Properties of Sandwich-Type Panels Made from Bamboo and Rice Straw

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Abstract

This study presents the evaluation of some important properties of sandwich-type panels made from bamboo (*Dendrocalamus asper*) and rice straw (*Oryza sativa*). A total of 32 experimental panels with an average target density ranging from 0.65 to 0.80 g/cm^3 were produced. The sandwich-type experimental panels were made from a mix of 95 percent bamboo and 5 percent rice straw particles as the core layers and a mix of 95 percent bamboo and 5 percent rice straw fibers as the face layers. Mechanical properties of the specimens, including modulus of elasticity, modulus of rupture, internal bond strength, hardness, face screw holding strength, formaldehyde emission, thickness swelling, and surface roughness, were determined. Experimental results showed that both physical and mechanical properties of the samples were favorable. Panel type D, with 50 percent fiber and 50 percent particle and a density of 0.80 g/cm^3, had the highest strength characteristics. Mechanical properties of the panel satisfied the minimum requirements for interior particleboard panels for general use based on Japanese Industrial Standard A-5908 of 1995. It appears that using only 5 percent rice straw did not adversely influence overall properties of the samples. This study indicates that bamboo and rice straw furnish can be used as a viable alternative to wood in the form of three-layer, sandwich-type panels with enhanced surface quality as substrate for thin overlays to manufacture panels products for furniture and cabinet units.

The utilization of nonwood resources to manufacture wood composites is getting more popular in many countries. Most developing countries are rich in agricultural products, which create large amounts of waste fiber. Rice straw, jute, coconut fiber, oil palm, and bagasse are only some of the resources that can be used to produce different types of value-added interior composite panels, including particleboard and medium-density fiberboard (MDF). In addition to agricultural waste fiber, bamboo is also getting more attention from composite panel manufacturers in Asian countries as an alternative raw material. Currently, wood composite panels are produced from forest plantations of various species, including rubberwood (*Hevea brasiliensis*) and sawmill waste in Thailand. The decrease in forest resources even among plantation forests in Thailand during the last several decades has prompted wood composite panel producers to find alternative raw material resources rather than using solid wood. Therefore, nonwood species are being considered as raw material for panel manufacture to maintain the sustainability of natural resources in Thailand.

Bamboo is a well-known and very popular construction material not only in Thailand but also in other tropical countries. It has the great advantage of having a very fast growth rate. Some species can grow 1 m/day in the growing season (Lee et al. 1996). Both physical and mechanical properties of bamboo are better than those of many solid wood species. Bamboo is the subfamily of Bambusidae, which is the most important diverse group of plants in the grass family. Currently, it has limited use as scaffolding, plywood, flooring, and novelty items in Thailand (Chen and Hua 1991, Chew et al. 1994, Fuyuan and Jianmin 1998). Although great interest exists in using bamboo for value-added composite panel manufacture, no industrial-scale production is occurring in the country at this time. Several preliminary experimental studies have been carried out to explore bamboo as a raw material for particleboard and

