Mechanical Properties of Wood Plastic Composite Panels Made From Waste Fiberboard and Particleboard

Majid Chaharmahali,[1] **Mehdi Tajvidi,**[2] **Saeed Kazemi Najafi**[1]

[1]*Department of Wood and Paper Science and Technology, College of Natural Resources and Marine Sciences, Tarbiat Modares University, Noor, Iran*

[2]*Department of Wood and Paper Science and Technology, College of Natural Resources, University of Tehran, Karaj, Iran*

The possibility of producing wood-plastic panels using a melt blend/hot press method was studied in this research. The studied panels were compared with conventional medium density fiberboard (MDF) and particleboard (PB) panels. Wood-plastic panels were made from high density polyethylene (as resin) and MDF waste and PB waste (as natural fiber) at 60, 70, and 80% by weight fiber loadings. Nominal density and dimensions of the panels were 1 g/cm^3 and 35 × 35 × 1 cm^3, respectively. Mechanical properties of the panels including flexural modulus, flexural strength, screw and nail withdrawal resistances, and impact strength were studied. Results indicated that the mechanical properties of the composites were strongly affected by the proportion of the wood flour and polymer. Maximum values of flexural modulus of wood plastic panels were reached at 70% fiber content. Flexural strength, screw and nail withdrawal resistance, and impact strength of wood plastic composites declined with the increase in fiber content from 60 to 80%. This was attributed to the lack of compatibility between the phases. The produced panels outperformed conventional PB panels regarding their mechanical properties, which were acceptable when compared with MDF panels as well. The best feature in the produced panels was their screw withdrawal resistance, which is extremely important for screw joints in cabinet making. POLYM. COMPOS., 29:606–610, 2008. © 2008 Society of Plastics Engineers

INTRODUCTION

The word "waste" projects a vision of a material with no value or useful purpose. However, technology is evolving that holds promise for using waste or recycled wood and plastics to make an array of high performance composite products that are themselves potentially recyclable [1]. When natural fibers, resins, and other materials are used as raw materials for products such as paper, they require extensive cleaning and refinement, but when recovered fibers, resins, and other materials are used to manufacture composites, they do not require extensive preparation. This will, in turn, greatly reduce the potential cost of manufacturing [1].

Wood plastic composites (WPCs) are defined as composite materials containing wood (in various forms) and thermoplastic materials. These materials are a relatively new family of composite materials, in which a natural fiber and/or filler (such as wood fiber/flour, kenaf fiber, hemp, sisal, etc.) is mixed with a thermoplastic such as polyethylene (PE), polypropylene (PP), poly vinyl chloride (PVC), etc. Compared with the traditional synthetic fillers, natural fillers present lower density, less abrasiveness, lower cost, and they are renewable and biodegradable [2]. WPCs are becoming more and more commonplace by the development of new production techniques and processing equipment. Around 100 companies involved in WPC manufacturing have been identified worldwide [2].

In WPC manufacturing, virgin plastics such as high and low density polyethylene (HDPE and LDPE), PP, and PVC are commonly used. As for virgin plastics, any recycled plastic that melts and can be processed below the degradation temperature of wood (lignocellulosic fillers) (around 200°C) is usually suitable for manufacturing WPCs. Plastic wastes are one of the major components of global municipal solid waste and present a promising raw material source for WPCs, thanks to their large amount of daily generation and low cost. For example, a city in a developed country with a population of 3 million inhabitants produces around 400 tons plastic waste per day with an annual increase of 25% [3]. Hence, the development of new value-added products (WPCs), with the aim of utilizing the wood waste (this means no need for additional wood resources) and low cost recycled plastics (which would otherwise be added to landfills), would be indispensable.

Correspondence to: Mehdi Tajvidi; e-mail: mtajvidi@ut.ac.ir
DOI 10.1002/pc.20434
Published online in Wiley InterScience (www.interscience.wiley.com).

TABLE 1. Particle size distribution of the ingredients used to make composite panels (wt%).

