

Selected properties of MDF and flakeboard overlaid with fiberglass mats

Zhiyong Cai*

Abstract

Nonwoven fiberglass face laminates have long been applied to consolidated wood-based composites to improve their performance and serviceability. In this study, fiberglass mats with 50 percent resin binder were applied as face laminates to unconsolidated wood fiber or flake mats, then hot-pressed to make overlaid medium density fiberboard and flakeboard. Fiberglass reinforcement improved mechanical, surface quality, and water-resistance properties. Such improvement could make fiberglass reinforcement during composite processing very attractive for enhancing the properties and durability of mat-formed engineered wood composites. This approach also might contribute to the future development of exterior wood composite products.

To promote the sustainability of wood as a natural resource and to improve the structural efficiency of engineered wood composites, fiberglass has long been used to reinforce pre-formed wood composites. Research efforts to reinforce wood products with synthetic fibers started in the early 1960s, with investigations that focused on the flexural bending properties of wood-fiberglass composite beams (Wangaard 1964, Biblis 1965). Since then, many researchers have taken advantage of the high strength of fiberglass to increase the strength and stiffness of wood-based composites; that is, laminated structural beam/lumber (Wangaard 1964; Biblis 1965; Rowlands et al. 1986; Tingley 1988, 1996), plywood (Biblis and Carino 2000), structural particleboard (Saucier and Holman 1975), hardboard (Steinmetz 1974, Smulski and Ifju 1987), and wood fasteners (Soltis et al. 1998). Most of these studies focused on the structural analysis of the behavior of reinforced composites and the mechanical improvement provided by laminating fiberglass to wood products after production.

Polyester woven fiberglass laminates were reported to have an average tensile modulus of rupture (MOR) of about 275.0 MPa and a modulus of elasticity (MOE) of 17.2 to 20.1 GPa (Biblis and Carino 2000). The incorporation of a relatively small volume of fiberglass was found to increase the bending MOE and MOR of reinforced wood composites significantly. Fiberglass reinforcement levels of 3.5 to 7.0 percent by volume increased in-design bending strength from 10 to 20 percent (Spaun 1981).

An economic feasibility study was performed for a manufacturing process that used synthetic E-glass fiber, Douglas-fir veneer, and phenol-formaldehyde (PF) resin to produce reinforced laminated veneer lumber (Laufenberg et al. 1984). The result of cash flow and secondary analyses using product prices and grades indicated the profitability of manufacturing high-yield structural components using fiberglass reinforced parallel laminated lumber. Although the improved structural performance of fiberglass-reinforced wood composites was impressive, few of these composites were marketed successfully as a result of reluctance on the part of prospective users of the product to switch and the high price for the perceived structural benefits of the strength reinforcement (Biblis and Carino 2000).

In 2002, the consumption of medium density fiberboard (MDF) in the United States was 2.7 million cubic meters, an increase of about 14.6 percent from the previous year (Howard 2004). Compared with other nonstructural panel products, MDF is expected to offer particularly strong growth in the near future because of its wide range of application in interior uses, such as furniture and cabinets. The use of MDF has been extended to other manufacturing industries as well. MDF shows superior surface quality, moulding and edge performance, and screw withdrawal retention. Because of its low formaldehyde emission and high dimensional stability, MDF is being developed using PF or diphenylmethane diisocyanate (MDI) resin binders. Increasingly, MDF is being used in building construction, but not as yet as a critical structural material. Improvements in strength and durability, however, may render MDF suitable as an exterior structural material.

Structural flakeboard, such as sheathing and flooring, is the dominant material in the residential construction market. In 2004, the annual consumption of oriented strandboard (OSB) was about 20 million cubic meters in the United States (Howard 2004). The annual production and consumption of OSB are expected to increase.

