Physical and Mechanical Properties of Flakeboard Reinforced with Bamboo Strips

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Abstract

The objective of this study was to investigate the physical and mechanical performance of flakeboard reinforced with bamboo strips. The study investigated three different bamboo strip alignment patterns and an experimental control. All panels were tested in static bending both along parallel and perpendicular to the lengths of the bamboo strips. Internal bond strength, thickness swelling, linear expansion, and water absorption were also examined. As expected, modulus of rupture (MOR) and modulus of elasticity (MOE) were substantially greater for all three experimental panel types as compared to the control group. Linear expansion (LE) was also improved for all three experimental panel groups. The bamboo strip alignment patterns had no significant effect on thickness swelling, water absorption and internal bond. The sample means for MOR, MOE, and LE tested perpendicular to the bamboo strip lengths yielded slightly lower mean values than corresponding samples tested parallel to the bamboo strips lengths. This difference in mechanical properties is largely attributed to low panel density in the failure zones.

Introduction

Oriented strand board (OSB) is rapidly dominating markets that were previously exclusively satisfied by plywood. The primary benefits of OSB included lower cost and fairly similar properties compared to structural plywood. Although OSB is widely accepted in the market, some properties still limit its potential utilization such as lower bending strength and higher linear expansion and thickness swelling as compared to plywood.

It is widely known that the key to improve most mechanical and physical properties of flakeboard is to properly align the wood flakes. This technology was developed in the 1970s and has been steadily improved through continued research and development. There has been some research in recent years to better understand the effects of flake alignment on board properties (McNatt 1992, Shupe et al. 2001).

One means of possibly enhancing the bending properties of flakeboard is to reinforce the panels with bamboo strips. Bamboo, a fast-growing, economical, and renewable material, has higher strength as compared to most wood species. For example, research has shown that bending strength (MOR) of Moso bamboo (Phyllostachys pubescens) is 21,756-26,107 psi (150-180 MPa) (Li 2003) and loblolly pine (Pinus taeda) has a MOR of 7,252–12,618 psi (50-87 MPa) (Koch 1972). Previous research by Li (2003) on Moso bamboo has shown that the mean specific gravity (SG) based on air dry conditions was 42 pcf (0.67 g/cm3), modulus of rupture (MOR) was 21,915 psi (151.1 MPa), and modulus of elasticity was 1.55×10^6 psi (10.7 GPa).

Previous studies have shown that bamboo may have potential to be used to reinforce wood composites (Lee 1996, 2001; Wang 1993). Similar to steel reinforced concrete, bamboo can be used to reinforce wood flakeboard to improve selected properties. Therefore, the objective of this study was to determine the effect of bamboo strips as a reinforcing agent on the mechanical and physical properties of wood flakeboard.

Materials and Methods

Wood flakes and bamboo strips manufacture

Mixed hardwood flakes were obtained from a local OSB manufacturer. The flakes were processed through a portable lawn shredder and screened in the laboratory. The flakes measured 2.5-4.5 in., (63.5-114.3 mm) in length, 0.018 in. (0.45 mm) thickness, and variable width. The flakes were dried to average moisture content (MC) of 3% and then placed into sealed plastic bags for storage.

The experimental bamboos were harvested from the Kisatchie National Forest near Alexandria, Louisiana. Bamboo strips were sawn into two widths of 0.5 and 0.25 in. (12.7 and 6.5 mm) and then all strips were planed to 0.125 in. (3.18 mm) thickness and oven dried under 221°F (105^{o}C) for approximately 12 h to reach an averaged MC of 3%.

As Fig. 1 showed, type A was reinforced with bamboo strip of 0.5 inch width at corrugated alignment, type B was reinforced with 0.5 inch width bamboo strip arranged at same level alignment, and also type C was reinforced with 0.25 inch width bamboo strip arranged at same level alignment. Type S was control.

