WASTE PAPERBOARD IN COMPOSITION PANELS

AMIR ESHRAGHI and HABIBOLLAH KHADEMIESLAM

Department of Wood and Paper Science and Technology, Science and Research Branch, Islamic Azad University, P.O. Box 14515/775, Tehran, Iran

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Waste paperboard could potentially be used as raw material for fiber or particle based composites without the resorting, deinking, and decontamination required for paper manufacturing. The objective of this study was to evaluate single-layer particleboards made with various ratios of waste paperboard fibers to wood particles. Urea formaldehyde resin in different amounts of 9 and 10% were applied. Static bending strength, internal bonding, and thickness swelling were measured. The results indicated that applying waste paperboard fibers satisfied the minimum MOR (modulus of rupture) and MOE (modulus of elasticity) requirements for load-bearing boards for use in humid and dry conditions, respectively. The IB (internal bonding) values of all panel types decreased with the addition of waste paperboard fiber. However, all of the produced panels met the IB requirement for general purpose end-use. By increasing the resin content, all properties of the boards and particularly internal bond and thickness swelling were improved. Nevertheless, thickness swelling values were higher than those required. For this reason, additional work needs to be done to improve the physical properties of the particleboard produced from waste paperboard fibers.

Keywords: waste paperboard fibers, wood chips, urea-formaldehyde resin, particleboard

INTRODUCTION

The demand for composite wood products, such as plywood, oriented strand board (OSB), hardboard, particleboard, medium density fiberboard, and veneer board products has recently increased substantially throughout the world. Particleboard represents 57% of total consumption of wood based panels and its demand is continuously growing with 2-5% annually. The demand for particleboards in the sectors of housing construction, furniture manufacturing, and interior decoration (wall and ceiling paneling) has continued to increase.[1] Particleboard is a panel material manufactured under pressure, made from particles of wood and/or other lingocellulosic fibrous materials (for example, wood chips, sawdust, and flax shaves) with the addition of an adhesive.[2] The demand for wood in the forest product industry has been growing, but the production of industrial wood from natural forests continues to decline. There is still an ongoing research interest to find alternative sources of raw materials for composite manufacturing.[3] Waste paper could potentially be used as raw material for fiber or particle based composites without the resorting, deinking, and decontaminating required for paper manufacturing.[4] Waste paperboard or OCC (Old Corrugated Container) could be a good alternative raw material because, 1) this material is a recycled fiber resource available almost anywhere in the country; 2) it is relatively low-priced compared to office waste paper; 3) it is a relatively clean source of fiber without significant fillers or plastic contaminants.[5] Therefore, alternative nonwood based materials may play an important role in the forest product industry.[6,7] Much research has been done on the use of nonwood based resources for particleboard manufacturing. Most of these studies found nonwood based materials to be practical for particleboard manufacturing.[6,8-10] Abdolzadeh *et al*. studied the possibility of using OCC in the surface layers of particleboard in order to improve surface properties of the product, decrease adhesive consumption, and facilitate the use of lingocellulosic resources.[11] Grigoriou also investigated one-layer boards made with various ratios (0:100, 15:85, 25:75, 50:50, 75:25, and 100:0) of wastepaper flakes to wood particles mixtures (wt:wt).[4] The purpose of this research is to study the use of waste paperboard fibers to make single-layer particleboard and to examine the mechanical and physical properties of the panels to determine the influences of OCC fibers and adhesive.

