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Physical and mechanical properties of medium density fibreboards from bamboo and tallow wood fibres

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Abstract—Chinese tallow tree is an invasive and noxious species throughout the southern USA. It is inferior for many wood-processing applications. However, it may be acceptable when mixed with bamboo fibre for medium density fibreboard (MDF). The objective of this study was to investigate the physical and mechanical characteristics of MDF manufactured from three Honduran bamboo species (*Dendrocalamus aspera, Bambusa arundinacea* and *Guadua angustifolia*), Chinese tallow tree wood (*Sapium sebiferum*), or a mixture bamboo and tallow fibres (mixed) bonded with urea formaldehyde resin. Experimental results showed that modulus of rupture (MOR) and modulus of elasticity (MOE) of bamboo/tallow mixed fibreboard is favourable. *B. arundinacea* exhibited the best performance in both bamboo fibreboards and mixed fibreboards for MOR, MOE and internal bond (IB) strength, with the expectation of MOR of the mixed fibreboard. The results also showed that the MOR and MOE of mixed fibreboard were lower than that of bamboo fibreboard and higher than that of tallow fibreboard. The results showed MOR, MOE and IB strength of the boards had a linear relation with an increase in the compaction ratio. There were no significant differences in water absorption, thickness swelling and linear expansion between the bamboo and mixed MDF. This study indicated that bamboo fibre can be a viable alternative to wood fibres for MDF, particularly when mixed with tallow wood.

Key words: Bamboo; tallow; urea formaldehyde; fibreboard; compaction ratio.

INTRODUCTION

Bio-based materials other than wood are receiving increasing attention as possible alternatives to wood to lessen the harvest demand on forests and assist with forest conservation efforts. Bamboo is an inexpensive and fast-growing resource with favourable physical and mechanical properties comparable to some common wood species. Bamboo has great potential as an alternative to wood for many applications.

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Several studies have contributed considerably to the understanding of bamboo properties, as well as to the improved processing for broader uses. Bamboo-based composites in particle form [1], strand form [2], fibre form [3–5] and plywood [6] have been studied extensively.

Chinese tallow (*Sapium sebiferum*) was introduced to the United States in the late 1700s. Chinese tallow has spread to a variety of natural habitats in the south-eastern United States. Native prairies invaded by Chinese tallow suffered altered ecosystem structure as a result of the monospecific stands of tallow trees that persisted. It is virtually impossible to eliminate by known methods, though many efforts to achieve effective control are being explored. Currently, tallow is controlled by mechanical means as well as herbicide measures. The ability of this species to drastically modify natural landscapes has earned it a spot on The Nature Conservancy's list of 'America's Least Wanted — The Dirty Dozen' [7]. Recent United States Department or Agriculture (USDA) surveys revealed Chinese tallow 'occupied' an amount equivalent to 7.4% of the total tree biomass in these forests. Therefore, due to its ability to rapidly reproduce and grow, it has great utilization potential for the forest products industry.

This study was conducted to determine the properties of medium density fibreboard (MDF) panels from bamboo and tallow wood fibres. In particular, there were two objectives in this study. The first objective was to investigate the feasibility of three Honduran bamboo fibres and tallow wood fibres as raw material for the manufacture of MDF. The second objective was to investigate the effect of a combination of bamboo and tallow fibre on the physical and mechanical properties of MDF.

MATERIALS AND METHODS

Experimental design

The experiment used a 2×3 factorial design. One factor was the different bamboo species (*Dendrocalamus aspera*, *Bambusa arundinacea* and *Guadua angustifolia*). The other factor was the percentage of tallow fibre in the panel furnish. Panels were made with 100% bamboo for each bamboo species. The ratio of bamboo fibre to tallow wood fibre in the mixed fibreboards was 50 : 50. Panels made exclusively of tallow wood were also used for a general comparison with bamboo and mixed fibreboards. Three panels were made for each type of fibreboard. A total of 21 panels were made.