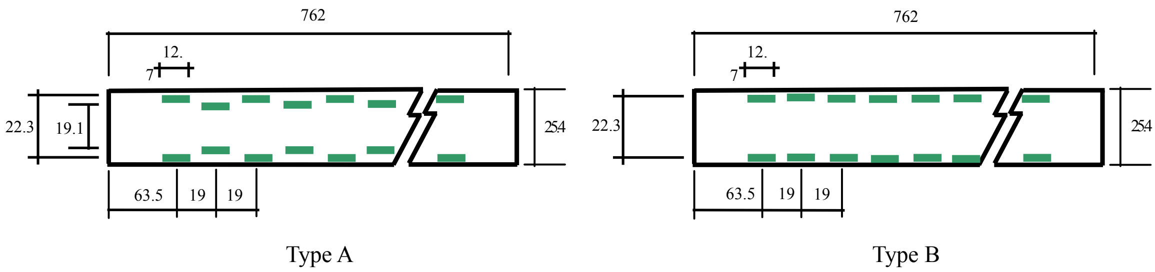


Fig. 1. Cross sectional sketch of various structural flakeboard panel types reinforced with bamboo strips (Type A, B, and C) and control panels with no bamboo strips (Type S).

Compared type B with type C for the two width strips with same alignment, there were similar mechanical properties of MOR and MOE whether parallel or perpendicular to bamboo strips length. In addition, Type B and Type C had no significant deference on TS, WA and LE.

Commercial phenol formaldehyde (PF) resin for flakeboard manufacture was obtained for the experiment. The PF resin properties measured in the laboratory were: pH = 10.9, specific gravity = 1.2, solids content = 51%, and viscosity = 175 cps.

Board fabrication

After the flakes were dried, a common, PF was applied to the flakes and the bamboo strips. The resin content was 5% based on oven-dry furnish weight. No wax was applied. The target board density and thickness were 0.7 g/cm^3 (44 pcf) and 25.4 mm (1 in.).

The flakes were placed into a forming box measuring 914×762 mm (36×30 in.), and the bamboo strips were aligned in two layers in the furnish for panel Types A, B, and C as indicated in Fig. 1. Wood flakes mats were randomly formed, and three different bamboo alignment patterns were used. The control boards (Type S) were fabricated without bamboo strips.

Panels were pressed at 374°F (190°C) for 15 min. with a press closing time of 50 seconds. Each type of panel was replicated twice. All boards were conditioned at room temperature 72±2°F (22±2°C) and 45±1% relative humidity for 72 h prior to subsequent testing.

Physical and mechanical property test

After conditioning the panels were tested for modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond (IB) in accordance with ASTM D1037-99 (ASTM 2003). Four bending test samples measuring 76.2×660.4 mm (3×26 in.) were cut from each board for MOR, MOE, SG, and MC determination. Of these four samples, two were cut parallel to the bamboo strips length and another two were cut perpendicular to the bamboo strips. Eight IB samples each measuring 25.4×25.4 mm (2×2 in.) were cut from the bending samples after the bending tests.

Panel durability and dimensional stability were evaluated by an oven-dry vacuum-pressure soak method (ODVPS) in accordance with APA Test Method PS1-95 (APA 1999). From each board, four samples measuring 3.0×26.0 in. (76.2×660.4 mm) with the sample length parallel to the lengths of the bamboo strips were cut for the evaluation of linear expansion (LE), thickness swelling (TS) and water absorption (WA). LE and TS values are based on the change from the oven dry condition to the end of the ODVPS cycle. The ODVPS samples were dried at 216°F (102^{o}C) for 24 h and then placed into a pressure cylinder with tap water, which was subjected to a vacuum of 685.8±50.8 mm Hg for 1 h followed by pressure of 0.55 MPa for 2 h.

The ODVPS samples after the dimensional stability test received an additional treatment of oven drying for 24 h followed by 48 h of conditioning at room temperature. MOR, MOE, and IB were then determined from these samples.