EXPERIMENTAL

Materials and methods

Old corrugated container was supplied by East Carton Company, aspen wood was obtained from Alborz Institute, and urea formaldehyde adhesive was supplied by the Isfahan Company. After preparing the OCC and slicing them into small pieces, the hydropulper apparatus mixed the pieces with water to make the pulp, after which the pulp was dried to about 1% moisture content. In order to prevent moisture exchange with the environment, OCC fibers were kept inside plastic bags. A drum chipper was used to produce chips, the ring flaker converted chips to flakes, and finally the flakes were screened. By using a rotary drier, the flakes were dried until the moisture content reached 1%. Flakes and OCC fibers were blended by a laboratory blender. For mat forming, the weighed mixture was sprayed into a mold with dimensions 30×32 cm^2. The mat was then pressed by a hydraulic press (Burkle L100). After pressing, the particleboards were conditioned at a temperature of 20±2 ºC and 65±5% relative humidity, and then the samples were resized and cut to standard size for static bending strength, internal bonding, and thickness swelling tests. Variables included two amounts of adhesive, 9% and 10%, and three ratios of OCC fibers to wood flakes (25/75, 50/50, and 75/25). Other factors, such as pressing pressure (30 kg cm^{-2}), pressing temperature (165 ºC), pressing time (5 min), pressing closing rate (4.5 mm s^{-1}), board density (0.75 g cm^{-3}), board thickness (10 mm), and moisture of mat (12%) were fixed. The pH and density of the urea formaldehyde used were of 8.42 and 1.26 g cm^{-3}, respectively. Other features of the urea formaldehyde included gel time (92 s), viscosity (220 CP), and solid content (63.5%). In total, there were 6 treatments and 3 replications, leading to 18 samples. Thickness swelling, static bending strength, and internal bond were determined according to EN 317 (1993), EN 310 (1993), and EN 319 (1993), respectively.[12-14] The results obtained for the physical and mechanical properties were analyzed using a Randomized Complete Block experimental Design (RCBD), by Duncan's Multiple Range Test (DMRT) and the analysis of variance. With this statistical method, independent and interactive effects of each of the variables on the studied properties were analyzed at 95 and 99% levels of confidence. Table 1 shows the experimental design of the study.

Table 1
Experimental design used in the study

Board type	Wood (%)	OCC fibers (%)	Adhesive (%)
A	75	25	9
B	75	25	10
C	50	50	9
D	50	50	10
E	25	75	9
F	25	75	10

RESULTS AND DISCUSSION

Mechanical properties

The average modulus of rupture, modulus of elasticity, and internal bonding values are shown in Table 2. The data obtained in this research showed that the effects of all variables on mechanical properties in terms of MOR, MOE, and IB were significant, except for the effect of the adhesive on MOE (Table 3). The MOR data ranged from 19.92 to 26.08 Mpa. The highest MOR (26.08 Mpa) and MOE (2712 Mpa) values were observed for particleboards D and C, respectively, containing 50% OCC fibers. On the other hand, the lowest MOR (19.92 Mpa) and MOE (2355 Mpa) values were obtained for E type panels including 75% OCC fibers. The results indicated that an increase of more than 50% of the OCC fibers in the mixture significantly decreased the MOR and MOE values of the particleboards. Panels A, B, C, and D satisfied the minimum MOR requirements for heavy-duty load-bearing boards for use in humid conditions stated in the EN Standard (EN 312, 2005).

Average MOE values of the panel types A, B, C, and D met the minimum requirement for load-bearing boards for use in humid conditions stated in the EN 312 Standard. The fact that MOR and MOE improved by OCC fibers up to 50% may be attributed to the considerably higher aspect ratio of OCC fibers than of wood particles and higher compaction ratio of OCC fibers. But the reduction of MOR and MOE for OCC fiber contents above 50% is related to the fact that OCC fibers are damaged and weaker than wood particles (Figures 1 and 2).

Table 2
Average values of MOR, MOE, IB, TS 2 and TS 24*

Board Type	Modulus of rupture (Mpa)	Modulus of elasticity (Mpa)	Internal bonding (Mpa)	Thickness swelling (2 h) (%)	Thickness swelling (24 h) (%)
A	22.993(.29)	2590.00(54)	0.647(.03)	21.390(.90)	24.560(.59)
B	24.823(.38)	2665.00(75)	0.703(.03)	20.447(.27)	23.753(.34)
C	24.910(.89)	2712.00(40)	0.510(.01)	25.063(.76)	29.067(.80)
D	26.083(.60)	2677.33(107)	0.550(.01)	23.710(.90)	26.753(.40)
E	19.923(1.0)	2355.00(78)	0.360(.01)	28.663(1.17)	31.377(1.17)
F	21.417(.37)	2435.33(33)	0.390(.02)	26.153(1.0)	29.310(.78)
Requirements [1]	min.12.5	-	min. 0.28	-	-
Requirements [2]	min. 14	min. 1800	min. 0.4	-	-
Requirements [3]	min. 17	min. 2300	min. 0.4	-	16
Requirements [4]	min. 18	min. 2550	min. 0.45	-	11
Requirements [5]	min. 20	min. 3150	min. 0.6	-	15
Requirements [6]	min. 22	min. 3350	min. 0.75	-	9