Although existing wood composites exhibit many desirable characteristics as a renewable engineering material, their lack

The author is a Materials Research Engineer, USDA Forest Products Lab., Madison, WI (zca@fs.fed.us). This paper was received for publication in January 2006. Article No. 10155.

*Forest Products Society Member.

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of water resistance, dimensional stability, and durability when exposed to harsh exterior conditions represent major drawbacks (Sun et al. 1994). As a consequence, many research efforts have focused on modifying wood materials to improve their physical properties such as thickness swell (TS), water absorption (WA), and durability. The most popular methods developed for improving dimensional stability have been impregnation of wood material with low viscosity PF resin, densification of resin-treated wood material, and binding with poly-isocyanate resin (Rowell and Banks 1985, Sun et al. 1994).

Fiberglass reinforcement has the potential for enhancing the engineering performance and water and decay resistance of both fiber- and flake-based wood composites. A novel nonwoven fiberglass mat has been invented to improve wood products (Kajander 2001). A slurry of glass fibers is metered into a stream of cationic to nonionic whitewater, then formed into a wet nonwoven mat on a moving, permeable surface. The mat is then bonded with a resin mixture (furfural alcohol formaldehyde, PF, or melamine formaldehyde) in aqueous solution. The resin binder is dried and partially cured to provide adequate strength to facilitate handling and further processing of the fiberglass mat. The resinated fiberglass mat retains significant capacity to further react and subsequently bond to wood furnishes under the heat and pressure of wood composite processing and final curing.

The objectives of the study reported in this paper were 1) to examine the compatibility of fiberglass and both fiber- and flake-based wood materials integrated during composite production and 2) to evaluate the mechanical and physical performance of MDF and flakeboard overlaid with fiberglass.

Materials and methods

A roll of StabilStrand fiberglass mat (0.7 by 30.0 m) was provided by Johns Manville Corporation (Toledo, OH). The fiberglass mat weighed about 0.15 kg/m² and consisted of 50 percent fiberglass and 50 percent PF resin binder. The MDF fiber was a mixture of wood species (about 30% maple, 30% cherry, 30% aspen, and 10% white pine) and was obtained from a commercial MDF plant in Pennsylvania. The MDF fiber was conditioned to an average moisture content (MC) of 9.4 percent before blending with the resin. The flakeboard was made from aspen flakes provided by a commercial OSB plant in northern Wisconsin. The flakes were conditioned to an average 8.8 percent MC. Liquid MDI resin (Rubinate 1840) with 100 percent solids content was provided by Huntsman LLC (Salt Lake City, UT).

For the MDF panels, a MDI resin content of 4.0 percent (based on oven-dried weight) was selected, based on the author's experience in developing an exterior MDF product. For the flakeboard panels, a MDI resin content of 2.5 percent (oven-dried wood weight) was chosen, according to current MDI usage in commercial OSB mills. The resinated fibers or flakes were arranged randomly into a 508- by 508-mm mat on a bottom caul plate. Release papers were used between the resinated fibers or flakes and both the top and bottom caul plates to prevent sticking. The thickness of the mat before pressing was about 150 mm and the target thickness of the pressed panel was 12.7 mm.

A probe was inserted in the middle of each mat to monitor temperature and gas pressure. The mat, including the caul plates, was transferred to a conventional oil-heated press

(910- by 910-mm) with a computerized control system. The press temperature was 180°C. The press was initially closed quickly until the mat reached 108 percent of final target thickness (12.7 mm), which took about 20 seconds. Over the next 100 seconds, the mat was further compressed to its final thickness, at which time the core temperature exceeded 100°C. The panel was held at the target thickness for 80 seconds for flakeboard and 120 seconds for MDF before the press was opened gradually, over a 40-second period, to release internal steam pressure.