	Particle size distribution				
Material	Mesh size <30	Mesh size 30–40	Mesh size 40–50	Mesh size 50–100	Mesh size >100
Particleboard flour	15	16	20	30	19
MDF flour	12.5	11.5	16	29.5	30.5

The utilization of recycled plastics for the manufacture of WPCs has been studied by a number of authors [3–8]. Applications of such materials include floor parquet, flower vases, waste paper baskets, park benches, picnic tables, and plastic lumbers [7]. Properties of some waste plastics are similar to those made from virgin materials. For instance, only slight changes in mechanical properties of recycled PE have been reported [8]. The use of plastic and wood wastes seems inevitable and present opportunities are promising [9, 10].

The ultimate goal of the present research was to develop technology to convert recycled medium density fiberboard (MDF) and particleboard (PB) waste fiber and plastic (HDPE) into durable products that are recyclable, and at the same time, environmentally friendly.

MATERIALS AND METHODS

Recycled HDPE

Recycled HDPE was obtained from milk bottles with a melt flow index of 18.4 g/10 min (170°C).

Recycled MDF

This waste was obtained from Khazar Choob Company, Amol, Iran, and was composed of two parts: MDF sawdust obtained from panels sawing and MDF flour obtained by grinding pieces of MDF. These two parts were mixed at a ratio of 50:50 by weight.

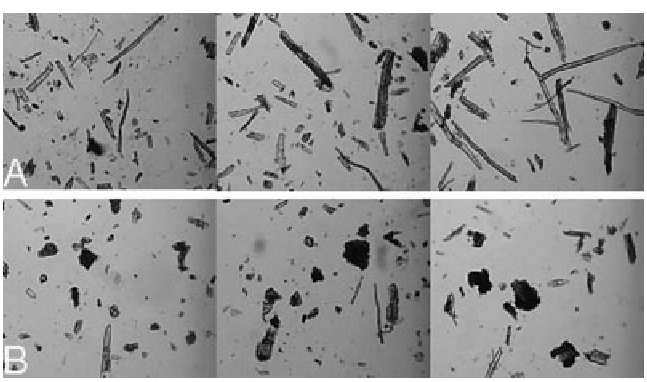

FIG. 1. Microscopic photograph of recycled MDF (RMDF) (A) and recycled particleboard (RPB) fibers (×100).

Recycled PB

This waste was obtained from Gonbad Paticleboard Company, Gonbad, Iran, and was composed of two parts: PB sawdust obtained from panels sawing and PB flour obtained by grinding pieces of PB. These two parts were mixed at a ratio of 50:50 by weight.

MDF and PB Panels

MDF and PB panels were obtained form Khazar Choob Company and Gonbad Paticleboard Company, respectively.

EXPERIMENTAL

Raw Material Size Classification

Particle size distribution of both fibers was determined by screening through predetermined mesh size screens. The results are presented in Table 1. A microscopic view of the fibers is also presented in Fig. 1 where it is observed that MDF flour is much more fibrous than PB flour indicated by its longer fibers and higher aspect ratios.

Mixing Process

Oven-dried MDF and PB flour with a moisture content of less than 3% and plastic granules were weighed for each formulation according to Table 2 and were blended in a Borna Pars Mehr laboratory counter-rotating intermeshing twin screw extruder (Tehran, Iran) at 170°C. Mixing process took 5 min on average. The compounded materials were then pelletized and dried at 105°C for 24 h before panel making.

Panel Processing

The wood-plastic pellets were poured into a mold frame (measuring 35 × 35 × 1 cm^3) and spread to fill the frame evenly. Two 0.3-cm spacers were taped to each side of the forming frame. These prevented the hot press from closing

TABLE 2. Composition of evaluated formulations[a] (wt%).

Sample no.	Formulation	Fiber content (%)	Plastic content (%)
1	RPB(60)	60	40
2	RPB(70)	70	30
3	RPB(80)	80	20
4	RMDF(60)	60	40
5	RMDF(70)	70	30
6	RMDF(80)	80	20
7	RMDF+RPB(60)	60	40
8	RMDF+RPB(70)	70	30
9	RMDF+RPB(80)	80	20

[a] RPB, recycled particleboard; RMDF, recycled MDF.

completely and reduced the probability of the formation of internal air voids in the panel. The entire assembly was placed into an oil-heated press at 200°C. The press cycle consisted of two phases. The first phase involved closing of the press for 20 min. In the second phase, the press was opened and the spacers were removed from the assembly and the press was closed completely for 5 additional minutes. The assembly was then transferred into a cold press [6]. Three WPC boards were manufactured for each formulation. The boards were conditioned at constant room temperature and relative humidity prior to testing.

