PROPERTIES OF HARDBOARDS MADE FROM ACETYLATED ASPEN AND SOUTHERN PINE

Poo Chow
Professor

and

Zhaozhen Bao
Former Graduate Student

Department of Natural Resources and Environmental Sciences
W-503 Turner Hall
1102 S. Goodwin Ave.
Urbana. IL 61801

John A. Youngquist

and

Roger M. Rowell
Project Leaders

James H. Muehl
Forest Products Technologist

and

Andrzej M. Krzysik
Visiting Scientist

USDA Forest Service
Forest Products Laboratory
One Gifford Pinchot Drive
Madison. WI 53705-2398

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ABSTRACT

The effects of fiber acetylation, resin content, and wax content on mechanical and physical properties of dry-process hardboard made from aspen and southern pine were investigated.

Test results indicate that the modulus of rupture (MOR) and modulus of elasticity (MOE) of the hardboard specimens were decreased due to the fiber acetylation. Tensile stress parallel to face and internal bond (IB) were generally higher for untreated boards than for acetylated boards. Water absorption (WA) and thickness swelling (TH.S) were both reduced markedly by acetylation. In general, increasing resin content from 3% to 7% brought increases in MOR, MOE, tensile stress, and IB and improved WA and TH.S. Addition of the 0.5% wax content usually caused reductions in these mechanical properties, but improved WA and TH.S in some cases. Linear expansion (LE) in the dimensional stability test (from 30% to 90% RH) was significantly reduced by acetylation and influenced by wood species. Neither resin nor wax contents significantly affected the LE value of hardboard specimens in this study.

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INTRODUCTION

Hardboard, a sheet material manufactured from wood or other ligno-cellulosic materials, has been developed in many aspects since its first appearance. As a wood-based material, it retains some physical and mechanical properties of the original wood from which it is made. However, since bonding agents or other additives may be added intentionally during manufacturing to improve board properties, the final products of hardboard can gain some additional or particular properties for the requirements of different specific end uses.

Many research projects have been conducted to investigate the effects of some common factors such as moisture content, binders, additives. kind of fiber treatments, etc., on board physical and mechanical properties (Chow 1978; Chow et al. 1987; Hsu 1987; Hsu et al. 1988: Rowell 1986, 1987; Ruffin 1960; Suchsland 1965; Suchsland and Woodson 1986; Suzuki et al. 1976). Efforts had been made primarily for enhancing the board strength properties (MOR, MOE, tensile strength, IB), or improving the board dimensional stability and durability under environmental variation.

Stamm (1964) reported that acetylation can improve the dimensional stability of wood. Youngquist and others (1990b) 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. Bending stiffness was improved by steam pretreatment compared to no treatment of acetylation. Hsu(l987) and Hsu et al. (1988) pointed out that the excessive thickness swelling (TH.S.) of wood-based composites was due to mainly the springback of compressed wood. They suggested that the most efficient way of reducing this springback effect is to minimize the buildup of internal stress in the board by steam pretreatment which, in turn, will reduce the springback of the compressed wood, and thus the thickness swelling could be minimized. Hsu also indicated that a proper steam pretreatment not only improved dimensional stability, but also improved mechanical properties of hardboard. Rowell (1986, 1987) reported that treatment of acetylation on wood fibers, flakes, and strands can greatly improve dimensional stability properties of boards. Suzuki and others (1976) investigated that the water absorption and swelling in thickness decreased with increasing addition of resin and paraffin wax and with its apparent density. Addition of both resin and paraffin wax resulted in lower water absorption 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 adopted to enhance the mechanical and physical properties of hardboard: (1) controlling the resin content and wax content at an optimum level to reach a satisfactory range of MOR, MOE, tensile strength, IB, water absorption, and thickness swelling; (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, water absorption and thickness swelling will be reduced.

The objective of this study were to: a) determine the effects of acetylated treatment of wood fibers on mechanical and physical properties of dry-process hardboard made from aspen and southern pine, and b) determine the effects of two levels of wax and phenolic resin content on various board properties.

