International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:4, No:4, 2010

Physical and Mechanical Properties of Particleboard from Bamboo Waste

Vanchai Laemlaksakul

***Abstract*—**This research was to evaluate a technical feasibility of making single-layer experimental particleboard panels from bamboo waste (*Dendrocalamus asper* Backer) by converting bamboo into strips, which are used to make laminated bamboo furniture. Variable factors were density (600, 700 and 800 kg/m^3) and temperature of condition (25, 40 and 55 °C). The experimental panels were tested for their physical and mechanical properties including modulus of elasticity (MOE), modulus of rupture (MOR), internal bonding strength (IB), screw holding strength (SH) and thickness swelling values according to the procedures defined by Japanese Industrial Standard (JIS). The test result of mechanical properties showed that the MOR, MOE and IB values were not in the set criteria, except the MOR values at the density of 700 kg/m^3 at 25 °C and at the density of 800 kg/m^3 at 25 and 40 °C, the IB values at the density of 600 kg/m^3, at 40 °C, and at the density of 800 kg/m^3 at 55 °C. The SH values had the test result according to the set standard, except with the density of 600 kg/m^3, at 40 and 55 °C. Conclusively, a valuable renewable biomass, bamboo waste could be used to manufacture boards.

***Keywords*—**Particleboard, Urea Formaldehyde Resin, Bamboo Waste

I. Introduction

THE demand for wood composites from waste wood has been increasing as timber resources in natural forests decline. The use of renewable biomass as a raw material in composites production was one approach and the use of renewable biomass may result in several benefits such as environmental and socioeconomic [1]. Today renewable biomass are mostly accepted as waste materials and are mostly ploughed into the soil or burnt in the field.

According to the end uses of wood-wastes and their possible reuse products, particleboard has found typical applications as flooring, wall and ceiling panels, office dividers, bulletin boards, furniture, cabinets, counter tops, and desk tops [2], and it seems that the manufacture of particleboard from recycled wood-based wastes is the most common way to reuse such waste materials [3, 4].

The particleboard is a panel product manufactured under pressure from particles of wood or other lignocelluloses materials and an adhesive. Particleboard has been widely used throughout the world for furniture manufacture and house construction, including flooring systems, etc. [5]. Recently, the demand for the particleboard has continued to increase for housing construction and furniture manufacturing [6].

Bamboo plants are botanically considered as a special group in grass family which can be planted easily into any kind of land. Bamboo is very fast growing plant with very high strength so it can be used as a structural material. It has higher tensile strength than other wood [7]. A new product made from bamboo strips, known as bamboo laminate became available in Europe and America for flooring material in place of hardwoods. However, the conversion of bamboo into strips is average potential output to 34.3% [8]. Although the utilizable portion of bamboo for producing laminates is low, it offers good potential for processing bamboo into a wood substitute material as show in Fig.1. The remaining portion from the process could be used for the particleboard production.

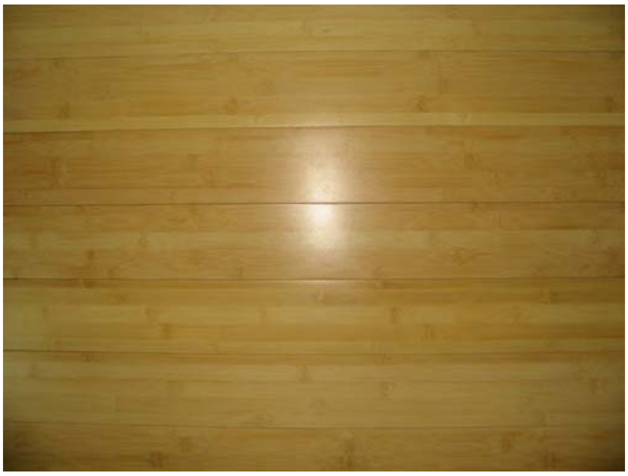

Fig. 1 Laminated bamboo

Vanchai Laemlaksakul is an Associate Professor in the Industrial Engineering Technology Department, Excellent Center of Furniture Industry Research and Development (ECoFurniture), College of Industrial Technology, King Mongkut's University of Technology North Bangkok (KMUTNB), Bangkok, Thailand (phone: 662-913-2500 ext. 6501; fax: 662-587-4356; e-mail: vcl@kmutnb.ac.th).