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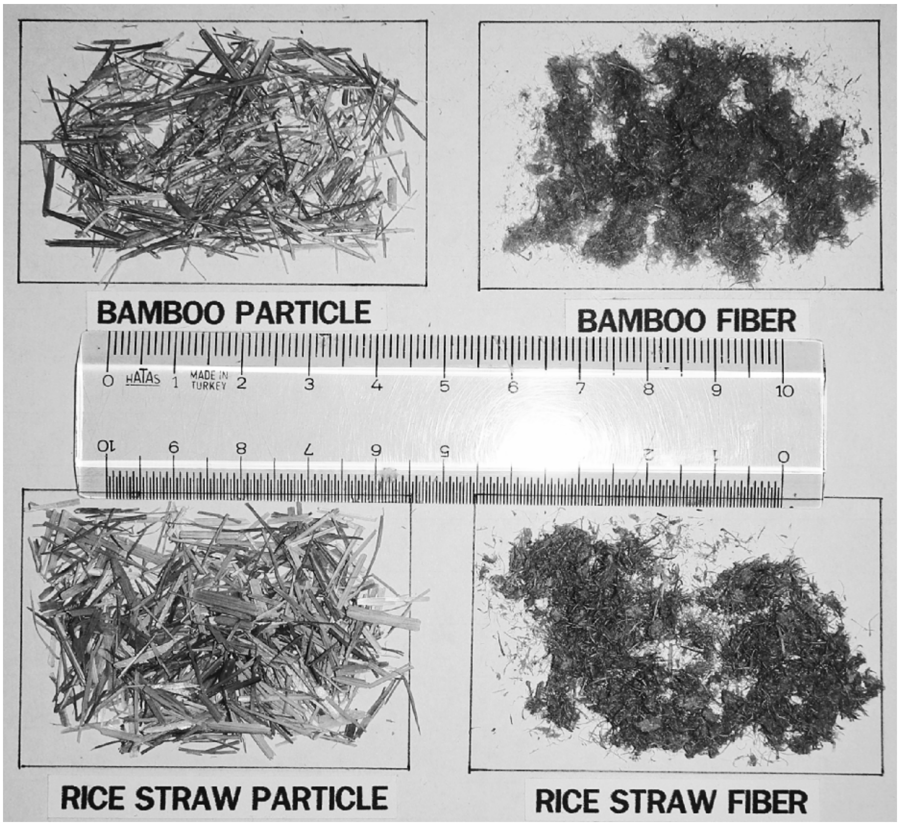

Figure 1.—Bamboo and rice straw particles and fibers.

fiberboard manufacture in Thailand (Hiziroglu et al. 2004, 2005). Both investigations concluded that panel samples made from 100 percent bamboo exhibited physical and mechanical properties comparable to those of typical commercially produced panels (Hiziroglu et al. 2004). Also, other studies conducted in China have explored the possible use of both structural and nonstructural panels made from bamboo (Ye 1991, Zhao 2000, Changtian 2002, Zheng and Guo 2003, Li et al. 2004, Xuhe 2005).

Rice is one of the most important crops in Thailand, with an area of 9,000,000 ha. However, rice straw is not used very efficiently after harvesting is completed (Inglesby et al. 2004). A limited amount of rice straw is used as bedding material for vegetable and fruit growing, but the majority is either land filled or burned, causing serious environmental pollution (Chow et al. 1993, Jenkins et al. 1995). In a previous work, rice straw particles and fibers were used as filler to manufacture experimental panels (Hiziroglu et al. 2004). It was found that if a limited amount of either rice straw particle or fiber was added to bamboo furnish, the properties of either particleboard or MDF panels would not be adversely influenced (Hiziroglu et al. 2005).

Most interior wood composite panels, such as particleboard and MDF, are mainly used as substrate for thin overlay to produce furniture units. In particular, MDF, having a very smooth surface that creates little telegraphing effect during its service life as an overlay, is an ideal substrate for furniture production. Although particleboard is also used as substrate for thin overlays, its rough surface may create certain problems, such as showing through the thin films or in direct finishing applications. The overall cost of MDF is greater than that of particleboard, and MDF has more complicated manufacturing process. Therefore, the objective of this study was to combine two different types of raw materials from bamboo and rice straw to produce experimental, sandwich-type panels. It is expected such panels will have not only a smooth surface with a thin layer of fibers on the face layers but also enhanced properties. Both physical and mechanical properties of the samples were evaluated to find out if such panels have properties comparable to those of commercially made composite panels from other species.

