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THE EFFECTS OF MILD CHEMICAL EXTRACTIONS ON THE DIMENSIONAL STABILITY OF UF AND PF BONDED RED OAK FLAKEBOARD[1]

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ABSTRACT

Red oak (*Quercus rubra* L.) flakes were chemically extracted under mild conditions to determine the effects on red oak flakeboard properties, particularly dimensional stability. Flakes were extracted with weak acetic acid solutions or water under selected treatment pressures and treatment times. Weight loss values of extracted flakes ranged from 4 to 25%. Phenol formaldehyde (PF) and urea formaldehyde (UF) bonded flakeboards were manufactured using either red oak or chemically extracted red oak flakes. Physical and mechanical properties evaluated were modulus of elasticity, modulus of rupture, internal bond, water immersion related properties, and linear expansion. Static bending properties of flakeboards using extracted flakes for both resins, even at high levels of flake weight loss, were similar to boards from unextracted flakes. Internal bond average values for the extracted flakes were lower for the PF boards compared to the controls. Internal bond values for the UF boards were similar to the controls. Dimensional stability values for the PF boards were similar for the extracted and control boards. Dimensional stability tests on the UF boards produced the following results: (1) 2-hour dimensional stability values were improved for the extracted versus control boards; (2) 24-hour dimensional stability values for the extracted boards were similar to the control boards; and (3) linear expansion values for the extracted boards were similar to the control values.

Keywords: Phenol formaldehyde, urea formaldehyde, flakeboard, dimensional stability.

INTRODUCTION

Utilization of low quality, high-density hardwoods as furnish for reconstituted wood panels could provide new markets for low quality trees. However, to achieve this goal, new processing and production techniques may need to be developed. One such technique may be related to chemical extraction for control of furnish variations and reduction in wood density. These extractions may render high-density hardwoods more suitable for reconstituted panel production.

[1] This project was supported by McIntire-Stennis Project 2618.

Removal of wood constituents by chemical extraction will change the properties of wood compared to untreated material (Davis and Thompson 1964; MacLean 1951, 1953; Koch 1972). Chemical pretreatments of flakes to improve bonding have been reported by a number of investigators (Zavarin 1984; Chapman and Jenken 1986; Roffael and Rauch 1974; Rowell et al. 1986; Jahan-Latibari 1982). Blankenhorn et al. (1989) evaluated the feasibility of using mild chemical pretreatments (water, sodium hydroxide, and acetic acid) to chemically extract red oak and hard maple flakes prior to processing into flakeboards. The results of the chemical treatments were different for red oak and hard maple. Mechanical properties of the test panels were reduced for both species as a result of most treatments in that study. Generally, the reduction in mechanical properties for both species was less for the acetic acid treatments than either the sodium hydroxide or water treatments. The boards in that study were made using flakes with a wide range in flake weight loss values in each panel. The modulus of rupture values for acetic acid treated red oak flakes were not significantly different from red oak control values. Slight improvements in dimensional stability values were implied in boards fabricated with water and acetic acid treated red oak flakes. The data showed that chemically extracted flakes could be produced without serious detriment to many of the panel properties. Therefore, this study was undertaken to quantify any improvements in dimensional stability values in phenol formaldehyde (PF) and urea formaldehyde (UF) red oak and extracted red oak flakeboards.

PROCEDURES

The procedures used to chemically extract red oak flakes (*Quercus rubra*) were similar to those outlined by Blankenhorn et al. (1989). Red oak flakes were treated with either water or 4% acetic acid (140 g glacial acetic acid in 3,360 g water) in a M/K Mini-mill laboratory digester to a selected target weight loss (Table 1) associated with each treatment condition. Treatment pressures and times associated with the target weight loss values are given in Nicholls (1989).