A QMS density profiler (QDP-01X) was used to scan changes of the board density. The scanning directions are indicated by the double arrows in Fig. 1. Four samples measuring 1.0 in^2 (25.4 mm^2) were scanned through the thickness direction, at a location known to contain a bamboo strip, to determine thickness direction density profiles (thickness density). An additional four specimens measuring 5.9×2.0 in. (150 by 50.8 mm) from each panel were scanned perpendicular to the board surface to ascertain plane direction density profiles (plane density).

Results and Discussion

Mechanical properties

The mean mechanical properties of the panels are shown in Figs 2-5. In the air dry condition, all three experimental panels (Type A, B, and C) yielded MOR (Fig. 2) and MOE (Fig. 3) values much greater than the control panels (Type S).

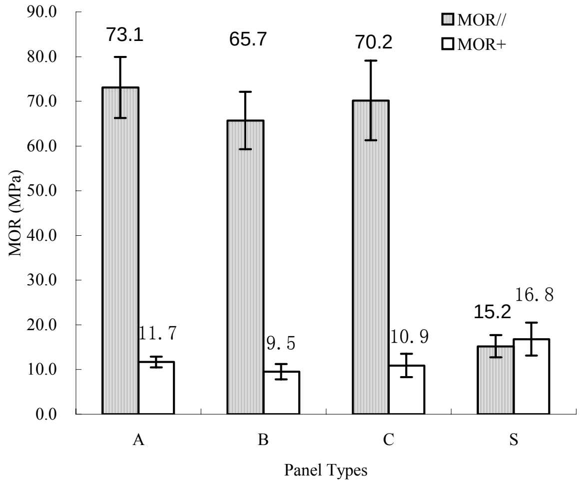


Fig. 2. Modulus of rupture of bamboo reinforced flakeboard and control panels tested parallel and perpendicular to bamboo strip lengths at air-dry test conditions. The errors bars denote one standard deviation.

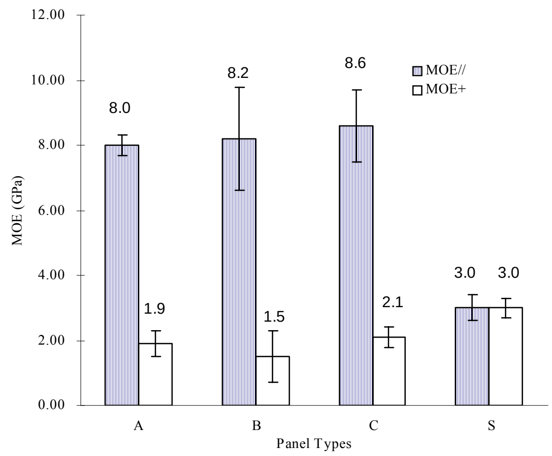


Fig. 3. Modulus of elasticity of bamboo reinforced flakeboard and control panels tested parallel and perpendicular to bamboo strip lengths at air-dry test conditions. The errors bars denote one standard deviation.

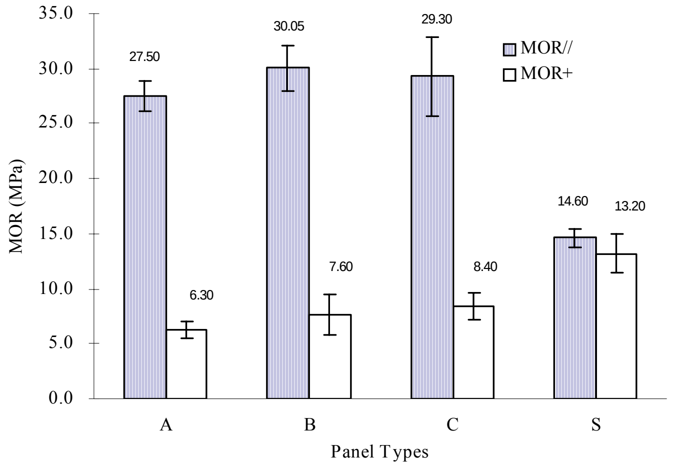


Fig. 4. Modulus of rupture of bamboo reinforced flakeboard and control panels tested parallel and perpendicular to bamboo strip lengths after ODVPS treatment. The errors bars denote one standard deviation.