Panels were tested with 6.35 mm target thickness and 0.75 specific gravity (SG), based on air dry dimensions and oven dry weight. Urea formaldehyde (UF) resin was applied at a level of 8% based on resin solid content and oven-dry fibre (or fibre mix) weight.

Raw materials

Three bamboo species were obtained from Lancetilla National Park near Tela, Honduras, i.e. *D. aspera*, *B. arundinacea*, *G. angustifolia*. Representative culms of each species were harvested and cut into 1.3-m-long sections. Fifteen sections were obtained from each culm. The nodes were removed before defiberisation. No attempt was made to remove the epidermis of the bamboo. The bamboo chips (approximately $0.5 \times 1 \times 2$ cm) were steamed for 30 min under atmospheric pressure. The material was then ground to fibre in a Sprout-Waldron model 105-A 305-mm-diameter atmospheric refiner. Tap water was added to the chip feed to reduce consistency and to remove furnish from the refiner case. Excess water from the fibre slurry was removed *via* a laboratory vacuum in a Deckerbock. The fibre mat removed from the Deckerbock was broken into small bundles and was then dried at 60°C for 24 h. These dried fibre bundles were then separated into fibres in the refiner again. The fibres were conditioned to a moisture content of 3–4% prior to panel assembly.

Tallow trees (15 years old) were harvested in Pineville, LA, USA. The diameter at the breast height was 13 cm. Wood materials were chipped from debarked tallow wood. The tallow chips were then steamed for 5 min and then refined by the same processes as that of bamboo fibres. UF resin was obtained from Dynea (Winnfield, LA, USA). The solid content of the resin was 60% and was used for all of the panels.

Mat forming and panel fabrication

To prepare each panel, furnish was weighed and then placed in a rotating drum-type blender. For mixed mats, 50 : 50 bamboo and tallow fibres were weighed and mixed in the blender. To ensure a homogeneous mixture of bamboo and tallow fibre, the mixed fibres were first rotated in the blender for 2 min before resin application. The UF resin, in an amount equal to 8% of the oven-dry weight of the furnish, was then weighed and applied by using a pneumatic single-spray-gun applicator.

After blending, each furnish was carefully felted into a 36×36 cm box. Neither furnish type was oriented during the forming process. The moisture content of the mat was approximately 8–10% before hot pressing. The mat was transferred to a 60×60 cm single-opening hot press with the platen temperature at 177°C. Press time was 3.5 min after platen closure. Board pressure during closing was 2.76 MPa and was increased to 3.45 MPa after reaching the target thickness. Stops were used to control a given thickness of 6.45 mm. After pressing, all the panels were cooled at room temperature and the panels were trimmed to a final size of 30×30 cm.

Sampling and testing

Each panel was conditioned at room temperature for 24 h before being cut into 3 static bending specimens of 5×25 cm and 2-dimensional stability specimens of 5×20 cm. Specimens were conditioned in a climate chamber of 50% relative humidity and 26°C for two weeks before testing.

A three-point static bending test for modulus of rupture (MOR) and modulus of elasticity (MOE) and internal bond strength (IB) test were performed in conformance with ASTM D1037 standards [8] using an Instron universal testing machine. Four specimens (5 × 5 cm) for IB testing were cut from each bending specimen. For dimensional stability evaluation, specimens were immersed in water for 24 h at ambient temperature. Linear expansion (LE), water absorption (WA) and thickness swelling (TS) were performed in conformance with ASTM D1037 [8].

The SG, the ratio of the density of a material to the density of water using the same units for each, of the three bamboo species and tallow wood was determined with an Amsler VM9 volume meter in this study. The SG was based on air dry volume and oven dry weight. All samples for SG were taken at breast height. The SG was measured incrementally from the outer layer to the inner layer of the bamboo. Bamboo samples, approximately 0.1 × 1 × 2 cm, were tangentially cut with a razor blade.

Fibre size distributions of bamboo and tallow wood fibres were determined on a Bauer–McNett screen system. Three samples of each type, weighing 100 g each, were processed and their results averaged. All size classifications were conducted on air-dry material.

