Effects of recycled fiber on the properties of fiberboard panels

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Abstract

This study examined the effects of recycled and virgin wood fiber on the properties of fiberboard. Replacing virgin fiber with recycled fiber adversely affected physical and mechanical properties of fiberboard. Bending properties and dimensional stability were linearly dependent on virgin fiber ratios. Based on strength properties, panels with 20 and 40 percent recycled fiber contents conformed to standards for class 4-service and class 5-industrialite hardboard, respectively. All panels with recycled fiber content greater than 40 percent failed to meet any commercial requirement.

Municipal solid waste (MSW) is a significant problem in the United States. In 1993, 12.7 × 10^6 tons (12.4 × 10^6 t) of woodwaste was generated in the United States as part of MSW. This amounted to nearly 7 percent of all MSW generated. Of this woodwaste, 1.3 × 10^6 tons was recovered for recycling or composting, and 12.4 × 10^6 tons was discarded, either combusted or sent to landfills. The exact proportion of discarded waste that was combusted is available only for overall MSW, not for specific materials within the waste stream (Ince and McKeever 1995). Nevertheless, the study clearly indicates that fiber sources are abundant in the waste stream.

Previous attempts have been initiated to use recycled fiber to make panel products. The strength properties of the resulting products, however, either failed to meet commercial standards (Laundrie and McNatt 1975, Rowell and Harrison 1992, Rowell and Lange 1994) or marginally passed the standards (Krzysik et al. 1992). Therefore, virgin fiber has been blended with recycled fiber to improve panel mechanical properties (Deppe 1985, Krzysik et al. 1993, Stokke and Liang 1994).

The objective of this study was to evaluate the effect of virgin fiber and recycled fiber on fiberboard panel properties. This paper represents the first of a series of investigations on effects of recycled materials on fiberboard panel properties. Subsequent experiments will investigate wood fiber-polyethylene composites properties.

Materials and methods

Panels were produced using six (A to F) different ratios of virgin to recycled wood fiber content. The percentages of recycled and virgin fiber, respectively, for the six groups are as follows: A: 0/100, B: 20/80, C: 40/60, D: 60/40, E: 80/20, and F: 100/0, by weight of the total fiber for the panels.

Fibers were sprayed with urea-formaldehyde (UF) resin in a drum blender as described by Liang et al. (1994). Virgin southern pine fibers (VIR) and recycled old corrugated cardboard (OCC) were the raw materials for the study. The virgin fiber was generated by a local medium density fiberboard plant using a kraft process. Urea-formaldehyde (UF) (Chembond UF), with 65 percent solid content, pH = 8.0, was supplied by Dynea. The OCC fiber was generated with a laboratory disk refiner at atmospheric conditions. The disks were Sprout Waldron with a plate patent of C-2975 to 1. These disks allow for the shredding of the material, rather than cutting, and allow for the material to maintain its fibrous nature. The experimental design was a completely randomized design.

For panels containing both virgin and recycled fibers (Groups B, C, D, and E), the two types of fibers were first

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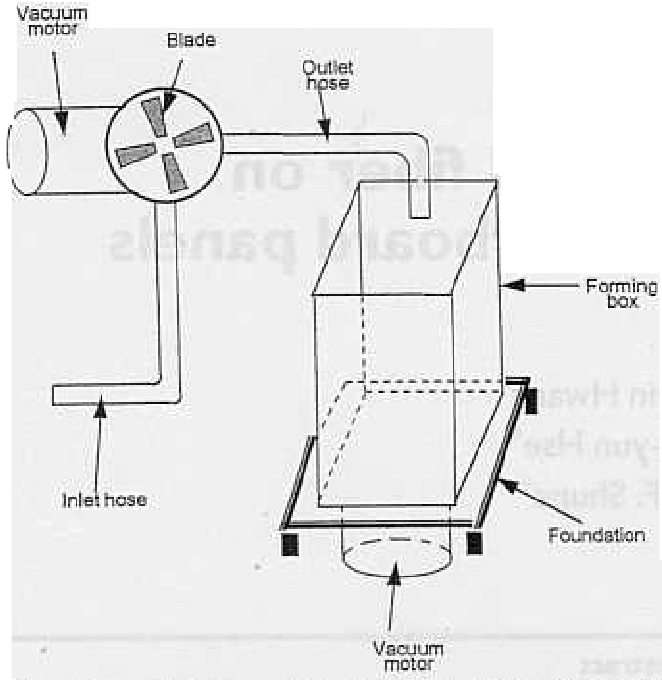

Figure 1. — Schematic of laboratory air-forming system for the experimental fiberboard.

hand-mixed to achieve a better fiber mixture, then blended with UF resin (10% by weight) in a laboratory-scaled drum blender. The mixture was then air-laid in a specially designed automatic air-forming system. The air-forming apparatus is illustrated in **Figure 1**. In panels containing only one type of fiber, no hand-mixing was performed.