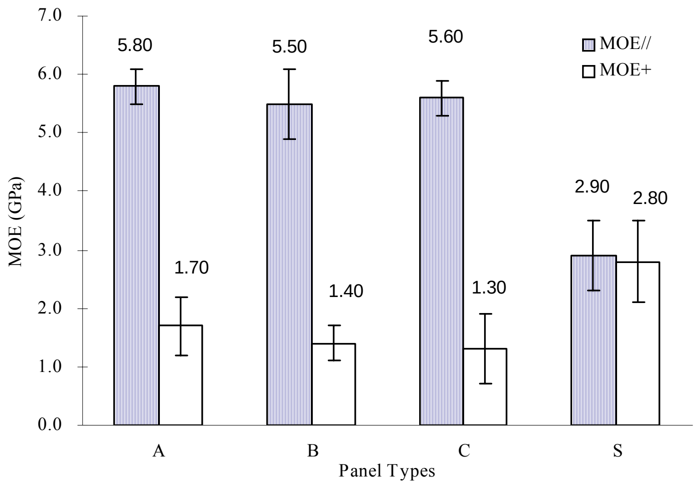


Fig. 5. Modulus of elasticity of bamboo reinforced flakeboard and control panels tested parallel and perpendicular to bamboo strip lengths after ODVPS treatment. The errors bars denote one standard deviation.

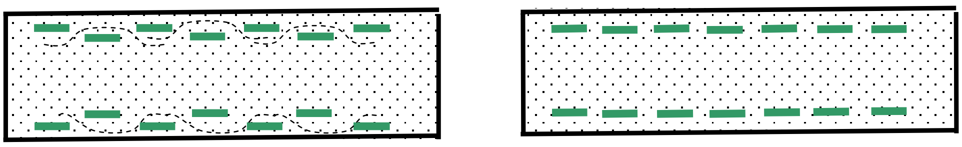
Seen from Fig. 1,compared type A with type B and C, it was found that especially under air condition, MOE of type A was better than that of type B. That was because type A had a corrugated pattern between flakes and bamboo strips so as to more bending stiffness (EI), but type B and C had not this pattern because of same level alignment of bamboo strips.

It is generally understood that flake alignment can increase panel MOR and MOE as much as twice as that of similar panels made with randomly oriented flakes. In this study, the MOR mean values of bamboo strip reinforced flakeboards that were tested parallel to the bamboo strip lengths at air dry conditions was five times greater than that of the control samples (Fig. 2). MOE tested parallel to the bamboo strip lengths and at air dry conditions was three times greater than that of the control MOE mean values (Fig. 3).

After the ODVPS treatment, the MOR values of the panels tested parallel to the bamboo strip lengths were 3988.5 psi (27.5 MPa) for type A, 4423.6 psi (30.5 MPa) for type B, and 4249.6 psi (29.3 MPa) for type C. The mean air dry condition values tested perpendicular to the bamboo strip length were 913.7 psi (6.3 MPa) for type A, 1102.2 psi (7.6 MPa) for type B, and 1218.3 psi (8.4 MPa) for type C (Fig. 4). Thus, the mean MOR values of the panels tested parallel to bamboo strips length are 3.5-4 times greater than the panels tested perpendicular to the bamboo strip length.

