Properties of Rubberwood Medium-Density Fiberboard Bonded with Starch and Urea-Formaldehyde

Songklod Jarusombuti
Piyawade Bauchongkol
Salim Hiziroglu
Vallayuth Fueangvivat

Abstract

The objective of this study was to evaluate some of the properties of experimental medium-density fiberboard panels made from rubberwood (*Hevea brasiliensis*) using a combination of cassava (*Manihot utilissima*) starch and a low percentage of urea-formaldehyde (UF) resin as a binder. Experimental panels with density levels of 0.65 and 0.80 g/cm^3 were made using 10 percent starch, 10 percent starch and 3 percent UF, and 10 percent UF for the control samples. The panels manufactured with 10 percent starch did not have satisfactory physical and mechanical properties based on Japanese Industrial Standards. However, average modulus of elasticity, modulus of rupture, and thickness swelling values of the sample types E and F manufactured using a combination of starch and UF were 2,044 MPa, 22.49 MPa, and 35.50 percent, respectively, which met required limits listed in Japanese Industrial Standard A-5908. The results of this study indicated that starch can be used as a viable alternative binder with limited addition of UF resin without having any significant adverse influence of bending properties of the samples. Based on formaldehyde emission tests, specimens made with 3 percent UF had an average value of 18.5 mg/100 g, while control samples having 10 percent UF resulted in 38.5 mg/100 g.

Rubberwood is the common name for the timber of *Hevea brasiliensis* tree. It is an indigenous species to the Amazon forests in Brazil. The first introduction of rubberwood to Southeast Asia was in 1876. Currently Thailand, Indonesia, and Malaysia have 6.65 million hectares of rubber tree plantations for latex production (Krukanont and Prasertsan 2004). A rubber tree can have a diameter of 25 to 45 cm at breast height and a height of over 10 m within 25 years, which is the age at which the tree can no longer be used for efficient rubber production (Hong and Sim 1994). The success of rubberwood use in Malaysia in the early 1990s has led to the development of similar industries in other Southeast Asian countries, including Thailand. The rise in population from less than 18 million in the early 1960s to more than 67 million today has caused a significant reduction in forest resources in Thailand even though commercial logging has been banned since 1989 (Falvey 2000). The rubberwood sawn timber industry in Thailand is relatively well developed with more than 100 mills. The downstream processing activities of rubberwood have been growing very rapidly because of decreasing supplies of natural timber sources as well as limited teak plantation in northern Thailand. Thai sawn rubberwood timber export has been increasing within the last decade. During the early 1980s, the rate of forest loss in Thailand was more than that of all Southeast Asian countries averaged by nearly two and one-half times (Falvey 2000). Rubberwood also plays a vital role as a raw material in the medium-density fiberboard (MDF) industry in Thailand. Almost 90 percent of all MDF industry in the country uses low quality rubberwood that is not suitable for furniture and other solid wood products to manufacture MDF panels. Its low cost and anatomical structure such as ideal fiber length are some of the parameters that make this species very attractive to fiberboard producers. MDF is also a prime panel product

---

The authors are, respectively, Associate Professor, Dept. of Forest Products, Kasetsart Univ., Bangkok, Thailand (fforsoj@ku.ac.th); Wood Technologist, Royal Forest Dept., Bangkok, Thailand (vallayuth@yahoo.com); Professor, Dept. of Natural Resource Ecology and Management, Oklahoma State Univ., Stillwater (salim.hiziroglu@okstate.edu [corresponding author]); and Wood Technologist, Royal Forest Dept., Bangkok, Thailand (meawthai@hotmail.com). This paper was received for publication in September 2011. Article no. 11-00114.

Forest Prod. J. 62(1):58–62.

widely used as substrate for furniture and cabinet manufacture in Thailand.

Urea-formaldehyde (UF) is the most commonly used binder because of its cost, fast curing time, and clear color in MDF production (Roffael 1993, Pichelin et al. 2006). It is a widely used cross-linking agent in the production of many interior panels (Maloney 1993). However, its low moisture resistance and formaldehyde emission are two important negative properties of this adhesive (Moubarik et al. 2010a). Exposure to formaldehyde emissions from the adhesive gained attention as a public issue as a result of health concerns and environmental pollution since the 1980s. UF resin is a result of the reaction of urea in an aqueous solution. It is a condensation product of urea and formaldehyde. A very small amount of formaldehyde exists in the adhesive, with the major proportion in the condensed form, which cures under the effect of heat and pressure during panel manufacture. However, a small amount of formaldehyde is still released into the atmosphere during the service life of the panels (Roffael 1993). The main mechanism resulting in formaldehyde emission from UF-bonded MDF is related to unreacted free formaldehyde from the adhesive and hydrolysis of partially and completely cured binder (Nihat and Nilgun 2002).