MATERIALS AND METHODS

Eight groups of aspen hardboard and eight groups of southern pine hardboard, both with a nominal dimension of 254 by 254 mm by 3.2 mm, were involved in this study. The commercially refined aspen and southern pine fibers were either pretreated by acetylation to an acetyl weight gain of 23%, or they lacked any treatments (control). A high loading of acetyl weight gain of 23% was chosen based on the preliminary test results. (This loading level will achieve the best dimensional stability of hardboard. A lower level of acetylation will result in an inferior fiber quality.) Then wax and resin were sprayed on the dried fibers as they tumbled in a rotating drum. Tumbling was continued for 5 min 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 and resin-wax clumps. Mats were formed on a 254 by 254 mm vacuum forming box where the fibers were passed through a 5.7-mm screen and onto a 1.3-mm screen, then flipped over the mat onto a caul plate. The boards were pressed on a manually controlled, steam-heated press. The pressing temperature was 190°C. The press time was 8 min. For control untreated boards, the maximum pressure of 7.24 MPa was exerted, and for the acetylated boards, the maximum pressure was 10.34 MPa because of the stiffness of the acetylated fibers. After pressing, all boards were trimmed to 254 by 254 mm.

EXPERIMENTAL DESIGN

The experiment was a factorial design test with 2 levels of treatment (acetylation and control), 2 levels of phenol-formaldehyde resin content (3 and 7%), and 2 levels of wax content (0 and 0.5%). For each combination of independent variables, five boards were made. A total of 80 boards were made from aspen and southern pine fibers in this study. A factorial analysis was conducted through the use of a randomized complete block (RCB) to determine the effects of different combinations of treatments (independent variables) used on each dependent variable (testing result).

TESTING

All sample boards were put into a climate chamber for a week with a relative humidity of 50 ± 2°C and a temperature of 23 ± 2°C. Then weight and thickness measurements were made on each individual board. Specimens were cut into the required sizes and shapes in accordance with the standard procedures (ASTM 1993). Test procedures of static bending, tensile strength parallel and perpendicular to surface, water absorption, and thickness swelling after a 24-h water soak were conducted. Water absorption and thickness swelling in the 2-h water boiling test were determined according to the Canadian Standard Association CSA3-0188 (1975).

RESULTS AND DISCUSSION

Factorial analysis

Table 1 presents results of the experiment and determined effects of four factors and their interactions on all properties of hardboard specimens. The table shows that all factors were significant, except for the main effect C and the interaction AXC, BXC, AXBXC, CXD, AXBXD, BXCXD, and AXBXCXD for the bending, tension, 24-h soak, and 2-h boil experiment. The linear expansion tests were affected only by the factors A (treatment) and D (species).

Bending properties and tensile properties

The average specific gravity of all specimens was about 1.00. Table 2 and Table 3 show the average values of each designative combination of treatments of board mechanical and physical properties for aspen hardboard and southern pine hardboard, respectively. As shown in the tables, for southern pine, the control boards had significantly higher MOR and MOE values at both resin and wax levels compared to acetylated boards. In contrast, acetylated aspen board possessed higher average MOR and MOE values than control board in the groups with wax, but not in the groups without wax (Table 2). Tensile stress parallel to surface was decreased owing to the treatment of fiber acetylation. This was noted for both species (Tables 2,3). A reduction in average internal bond (IB) values caused by acetylation was observed only for southern pine boards. The test results indicated that, in gen-

TABLE 1. *Factorial analysis.*

Independent variable	Dependent variable: Bending MOR	Bending MOE	Tension Parallel to face	Tension IB	24-h soak TH.S	24-h soak WA	2-h boil TH.S	2-h boil WA	30% to 90% RH TH.S	30% to 90% RH LE
Treatment (A)	S[a]	S	S	S	S	S	S	S	S	S
Resin (B)	S	S	S	S	S	S	S	S	S	NS
AXB	S	S	S	S	S	S	S	S	S	NS
Wax (C)	S	S	S	S	S	S	NS	NS	S	NS
AXC	S	NS	S	S	S	S	S	S	NS	NS
BXC	S	NS	S	S	S	S	S	S	NS	NS
AXBXC	NS[b]	S	NS	NS	S	S	S	S	NS	NS
Species (D)	S	S	S	S	S	S	S	S	S	S
AXD	S	S	S	S	S	S	S	S	S	S
BXD	S	S	S	S	S	S	S	S	S	NS
CXD	S	NS	S	S	S	S	NS	NS	S	NS
AXBXD	S	S	S	S	S	S	NS	NS	S	S
AXCXD	S	S	S	S	S	S	S	S	S	S
BXCXD	S	NS	S	S	S	NS	NS	NS	NS	NS
AXBXCXD	S	NS	S	NS	NS	NS	NS	NS	NS	NS