Materials and Methods

Bamboo and rice straw furnishes were harvested from bamboo plantations in the central region and Khon Kean, Thailand, respectively. Bamboo samples were chipped into particles using a laboratory-type hammermill; rice straw was shredded into smaller pieces. Both materials were dried to 3 percent moisture content (MC) in a laboratory oven. Bamboo and rice straw particles were disintegrated in a laboratory-type defibrator using a pressure of 0.80 MPa at a temperature of 165°C for 2 minutes for the face layer of the panels. The defibrated fiber was dried in a kiln at a temperature of 90°C to 4 percent MC. Figure 1 shows bamboo and rice straw particles and fibers used in this study.

A total of 32 panels, eight for each type with a dimension of 35 by 35 by 1 cm, were manufactured for the experiments. The core layer of the panels had a homogeneous mix of 95 percent bamboo and 5 percent rice straw particles using 8 percent urea-formaldehyde adhesive. Fibers of bamboo and rice straw were mixed at the same ratio for the face layers of the panels using 10 percent urea-formaldehyde adhesive. Particles and fibers were mixed

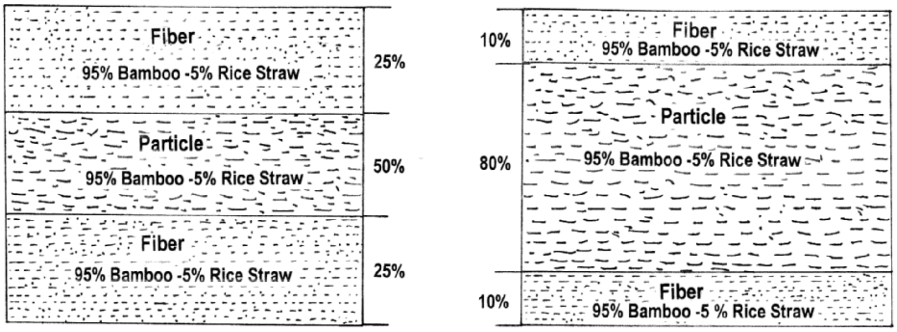

Figure 2.—Configuration of sandwich-type panels.

Figure 3.—Unpressed panel mat.

with the adhesive and 0.5 percent wax separately in a rotating-type mixer equipped with pressurized spray gun. Three-layer mats were manually formed in a Plexiglas box with a face to core to face layer ratio of 10:80:10 and 25:50:25 and were then pressed in a hot-press at a temperature of 170°C under a pressure of 5.2 MPa for 5 minutes. Average target density of the panels ranged from 0.65 to 0.80 g/cm^3. Figures 2 and 3 illustrate the panel configuration and three-layer unpressed mat, respectively.

Panels were conditioned in a climate room with a temperature of 20°C and a relative humidity of 65 percent for approximately 2 weeks. After conditioning, both bending modulus of elasticity (MOE) and modulus of rupture (MOR), internal bond (IB) strength, as well as face screw holding strength of the samples were determined using an Instron Testing System Model-22 5500-R equipped with a 6,000-kg load cell. The thickness swelling values of the samples were also measured after 2- and 24-hour water soak.

Samples with 10 by 10-cm surface area were used for hardness test. Ten random measurements were taken from the surface of each sample. A Com-10 testing system equipped with a 1,000-kg load cell was used for the test. The test setup allowed continuous recording of load as a function of penetration depth of a standard steel ball (11.28 mm in diameter) into the surface of the sample. The maximum applied load in kilograms at a half-ball penetration was used as the hardness value. Table 1 displays the experimental schedule. Tests were conducted following Japanese Industrial Standard (JIS) A-5908 (JIS 1995). Formaldehyde emissions of the panels were determined with the perforator method based on the EN 120 (European Committee for Standardization 1993) procedure. Density profiles of the panels were also tested using an x-ray density profilometer.