The panels were pressed at 350°F for 5 minutes. A total of 18 panels with nominal dimensions of 12 by 12 by 1/4 inches were made with three replicates for each virgin fiber level. All panels were conditioned at room ambient conditions of 65 percent RH for 3 weeks to obtain constant weights. The equilibrium moisture content of the panels averaged 5.9 percent. After conditioning, each panel was cut to yield two static bending specimens, two water soaking specimens (one each for 2-hr and 24-hr soak test), and five specimens for tensile strength perpendicular to the face (internal bond). The mechanical tests were performed in accordance with ASTM D1037-93 (ASTM 1994). The water soaking tests consisted of soaking 2- by 10-inch specimens in tap water for 2 or 24 hours. Specimen weights and thickness values were recorded before and after soaking. The effects of recycled fibers on the panel properties were evaluated by analysis of covariance at alpha = 0.05 and the Tukey mean separation test. Contract and linear regression analyses were also employed.

Results and discussion

Table 1 shows the physical and mechanical properties of hardboard made from different compositions of virgin fibers and recycled fibers. The following mechanical properties were studied: internal bond (IB), modulus of rupture (MOR), modulus of elasticity (MOE), water absorption (WA), thickness swelling (TS). The physical and mechanical properties values differed significantly with the addition of recycled fibers. However, due to large variations in properties, Hartly F-max tests were performed to test the assumption of homogeneity, and the results necessitated further analyses using

Table 1. — Mean physical and mechanical properties of fiberboards made from various fiber compositions.

Property	Panel group[a] A	B	C	D	E	F
MC (%)	4.6 A[b] (0.36)[c]	4.7 A (0.11)	5.3 B (0.17)	5.4 B (0.24)	5.4 B (0.05)	5.4 B (0.07)
Density (pcf)	48.3 A (1.42)	46.3 AB (1.58)	46.9 AB (1.42)	45.8 AB (1.21)	43.8 B (2.36)	43.1 B (1.42)
IB (psi)	130.7 A (7.38)	83.59 B (15.04)	71.3 B (8.60)	44.0 C (4.70)	35.4 CD (1.88)	21.8 D (2.12)
MOR (psi)	4,538 A (1,612)	3,029 AB (547)	2,734 AB (301)	1,969 B (349)	1,392 B (386)	1,051 B (127)
MOE (10^3 psi)	410 A (131)	311 AB (53)	301 AB (40)	207 B (57)	177 B (38)	135 B (19)
WA2 (%)	75.0 D (9.20)	89.4 CD (9.30)	95.5 CD (6.72)	109.2 BC (5.59)	127.9 AB (13.04)	139.6 A (6.51)
WA24 (%)	87.6 D (5.77)	102.3 CD (6.50)	105.7 CD (5.99)	117.0 BC (4.86)	135.7 AB (13.02)	146.2 A (6.36)
TS2 (%)	21.7 E (2.82)	24.9 DE (1.13)	26.9 CD (0.56)	29.8 BC (0.94)	32.7 AB (1.03)	35.6 A (0.59)
TS24 (%)	25.0 D (2.03)	27.6 CD (0.68)	29.3 C (0.48)	32.6 B (0.86)	35.9 A (1.62)	38.8 A (0.24)

[a]The amounts of recycled fibers for the groups are as follows: A = 0 percent; B = 20 percent; C = 40 percent; D = 60 percent; E = 80 percent; and F = 100 percent by weight.
[b]Mean values with the same capital letter are not significantly different, based on the Tukey test at alpha = 0.05.
[c]Values in parentheses are standard deviations.

contrast analysis (**Table 2**). All physical and mechanical properties, except IB, were found to be linearly dependent of the virgin fiber ratio. It is noted that the relationship of IB with fiber ratio was quadratic. Regression analyses were subsequently performed to estimate the coefficients (**Table 3**).

Table 3 shows a linear relationship between panel density and virgin fiber ratio, and that 58 percent of the variation (r^2 = 0.5838) in panel density was attributed to virgin fiber ratio. The reduction in panel density with increasing recycled fibers may be caused by the automatic air-forming system. Since recycled fibers are lighter in weight and smaller in size, the unadjustable motor speed tends to blow off more recycled fibers than virgin fibers, leading to a slight reduction in panel density. Moreover, mats made from recycled fibers are more difficult to compress but easier to spring back, thus contributing further to the variations in panel density.

According to the r^2 in **Table 3**, virgin fiber ratio contributed approximately 95 percent of the variation in the IB of fiberboard. The relationship was due to variations in panel density and inferiority in individual strength properties of recycled fiber. In addition, the finer recycled fibers may increase the surface area, which results in lower resin coverage per unit surface area. If the recycled fibers were hydrophilic, then there may be overpenetration of the adhesive. It was speculated that the resin and additives might make the OCC fibers more hydrophilic. The contact angles of the virgin and OCC fibers were tested to explore this theory but showed no statistically significant difference (Hwang 1998). The IB, however, can be improved by adding more adhesive (Rowell and Harrison 1992, Krzysik et al. 1993).