[a] S—Significant at 5% level.
[b] NS—Not significant at 5% level.

eral, the treatment of acetylation on wood fiber caused a reduction in board strength, except for the board made from aspen. Rowell and Banks (1987) reported 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 flake and therefore resulted in poor penetration of water-soluble phenol-formaldehyde resin. In like manner, the acetylated fibers would result in a lower nettability and subsequently poor penetration of resin. This affected the bonding strength of board; and as a result, the MOR, MOE, tensile stress, and IB values were reduced for acetylated boards. Increasing resin content from 3 to 7% resulted in significant improvements in MOR, MOE, tensile stress, and IB values at both levels of wax content (0 and 0.5%) in most cases. The addition of the 0.5% wax caused some reductions in average MOR and MOE values. The same decreasing tendency in average tensile stress and IB values resulting from the addition of wax was also observed. (Table 2 and 3). It can be explained that the wax retards water uptake and interferes with internal bond (IB) and other strength development.

water absorption and thickness swelling

In the 24-h water soaking test (Tables 2 and 3), acetylated boards possessed very low average TH.S values compared to control boards for both species. Acetylated board showed satisfactory TH.S values, which were less than the maximum allowable thickness swelling value for standard and tempered hardboard required by ANSI/AHA (1988) (< 35% for standard board and < 20% for tempered board). Acetylated board had significantly lower average TH.S values than those for control board. The average TH.S values for control board ranged from 19.4% to 35.0% for aspen and 15.7% to 31.0% for southern pine, respectively (Table 2 and Table 3). Improvement in WA (decrease in values) after 24-h soaking was also obtained by acetylation. Rowell (1986) 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 moisture content. This may be suitable for interpreting that WA and TH.S were reduced by acetylation as compared with the board without such acetylated treatment. Similarly, in a 2-h water boiling test, WA and TH.S values were decreased significantly by acetylation. Increasing resin content from 3% to 7% and adding the 0.5% wax, as expected, did improve WA and TH.S in most cases, with a few exceptions in untreated aspen boards (Tables 2 and 3). Moreover, no significant differences in thickness swelling and water absorption were observed between the groups with and without wax in the 2-h water boiling tests (Tables 1, 2 and 3), indicating that the effect of wax on WA and TH.S was not as substantial as it was in the 24-h water soaking. The purpose of adding wax was to reduce surface energy of fibers, therefore making it more hydrophobic and less susceptible to moisture influence (Youngquist et al. 1990). In the water boiling test, applied wax tended to be melted after being subjected to such great heat for 2 h. and subsequently, the effects of wax were impaired. The boil test clearly breaks up the bonds in the untreated boards. generating void space and causing large springback in thickness and water absorption.

Linear expansion

The results of the statistical analysis (Table 1) show that neither resin nor wax content significantly affected the LE value of the hardboard. Only fiber treatment and wood species were important factors in influencing LE property of the board specimen. Hardboards made from southern pine obtained a significantly lower average LE value than those of the board made from aspen fiber. The dimensional changes in both length (LE) and thickness (TH.S) directions from 30% relative humidity to 90% relative humidity are listed in Table 2 and Table 3. Marked improvements (decrease in values) both in LE and TH.S were obtained by acetylation. Likewise, an increase in resin content from 3% to 7% resulted in some reductions in LE and TH.S in some cases for the untreated boards. The addition of the 0.5% of wax did not significantly affect the TH.S and LE in a fixed trend, i.e., increase and decrease in TH.S and LE occurred virtually equally in the tests, as evidenced in both tables.