The purpose of this research is to study the use of the bamboo waste (*Dendrocalamus asper* Backer) or Pai Tong from conversion of bamboo into strips to make single-layer particleboard and to examine the mechanical and physical properties of panels to determine the influences of density and temperature of condition. Information is required before the commercialization of these bamboo residues to create value added products.

II. Materials and Methods

A. Materials

Chips were prepared from waste of bamboo culms (*Dendrocalamus asper* Backer) or Pai Tong, which were collected and then classified from the conversion of bamboo into strip (Fig.2). The adhesive used was urea formaldehyde (UF) resin at 86.94% solid content (SC).

B. Manufacturing Particleboard

Particleboards were manufactured in the Wood Engineering Technology Laboratory, Department of Industrial Engineering Technology, King Mongkut's University of Technology North Bangkok (KMUTNB), Thailand, using standardized procedures that simulated industrial production. Chips were divided into coarse chips, which passed through a 4 mesh and were retained by 8 mesh screen, and fine chips, which passed through an eight-mesh and were retained by a 20 mesh screen. The ratio of coarse/fine chips used for particleboard was 2:1. The chips were oven-dried to 4% moisture content (MC). Dried chips were then blended with UF resin in a rotating drum type mixer fitted with a pneumatic spray gun. Based on oven dry particle weight, 13% UF resin was applied. No wax or any other additives were applied for panel manufacturing. As a hardener, ammonium chloride (NH_4Cl) was applied with 1 wt%.

The materials were placed in a mould of 400 mm x 400 mm box. The adhesive coated was then inserted into the cold press and pressed to reach 20 mm thickness and was then compressed on aluminum cauls in a hot press until it reached 15 mm stoppers at a temperature of 120 °C using a pressure of 150 kg/cm^2 for 5 min. The target density was 600, 700 and 800 kg/m^3.

C. Test Procedure

Finished boards were kept in an open space approximately for a week to remove formaldehyde trapped inside. Then, all boards were cut to obtain 360 mm x 360 mm rectangles by trimming 20 mm thick strips along the edges. Test samples were cut from particleboard and the following properties were determined in accordance with appropriate Japanese Industrial Standard (JIS A 5908, 1994) [9]. Specimens were condition to equilibrium at a temperature (25, 40 and 55 °C) for 24 h before testing. 153 specimens were used for the mechanical and physical properties (Fig.3).

Fig. 2 Conversion of bamboo into strip

Fig. 3 Specimens for the mechanical and physical properties

1) Static Bending Test

Bending specimens of 50 mm wide 275 mm long were cut from each full particleboard. A concentrated bending load was applied at the center with a span of 15 times the thickness of the specimen. The bending modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated from load deflection curves according to the following formula.

$$\text{MOR} = \frac{3P_bL}{2bh^2} \quad (1)$$

$$\text{MOE} = \frac{P_{bp}L^3}{4bh^3Y_p} \quad (2)$$

Where P_b is the maximum load (N), P_{bp} is the load at the proportional limit (N), Y_p is the deflection corresponding to P_{bp} (mm), b is the width of the specimen (mm), h is the thickness of the specimen (mm), and L is the span (mm).

2) Internal Bond Strength

The tensile strength perpendicular to the surface was determined using three conditioned specimens of 50 mm x 50 mm from each particleboard. The rupture load (P_s) was determined and internal bond strength was calculated using the following formula.

$$IB = \frac{P_s}{bl} \quad (3)$$

Where P_s is the rupture load, and l is the length of the specimen.