Mechanical Tests

Flexural Bending Properties. Three-point static bending tests were carried out according to DIN-EN 310 specification [11]. Six replicates of each formulation were tested using a computer-controlled DARTEC machine. The speed of the crosshead was set at 5 mm/min. Data were collected and used to calculate the modulus of elasticity and flexural strength.

Screw Withdrawal. This test was carried out according to DIN-EN 320 specification [12]. Six replicates of each formulation were tested using a computer-controlled INSTRON machine (model 4486). The crosshead speed was set at 10 mm/min.

Nail Withdrawal. Nail withdrawal test was carried out according to ASTM D 1037 specification [13]. Similar to the screw withdrawal test, six replicates of each formulation were tested using a computer-controlled INSTRON machine (model 4486). The speed of the crosshead was set at 1.5 mm/min.

Impact Tests

Unnotched Izod impact tests were carried out according to ASTM D 256-90 specification. Nine replicates of each formulation were tested using a DMG Izod testing machine.

Statistical Analysis

The collected data have been statistically analyzed in a completely randomized design and Duncan's multiple rang test was used for grouping the means. All comparisons have been made at 95% confidence.

RESULTS AND DISCUSSION

Figure 2 illustrates the effect of fiber type and content on the flexural modulus of the WPCs. Data points for PB and MDF are also presented for comparison. It can be observed that the flexural modulus of WPCs increased with the increase in fiber content from 60 to 70% and then decreased as the fiber content reached 80%. MDF boards had the highest modulus values when compared with all other formulations. Formulations containing recycled MDF (RMDF) exhibited slightly higher modulus values, which could be attributed to the higher aspect ratios of RMDF fibers (Fig. 1).

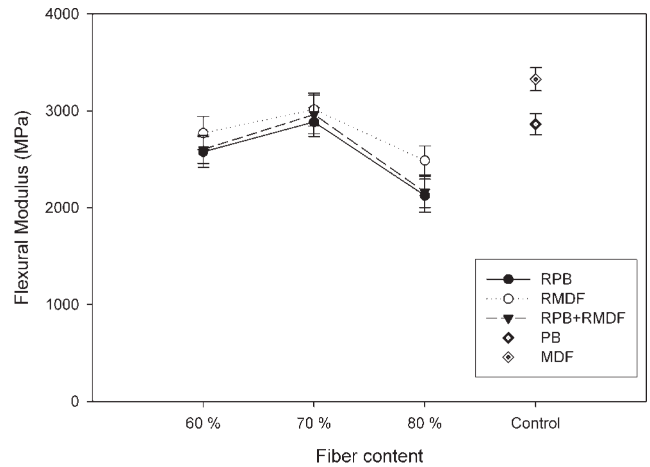

FIG. 2. Effect of fiber type and content on the flexural modulus of the composites.

The moduli of natural fibers are higher than that of HDPE [8]. Hence, when fiber content of WPCs increased from 60 to 70%, the moduli of the composite materials increased. However, in wood-plastic composites with higher levels of fiber content, plastics are utilized as adhesives for bonding wood particles/fibers together. When the fiber content increased from 70 to 80% no sufficient adhesive bonding was present to achieve higher modulus values and WPC samples were easily bent under load. Sanadi et al. [14] have reported similar results indicating a decrease of the modulus with the increase in fiber content from 60 to 80%. Statistical analysis has confirmed that the three formulations containing 70% fiber content have significantly higher modulus values than the two other fiber content levels for all fiber types. The modulus values of composites containing 70% of various fibers are comparable to that of PB; however, they are less than that of MDF. Therefore, the produced composites could compete with conventional PBs as far as their stiffness is concerned.