TABLE 2. *Average values of mechanical and physical properties of acetylated and untreated aspen hardboard.*

Fiber treatment	Resin (%)	Wax (%)	MOR (MPa)	MOE (MPax100)	Tensile (MPa)	IB (MPa)	24-h soak[a]		2-h boil[b]		30% RH to 90% RH	
							TH.S (%)	WA (%)	TH.S (%)	WA	TH.S	LE (%)
Untreated	3	0.5	42.01[c]	40.64	27.91	0.37	35.0	48.0	65.4	88.6	12.9	0.383
	7	0.5	61.92	45.46	45.31	0.84	24.7	31.9	37.9	68.0	9.6	0.384
	3	0	62.83	56.17	42.95	1.19	33.7	57.3	46.9	84.0	10.5	0.404
	7	0	87.09	61.91	58.92	2.14	19.4	44.9	29.4	52.0	8.2	0.357
Average			63.46	51.04	43.93	1.14	28.2	45.5	44.9	73.1	10.3	0.382
Acetylation	3	0.5	50.75	53.42	24.2	1.8	4.2	30.6	12.8	39.2	2.9	0.288
	7	0.5	75.21	61.52	44.23	2.21	3.3	25.6	10.6	35.9	4.4	0.279
	3	0	61.43	49.95	34.03	1.43	3.8	30.3	12.9	39.3	3.2	0.294
	7	0	66.51	53.62	34.56	2.34	4.0	30.7	11.8	36.9	4.0	0.305
Average			62.23	54.63	34.25	1.94	3.8	29.3	12.0	37.8	3.6	0.277

[a] Water absorption (WA) and thickness swelling (TH.S) were determined after boards had been soaked for 24 h.
[b] Water absorption (WA) and thickness swelling (TH.S) were determined after boards had been boiled in water for 2 h.
[c] Each value is an average for 10 tests (MOR, MOE, Tensile, and IB). Each value is an average for 5 tests (TH.S, WA, and LE).

TABLE 3. *Average values of mechanical and physical properties of acetylated and control southern pine cardboard.*

Fiber treatment	Resin (%)	Wax (%)	MOR (MPa)	MOE (MPax100)	Tensile (MPa)	IB (MPa)	24-h soak[a] TH.S (%)	24-h soak[a] WA (%)	2-h boil[b] TH.S (%)	2-h boil[b] WA (%)	30% RH to 90% RH TH.S (%)	30% RH to 90% RH LE (%)
Untreated	3	0.5	57.54[c]	47.42	36.73	1.24	26.1	27.1	47.8	79.1	13.8	0.313
	7	0.5	79.65	57.00	46.92	1.77	15.7	22.5	29.1	55.9	9.9	0.318
	3	0	78.58	62.43	45.83	1.91	31.0	52.0	42.2	63.9	11.6	0.293
	7	0	80.22	61.13	43.60	1.91	23.0	35.7	31.5	50.8	9.9	0.324
Average			74.15	57.61	43.11	1.71	24.0	34.3	37.7	62.4	11.3	0.312
Acetylation	3	0.5	27.33	37.34	15.61	0.66	3.5	19.0	16.1	44.9	3.0	0.147
	7	0.5	45.75	56.15	27.7	1.22	3.2	12.4	20.2	39.1	3.1	0.147
	3	0	33.49	44.53	17.89	1.05	3.4	32.9	16.4	42.9	2.7	0.188
	7	0	45.15	53.9	27.95	1.4	4.4	26.0	18.9	37.9	2.5	0.223
Average			34.48	47.97	22.29	1.08	3.6	22.6	17.9	41.2	2.8	0.176

[a] Water absorption (WA) and thickness swelling (TH.S) were determined after boards had been soaked in water for 24 h.
[b] Water absorption (WA) and thickness swelling (TH.S) were determined after boards had been boiled in water for 2 h.
[c] Each value is an average for 10 tests (MOR, MOE, Tensile, and IB). Each value is an average for 5 tests (TH.S, WA, and LE).

CONCLUSIONS

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

1. Most hardboard samples made in this study showed good bending strength and stiffness properties, depending on treatments. resin content, and wood species. Addition of 0.5% wax reduced the average bending MOR and MOE, tensile stress parallel to surface, and IB values in most of the board specimens.

2. Treatment of acetylation on fibers resulted in a marked loss in MOR and MOE values except for the aspen hardboard with wax. Both MOR and MOE values increased with increasing resin content. Addition of 0.5% wax caused a decrease in MOE values except for the acetylated aspen boards.

3. Tensile strength values parallel to surface and IB for control boards were generally higher than those for acetylated boards for both wood fiber species except for the untreated aspen board. Increasing resin content from 3 to 7% improved both tensile stress and IB values significantly in most cases. Generally, addition of 0.5% wax caused a reduction in both tensile stress and IB.