The dependency of bending properties on virgin fiber ratio is shown in **Table 1**. As seen by the r^2 value in **Table 3**, at least 70 percent of the variation in both MOR and MOE can be

Table 2. — *Contrast analysis of physical and mechanical properties of fiberboards with different fiber compositions.*[a]

Property	Contrast	DF	MS	F	p
Density					
	Linear		51.3365	19.77	0.0008**
	Quadratic		0.5752	0.22	0.6463
	Cubic		0.2315	0.09	0.7704
	Error	12	2.5961		
IB					
	Linear		21972.4035	342.64	0.0001**
	Quadratic		1183.6067	18.46	0.0010**
	Cubic		163.9225	2.56	0.1358
	Error	12	64.1277		
MOR					
	Linear		22887483.73	41.89	0.0001**
	Quadratic		793074.48	1.45	0.2515
	Cubic		140908.76	0.26	0.6208
	Error	12	546373.44		
MOE					
	Linear		148944.5733	33.58	0.0001**
	Quadratic		1438.4121	0.32	0.5795
	Cubic		51.2641	0.01	0.9162
	Error	12	4435.0344		
WA2					
	Linear		8740.3954	114.02	0.0001**
	Quadratic		48.6289	0.63	0.4412
	Cubic		0.0145	0.00	0.9892
	Error	12	76.6559		
WA24					
	Linear		7011.2563	121.91	0.0001**
	Quadratic		57.3526	1.00	0.3377
	Cubic		3.0165	0.05	0.8227
	Error	12	57.5117		
TS2					
	Linear		396.0419	200.63	0.0001**
	Quadratic		0.2433	0.12	0.7316
	Cubic		0.1497	0.08	0.7877
	Error	12	1.9740		
TS24					
	Linear		404.2689	295.21	0.0001**
	Quadratic		1.9119	1.40	0.2603
	Cubic		0.1411	0.10	0.7537
	Error	12	1.3694		

[a]** = significant at alpha = 0.01

Table 3. — *Statistics and estimated parameters for linear regression analysis of fiberboard properties.*

Panel	Statistics			Estimated		
property	F	p	r^2	b_0	b_1	b_2
Density	22.44	0.0002	0.5838	43.2184	0.0494	
IB	139.40	0.0001	0.9489	24.1488	0.2101	0.008127
MOR	46.26	0.0001	0.7430	801.4444	33.0133	
MOE	40.16	0.0001	0.7151	123.6282	2.6632	
WA2	132.75	0.0001	0.8924	138.3538	−0.6451	
WA24	127.24	0.0001	0.8883	144.6268	−0.5778	
TS2	256.34	0.0001	0.9412	35.4614	−0.1373	
TS24	328.70	0.0001	0.9536	38.4779	−0.1387	

explained by virgin fiber ratio. The reasons for these adverse effects in recycled fibers are the same as those given for IB. However, the adverse effect on the strength property was more drastic for IB than MOR and MOE.

The effect of virgin fiber ratio on 2-hour (WA2) and 24-hour (WA24) water absorption is shown in **Table 1**. In both WA2 and WA24, 89 percent of the variations were attributed to virgin fiber ratio based on the r^2 values in **Table 3**. The slopes of these two lines were slightly different, showing that the effect of fiber composition was slightly stronger on WA2 than on WA24. In this study, fiberboards made from recycled fiber show enormous water uptake, which was far above the 40 percent commercial standard for 1/4-inch service class hardboard (Suchsland and Woodson 1986). This finding is attributable to these panels being fabricated in the laboratory and they neither received heat treatment nor were subjected to oil tempering.

The dependencies of 2-hour (TS2) and 24-hour (TS24) thickness swelling on virgin fiber ratio are shown in **Table 1**. The slopes of the two straight lines were negative and almost identical (−0.1387 vs. −0.1373), respectively, indicating that recycled fiber adversely affected the thickness swelling. Equations for both TS2 and TS24 have considerably high coefficients of determination (greater than 0.9) (**Table 3**). The effect of adding recycled fiber can be explained from physical, chemical, and anatomical aspects. The average fiber length of OCC is considerably shorter than that of VIR; chemically, OCC has higher holocellulose content and lower lignin content than VIR; and anatomically, OCC is "fuzzier" when compared with VIR.

The uptake of water in hardboard from recycled fibers was far from commercial standards, but the deviations of TS from standard value (30%) were less dramatic. If WA and TS are not considered, panel A qualifies for commercial class 2-standard hardboard, panel B for class 4-service hardboard, and panel C for class 5-industrialite hardboard. The addition of 60 percent or more recycled fibers failed to meet the requirements of any commercial hardboard.

Conclusions

Replacing virgin fiber with recycled fiber adversely affected physical and mechanical properties of fiberboard. Bending properties and dimensional stability were linearly dependent on virgin fiber ratios. At least 70 percent, based on the r^2, of the variations in these properties can be attributed to fiber composition. IB strength showed a polynomial relationship with virgin fiber ratio. As high as 95 percent, based on the r^2, of the variations in fiberboard IB can be explained by fiber composition. Based on strength properties, panels with 20 and 40 percent recycled fiber contents conformed to standards for class 4-service and class 5-industrial hardboard, respectively. All panels with recycled fiber content greater than 40 percent failed to meet any commercial requirement.

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