The MOE values showed a similar pattern as to MOR for both parallel and perpendicular testing. The percentage reduction ratio from air dry to ODVPS mean values for MOR was 60-68% and 34-36% for MOE. After the ODVPS treatment, MOR and MOE values of Type A, B and C panels tested parallel to the bamboo strip lengths were still approximately 2 times greater than that of the control (Figs 4 and 5). The ODVPS treatment had a minimal impact on MOR and MOE reduction for samples tested perpendicular to bamboo strip lengths.

As shown in Fig. 2, the MOR in the air dry condition of Type A panels was slightly greater than Type B and C for testing both parallel and perpendicular to the bamboo strip lengths. This finding can likely be attributed to better interlace of flakes between the two bamboo strip layers. Better flakes interlace come into being more glued-joint areas, especially it was benefit to improve strength of perpendicular to bamboo strips direction. Fig. 6 illustrates the interlace status of wood flakes between the bamboo strip layers for Type A, B, and C boards. Clearly, there were more void spaces between the bamboo strips in Type B and C panels, which led to lower density and poorer bending properties, particularly in the perpendicular direction. The experimental panels all yielded fairly similar mean values for MOR (Fig. 4) and MOE (Fig. 5).



Type A Types B and C

Fig. 6. Cross sectional sketch of wood flakes interlaced between bamboo strips layers.

There was non-uniformity for density through the thickness direction of all panel types (Fig. 7). As expected, surface layers density was higher than the core layers. Panel Types A, B, C had much higher face density than the control panels (Type S), which is probably due to the presence of the bamboo strips. Therefore, it follows that the panel groups with bamboo strips would have higher MOR and MOE mean values. Fig. 8 shows the density changes through the plane direction of all four of the panel types. The density of panel Type S had a small range from 41.1 pcf (0.66 g/cm^3) to 53.0 pcf (0.85 g/cm^3) with a mean value of 43.7 pcf (0. 70 g/cm^3). Conversely, panel Types A, B, and C all had wide panel density ranges. The maximal values were near 56.2 pcf (0.90 g/cm^3), and the minimal values were below 37.5 pcf (0.60 g/cm^3). The lower density panels, as expected, yielded poor mechanical properties, particularly in the panels tested perpendicular to the bamboo strip lengths. However, since panel Type A contained flakes with a better interlace structure, it yielded panels with greater static bending strength perpendicular to the bamboo strip lengths than panel Type B and C.

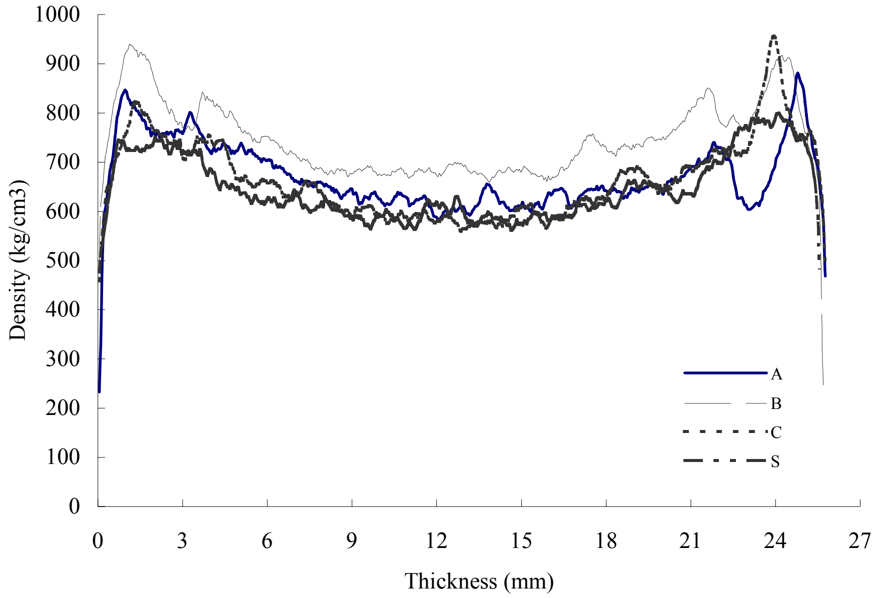


Fig. 7. Density profile in the panel thickness direction of three different bamboo reinforced flakeboard panel types and control panels.

