	S	NS	S	S	S	NS	S
A × B	S	NS	NS	NS	NS	S	NS	S	S
A × C	S	NS	NS	S	S	S	S	S	NS
B × C	S	NS	S	NS	NS	S	S	NS	NS
A × B × C	S	NS	S	S	NS	NS	S	NS	NS

[a] S = significant at 5 percent level; NS = not significant at 5 percent level.
[b] MOR = modulus of rupture; MOE = modulus of elasticity; tensile strength = parallel to the surface; IB = internal bond; TS = thickness swelling; WA = water absorption; LE = linear expansion.

TABLE 2.— Average values of mechanical and physical properties of hemlock hardboards.[a]

Fiber treatment	Resin	Wax	MC	Specific gravity	MOR	MOE	Tensile strength	IB	24-hour soak TS	24-hour soak WA	30% RH to 90% RH TS	30% RH to 90% RH WA	30% RH to 90% RH LE
	(%)	(%)	(%)		(psi)	($\times 10^3$ psi)	(psi)	(psi)	(%)	(%)	(%)	(%)	(%)
Control	3	0.5	6.1[b]	1.03	6,675	697	3,938	133	22.57	24.58	12.86	9.07	0.459
(untreated)	7	0.5	6.5	1.05	8,846	736	5,517	224	17.02	24.63	10.40	9.01	0.402
	3	0	7.1	1.04	7,633	770	3,961	207	32.96	57.96	12.32	9.07	0.453
	7	0	6.6	1.04	9,564	864	4,921	293	20.88	41.62	8.95	8.71	0.417
Average			6.6	1.04	8,180	767	4,584	214	23.35	37.19	11.15	8.96	0.433
Acetylation	3	0.5	2.8	1.04	5,916	623	3,263	172	3.79	19.19	3.51	4.19	0.234
	7	0.5	3.1	1.01	7,580	685	4,197	206	2.04	16.88	1.78	4.98	0.284
	3	0	3.2	1.05	5,573	671	3,483	205	3.44	25.27	2.55	3.73	0.152
	7	0	2.8	1.00	7,410	722	4,648	284	2.37	18.86	1.66	4.74	0.244
Average			3.0	1.03	6,619	675	3,898	217	2.90	20.05	2.38	4.41	0.204
Steam	3	0.5	6.0	1.03	6,086	950	4,591	200	19.28	51.01	6.52	6.70	0.374
	7	0.5	6.1	1.02	7,551	988	5,164	308	12.97	28.40	6.24	6.41	0.405
	3	0	6.5	1.03	6,471	883	3,920	172	18.09	33.27	7.37	6.53	0.309
	7	0	6.1	1.05	7,810	1,056	5,426	277	15.48	40.92	6.69	6.51	0.450
Average			6.2	1.03	6,980	969	4,775	239	16.46	38.40	6.68	6.54	0.385

[a] Refer to Table 1 for definitions of abbreviations. Each MC, tensile, IB, TS, and WA (24-hr. soak) value, and each TS, WA, and LE (30% to 90% RH) value is an average of five tests. Each MOR and MOE value is an average of 10 tests.
[b] After conditioning at 50 percent RH and 72°F.

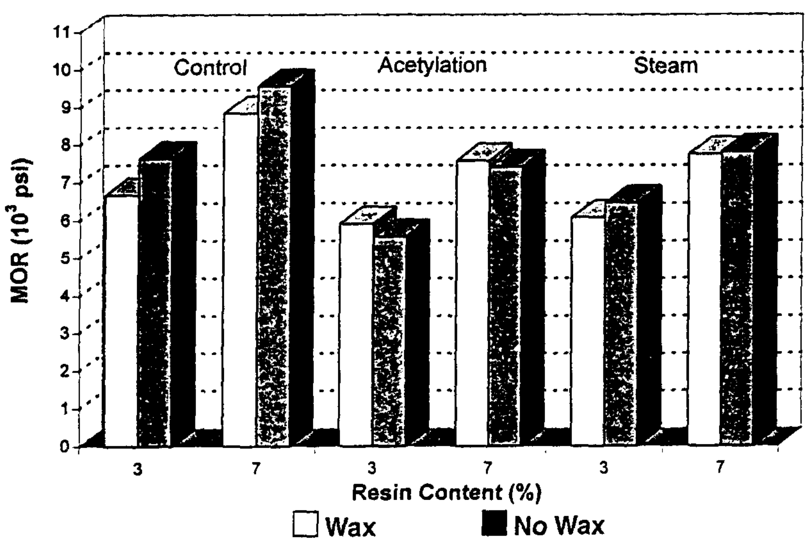

Figure 1. — Effects of treatment, resin content, and wax content on MOR.