*Values in parentheses are standard deviations
[1] for general purpose boards for use in dry conditions; [2] for interior fitments (including furniture) for use in dry conditions; [3] for load-bearing boards for use in dry conditions; [4] for load-bearing boards for use in humid conditions; [5] for heavy-duty load-bearing boards for use in dry conditions; [6] for heavy-duty load-bearing boards for use in humid conditions

Table 3
Independent and interactive effects of variable factors

Signs	Variable factor	Modulus of rupture (Mpa)	Modulus of elasticity (Mpa)	Internal bonding (Mpa)	Thickness swelling (2 h) (%)	Thickness swelling (24 h) (%)
A	Independent effect of OCC fibers	××	××	××	××	××
B	Independent effect of adhesive	××	NS	××	×	××
A×B	Interactive effect of OCC fibers and adhesive	NS	NS	NS	NS	NS
Coefficient of variation		2.80	2.70	3.77	3.68	2.69

×× = Significant difference at 1% level ($p \leq 0.01\%$)

× = Significant difference at 5% level ($p \leq 0.05\%$), and NS = Not significant

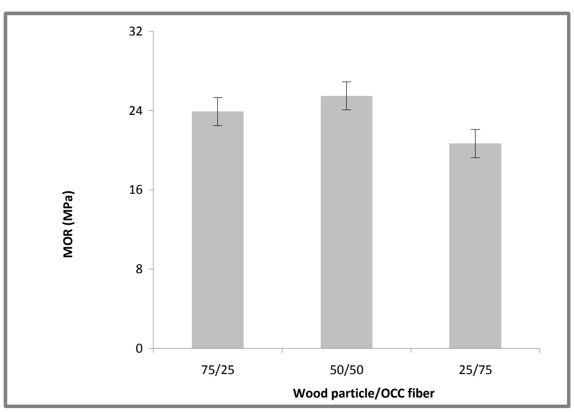

Figure 1: Effect of OCC fiber on MOR

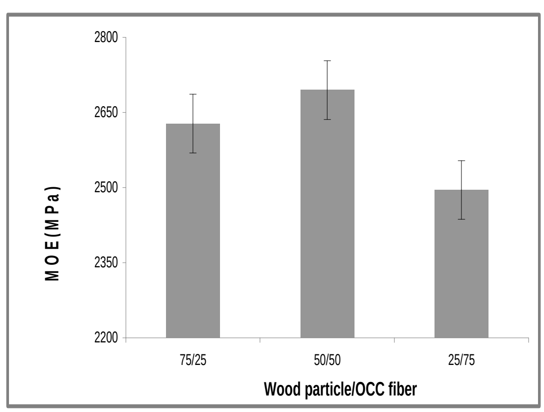

Figure 2: Effect of OCC fiber on MOE

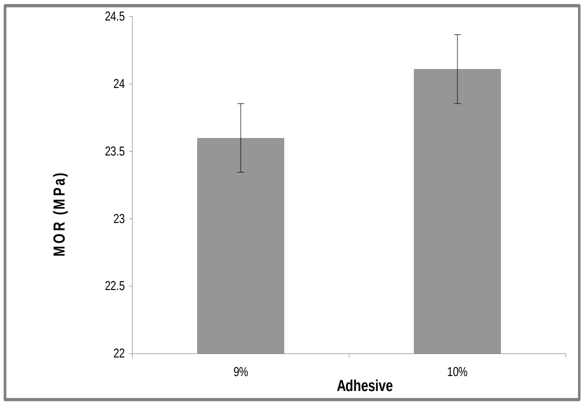

Figure 3: Effect of adhesive on MOR

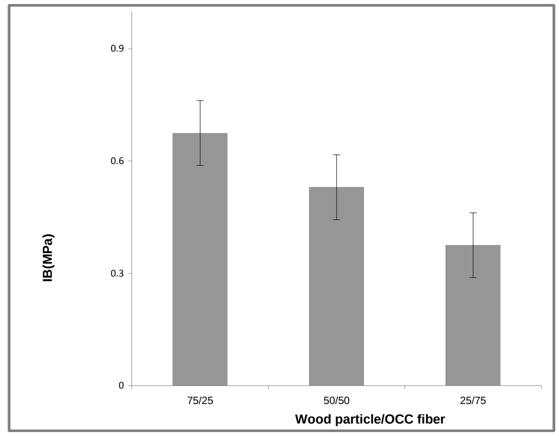

Figure 4: Effect of OCC fiber on IB

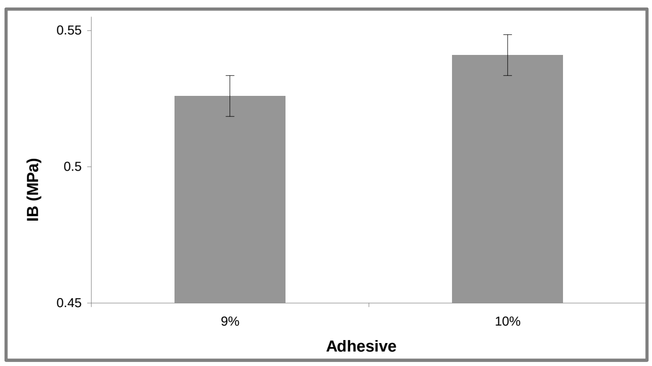

Figure 5: Effect of adhesive on IB

According to Maloney, the Modulus of Elasticity and Modulus of Rupture are strongly influenced by the particleboard compaction rate, particle geometry, percentage of adhesives, and density.[15] Tabarsa *et al*. investigated some of the applied properties of experimental particleboard panels made with bagasse, as an alternative fibrous raw material.[1] They concluded that boards made with bagasse exhibited superior mechanical properties, compared to poplar and mixed hardwood particleboards. As shown in Figure 3, an increase in the amount of adhesive leads to an improvement in the bond between wood particles and OCC fibers, which improves the MOR and MOE. Hwang *et al*. reported that in any approximate specific gravity range of the boards made of waste paperboard, the greater the resin contents of the board, the higher the MOR and MOE.[16]