Effects of bamboo fibre types and tallow addition on the properties of composites were evaluated by analysis of variance at the 0.05 level of significance. Tukey's Studentised Range tests were used to determine significant differences among mean values.

RESULTS AND DISCUSSION

Specific gravity of bamboo and tallow wood

The SG of the bamboo species and tallow wood is presented in Table 1. Among the bamboo species, *G. angustifolia* had the highest SG and *B. arundinacea* had the lowest. According to a previous study, *B. arundinacea* also had the lowest MOR and MOE [9]. The SG distribution of each bamboo from the outer layer to the inner layer is illustrated in Fig. 1. The SG distribution of each bamboo species showed a similar trend from the outer layer to the inner layer. For each species, SG

Table 1.
Specific gravity of three bamboo species from Honduras and Chinese tallow tree

Scientific name	Specific gravity[a]
Dendrocalamus aspera	0.57
Bambusa arundinacea	0.51
Guadua angustifolia	0.59
Sapium sebiferum	0.60

[a] Based on oven dry volume and weight.

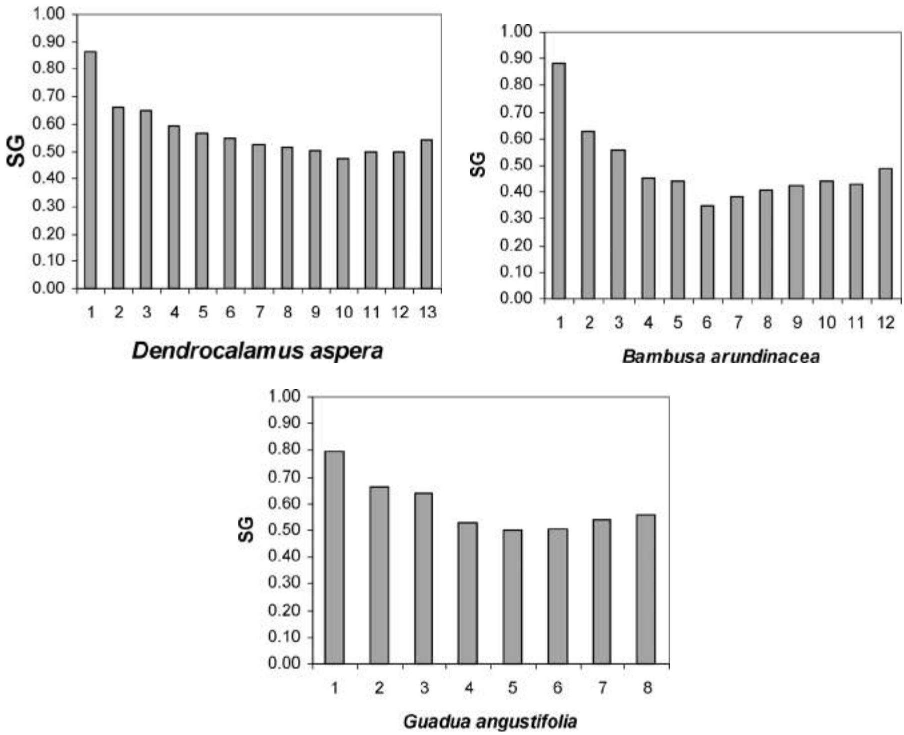

Figure 1. Horizontal density distribution of three Honduran bamboo species. Numbers on the x-axis represent layers from outer layer to the inner layer in ascending numerical order. Left is outside of culm wall, right is inside.

had the highest value in the outmost layer and then showed a dramatic decrease at the second layer. From the second layer to the middle layer, there was a gradual decrease; then, a slight increase in SG occurred from the middle layer to the inner layer.

The tallow wood had a specific gravity of 0.60. Tallow wood showed higher specific gravity than that of three bamboo species.

Fibre size characteristics

Fibre size of bamboos and tallow wood may provide some insight into the different mechanical properties of the manufactured panels. Fibre size distribution of the bamboo species and tallow is illustrated in Fig. 2. It is noted that tallow wood had a higher percentage of fine fibre that passed through 30 mesh screen as compared to that of the bamboo species (33% and >43%, respectively). *B. arundinacea* had the higher portion of coarse fibre (51%) retained on the 10 mesh screen. Figure 2 also showed tallow wood fibre has a more evenly distributed fibre size compared with bamboo fibres.