Because panels such as these are targeted for use in furniture manufacture as a substrate for thin overlays, their surface quality plays an important role in their service life. Stylus-type equipment was employed to evaluate surface quality of the samples. A Hommel T-500 portable profilometer was used for the roughness measurement. Three roughness parameters—average roughness (R_a), mean peak-to-valley height (R_z), and maximum roughness ($R_{\max}$)—were used for surface roughness evaluation of the samples. Specifications of these parameters have been discussed in previous studies (American National Standards Institute [ANSI] 1985, Mummery 1993, Hiziroglu 1996). Figure 4 shows the roughness profiles of the samples.

Results and Discussion

Physical and mechanical properties of the samples made from bamboo and rice straw material are presented in Table 2. Both MOE and MOR values of panel type D were 1,910 and 26.30 MPa, respectively, which were the highest among

Table 1.—Sample design.[a]

				No. of samples for each test					
Panel type	Face:core:face ratio	Density (g/cm^3)	No. of panels	Bending, MOE & MOR	IB	SH	TS	Hardness	Roughness
A	10:80:10	0.65	8	40	35	16	40	10	80
B	10:80:10	0.75	8	40	35	16	40	10	80
C	25:50:25	0.70	8	40	35	16	40	10	80
D	25:50:25	0.80	8	40	35	16	40	10	80

[a] SH = screw holding strength; TS = thickness swelling.

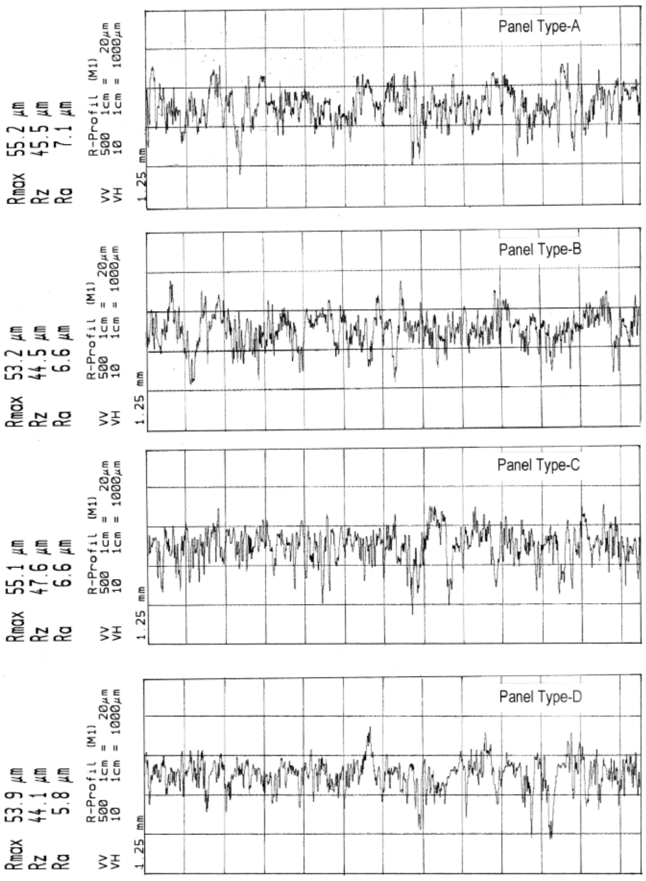

Figure 4.—Typical roughness profiles of the samples.

the four types of samples. Density of panel type D was also the highest, with an average value of 0.80 g/cm^3. Panel type B had the second highest bending properties, followed by panel type C. MOE values of panel types D and B, with fiber to particle ratios of 50:50 and 20:80 and a difference of 0.05 g/cm^3 in their densities, had a 3.8 percent difference in their MOE values. Panel types A and C, with the same density difference as the above samples, also had a 2.9 percent difference in their MOE values.