nol-formaldehyde resin. In like manner, the acetylated fibers would have resulted in a lower nettability and subsequently poor penetration of resin. This reduced the MC, MOR, MOE, and tensile strength values in acetylated boards. In contrast, steam treatment on wood fibers did not result in as much decrease in board strength of no-wax boards as did acetylation in most cases, and a considerable increase in board stiffness (increase in average MOE values) was found, compared to those for control boards. **Table 1** shows that treatment did not have a significant effect on IB value in this study. Increasing resin content from 3 to 7 percent resulted in significant improvements in MOR, MOE, tensile strength, and IB values at both levels of wax content (0% and 0.5%) in all cases, i.e., this occurred in all of the three treatment conditions **(Table 2, Figs. 1,2,** and **3)** The addition of the 0.5 percent wax content caused slight decreases in average MOR and MOE values. The same decreasing tendency in average IB values resulting from the addition of wax was also observed, but with exceptions for steam-treated boards. Moreover, no fixed trend of the effect of the addition of wax on tensile strength values could be found, as seen in **Table 2** and **Figure 3.**

WATER ABSORPTION AND THICKNESS SWELLING

The test results of WA and TS in the 24-hour, water-soaking test were tabulated in **Table 2.** Acetylated boards obtained extremely low average TS values compared to control boards. Steam-treated boards also had lower average TS values than control boards. Both boards demonstrated satisfactory TS values, which were lower than the maximum allowable TS value for standard and tempered hardboard (1) required by ANSI/AHA (< 25% for standard board and <209’0 for tempered board). Control boards had the highest average TS values in the three treatment levels, which were close or equal to the maximum allowable value in the ANSI/AHA standard. The greatest improvement in WA (decrease in value) after 24-hour soaking was obtained by acetylation. Rowell (7,8) pointed out that modifying the wood cell wall polymers (by acetylation) to make them more hydrophobic or bulking them with bonded chemicals would reduce the tendency of wood to swell and shrink with change in MC. This may be the reason why WA and TS were greatly reduced by acetylation as compared with the board without such an acetylated treatment. Steam treatment also improved WA and TS compared to control boards, but not as much as did acetylation. Increasing resin content from 3 to 7 percent and the addition of the 0.5 percent wax, as expected, did significantly improve WA and TS in most cases **(Table 1).**

LINEAR EXPANSION AND THICKNESS SWELL

The dimensional changes in LE, TS, and WA from 30 percent RH to 90 percent RH exposure were investigated. Test results are shown in **Tables 1** and **2.** Acetylated boards had the significantly smallest TS, WA, and LE values at both resin content levels and wax content levels, then followed in an increasing order by steam-treated and control boards. In other words, improvements in dimensional stability properties were obtained by acetylation and steam treatment, although the latter did not contribute as much as the former. **Table 1** shows that resin content did not affect the LE values in this study. **Table 2** shows that for acetylated boards, the TS value obtained from the 24-hour soaking test is only slightly higher than for TS value obtained from the humidity exposure between 30 and 90 percent RH. This phenomenon suggests that the short-term, 24-hour soaking test is a good indication of the water resistance of the hardboard specimens.

CONCLUSIONS

Based on the results of this study, the following conclusions can be drawn:

1. Most hardboard samples made in this study obtained good strength and dimensional stability properties, depending on treatment, resin content, and wax content.