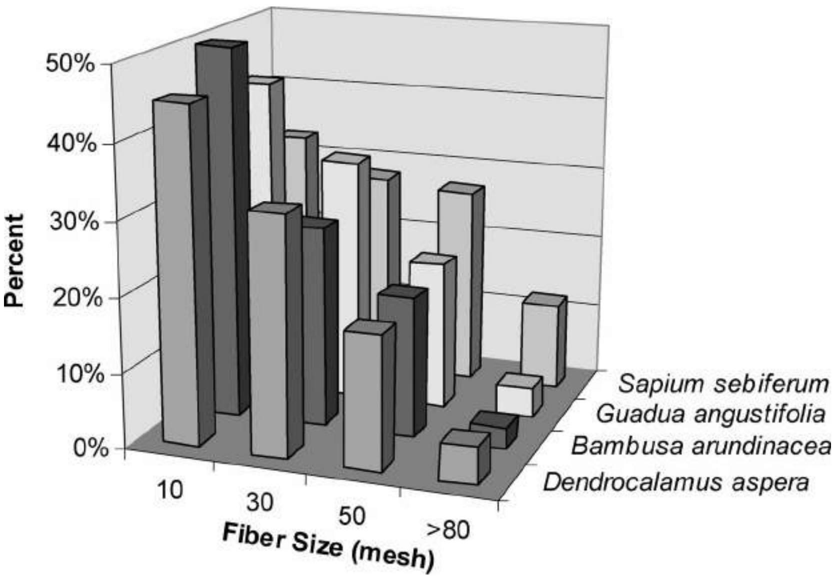

Figure 2. Fibre size distribution of three bamboo species and tallow wood.

Physical properties of the fibreboards

The result of the physical and mechanical properties tests of the three bamboo species and tallow panels is presented in Table 2. Each value is an average of 12 samples with the exception of IB, which is an average of 48 samples. The results show that in general, the physical and mechanical properties of bamboo and tallow panels are comparable to those properties of conventional MDF boards. The results in Table were statistically analysed and ANOVA results were presented in Table 3. The 100% tallow panels were excluded from the analysis.

Table 3 presents the ANOVA results for the physical and mechanical properties of the bamboo and tallow fibreboards. The result showed there is no significant difference between bamboo and mixed fibreboards in LE, WA and TS.

It is also interesting to note that tallow fibreboard had substantially lower LE and TS than the bamboo panels (Table 2).

Mechanical properties of the fibreboards

Among the three bamboo species, *B. arundinacea* panels exhibited the highest MOR, MOE and IB strength. The MOR, MOE and IB values of *D. aspera* fibreboard were the lowest. The higher strength of *B. arundinacea* can be partly attributed to its higher proportion of coarse fibres.

MOR and MOE of the panels from the three bamboo species were all significantly higher than that of the tallow panels; the IB strength of the tallow fibreboard was comparable to that of the MDF from the three bamboo species. It is also noted