It seems that panels made with fiber to particle ratios of 20:80 and 50:50 fibers did not show any significant difference in terms of bending at the 95 percent confidence level. However, MOE values of the samples made the same fiber to particle ratio but with a different density showed a significant difference at the 95 percent confidence level based on *t* test. Panel type B, with a density of 0.75 g/cm^3, had a 43 percent higher MOE value than that of panel type A. Similarly, panel type D, with the highest density, had a 44 percent higher value that that of panel type C. Bending properties of wood composites generally are directly related to their density levels, and based on the findings in this study, using two different fiber to particle ratios in these panels did not make any significant difference in their bending characteristics.

This was also supported by IB strength properties of the panels, with panel type C having the lowest value of 0.51 MPa. It appears that as the fiber percentage in the panels increased from 10 to 25 percent on each face layer of the samples, both bending MOE and MOR were not adversely influenced, because the density levels of the samples were only changed by 0.05 g/cm^3. However, as the density of the samples was reduced more than 0.05 g/cm^3 in conjunction with using the larger amount of fiber percentage on the face layers, it contributed some effects on panel properties, as can be seen in Figures 5, 6, and 7. In a previous study, MOE and MOR of experimental particleboard and MDF panels manufactured from a mixture of bamboo and rice straw ranged from 1,950 to 1,850 MPa and from 22.0 to 15.0 MPa, respectively (Hiziroglu et al. 2005). The findings in this study are comparable to the bending of panels made in the above and other past studies (Bai 1996, Lee et al. 1996). Based on JIS A-5908, 13.03 MPa is the minimum requirement for MOR of interior particleboard panels for general use (JIS 1995). All four types of samples in this study satisfied the MOR strength requirements for general use based on JIS as well as ANSI Standard A208.2 (JIS 1995, ANSI 2002).

In general, rice straw is characterized by lower amount of cellulose and a higher amount of extractive material (Summer 2000, Smith et al. 2002). Ash content in rice straw is relatively high, ranging from 9 to 14 percent, which may possibly result in nonuniform resin distribution influencing proper cure of the resin in the press (Jenkins et al. 1995). Short fiber length of rice straw means that lower-quality bonding between the fibers can possibly occur, which may also affect strength properties of the panel with higher rice straw content, such as panel type C. Panel type D had the highest hardness value of 632 kg, whereas the lowest value of 559 kg was found for panel type A (Fig. 8). No significant difference was found between hardness values of the samples made with different fiber to particle ratios. Clearly, density is also a major factor affecting hardness of the panels. Figure 9 shows a typical density profile of a sample.

Screw holding strength on the face of the samples was found to be lower than those stated in the standard. This finding suggests that such samples may have poor performance for different fastening applications. Average formaldehyde emission value of the samples was 22 mg/100 g, which is within the limit of the E2 emission class (Roffael 1993).

Table 2.—Average values of mechanical and physical test results of the panels.[a]

Panel type	Density (g/cm^3)	MOE (MPa)	MOR (MPa)	IB (MPa)	TS (%)	Hardness (kg)	Screw holding strength (kg)	Roughness (µm)		
								R_a	R_z	R_{max}
A	0.65	1,287 (14.3)	13.77 (10.3)	0.68 (14.2)	9.98 (11.7)	559 (13.4)	24.23 (12.1)	7.5 (9.9)	39.31 (6.4)	54.50 (10.2)
B	0.75	1,840 (14.9)	20.91 (11.2)	0.84 (13.5)	10.25 (12.3)	630 (15.0)	29.25 (14.3)	6.25 (7.9)	36.82 (8.2)	40.81 (10.9)
C	0.70	1,325 (13.2)	17.17 (10.9)	0.51 (12.9)	23.39 (14.2)	592 (13.7)	30.32 (11.3)	6.57 (9.8)	38.33 (6.9)	43.62 (9.8)
D	0.80	1,910 (14.8)	26.30 (13.1)	0.73 (13.4)	24.78 (13.4)	632 (9.93)	36.45 (13.3)	5.08 (10.5)	25.34 (7.4)	36.53 (11.2)

[a] Numbers in parentheses are coefficients of variation. TS = thickness swelling.