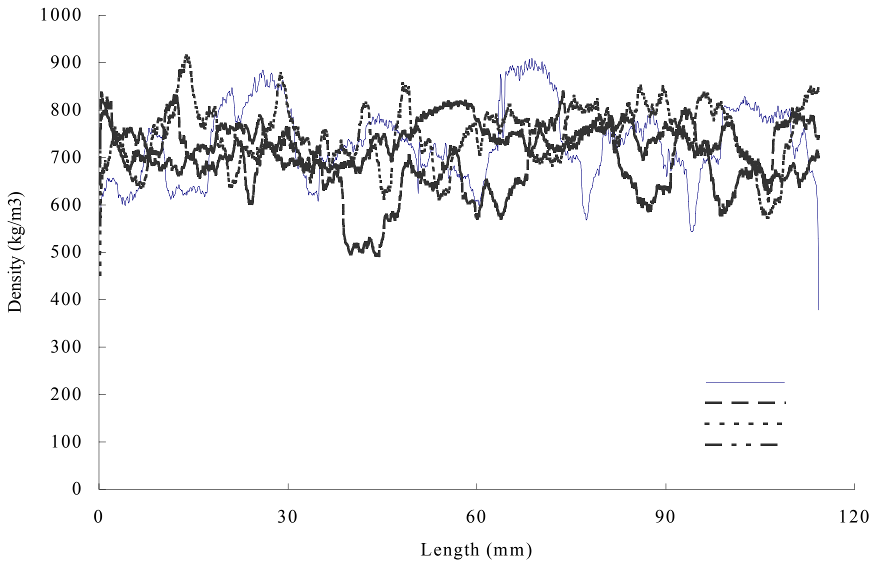


Fig. 8. The density profile changes through the plane direction of three different bamboo reinforced flakeboard panel types and control panels.

Bonding strength

As seen in Fig. 9, the various structural flakeboard patterns had little effect on the internal bond (IB) strength in either the air dry or ODVPS conditions. The IB mean values of Type A, B and C panels were not significantly different and were just slightly greater than that of Type S.

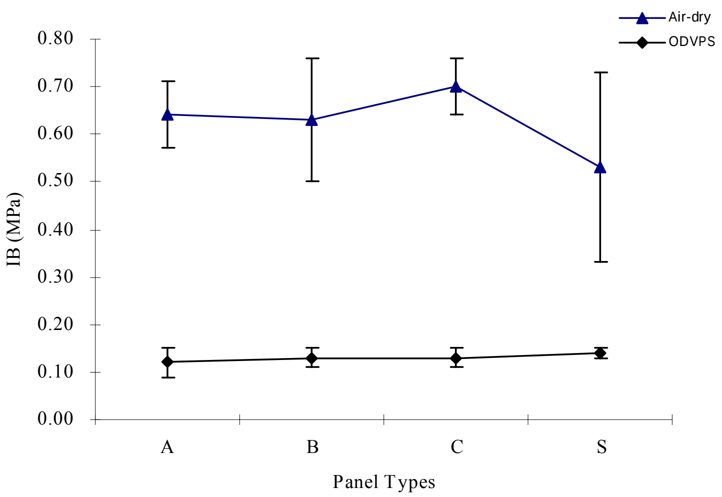


Fig.9. Internal bonding of flakeboard reinforced with bamboo strips at air-dry and ODVPS conditions

It is interesting to note that most IB failure occurred at the interface between the wood flakes, which has lower bond strength, and not between the flakes and the bamboo strips. This finding indicates that the resin performance in the interface between the wood and bamboo was satisfactory.