3) Thickness swelling

Specimens with dimensions of 50 mm x 50 mm were prepared for evaluation of the thickness swelling. The thickness at the middle of the test specimen was measured with a micrometer. Then the test specimens were place into water in parallel for 30 mm and soaked for 2 and 24 h before further measurement of the thickness. The Thickness swelling rate (TS) was determined from the following formula.

$$TS_2 = \frac{(t_2 - t_0)}{t_0} \times 100 \quad (4)$$

$$TS_{24} = \frac{(t_{24} - t_0)}{t_0} \times 100 \quad (5)$$

Where TS is the thickness swelling rate (%), t_0, t_2 and t_{24} are the thickness at the middle of the test specimen before soaking, and soaking in water for 2 and 24 h, respectively.

D. Statistical Analysis

For the experimental design of this study, density and temperature of condition are major factors. Data for each test were statistically analyzed. The effects of density and temperature on the particleboard panels' properties were evaluated by two-way analysis of variance (Two-way ANOVA) at 95% confidence level. When the ANOVA indicated a significant difference, a comparison of the means was done employing Scheffe to identify which groups were significantly different from other groups at 95% confidence level.

III. Result and Discussion

A. Properties of Particleboard

Average values of experimental particleboard panels are presented in Table 1. Based on JIS A 5908-1994 standard, 18 and 3000 MPa are the minimum requirements for MOR and MOE of particleboard panels for general uses and furniture manufacturing. The test result of mechanical properties showed that the MOR, MOE and IB values were not in the set criteria, except the MOR values at the density of 700 kg/m^3 at 25 $^\circ$C and at the density of 800 kg/m^3 at 25 $^\circ$C and 40 $^\circ$C (Fig. 4), IB values at the density of 600 kg/m^3, at 40 $^\circ$C, and at the density of 800 kg/m^3 at 55 $^\circ$C (Fig. 5). Figure 6 shows that the screw holding strength (SH) of particleboards manufactured at density 700 and 800 kg/m^3 is higher than JIS A 5908-1994 standard (500 N). Moreover, the SH values were found to be increased with increasing density ratio.

B. Analysis of variance on the density and temperature

Analysis of variance on the density and temperature of condition on the mechanical properties of the particleboards are given in Table 2. The test results related that temperature has an effect on MOR and IB but density has impacts on all variables. It was also found that an interaction between temperature and density affects to IB at (0.05) significant level.

As shown in Table 3, it was found that MOR at density 700 and 800 kg/m^3 is higher than at 600 kg/m^3. However, MOR at density 700 and 800 kg/m^3 is not found to be different. From table 4, it is showed that MOR at temperature 55 $^\circ$C is less than at 40 $^\circ$C and 25 $^\circ$C.

As shown Table 5, the density at 600 kg/m^3 yields less MOE than at 700 kg/m^3 and 800 kg/m^3 respectively but MOE at density 700 kg/m^3 and 800 kg/m^3 is not different.

Table 6 shows that at the temperature 40 $^\circ$C yields the highest IB under the density 600 and 700 kg/m^3. However, when it turns to use density at 800 kg/m^3, the IB at temperature 40 $^\circ$C and 55 $^\circ$C is not different.

TABLE I
TEST RESULT FOR PARTICLEBOARD PANELS MADE FROM WASTE BAMBOO

Density (kg/m^3)	Temperature (°C)	Bending properties (MPa) MOR	MOE	IB (MPa)	SH (N)	TS (%)
600	25	15.9 (3.1)	1541 (236.7)	0.19 (0.01)	557 (74.0)	7.1 (1.2)
	40	8.6 (2.2)	876 (207.5)	0.35 (0.03)	303 (76.2)	6.2 (0.8)
	55	6.5 (0.6)	749 (49.9)	0.08 (0.01)	218 (18.9)	6.1 (1.4)
700	25	19.9 (1.7)	2037 (49.2)	0.20 (0.01)	576 (86.2)	6.4 (1.9)
	40	15.5 (3.4)	1815 (135.0)	0.25 (0.01)	626 (92.9)	6.5 (1.8)
	55	14.2 (3.2)	1781 (235.5)	0.19 (0.01)	643 (72.1)	6.3 (2.1)
800	25	21.1 (3.2)	2150 (211.1)	0.17 (0.04)	662 (114.1)	6.2 (1.5)
	40	21.5 (4.0)	2166 (187.2)	0.29 (0.05)	927 (126.6)	6.3 (1.4)
	55	16.8 (3.0)	2159 (288.2)	0.31 (0.03)	873 (115.9)	6.0 (0.9)

MOR: modulus of rupture; MOE: modulus of elasticity; IB: internal bonding strength; SH: screw holding strength: TS: thickness swelling. Numbers in parentheses are standard deviations.