4. For 24-h water soaking and 2-h boil tests, WA and TH.S values were significantly reduced by acetylation. Increasing resin content reduced WA and TH.S values for most cases. Addition of wax did significantly decrease 24-h WA and TH.S values for southern pine board and WA value for aspen board. In the 2-h water boiling test, wax did not significantly influence both the WA and TH.S values.

5. The average linear expansion and thickness swelling values in the dimensional stability test (from 30% to 90% RH) were significantly decreased by acetylation. Southern pine hardboard showed a significantly lower average LE value than that of the aspen board. However, both resin and wax factors did not result in significant effect on LE property.

REFERENCES

AMERICAN HARDBOARD ASSOCIATION (AHA). 1988. Basic hardboard. ANSI/AHA A135.4. 1988. American

National Standard/American Hardboard Association. Palatine, Il. 5 pp.

American Society for Testing and Materials (ASTM). 1993. Standard methods of evaluating the properties of wood-base fiber and particle panel materials. ASTM D 1037. Philadelphia, PA.

Canadian Standard Association (CSA). 1975. Mat-formed wood particleboard. Can 3-0188. 0-M-78. Canadian Standard Association. Ontario. Canada.

Chow, P. 1978. Phenol adhesive bonded medium-density fiberboard from *Quercus rubra* L. board and sawdust. Wood Fiber 11(2):92–98.

———, J. Q. McNatt, and Y. L. Xiong. 1987. Effects of accelerated weathering on some physical and mechanical properties of wood-based building panels. Pages 97–103 *in* Proc. Fourth International Conference on Durability of Building Materials Components, Singapore.

Hsu, W. E. 1987. Steam pretreatment of wood fibers. Pages 65–71 *in* Wood Science Seminar 1: Stabilization of the Wood Cell Wall. Michigan State University, East Lansing, MI.

———, W. Schwald, J. Schwald, and J. A. Shield. 1988. Chemical and physical changes required for producing dimensional stable wood-base composites. Wood Sci Technol. 22:281–289.

Rowell, R. M. 1986. Chemical modification of wood substance. Proc. Wood Technology, Chemistry, and Construction. USDA, Forest Serv., Forest Prod. Lab., Madison, WI.

———, 1987. Can the cell wall be stabilized? Pages 53–64 *in* Wood Science Seminar 1: Stabilization of the Wood Cell Wall. Michigan State University. East Lansing, MI.

———, and W. B. Banks. 1987. Tensile strength and toughness of acetylated pine and lime flakes. Br. Polymer J. 19:478–482.

Ruffin, E. T. 1960. Exterior durability of hardboard. Forest Prod. J. 10:336–341.

Stamm, A. J. 1964. Wood and cellulose science. The Ronald Press Co., New York, NY. 549 pp.

Suchsland, O. 1965. Swelling stresses and swelling deformations in hardboard. Michigan State Univ. Agric. Exp. Sta. Quart. Bull. 47(4):591–605.

———, and G. E. Woodson. 1986. Fiberboard manufacturing practices in the United States. USDA Forest Serv. Agric. Handbook No. 640. U.S. Government Printing Office, Washington, DC. 263 pp.

Suzuki, H., H. Takahashi, and K. Endoh. 1976. On water absorbability of dry process fiberboard. J Japan Wood Res. Soc. Mokuzai Gakkaishi. 22(10):557–563. Hokkaido Forest Products Research Institute, Asahikawa, Hokkaido, Japan.

Youngquist, J. A., J. Muehl, A. Krzysik, and T. Xin. 1990a. Mechanical and physical properties of wood/plastic fiber composites made with air-formed dry-process technology. Pages 159–162 *in* Proc. Joint International Conference on Processing and Utilization of Low-grade Hardwoods and International Trade of Forest-Related Products. June 11–13, 1990, Taipei, Taiwan.

———, R. Rowell, N. Ross, A. M. Krzysik, and P. Chow. 1990b. Effects of steam and acetylated fiber treatment, resin content and wax on the properties of dry-process hemlock hardboard. Pages 254–257 *in* Proce. Utilization of Low-grade Hardwoods and International Trade of Forest-related Products. June 11–13, 1990, National Taiwan University, Taipei, Taiwan.