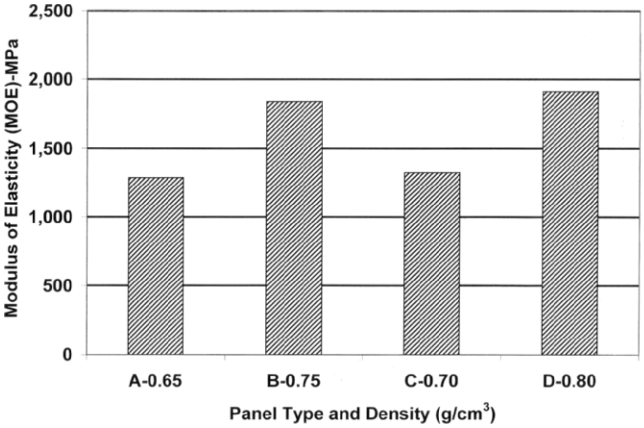

Figure 5.—Modulus of elasticity of the panels.

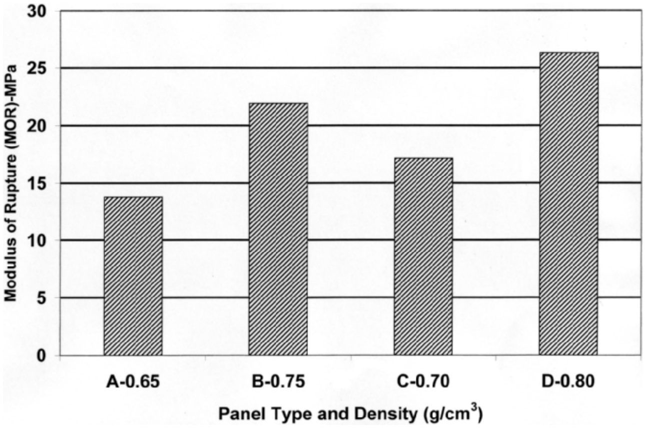

Figure 6.—Modulus of rupture of the panels.

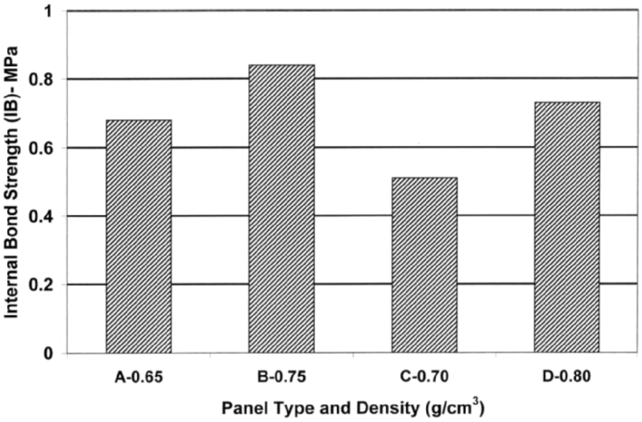

Figure 7.—Internal bond strength of the panels.

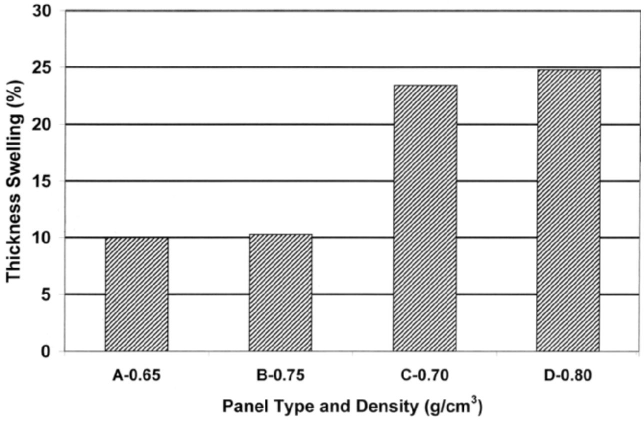

Figure 8.—Thickness swelling of the panels.