To examine the effect of fiberglass reinforcement on MDF performance, four 559- by 559- by 12.7-mm panels were made without reinforcement (MDF panels) and four panels were reinforced with fiberglass (G-MDF panels). For the G-MDF panels, fiberglass mats were overlaid on the top and bottom faces of the wood fiber mats before hot-pressing. Similarly, four untreated (no reinforcement) flakeboard (FB) panels and four fiberglass-reinforced flakeboard (G-FB) panels were made for comparison. The fiberglass in the panel was about 3.5 percent of oven-dried wood weight. The target density of the untreated panels was 700 kg/m³; the fiberglass was added to the target density.

Eight 51- by 51-mm samples for internal bond (IB) tests, two 76- by 356-mm samples for bending tests (MOE and MOR), two 152- by 152-mm samples for the 24-hour water soak test, and two 152- by 152-mm samples for the 2-hour boil test were cut from each 559- by 559-mm panel. All samples were conditioned at 22°C and 65 percent relative humidity (RH) for 3 weeks before testing according to ASTM D 1037 (ASTM 2001). The density of each panel was individually measured at current MC at time of test. Shortly after the mechanical bending test, the average MC of the test samples was 7.2 percent, with a standard deviation (SD) of 0.33 percent.

The properties evaluated in the 24-hour water soak (24-hour water immersion at room temperature) and 2-hour boil tests were WA, defined as the weight of the absorbed water divided by the oven-dry wood weight; internal TS measured 25.4 mm interior to the edges as described in ASTM 1037, and edge TS measured exactly on specimen edges. There were eight replicates for each test (four panels, two replicates per panel). After water soak and 2-hour boil tests, the specimens were oven-dried to measure oven-dry weight and then trimmed for the IB test. The specimens were reequilibrated at 22°C and 65 percent RH for the IB retention test.

The modified Janka ball test was used to measure surface hardness, using an 11.28-mm-diameter ball as specified in ASTM D 1037. Hardness is defined as the load at which the ball has penetrated to half its diameter.

To make a MDF panel with the target density, an additional 10 percent of wood fibers was added to compensate for wood fibers lost during hot pressing. Although the panel-making process was kept the same, variations nevertheless occurred in panel density. To allow comparison of panel properties at the same density level, covariance analysis (Neter et al. 1996) was used to adjust mean density values.

For better comparison of the performance of wood composites made with and without fiberglass reinforcement, lower and upper limits of the confidence interval ($p = 0.05$) for each adjusted average value were calculated using basic analysis of variance (ANOVA). Graphs were created to visually assess the relative differences of each parameter. There was a 95 per-

Table 1. – Mechanical properties with (Adj) and without (actual) covariate adjustment for density.

Sample ^a	Density (kg/m ³)		MOE (GPa)		MOR (MPa)		IB strength (MPa)						Hardness (kg)	
							Original		After 24-h soak		After 2-h boil			
	Actual	Adj	Actual	Adj	Actual	Adj	Actual	Adj	Actual	Adj	Actual	Adj	Actual	Adj
MDF ^c	664	700	2.64	2.74	27.8	29.4	1.06	1.12	0.69	0.72	0.58	0.61	581.1	591.0
G-MDF	709	700	3.31	3.25	33.4	33.0	1.12	1.01	1.01	1.00	0.94	0.92	666.8	658.3
Flakeboard	723	700	6.01	5.80	43.3	41.9	0.83	0.81	0.56	0.54	0.31	0.30	462.0	446.9
G-FB	737	700	7.14	6.73	51.3	48.7	0.85	0.81	0.63	0.58	0.28	0.26	644.0	611.3

^aG-MDF = fiberglass-reinforced MDF and G-FB = fiberglass-reinforced flakeboard.

Table 2. – Physical properties with (Adj) and without (actual) covariate adjustment for density.