The weight loss of each sample was carefully monitored. For each treatment condition, samples with weight losses within a selected range (associated with average weight loss distributions determined from many trials) were accepted for board manufacture (Nicholls 1989). All data and analyses were based on comparisons between actual weight loss values obtained after chemical extractions of the flakes. Most of the treatment conditions were selected to produce weight losses in the range of 4 to 10 percent of initial oven-dry wood weight. Some of the more severe treatments were targeted to produce weight losses in excess of 20% for comparison purposes.

Three nonoriented flakeboards were prepared for each of nine treatment conditions. All boards were manufactured under the following conditions:

panel size (not trimmed)—13 in. × 13 in.
(trimmed)—10.5 in. × 10.5 in.
board thickness (inches)—0.22 for PF boards and 0.24 for UF boards
target density (pcf)—46 for PF boards and 44 for UF boards
resin level (%)—5 for PF boards and 7.5 for UF boards
additives—none

TABLE 1. *Weight loss of chemically modified red oak flakes used for manufacturing phenol formaldehyde and urea formaldehyde flakeboards.*

Targeted weight loss range (%)[1]	Average weight loss (%) by treatment[2]	
	PF boards	UF boards
Water treatments		
4.0–5.5	4.4	4.6
	(f)	(f)
5.5–6.5	6.1	6.1
	(e)	(e)
7.0–8.0	7.7	7.4
	(d)	(d)
8.5–10.0	9.3	9.9
	(c)	(c)
13.0–15.0	13.8	14.4
	(b)	(b)
22.0–25.0	23.5	23.8
	(a)	(a)
4% Acetic acid treatments		
4.0–5.0	4.7	4.6
	(f)	(f)
6.5–7.5	6.7	7.2
	(e)	(d)
8.5–10.0	9.1	9.1
	(c)	(c)

[1] Percent weight loss is percent of oven-dry weight.
[2] Column means having common letters are not significantly different at the 0.05 level by the Waller-Duncan test procedure.

press conditions—330F, about 44 sec to stops, 7 min total press time for PF boards and 310F, about 44 sec to stops, 5.5 min total press time for UF boards

The phenol formaldehyde resin used was Resi-Stran GP 3139 oriented strandboard resin provided by Georgia Pacific Corporation, and the urea formaldehyde resin used was WW 101 for particleboard and wood composites manufactured by Borden Chemical Company.

Properties tested following ASTM standard D-1037 (ASTM 1984) were: flakeboard density; bending properties-modulus of elasticity (MOE) and modulus of rupture (MOR); internal bond (IB); thickness swell, water absorption, and volumetric expansion for 2- and 24-hour water soak; and linear expansion. Mechanical properties specimens were tested oven-dry rather than at the specific ASTM equilibrium moisture content (EMC), and linear expansion was measured from oven-dry to 90% relative humidity rather than 50% to 90% relative humidity specified in the standard. Analysis of variance tests were used to determine significant differences (0.05 confidence level) among all test boards.

RESULTS AND DISCUSSION

Weight loss

The weight losses of extracted red oak flakes selected for fabrication into flakeboards are summarized in Table 1. As expected, an increase in the severity of either water or acetic acid treatment resulted in marked reductions in the oven-

TABLE 2. *Average density and mechanical properties for specimen from boards manufactured from chemically modified red oak flakes and bonded with phenol formaldehyde resin.*[1]

Treatment	Average flake weight loss (%)	Average MOE (psi)	Average MOR (psi)	Average oven-dry density (pcf)	Average IB strength (psi)
Water	4.4	609,410	5,030	46.13	123.1
		(a)	(a)	(abc)	(ab)
	6.1	512,560	4,470	44.25	112.2
		(a)	(a)	(de)	(b)
	7.7	481,670	3,940	43.63	129.7
		(a)	(a)	(e)	(ab)
	9.3	488,860	4,100	46.16	105.6
		(a)	(a)	(abc)	(b)
	13.8	537,390	3,900	47.76	119.9
		(a)	(a)	(a)	(ab)
	23.5	525,790	4,660	47.25	124.3
		(a)	(a)	(ab)	(ab)
4% Acetic acid	4.7	459,430	3,730	44.21	121.8
		(a)	(b)	(de)	(ab)
	6.7	486,160	3,930	44.38	124.5
		(a)	(a)	(cde)	(ab)
	9.1	550,290	4,090	45.43	108.6
		(a)	(a)	(cde)	(b)
Control (untreated)		569,590	4,790	45.72	157.1
		(a)	(a)	(bdc)	(a)