International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:4, No:4, 2010

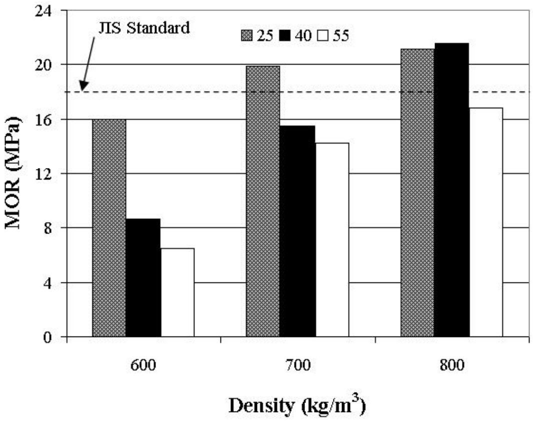

Fig. 4 Effect of density on MOR values of panel.

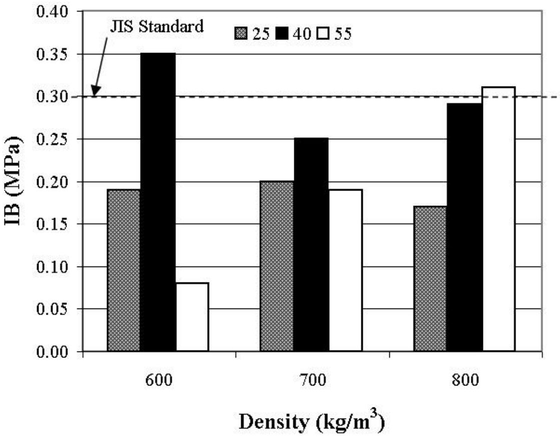

Fig. 5 Effect of density on IB values of panel.

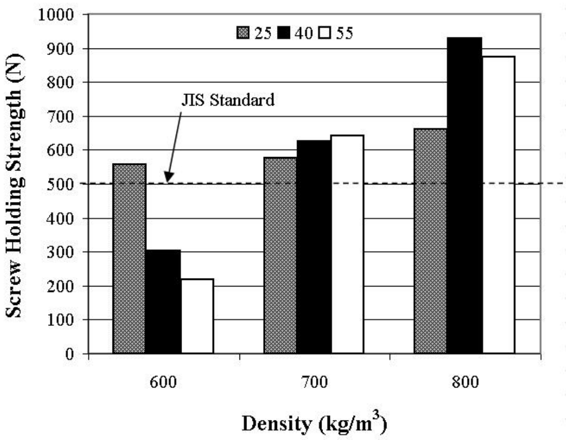

Fig. 6 Effect of density on SH values of panel.

TABLE II
FACTORS AFFECTING MECHANICAL PROPERTIES OF PARTICLEBOARD PANELS

Properties	Bending properties		IB	SH
	MOR	MOE		
Temperature	*	NS	*	NS
Density	*	*	*	*
Temperature & Density	NS	NS	*	NS

significant difference at the 5% level; NS: not significant

TABLE III
MEAN DIFFERENCE TEST OF DENSITY ON MOR VALUES

Density (I)	Mean	Density (J)	Mean Difference (I-J)	Sig.
600	10.37	700	-6.17*	0.01
		800	-9.47*	0.00
700	16.54	600	6.17*	0.01
		800	-3.30	0.21
800	19.84	600	9.47*	0.00
		700	3.30	0.21

significant difference at the 5% level

TABLE IV
MEAN DIFFERENCE TEST OF TEMPERATURE ON MOR VALUES

Temperature (I)	Mean	Temperature (J)	Mean Difference (I-J)	Sig.
25	19.01	40	3.79	0.14
		55	6.49*	0.01
40	15.22	25	-3.79	0.14
		55	2.70	0.34
55	12.52	25	-6.49*	0.01
		40	-2.70	0.34