Sample ^a	24-h water soak ^a						2-h boil					
	Edge TS (%)		Internal TS (%)		WA (%)		Edge TS (%)		Internal TS (%)		WA (%)	
	Actual	Adj	Actual	Adj	Actual	Adj	Actual	Adj	Actual	Adj	Actual	Adj
MDF	20.1	21.2	13.1	13.8	18.4	19.4	27.8	27.9	20.2	22.6	23.6	24.1
G-MDF	13.9	13.7	5.6	5.5	10.6	10.5	24.6	25.1	15.9	18.4	16.2	16.4
Flakeboard	24.6	23.8	13.0	12.6	26.9	26.1	43.1	44.4	39.9	41.6	65.6	63.2
G-FB	21.2	20.1	7.6	7.3	18.5	17.6	40.6	42.0	37.7	40.9	61.0	59.5

^aG-MDF = fiberglass-reinforced MDF and G-FB = fiberglass-reinforced flakeboard.

cent probability ($p = 0.05$) that the population mean was within the interval.

Results and discussion

The actual and adjusted average mechanical and physical performance data are presented in **Tables 1** and **2**, respectively. Adjusted means with 95 percent confidence intervals are depicted in **Figures 1** to **5**. In general, the flakeboard exhibited a larger variation in both physical and mechanical properties compared with the MDF panels.

Strength properties

After mat consolidation, the thickness of the fiberglass layer on the faces of the wood composites was approximately 0.07 to 0.10 mm. The effective MOE (E_e) of a composite material is given by:

$$E_e = \frac{\sum_i^n E_i I_i}{I} \quad [1]$$

where: E_i and I_i are MOE and moment of inertia of the i th layer in the thickness direction, respectively, and I is the moment of inertia of the entire composite.

If the MOE value of the thin fiberglass layer is about 17.2 GPa (Biblis and Carino 2000), the reinforcement could theoretically provide a 20-percent increase in MOE for MDF and about an 8-percent increase in MOE for flakeboard panels. As **Figure 1** indicates, the fiberglass layer improved both the strength and stiffness of MDF and flakeboard panels. For example, the adjusted average MOE value increased 19 percent for MDF and 16 percent for flakeboard, and the adjusted MOR value increased 12 percent for MDF and 16 percent for flakeboard. The actual increase in average MOE was slightly higher than the theoretical calculation. One probable reason was variation in controlling the target board density during the board manufacturing process (raw material and process conditions). The density of the G-MDF panels was higher than

that of the untreated panels because of the additional weight (3.5%) of the fiberglass and because fewer wood fibers were lost from the fiberglass-reinforced mats during pressing. Furthermore, within-panel variations in density occurred because of the difficulty in forming a uniform mat in the laboratory. Although fiberglass reinforcement consistently improved strength properties on an adjusted average basis, variation in panel density masked any statistical significance in improved properties for flakeboard. Only MDF panels showed significant improvement in mechanical properties (**Fig. 1**).

IB strength

The IB test normally indicates the weakest binding strength within a composite, usually in the lower density core layer. During the IB test, the fiberglass mat, which consisted of 50 percent PF binder, was effective in bonding the wood fiber or flakes, and almost all IB samples failed in the core layer. No separation between the fiberglass mat and wood fibers or flakes was observed. The fiberglass mats, which were overlaid on the panel faces, were not expected to improve IB values, and virtually no effect was observed aside from increased density (**Fig. 2**). After the 24-hour water-soak and 2-hour boil tests, IB strength (ratio of IB values before and after test) differed in MDF and flakeboard (**Fig. 2**). For untreated MDF, IB strength was 64 percent and 55 percent after water soak and boil tests, respectively. For G-MDF, IB retention significantly improved to 99 percent and 91 percent after the water soak and boil tests, respectively. The consolidated thin fiberglass layers on the faces of large specimens seemed to restrain water penetration into the core layer, which in turn decreased subsequent damage to resin bonding. This shows a potential use for fiberglass-reinforced MDF products in exterior applications such as siding or sheathing. There was no significant difference in IB strength between untreated and fiberglass-reinforced flakeboard panels; however, voids in the edges allowed water to penetrate into the core, which swelled and thereby degraded the resin binding in the core of the small IB specimens.