[1] Means within columns having common letters are not significantly different at the 0.05 level by the Waller-Duncan test procedure.

dry flake weight. In three separate treatments, no statistical differences in weight loss were observed between water and acetic acid treatments.

The amount of cell wall and extractive material removed in red oak flakes treated with 4% acetic acid resulted in less than 10% weight loss. These results were in general agreement with those observed in an earlier study (Blankenhorn et al. 1989). Similar results were reported by Kass et al. (1970) who observed a weight loss of about 10% after soaking solid white oak beams for an extended time in 10% hydrochloric acid solution. The low weight loss associated with the acetic acid treatment was in agreement with previous results that identified the good resistance of wood to organic acids (Wangaard 1966).

Flake coloration was influenced by treatment conditions. Acetic acid treatments resulted in lighter colored flakes compared to the untreated control flakes. Water treatments producing about 25% weight loss resulted in darker flakes than control flakes. The high weight loss treatments resulted in dark brittle flakes with a high proportion of fines.

Phenol formaldehyde board properties

Modulus of elasticity and modulus of rupture average values for chemically extracted flakeboards were not significantly different from the control average values (Table 2). As weight loss increased for the acetic acid treatments, the average MOE and MOR values tended to increase (Table 2). Average values for all treatments ranged from about 460,000 to 610,000 psi and 3,900 to 5,000 psi for MOE and MOR, respectively.

Trends in the internal bond strength values were difficult to identify (Table 2). All treatments resulted in lower average internal bond strength values compared

TABLE 3. *Average thickness swell, water absorption, volumetric expansion, and linear expansion for specimens from boards manufactured from chemically modified red oak flakes and bonded with phenol formaldehyde resin.*[1]

Treatment	Percent (%)							
	Average flake weight loss	Average thickness swell		Average water absorption		Average volumetric expansion		Average linear expansion[2]
		2 h	24 h	2 h	24 h	2 h	24 h	
Water	4.4	19.0	29.6	46.7	80.9	19.6	30.1	0.24
		(a)	(a)	(a)	(a)	(a)	(a)	(bcd)
	6.1	20.9	30.7	49.1	76.0	21.5	31.4	0.23
		(a)	(a)	(a)	(a)	(a)	(a)	(bcd)
	7.7	22.1	31.4	58.7	83.8	22.5	32.0	0.22
		(a)	(a)	(a)	(a)	(a)	(a)	(bcd)
	9.3	19.1	32.9	41.5	79.7	19.6	33.7	0.27
		(a)	(a)	(a)	(a)	(a)	(a)	(ab)
	13.8	23.3	31.6	58.8	83.1	23.8	32.0	0.26
		(a)	(a)	(a)	(a)	(a)	(a)	(bc)
	23.5	21.5	27.3	56.8	79.7	22.2	28.2	0.31
		(a)	(a)	(a)	(a)	(a)	(a)	(a)
4% Acetic acid	4.7	19.6	30.0	51.6	82.5	20.2	30.8	0.21
		(a)	(a)	(a)	(a)	(a)	(a)	(bcd)
	6.7	19.7	29.6	45.5	81.9	20.3	30.4	0.20
		(a)	(a)	(a)	(a)	(a)	(a)	(d)
	9.1	18.8	32.4	37.9	77.5	19.4	33.1	0.22
		(a)	(a)	(a)	(a)	(a)	(a)	(bcd)
Control (untreated)		24.2	29.5	62.3	78.0	24.6	19.8	0.21
		(a)	(a)	(a)	(a)	(a)	(a)	(cd)

[1] Means within columns having common letters are not significantly different at the 0.05 level by the Waller-Duncan test procedure.
[2] Linear change from oven dry condition to equilibrium with 90% relative humidity.

to the control boards. Only three chemical treatments (weight loss of 6.1 and 9.3 for water treatment and 9.1 for acetic acid treatment) produced boards that were significantly different. All treatment averages were in general agreement with previous work (Blankenhorn et al. 1989) and were distributed within a fairly narrow range between about 106 and 130 psi, except the control average value, which was considerably higher.