2. MOR for all control boards was significantly higher than that of acetylated boards. Generally, the acetylation treatment resulted in about a 20 percent loss in MOR values. Also, increasing resin from 3 to 7 percent caused a significant improvement in MOR and MOE. Addition of 0.5 percent wax content usually brought about a slight decrease in the average board MOR values of control hardboards.

3. MOE was significantly improved by steam pretreatment when compared to control or acetylation. MOE increased with increasing resin content.

4. Tensile strength values for control boards were generally higher than those for acetylated boards. In contrast, IB values for control boards were significantly lower than those for acetylated boards. Increasing resin content from 3 to 7 percent improved both tensile strength and IB values significantly in all cases. Addition of 0.5 percent wax did not affect tensile strength and IB properties as much as did the resin.

5. For the 24-hour, water-soaking test, WA was greatly improved by acetylation. For acetylated boards, TS decreased substantially. Increasing resin and wax content significantly decreased WA and TS for all treatments.

6. The LE, TS, and WA in the dimensional stability test (from 30% to 90% RH) were all significantly decreased by acetylation. However, the changes in resin did not result in significant differences in LE values. The addition of 0.5 percent wax did not have a significant effect on TS values of specimens exposed to a high RH condition. Steam pretreatment on fibers improved

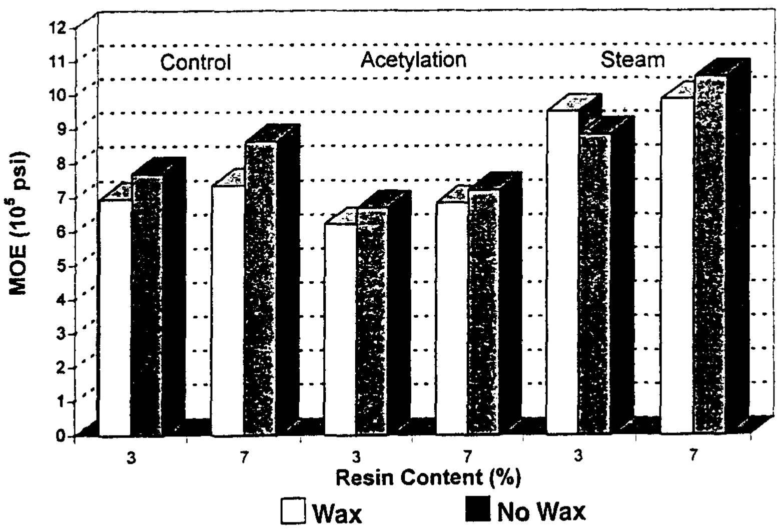

Figure 2. — Effects of treatment, resin content, and wax content on MOE.

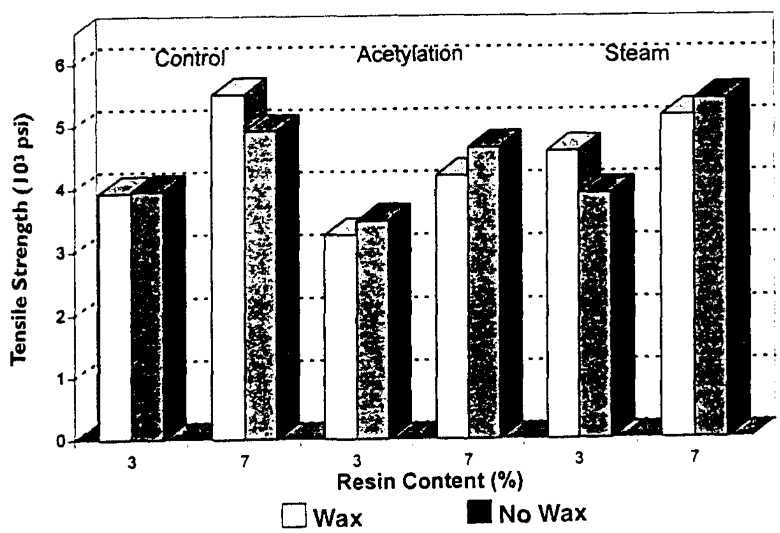

Figure 3. — Effects of treatment, resin content, and wax content on tensile strength parallel to the surface.

these properties, but not as much as did acetylation.

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