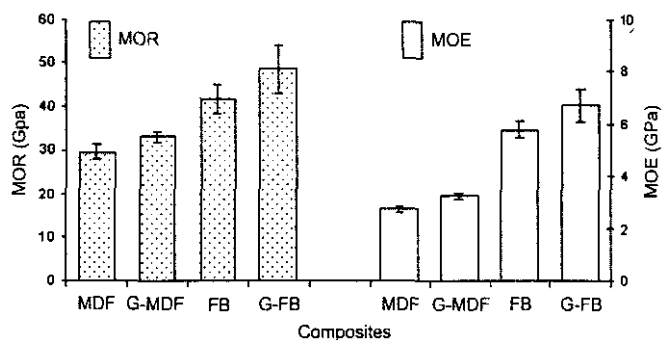


Figure 1. – Strength properties of untreated and fiberglass-reinforced MDF and flakeboard. G-MDF is reinforced MDF; G-FB is reinforced flakeboard.

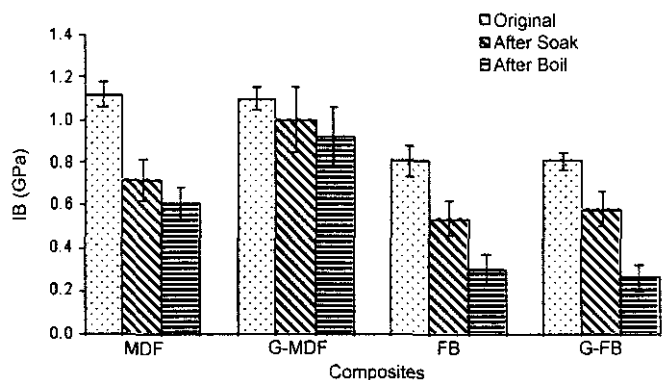


Figure 2. – IB strength of untreated and fiberglass-reinforced MDF and flakeboard before and after 24-hour water soak and 2-hour boil tests.

TS and WA

Water soak test. – TS and WA of panels after the 24-hour water soak test are presented in **Table 2** and **Figure 3**. For both MDF and flakeboard, the adjusted average values of all water soak properties (WA, edge TS, internal TS) were consistently and significantly improved by fiberglass reinforcement. Adjusted average WA was reduced about 46 percent for MDF and 33 percent for flakeboard. Adjusted average edge TS was reduced about 35 percent for MDF and 16 percent for flakeboard, and adjusted average internal TS was reduced about 60 percent for MDF and 42 percent for flakeboard.

Water boil test. – TS and WA after the 2-hour boil test are presented in **Table 2** and **Figure 4**. As in the water-soak test, fiberglass reinforcement consistently and significantly improved panel performance. For G-MDF, adjusted average values were reduced 32 percent, 10 percent, and 18 percent for WA, edge TS, and internal TS, respectively. Adjusted average values of flakeboard panels were reduced only about 6 percent, 2 percent, and 5 percent for WA, edge TS, and internal TS, respectively. Nonetheless, fiberglass reinforcement had an impressive effect on surface quality. The strong thin layer of fiberglass maintained the integrity of the surface flakes; no flakes were chipped off or separated from the panel. This result suggests that fiberglass reinforcement might be beneficial for OSB when used as an exterior siding product.