The 2-hour thickness swell average values for treated flakes were less than control board average values (Table 3). However, none of these differences were statistically significant. Acetic acid treatments generally resulted in lower 2-hour thickness swell values than most of the water treatments. However, the acetic acid and water treatments were not significantly different. The 24-hour thickness swell values for the samples from treated flakes were similar to control values (Table 3). Both 2- and 24-hour thickness swell results were generally higher than previously reported by Blankenhorn et al. (1989) using treatments of red oak flakes with 4% acetic acid.

All of the 2- and 24-hour average water absorption values for the boards made with treated flakes and the control boards were similar (Table 3). In general, 60–80% of the total water absorption for all boards occurred during the first two hours of the test. Percent absorption at 2 hours ranged from about 40 to 60% of initial oven-dry specimen weight. All 2-hour treatment average values were less than the control average values. The 24-hour water absorption test showed that all of the treatment average values, except 2, were greater than the control. Average

24-hour values were disturbed within a very narrow range between about 76% and 84% absorption.

The 2-hour and 24-hour average volumetric expansion values for boards from chemically extracted flakes were similar to the control values (Table 3). All 2-hour average values for boards from treated flakes were less than the control values. Volumetric and thickness dimensional changes followed similar trends.

Linear expansion average values for boards from chemically extracted flakes varied from 0.20 to 0.31% (Table 3). These observed linear expansion values are comparable to those reported by Heebink and Hann (1959) for linear expansion of red oak flakeboard manufactured from one-inch-long flakes. Results are also comparable to those reported by Blankenhorn et al. (1989) for flakeboards fabricated from red oak flakes that had been treated to about 6% weight loss with mild acetic acid solutions.

Almost all of the linear expansion average values for the treated flakes were slightly greater than the control average value. This overall result was not exhibited with the other dimensional stability tests. The linear expansion average values statistically different from the control average value were associated with water treatments producing average weight losses of 9.3% and 23.5%. These weight losses were also associated with the production of a high proportion of fines after water treatment. All three acetic treatment conditions produced boards with linear expansion values similar to or lower than control board values and values for boards made from water treated flakes.

Urea formaldehyde board properties

Modulus of elasticity average values for chemically extracted red oak flakeboards bonded with urea formaldehyde resin were not significantly different from the control average values (Table 4), except for the acetic acid 9.1% weight loss boards. Modulus of rupture average values for all chemically extracted flakeboards were not significantly different from the control values (Table 4), except for the 7.2 and 9.1% weight loss acetic acid treated boards. The average values for the 7.2 and 9.1% weight loss acetic acid treated boards were higher than the average MOR values for the control boards. As weight loss increased for the acetic acid treatments, the average MOE and MOR values tended to increase (Table 4). Average values for all treatments ranged from about 365,000 to 470,000 psi and 2,700 to 3,700 for MOE and MOR, respectively.

Trends in the internal bond strength values were difficult to identify (Table 4). Most treatments resulted in lower average internal bond strength values compared to the control boards, except for the highest two weight loss boards in both the water and acetic acid treatments. Only one chemical treatment (23.8% weight loss water treatment) produced boards that were significantly different from the control boards. All treatment averages were distributed within a fairly narrow range between about 80 and 118 psi and were in general agreement with previous work by Blankenhorn et al. (1989).