Table 2.
Physical and mechanical properties of bamboo and tallow fiberboards

Composite source: Bamboo	Weight ratio	C.R.	MOR (MPa)	MOE (MPa)	IB (MPa)	LE[a] (%)	WA (%)	TS (%)
Dendrocalamus aspera	100 : 0	1.27	33.25A[b] (2.29)	3.29AB (0.27)	0.68C (0.07)	0.36 A (0.11)	72.5A (11.6)	29.9A (2.8)
Dendrocalamus aspera	50 : 50	1.31	34.00A (4.04)	3.06AB (0.22)	0.68C (0.10)	0.31A (0.06)	84.5A (18.8)	26.3A (4.6)
Bambusa arundinacea	100 : 0	1.50	37.48A (1.76)	3.64A (0.18)	0.88AB (0.08)	0.35A (0.12)	64.5A (9.07)	27.9A (3.4)
Bambusa arundinacea	50 : 50	1.39	32.34A (2.99)	3.35A (0.15)	0.90A (0.04)	0.32A (0.11)	69.5A (5.99)	27.4A (2.7)
Guadua angustifolia	100 : 0	1.35	33.40A (3.96)	3.44A (0.25)	0.70BC (0.10)	0.36A (0.06)	72.0A (7.39)	26.3A (2.5)
Guadua angustifolia	50 : 50	1.29	30.62A (4.72)	3.07AB (0.39)	0.78B (0.08)	0.31A (0.07)	71.5A (5.12)	23.6A (2.5)
Sapium sebiferum[c]	0 : 100	1.25	29.56 (0.29)	2.92 (0.06)	0.80 (0.05)	0.16 (0.02)	75.5 (5.97)	18.5 (1.6)

Numbers in parentheses are standard deviations. C.R., compaction ratio; MOR, modulus of rupture; MOE, modulus of elasticity; IB, internal bond; LE, linear expansion; WA, water absorption; TS, thickness swelling.

[a] Measured along the longitudinal axis of the specimens.

[b] Tukey's Studentized Range (HSD) test, means with the same letter are not significantly different.

[c] For the comparison purpose with 100% bamboo panels, 100% tallow fiberboards were also made.

Table 3.
ANOVA results for the physical and mechanical properties of bamboo and tallow fiberboards

Source of variation	MOR	MOE	IB	LE	WA	TS
Bamboo	0.0568	0.0500	0.0016[a]	0.9873	0.2236	0.4266
Mixed	0.0207[a]	0.0125[a]	0.2655	0.2605	0.2943	0.2442
Interaction	0.0531	0.8035	0.4979	0.9873	0.5930	0.7590

Analysis based on 2 × 3 factorial experiment arranged in a completely randomized design with 3 replications. A = two tallow levels (1, panels with tallow fiber; 2, panels without tallow fiber); B = three bamboo levels (1, *Dendrocalamus aspera*; 2, *Bambusa arundinacea*; 3, *Guadua angustifolia*).

[a] Denotes significance at $\alpha = 0.05$.

that tallow fibreboard data showed less variation compared with that of bamboo fibreboards, which could be due to the more evenly distributed tallow fibre size.

The ANOVA results in Table 3 show that the interaction effect between bamboo and tallow fibre on the physical and mechanical properties of the panels was not significant. Regarding the effect of the bamboo fibres, the results indicate that the three bamboo fibre types had no significant difference for MOR and MOE.

However, the bamboo fibre types did show significant difference in IB strength. Concerning the effect of tallow fibre, tallow fibre addition to the MDF furnish significantly decreased the MOR and MOE. Tallow addition had no significant effect on IB strength.