Hardness

During the water soak and boil tests, the thin layer of fiberglass on the panel surfaces not only provided dimensional sta-

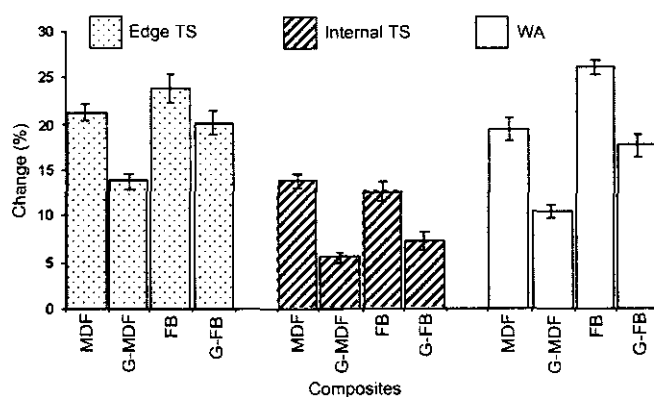


Figure 3. – Edge and internal TS and WA of untreated and fiberglass-reinforced MDF and flakeboard after 24-hour water soak test.

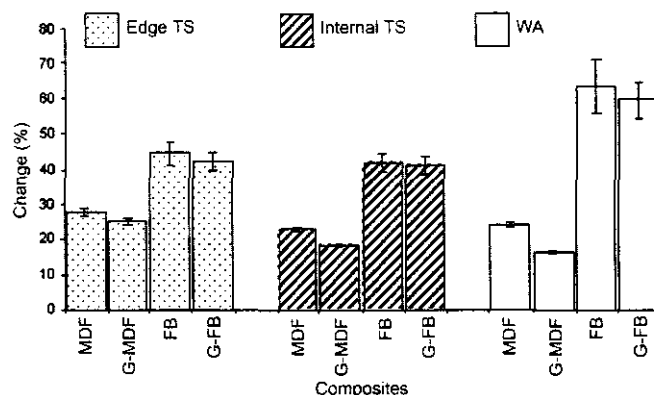


Figure 4. – Edge and internal TS and WA of untreated and fiberglass-reinforced MDF and flakeboard after 2-hour water boil test.

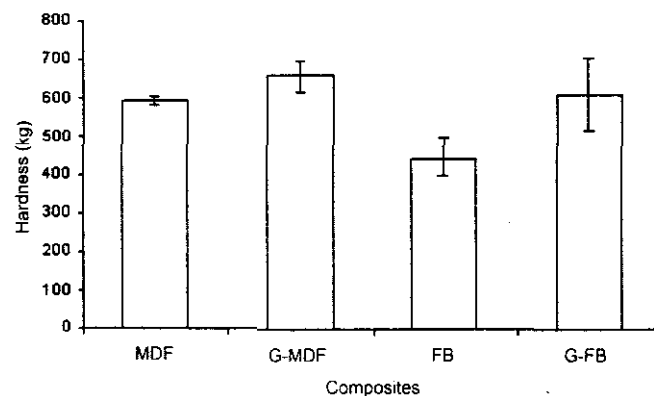


Figure 5. – Hardness of untreated and fiberglass-reinforced MDF and flakeboard.

bility but also improved surface quality. To further examine the effect of fiberglass reinforcement on surface quality, a surface hardness test was performed (**Table 1, Fig. 5**). Average surface hardness increased significantly for both MDF (11%) and flakeboard (37%). These results confirm that fiberglass reinforcement improves surface quality, especially for flakeboard. The significant improvement of surface hardness and integrity of wood composites resulting from the addition of the fiberglass reinforcement might increase the serviceability

and market potential of wood composites used as exterior siding products.

Conclusions

The effects of fiberglass reinforcement on selected mechanical and physical properties of MDF and flakeboard were examined. The results indicated that the consolidation of a thin layer of fiberglass on the surface of MDF and flakeboard improves MOE and MOR as well as resistance to TS and WA. A 3.5-percent addition of fiberglass increased MOE and MOR of MDF panels by 19 percent and 12 percent, respectively, reduced WA up to 46 percent, and reduced edge TS up to 35 percent. In addition to enhancing strength, fiberglass reinforcement improved surface quality and hardness. These improvements in mechanical, surface, and water resistance properties provide an attractive basis for promoting fiberglass-reinforced MDF and OSB as exterior products.

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