All 2-hour thickness swell average values for treated flakes were less than control board average values (Table 5), and all of the treated flakeboard values were significantly different from the control values. The three acetic acid treatments and water treatments producing less than 7.4% weight loss resulted in the lowest 2-hour thickness swell average values. These acetic acid and water treatments

TABLE 4. *Average density and mechanical properties for specimens from boards manufactured from chemically modified red oak flakes and bonded with urea formaldehyde resin.*[1]

Treatment	Average flake weight loss (%)	Average MOE (psi)	Average MOR (psi)	Average oven-dry density (pcf)	Average IB strength (psi)
Water	4.6	418,670	3,010	42.02	80.1
		(abcd)	(bc)	(ab)	(cd)
	6.1	382,760	2,780	40.29	80.6
		(cd)	(c)	(b)	(cd)
	7.4	368,100	2,870	40.39	77.9
		(d)	(c)	(b)	(d)
	9.9	365,160	3,010	41.05	90.1
		(d)	(bc)	(ab)	(bcd)
	14.4	436,700	3,520	43.55	98.6
		(abc)	(ab)	(a)	(bc)
	23.8	417,010	3,350	43.94	118.6
		(abcd)	(abc)	(a)	(a)
4% Acetic acid	4.6	363,870	2,870	40.36	89.4
		(d)	(c)	(b)	(bcd)
	7.2	454,800	3,610	42.73	100.7
		(ab)	(a)	(ab)	(ab)
	9.1	471,180	3,760	44.00	100.7
		(a)	(a)	(a)	(ab)
Control (untreated)		392,590	2,970	42.22	90.3
		(bcd)	(bc)	(ab)	(bcd)

[1] Means within columns having common letters are not significantly different at the 0.05 level by the Waller-Duncan test procedure.

produced values that were not significantly different. The 24-hour thickness swell average values for the treated flakes were similar to control average values (Table 5) and were not significantly different from control values. The 2-hour thickness swell results were similar to and the 24-hour thickness swell results were generally higher than those previously reported by Blankenhorn et al. (1989) using water and 4% acetic acid treatments on red oak flakes.

All of the 2- and 24-hour average water absorption values for the boards made with treated flakes and the control boards had similar (Table 5) trends to those in thickness swell. In general, about 25% of the total water absorption for all treated boards, and about 75% of the total water absorbed from the control boards occurred during the first two hours of the test. Percent absorption at 2 hours ranged from about 20 to 47% of initial oven-dry specimen weight for the treated boards compared to 74% for the controls. All 2-hour treatment average values were less than the control average values and were significantly different from control board values.

The 24-hour water absorption test showed that all of the treatment average values, except for 4.6% weight loss water treatment value, were less than the control, but all values were not significantly different for the control values. Average 24-hour values were distributed within a very narrow range between about 66% to 103% water absorption.

The 2-hour average volumetric expansion values for boards from chemically extracted flakes were significantly different from the control values (Table 5). All 2-hour average values for boards from treated flakes were less than the control average value. The 24-hour average volumetric expansion values were not sig-

TABLE 5. *Average thickness swell, water absorption, volumetric expansion, and linear expansion for specimens from boards manufactured from chemically modified red oak flakes and bonded with urea formaldehyde resin.*[1]