The outer layer of the bamboo is known to have poor gluability. Since this layer was removed from the bamboo strips, the interfacial bonding strength between the bamboo strips and wood flakes appeared to be better than that of the wood to wood bonding.

Physical Properties

Table 1 displays the mean values for SG, MC, LE, TS, and WA. These results indicate there were some differences in physical properties after ODVPS treatment. As expected, the LE of Type A, B and C panels cut parallel to the bamboo strip lengths were substantially lower as compared to the control (Type S) panels due to the lower shrinkage of the bamboo strips. The smallest LE mean value was 0.12% (Type A), and the greatest was 0.76% for (Type S) panels. The LE of the samples from Types A, B, and C panels tested perpendicular to the bamboo strip length showed slightly higher variability as compared to those tested parallel.

TS and WA, both parallel and perpendicular to the bamboo strip lengths, were nearly identical for the four panel groups. The mean TS values ranged from 23.31-26.44% in the parallel direction and 24.48-27.04% in the perpendicular direction. The WA mean values ranged from 88.08-95.86% in the parallel direction and 88.03-100.31% in the perpendicular direction. The control boards showed higher WA than the three other panels types due to lower WA for the bamboo. The different bamboo strip alignment patterns had no significant influence on TS and WA properties for the bamboo strip reinforced flakeboard groups. This observation suggests that the panels with bamboo strips had a strong direction-dependent characteristic for LE but only a slight influence on TS and WA. These results were similar to those reported by Geimer (1982) regarding the effect of flake alignment on LE and TS properties.

Table 1. Mean physical properties of various structural bamboo strips reinforced flakeboard (panel types A, B, and C) and control board (panel type C).

Panel Type	SG	MC	TS //[1]	TS ⊥[2]	LE //	LE ⊥	WA //	WA ⊥
		-------------	-------------	-------------	(%)	-------------	-------------	-------------
A	0.72	4.09	23.31	24.48	0.12	1.03	95.86	94.46
	(0.02)[3]	(0.20)	(1.85)	(0.60)	(0.03)	(0.08)	(0.64)	(1.18)
B	0.72	4.75	26.44	27.04	0.19	0.87	88.08	100.31
	(0.03)	(0.47)	(1.34)	(1.31)	(0.07)	(0.05)	(4.94)	(4.01)
C	0.73	4.41	26.06	26.23	0.15	1.03	88.13	88.03
	(0.02)	(0.48)	(1.56)	(1.06)	(0.06)	(0.09)	(2.36)	(1.31)
S	0.71	5.53	25.91	25.94	0.76	0.76	107.57	103.08
	(0.02)	(0.57)	(0.35)	(1.40)	(0.08)	(0.10)	(1.45)	(4.56)

[1]Measured parallel to bamboo strip lengths
[2]Measured perpendicular to bamboo strip lengths.
[3]Values in parentheses are standard variations.

Conclusions

This study investigated the effect of bamboo strip alignment on the physical and mechanical properties of structural flakeboard. Bamboo strip reinforced panels had greater MOR and MOE than control boards for panels tested parallel to the bamboo strip length direction in the air dry condition. However, when tested in the perpendicular direction, the bamboo strip reinforced panels yielded slightly lower MOR and MOE mean values than the control panels. In the air dry condition, Type A panels had the highest MOR mean value determined perpendicular to the bamboo strip lengths because of better material interlace. The ODVPS treatment resulted in a reduction of 60-68% for MOR and 34-36% for MOE as compared to samples tested in the air dry condition.

Alignment of bamboo strips did not significantly affect IB strength. Linear expansion was optimal when tested in samples cut parallel to the bamboo strip lengths. Thickness swelling and water absorption did not differ between samples tested in either the parallel or perpendicular direction to the bamboo strip lengths.

It is recommended that future studies focus on techniques for improving panel strength when tested with bamboo strip lengths perpendicular to the sample length. Further optimization studies are necessary to determine any industrial applications of this technology.

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