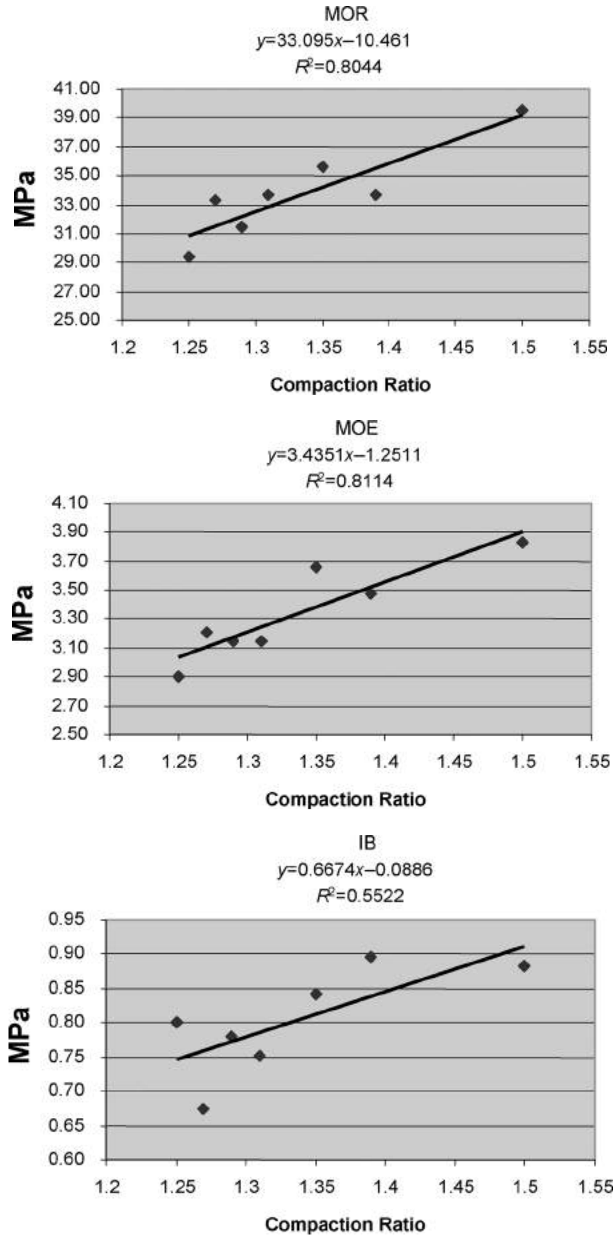

Figure 3. Relations between compaction ratio and MOR, MOE and IB strength of all experimental panels.

Compaction ratio vs. board mechanical properties

The SG of the four experimental materials ranged from 0.50 to 0.61 (Table 1). The SG of the manufactured panels was targeted at 0.75 and the resulting variation of SG among panels was minor. Many researchers had used the ratios of board density vs. furnish density to investigate the properties of manufactured composites [10–13]. The compaction ratio, which is the ratio of panel density to furnish density, seems to be a more effective tool to interpret mechanical property differences between different types of panels. The compaction ratio data are presented in Table 2. The influence of compaction ratio on the mechanical properties of the fibreboards is presented in Fig. 3. Generally the MOR, MOE and IB properties increased as compaction ratio increased and these results were expected and were consistent with results reported in early studies [10–13]. The low mechanical properties of the tallow fibreboard can then be reasonably attributed to its lowest compaction ratio.

According to Fig. 3, MDF made with a higher compaction ratio showed higher strength properties than those made of lower compaction ratio because of the greater contribution to tensile and stiffness properties of the manufactured fibreboards by the bamboo fibre component, as compared with the tallow component. Higher compaction ratio brings more fibres into contact with each other and thus more bonds will be formed. Among the correlation between strength properties and compaction ratio, MOE had the highest correlation ($R^2 = 0.81$) with compaction ratio while IB strength had the lowest correlation ($R^2 = 0.55$) with compaction ratio.

CONCLUSIONS

The purpose of this study was to investigate the physical and mechanical characteristics of bamboo, tallow and bamboo/tallow mixed medium density fibreboard bonded with urea formaldehyde resin. The SG and its horizontal distribution of three bamboo species were determined. The SG of all three bamboo species decreased from the outer layer to the middle layer and then slightly increased from the middle layer to the inner layer.

Fibreboard made with *B. arundinacea* had the highest MOR, MOE and IB strength among the bamboo panels as well as the tallow fibreboards. Tallow fibreboard showed the lowest MOR and MOE. Mixed fibreboards made with *B. arundinacea* exhibited the highest mechanical strength, except for MOR, among the three groups of mixed fibreboards.

The MOR and MOE value of the manufactured mixed fibreboards were between that of bamboo panels and tallow fibreboards. There was no significant difference between IB strength among panels.

MOR, MOE and IB data showed a positive relationship with increasing compaction ratio for all types of tested fibreboards. Panels made with a higher compaction ratio showed higher strength properties than those made from lower compaction ratio.

The inherent fibre size differences of the bamboo and tallow fibres studied proved to be a factor that affected MOR, MOE and IB strength of the mixed fibreboards.

Bamboo constitutes a significant amount of sugar components. Further study should be done to investigate the durability of MDF from bamboo and tallow wood.

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