Treatment	Percent (%)							
	Average flake weight loss	Average thickness swell		Average water absorption		Average volumetric expansion		Average linear expansion[2]
		2 h	24 h	2 h	24 h	2 h	24 h	
Water	4.6	13.7	41.3	24.6	103.6	14.3	42.6	0.29
		(c)	(a)	(c)	(a)	(c)	(a)	(bc)
	6.1	16.7	44.5	22.3	89.9	17.5	46.4	0.29
		(bc)	(a)	(c)	(a)	(bc)	(a)	(bc)
	7.4	14.8	43.5	19.8	83.2	15.5	45.2	0.30
		(bc)	(a)	(c)	(a)	(bc)	(a)	(abc)
	9.9	17.8	41.2	31.6	90.7	18.6	43.0	0.36
		(bc)	(a)	(bc)	(a)	(bc)	(a)	(a)
	14.4	17.3	38.1	28.8	87.0	17.9	39.3	0.32
		(bc)	(a)	(c)	(a)	(bc)	(a)	(abc)
	23.8	21.4	33.6	46.8	94.4	22.3	35.2	0.36
		(b)	(a)	(b)	(a)	(b)	(a)	(ab)
4% Acetic acid	4.6	15.3	43.3	27.7	93.1	16.0	45.0	0.27
		(bc)	(a)	(c)	(a)	(bc)	(a)	(c)
	7.2	14.0	37.0	25.0	89.6	14.7	38.3	0.29
		(c)	(a)	(c)	(a)	(c)	(a)	(c)
	9.1	13.2	35.5	20.6	66.2	13.6	36.3	0.30
		(c)	(a)	(c)	(a)	(c)	(a)	(bc)
Control (untreated)		29.9	41.1	73.9	96.0	30.9	42.3	0.28
		(a)	(a)	(a)	(a)	(a)	(a)	(c)

[1] Means within columns having common letters are not significantly different at the 0.05 level by the Waller-Duncan test procedure.
[2] Linear change from oven dry condition to equilibrium with 90% relative humidity.

nificantly different from control values. Volumetric and thickness dimensional changes followed similar trends.

Linear expansion average values for boards from chemically extracted flakes varied from 0.27 to 0.36% (Table 5). These observed linear expansion values were comparable to those reported by Heebink and Hann (1959) for linear expansion of red oak flakeboard manufactured from one-inch-long flakes. Results were also comparable to those reported by Blankenhorn et al. (1989) for flakeboards fabricated from red oak flakes that had been treated to about 6% weight losses with mild acetic acid solutions.

Almost all of the linear expansion average values for the treated flakes were slightly greater than the control average value. This overall result was not exhibited with the other dimensional stability tests. The linear expansion average values that were statistically different from the control average value were associated with water treatments producing average weight losses of 9.9% and 23.8%. The 23.8% weight losses were associated with the production of a high proportion of fines after water treatment. All three acetic treatment conditions produced boards with linear expansion values similar to the control board values.

SUMMARY

The objective of this study was to investigate the effect of chemical extractions of red oak flakes on the properties of phenol formaldehyde and urea formaldehyde

bonded red oak flakeboard. Flakes were extracted with either weak acetic acid solutions or water. The red oak flake weight loss was carefully controlled, and ranged from approximately 4% to 25% of original oven-dry wood weight.

Static bending properties were generally statistically similar to control property values for both PF and UF bonded boards. Clearly, flake treatment, even under relatively harsh conditions, did not adversely affect board strength properties.

Internal bond values varied considerably with flake weight loss values. Internal bond strength was generally reduced for all chemical treatments for both resins. However, only three of the nine chemical treatments produced PF boards that were significantly different than the control, and only one of the nine chemical treatments produced UF boards that were significantly different than the control.

There were no statistical differences between treatment means for either 2-hour or 24-hour thickness swell, water absorption, and volumetric expansion determinations for PF boards. However, there were significant differences in the liner expansion average values for the PF boards.

All of the 2-hour thickness swell, water absorption, and volumetric expansion for the UF boards were significantly different from the control values and had average values lower than the control values. The thickness swell, water absorption, and volumetric expansion 24-hour average values were not significantly different from control 24-hour average value. Chemical extraction of red oak produced some short-term gains in dimensional stability of UF bonded red oak particleboard.

Acetic acid treatment produced linear expansion values for the UF boards similar to the control values. All of the water treatments produced higher average linear expansion values for the UF boards than the control boards. However, only two treatments (water treatments producing 9.9% and 23.8% weight loss) produced linear expansion values for the UF boards significantly different from control values.

It appears from these results that selected mild chemical extractions may produce some improvement in dimensional stability for UF boards. The 4% acetic acid treated UF boards appear to have slightly improved properties over the water treated and control boards.

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