IB values of the experimental panels ranged from 0.36 to 0.70 Mpa. The highest IB value was observed for B type panel, while the lowest was observed for E type panel. IB values decreased with the increasing of OCC fiber content in the panels. All of the produced panels met the IB requirement for general purpose end-use, while A, B, C, and D type particleboards met the minimum requirement for load-bearing boards for use in humid conditions stated in the EN 312 Standard. The significant negative influence of OCC fibers on internal bonding can be explained by the reduced bonding ability of OCC fibers, due to the fact that OCC fibers have a higher surface area than wood particles; therefore the resin coverage and consequently the bond ability is lower (Figure 4). Grigoriou stated that the addition of wastepaper decreased the internal bonding of the boards.[4] All mechanical properties, particularly internal bonding of the boards was improved when the resin level was increased from 9 to 10%. It can be interpreted from Figure 5 that more adhesive causes more saturated OCC fiber surfaces and results in stronger bonds and vice versa, which is consistent with the conclusion of Krzysik *et al*. They found that all properties of the boards made of wood fibers and newspaper mixtures in proportions of 50:50 and 0:100 improved when phenolic resin content increased from 3 to 7%.[17] Bekalo and Reinhardt also stated that an increase of the resin content from 8 to 12% of PMDI resulted in a substantial improvement of mechanical properties for coffee husk-wood boards.[18]

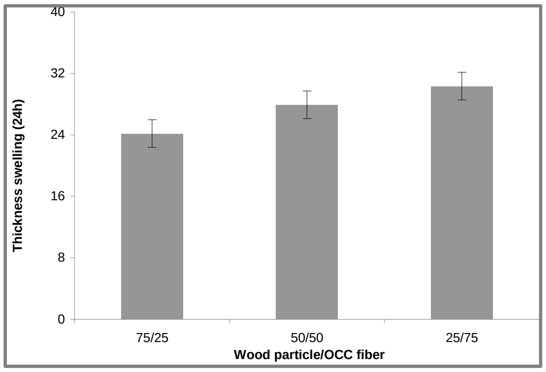

Figure 6: Effect of OCC fibers on TS (24 h)