Average thickness swelling of the samples at 2- and 24-hour water soaking ranged from 9.98 to 24.78 percent. Percentage of fiber in the panels was a dominant and more important parameter than density in controlling thickness swelling of the samples. Panel types A and B, made of 20 percent fiber and 80 percent particle, had 9.98 percent thickness swelling. However, panel types C and D showed an average value of 24.08 percent, with an average density of 0.75 g/cm^3. In a past study, MDF panels made from 20 percent rice straw and 80 percent bamboo with density levels comparable to those of this work had 18 percent thickness swelling. It appears that even 5 percent fiber and particle in the panels slightly reduced dimensional stability of the samples. Higher thickness swelling of panel types C and D can also be the result of a higher amount of fiber on the face layer, density level, as well as possible nonuniform glueline between fiber and particle layers within the samples. Only 0.5 percent wax was used for panel manufacture. If a higher amount of wax had been used, dimensional stability swelling of the samples would have been improved.

Surface characteristics of the samples were analyzed based on their R_a, R_z, and $R_{\max}$ values. As shown in Table 2, panel types B and C did not show any significant difference in their roughness values at the 95 percent confidence level based on *t* test. Both types of panels had very close density levels—namely, 0.70 and 0.75 g/cm^3. However, panel type A, with the lowest density, had a surface roughness with an average R_a value of 7.5 μm. On the other hand, panel type D, with 0.85 g/cm^3 density, had the smoothest surface, with an average R_a value of 5.08 μm. It seems that the overall density of panels plays an important role in determining the surface quality of the samples. In a previous study, R_a and R_z values of experimental MDF panels made from bamboo

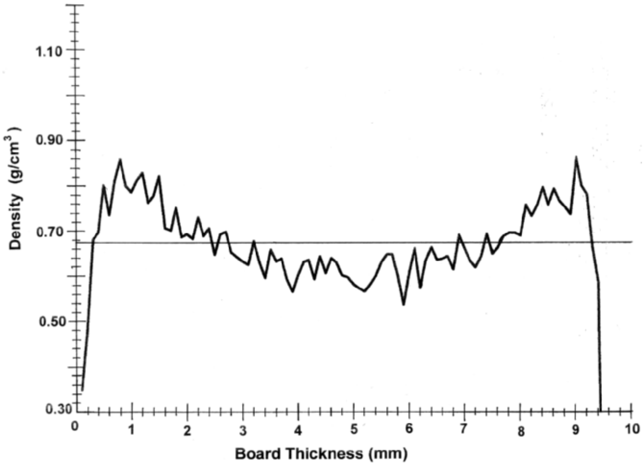

Figure 9.—Typical density profiles of the samples.

and rice straw were 5.22 and 35.40 μm, respectively. Currently, no standards exist to evaluate the surface quality of MDF. However, values determined in this study are in line with those of previous works. Based on the findings of this study, both physical and mechanical properties of experimental panels made from bamboo show promising characteristics for use as value-added products in further manufacturing steps.

No significant difference was found between densification of face layers of the samples with different fiber and particle ratios, as illustrated by the typical density profiles shown in Figure 9.

Conclusions

In this work, particles and fibers from bamboo and rice straw were used to make experimental, sandwich-type panels. Most properties of the panels were acceptable according to the JIS standard, with the exception of face screw holding strength. Effect of fiber to particle ratio of the sample was not a dominant parameter influencing overall panel properties, in contrast to their density. It seems that manufacturing such panels in a three-layer configuration would help not only convert underutilized nonwood species into value-added products but also provide panels with a smooth surface quality for further production processes in Thailand. In future studies, manufacturing panels using less adhesive to satisfy the E1 formaldehyde emission class and overlaying capability of the panels should be tested to gain more comprehensive information about the properties of such samples.

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