The flexural strengths of WPCs significantly decreased with the increase in fiber content from 60 to 80%. Flexural strength of MDF panels was considerably higher than those of WPCs. However, the composite materials had strength values in the vicinity of that of PB control panels, especially at 70% fiber content. No significant difference was observed between the three natural fiber types at any given fiber content (Fig. 3).

The considerable higher strength of MDF panels can be attributed to the process in which MDF is produced. In MDF processing, a fiber mat of an initial thickness many times the final thickness of the board is pressed in a hot press, which consolidates the mat into the target thickness. Wood fibers are mixed with around 10% urea formaldehyde resin, which is a thermosetting one. Therefore a densely consolidated board in which the surfaces contain cured

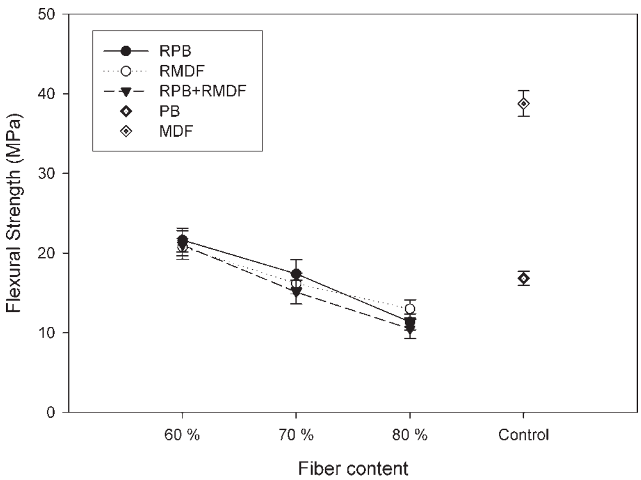

FIG. 3. Effect of fiber type and content on the flexural strength of the composites.

resin is produced. This results in high flexural strengths as this property is directly dependent on the quality of the surfaces where maximum bending stresses are present. The constant decrease in the strength values if WPCs as a function of fiber content is related to the lack of compatibility between the phases as no compatibilizer was used while preparing the panels. However, the produced panels are still good when compared with commercial PB.

The produced composite panels outperformed commercial MDF and PB panels regarding their screw withdrawal resistance. Figure 4 shows the effect of fiber type and content on this property of the WPCs. The screw withdrawal test determines the load required to pull a standard size screw from the panel specimen. It can be observed that screw withdrawal resistance in all cases significantly decreased with the increase in fiber content. WPCs made from 60% of recycled PB (RPB) fibers had the highest (212 N/mm) and PB control samples had the lowest (77 N/mm) screw withdrawal resistance. Screw withdrawal resistance values of MDF and PB samples were slightly higher and lower than those of WPCs made from 80% fiber, respectively. The higher capacity of the screws in the WPCs compared with that of MDF and PB is probably due to the ability of the thermoplastic to conform around the thread of the screw, allowing continuous load transfer along the thread [15]. Again, composites containing up to 70% fibers of any kind had better screw withdrawal resistances than conventional wood composite panels.

Figure 5 exhibits the effect of fiber type and content on the nail withdrawal resistance of the WPCs. The objective of the nail withdrawal test is to measure the peak load required to pull a standard size nail from the panel specimen. It can be observed that nail withdrawal resistance reduced with the increase in fiber content from 60 to 80%. The same trend was found for flexural modulus and strength and screw withdrawal but values of reduction are lower here. Nail withdrawal resistance values of the MDF and PB are close to each other and approximately the same as those of WPCs especially at 70% fiber content. Therefore, the produced WPC panels can have similar nail holding capacities to those of commercial MDF or PB.

The impact resistance is defined as the energy lost by the pendulum during the breakage of the sample. It is the sum of the energies required to produce fracture initiation, fracture propagation, bending of sample, production of vibration, friction loss in the bearing arm, and on the face of the sample after failure, etc. [6]. The impact strengths of various WPC panels are presented in Fig. 6. It can be seen that the impact strength significantly reduces with the increase in fiber content from 60 to 80%. Furthermore, composites made from 60% RMDF + PB and 80% RPB showed the maximum (340 J/m) and minimum (180 J/m) impact strengths, respectively. Again, the lower impact strengths at higher fiber contents indicate the lack of compatibility between the composite components. Pure HDPE does not break in a conventional unnotched Izod impact test. However, when fibers are added, the smooth surface of the specimen is subject to microscopic gaps which