significant difference at the 5% level

TABLE V
MEAN DIFFERENCE TEST OF DENSITY ON MOE VALUES

Density (I)	Mean	Density (J)	Mean Difference (I-J)	Sig.
600	1055.88	700	-822.17*	0.00
		800	-1103.00*	0.00
700	1878.04	600	822.17*	0.00
		800	-280.84	0.34
800	2158.88	600	1103.00*	0.00
		700	280.84	0.34

significant difference at the 5% level

TABLE VI
MULTIPLE COMPARISONS OF IB VALUES

Density	Temperature	Mean	Lower bound	Upper bound
600	25	0.19	0.17	0.22
	40	0.35	0.32	0.37
	55	0.08	0.05	0.11
700	25	0.20	0.17	0.22
	40	0.25	0.22	0.28
	55	0.19	0.16	0.21
800	25	0.17	0.14	0.19
	40	0.29	0.26	0.32
	55	0.31	0.28	0.33

IV. Conclusion

In this research, the residues of bamboo (*Dendrocalamus asper* Backer) or Pai Tong from conversion of bamboo into strips are used to make single-layer particleboard and the strength properties were examined. The MOR, MOE and IB values depend on various conditions of density. MOE and MOR at density 800 kg/m^3 are higher than at 600 and 700 kg/m^3. The interaction between temperature and density only has an impact on IB. The temperature at 40 °C and the density at 600 kg/m^3 yield the highest IB. Lastly, all testing results are found to be significant to the density at 800, 700, 600 kg/m^3 respectively. The density at 800 kg/m^3 and temperature conditions at 40 °C yields the highest result is acceptable to production. The above results suggest that it is completely feasible to make use of renewable biomass; residue bamboo could be used to manufacture particleboard panels.

Acknowledgment

This research was a part of a research project titled "Development of laminated bamboo furniture manufacturing" supported by the King Mongkut's University of Technology North Bangkok (KMUTNB), Thailand.

References

[1] R. M. Rowell, "A new generation of composite materials from agro-based fiber," in *Proc. 3rd International Conference on Frontiers of Polymers and Advanced Materials*, 1995, pp. 659–665.

[2] D. Wang, and X. S. Sun, "Low density particleboard from wheat straw and corn pith," *Industrial Crops and Product*, vol. 15, pp. 47–50, 2002.

[3] T. H. Yang, C. J. Lin, S. Y. Wang, and M. J. Tsai, "Characteristics of particleboard made from recycled wood-waste chips impregnated with phenol formaldehyde resin," *Building and Environment*, vol. 42, no. 1, pp. 189–195, 2007.

[4] C. Lykidis, and A. Grigoriou, "Hydrothermal recycling of waste and performance of the recycled wooden particleboards," *Waste Management*, vol. 28, pp. 57–63, 2008.

[5] J. A. Youngquist, "Wood-based composites and panel products," in Wood Handbook: Wood as an Engineering Material, Gen. Tech. Rept. FPL-GRT-113., USDA Forest Serv., Forest Prod. Lab, Madison, WI, pp. 1–31 (Chapter 10), 1999.

[6] T. Sellers, "Growing markets for engineered products spurs research," *Wood Technol*., vol. 127, no. 3, pp 40–43, 2000.

[7] S. H. Li, Q. Y. Zeng, Y. L .Xiao, S. Y. Fu, and B. L. Zhou, "Biomimicry of bamboo bast fiber with engineering composite materials," *Mater Sci. Eng*., vol. 3, pp. 125–130, 1995.

[8] V. Laemlaksakul, and S. Kaewkuekool, "Laminated bamboo materials for furniture – A systematic approach to innovative product design," *WSEAS Trans. on Advances in Eng. Education*, Issue 5, vol. 3, pp 424–430, May 2006.

[9] Japanese Industrial Standard Particle Boards (JIS A 5908 1994: Particle Board), 1994.