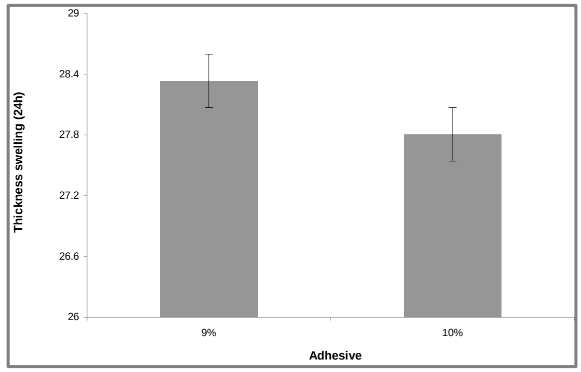

Figure 7: Effect of adhesive on TS (24 h)

Physical properties

Table 2 shows the average thickness swelling values of the panels after 2 and 24 h immersion in water. Statistical analysis of data showed that the effects of various variables on thickness swelling after 2 and 24 h water immersion of all experimental boards were significant (Table 3). Particleboards should have a maximum thickness swelling value of 16% for load-bearing boards for use in dry conditions after 24 h immersion. The TS values of the panels for 2 h immersion vary from 20.45% (type B) to 28.66% (type E) and these values are increased after 24 h immersion, varying from 23.75% (type B) to 31.38% (type E). None of the boards could meet the required level of thickness swelling for load-bearing boards for use in dry conditions. The OCC fiber usage exacerbated the thickness swelling of the panels significantly. The results indicate that as the OCC fiber content increased, the thickness swelling of the boards increased significantly. It is obvious that OCC fibers cause higher board swelling as a result of the lower adhesive content per surface area of OCC fibers, in comparison with wood particles. The reason is that OCC fiber has a considerably larger aspect ratio and consequently has a much larger surface area per weight unit than wood particle (Figure 6). Papadopoulos *et al*. made one-layer experimental particleboard from bamboo chips bonded with urea formaldehyde resin.[19] Bamboo chips were characterized as having higher length to thickness ratio than industrial wood chip particles. They concluded that increasing of bamboo chips improved mechanical properties and the particleboards conformed to the more stringent requirements of class M-3, while their TS values were far below the standards. The addition of 0.5% and 1% wax to the boards resulted in improved TS and satisfied the EN 312 Standard. By increasing the resin level from 9 to 10% for all board types, thickness swelling decreased significantly (Figure 7), which is consistent with the results of Guntekin and Karakus, who examined the possible feasibility of eggplant stalks in the production of particleboard.[9] They used certain ratios of urea formaldehyde and melamine urea formaldehyde adhesives. The results indicated that increasing of adhesive improved thickness swelling.

CONCLUSION

Based on the experimental results, the following conclusions were drawn:

- With increasing OCC fiber content up to 50%, the MOR and MOE values of the panels increased. However, further additions decreased the MOR and MOE values. Panels A, B, C and D satisfied the minimum MOR requirements for heavy-duty load-bearing boards for use in humid conditions, as well as the minimum MOE requirements for load-bearing boards for use in humid conditions. However, all of the panels (A, B, C, D, E and F) met the minimum MOR requirements for load-bearing boards for use in humid conditions and the minimum MOE requirements for load-bearing boards for use in dry conditions.

- The IB values of all panel types decreased with the addition of OCC fiber content. However, all of the produced panels met the IB requirement for general purpose end-use, while A, B, C, and D type panels met the minimum requirement for load-bearing boards for use in humid conditions.
- The thickness swelling of the panels after 2 and 24 h immersion increased with increasing OCC fiber content and none of the boards could meet the required level of thickness swelling for general uses.
- All the physical and mechanical properties improved by increasing the amount of adhesive.
- Based on the results, decreasing the thickness swelling by using wax or other hydrophobic substances during particleboard manufacturing can make OCC fibers a good alternative for wood particles.

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