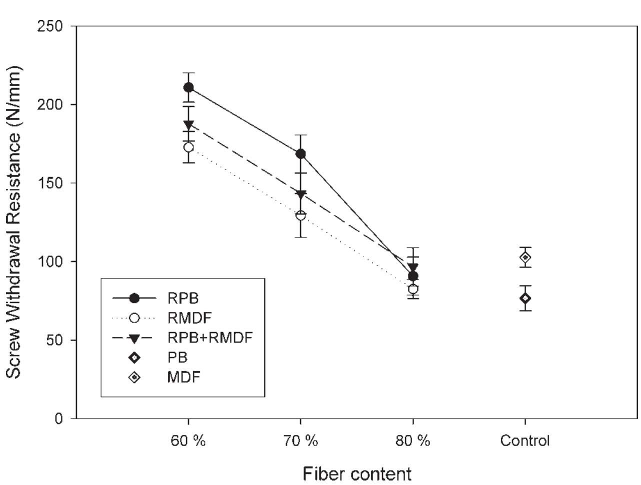

FIG. 4. Effect of fiber type and content on the screw withdrawal resistance of the composites.

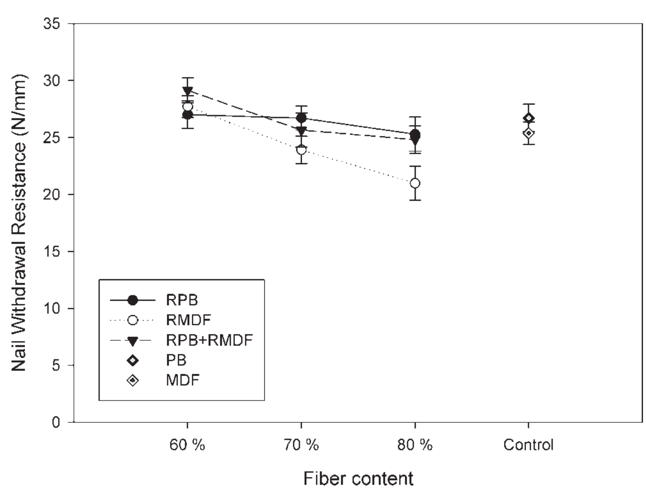

FIG. 5. Effect of fiber content and type on the nail withdrawal resistance of the composites.

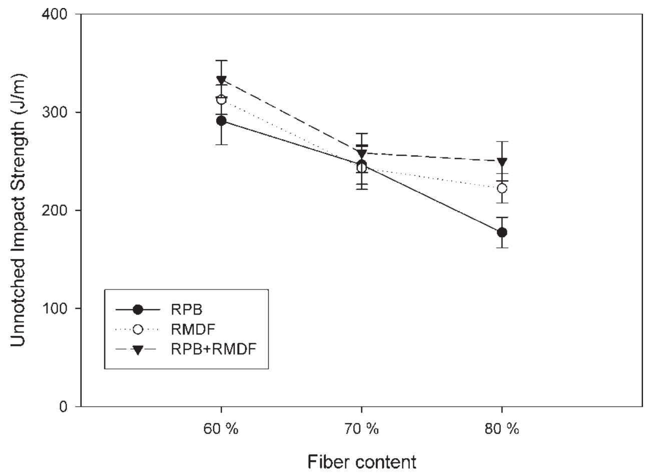

FIG. 6. Effect of fiber type and content on the unnotched impact strength of the composites.

change the breaking mechanism into a somewhat "notched" one where the resistance to crack propagation is tested [7]. Therefore, when fiber content increases, impact resistance decreases. It should also be mentioned that because the commercial PB and MDF had higher thicknesses than those of the produced panels, no comparison could be made between them. For this reason, data points of PB and MDF are not presented in Fig. 6.

CONCLUSIONS

The melt blend/hot press sequence used to manufacture WPCs using particles from recycled HDPE, waste MDF, and waste PB flours seems promising as the mechanical properties of the produced panels are comparable to those of conventional wood composites. Flexural strength, screw withdrawal resistance, nail withdrawal resistance, and unnotched impact strength reduced with the increase in fiber content from 60 to 80%, whereas flexural modulus first increased at 70% fiber content and then reduced at 80%. It seems that 70% fiber content (or 30% plastic content) is the optimum fraction to enhance the modulus of the composites. The comparison of the mechanical properties of the produced panels with those of MDF and PB revealed that they are superior to conventional wood composites especially PB in a good number of properties. Very slight differences were observed between the two lignocellulosic wastes or the combination of the two. This is a promising finding indicating that a mixture of these materials can be successfully processed into value added composite materials without undergoing dear separation processes. In wood industries using panel products, relatively equal amounts of PB and MDF are consumed, which in turn leads to proportional amounts of them turned into wastes.

The present study deliberately ignored the application of coupling agents to enhance compatibility between the wood and plastic fractions with the idea of suggesting a production technique as simple as possible. The use of such additives will inevitably help enhance the performance of such composites. However, further studies are required to be able to determine to what extent such additives can be beneficial. The presence of some cured urea-formaldehyde resin in PB and MDF wastes will also have effects on the mechanical performance of the manufactured composites. This can be a challenging area for future studies.

REFERENCES

1. R.M. Rowell, J.A. Youngquist, and D. Mcnatt, in *Proceedings of the 25th International Particleboard/Composite Materials Symposium*, Washington State University, Washington, 314 (1991).
2. C. Clemons, *Forest Prod. J.*, **52**, 10 (1992).
3. A.F. Avila and M.V. Duaret, *Polym. Degrad. Stab.*, **80**, 373 (2003).
4. J.A. Youngquist, G.E. Myers, J.H. Muehl, A.M. Krzysik, and C.M. Clemons, "Composites from Recycled Wood and Plastics (Project Summary)," U.S. Environmental Protection Agency, Cincinnati, OH (1994).
5. P. Chow, D.S. Bajwa, W. Lu, J.A. Youngquist, N.M. Stark, Q. Li, and C.G. Cook, in *Proceedings of the First Annual American Kenaf Society Meeting*, San Antonio, TX, 38 (1998).
6. D.P. Kamdem, H. Jiang, W. Cui, J. Freed, and L.M. Matuana, *Compos. A: Appl. Sci. Manuf.*, **35**, 347 (2004).
7. N.S. Kazemi, E. Hamidinia, and M. Tajvidi, *J. Appl. Polym. Sci.*, **100**, 3641 (2006).
8. K. Jayaraman and D. Bhattacharyya, *Resour. Conservat. Recycl.*, **41**, 307 (2004).
9. J.A. Youngquist, G.E. Myers, and T.M. Harten, in *Emerging Technologies for Materials and Chemicals from Biomass*, R.M. Rowell, T.P. Schultz, and R. Narayan, Eds., American Chemical Society, Washington, DC (1992). ACS Symposium Series 476, Chapter 4, Ligocellulosic-Plastic Composites from Recycled Materials, Proceedings of the ACS Symposium, August 26–31 (1990).
10. T.H. Wenger, J.A. Youngquist, and R.M. Rowell, in *Materials Interactions Relevant to Recycling of Wood-Based Materials*, *Vol.* **266**, R.M. Rowell, T.L. Laufenberg, and J.K. Rowell, Eds., Materials Research Society, Pittsburg, PA, 3 (1992).
11. European Standard. Annual Book of Din En Standard (1993). Din En 310.
12. European Standard. Annual Book of Din En Standard (1993). Din En 320.
13. American Society for Testing and Materials (ASTM). Annual Book of ASTM Standard, West Conshohocken, PA (1999). ASTM D 1037–96a.
14. A.R. Sanadi, J.F. Hunt, D.F. Caulfield, G. Kovacsvolgyi, and B. Destree, in *Proceedings of Sixth International Conference on Wood-Fiber Composites*, Forest Product Society, Madison, WI, 24 (2001).
15. R.H. Falk, D.G. Vos, S.M. Cramer, and B.W. English, *Forest Prod. J.*, **51**(1), 55 (2001).

 DOI 10.1002/pc