The formaldehyde concentration in the atmosphere is generally below 0.1 ppm; however, it can reach 0.1 ppm or more under certain conditions (Roffael 1993). Various studies investigated formaldehyde emission from different wood composite panels (Akbulut et al. 2000). Free formaldehyde percentage in the UF resin is less than 0.3 percent in most applications (Chow et al. 1993). The amount of formaldehyde emission is basically a function of raw material and production parameters; for example, press time and temperature are two main production variables, while species and resin amount can be considered important raw material characteristics influencing formaldehyde emission of the panels (Roffael 1993, Akbulut et al. 2000). In a previous work, experimental particleboard panels made from pine and spruce had lower formaldehyde emission as compared with panels made from beech (Akbulut et al. 2000). There are various approaches to reduce formaldehyde emission from the panels, including modifying resin chemistry and using a reduced amount of resin in the panels. Using a reduced amount of resin would be an ideal approach; however, both physical and mechanical properties of the panels are strongly related to the resin percentage. Therefore any reduction in resin use will adversely influence overall properties of the panels.

Cassava (*Manihot utilissima*) is a shrubbing tropical perennial plant that requires a minimum temperature of 26°C to grow. It is well adapted to humid seasons in the tropics. Cassava's starch roots produce more food energy per unit area than any other staple crop. Leaves are also eaten as a vegetable in many tropical countries. Cassava is recognized as one of the most important crops in Thailand. Overall production of the root is approximately 18 million tons from 1.5 million hectares each year, and half of this is converted into starch (Falvey 2000). The modified starch and syrup industries are the biggest consumers of cassava in Thailand. In various studies, soy protein, rice starch, and corn starch were used as binders to manufacture different types of wood composite panels (Zhongli et al. 2006; Yuan and Kaichang 2007; Moubarik et al. 2009, 2010b). To our knowledge there is no published research on the use of cassava starch in combination with a low percentage of UF to manufacture MDF panels so that formaldehyde emission of such panels can be reduced. Therefore, the main objective of this study was to produce experimental MDF panels from waste rubberwood fiber using 10 percent cassava starch along with a combination of 10 percent starch and 3 percent UF resin as the binder. Standard properties of the panels were evaluated to determine whether they were comparable to those of commercially manufactured products.

Materials and Methods

Waste rubberwood material from a local plywood manufacturer was used for panel manufacture. Large veneer pieces were chipped into particles using a laboratory type hammermill and were disintegrated in a pilot type of defibrator using a pressure of 0.80 MPa at a temperature of 165°C for 2 minutes to produce raw material for the panels. The defibrated fiber was dried in a kiln at a temperature of 90°C to a 4 percent moisture content. A total of 30 panels, 5 for each type, with a dimension of 35 by 35 by 1 cm were manufactured for the experiments as displayed in Table 1. Starch was diluted in water using a weight ratio of 73 g/100 g. In the case of panels made with a combination of starch and resin, diluted starch was sprayed onto the fibers prior to spraying UF resin in a rotating drum type mixer equipped with a pressurized spray gun. In all cases 0.5 percent wax was also added in the panels. Mats were manually formed in a Plexiglas box before they were pressed in a hot press at a temperature of 170°C under a pressure of 5.2 MPa for 7 minutes. Two types of panels were made with an average target density of 0.65 to 0.80 g/cm^3 for the experiments. Panels were conditioned in a climate room with a temperature of 20°C and a relative humidity of 65 percent for about 2 weeks. After conditioning the samples, the modulus of elasticity (MOE), modulus of rupture (MOR), and internal bond (IB) strength of the samples were tested on an Instron Testing System Model-22, 550R, equipped with a 6,000-kg load cell. The thickness swelling (TS) and water absorption (WA) values of the samples were also measured after a 2-hour water soak.

Samples with a 10 by 10-cm surface area were used for the Janka hardness test. Ten random measurements were taken from the surface of each sample. A Com-Ten 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 11.28-mm-diameter steel ball into the surface of the sample. The maximum applied load in kilograms at a half-ball penetration was used as the hardness value of the samples.

Table 1.—Sampling design.[a]

Panel type	Binder type	Density (g/cm^3)
A	10% UF[b]	0.65
B	10% UF	0.80
C	10% starch	0.65
D	10% starch	0.80
E	3% UF and 10% starch	0.65
F	3% UF and 10% starch	0.80

[a] For each panel type: number of panels = 5; bending modulus of rupture and modulus of elasticity = 20 MPa; internal bond strength = 10 MPa; formaldehyde emission = 4 mg/100 g; thickness swelling = 3 percent; hardness = 10 kg; and roughness measurement = 25 µm.

[b] UF = urea-formaldehyde.

All tests with the exception of hardness and surface roughness evaluation of the panels were conducted following Japanese Industrial Standard A-5908 (JIS 1995).

Formaldehyde emission of the samples was also determined using the perforator method, which involves the extraction of small MDF samples with toluene in perforator equipment. The extracted formaldehyde was collected in water and determined by the iodine method (Marutzky 1989, Kim and Kim 2005). Usually the formaldehyde content is expressed in milligrams of formaldehyde per 100 g of the sample. A total of 24 samples, 4 for each type of sample, were used for formaldehyde emission evaluation of the panels (European Committee for Standardization 1993).

Density profiles of each type of sample with dimensions of 5.0 by 5.0 cm were measured with an X-ray density profilometer.

Because such panels are targeted to be used for furniture manufacture as substrate for thin overlays, their surface quality plays an important role in their service life. A stylus type of equipment was used to evaluate surface quality of the samples. The Hommel T-500 portable profilometer was used for the roughness measurement. Three roughness parameters, i.e., 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 were discussed in previous studies (American National Standards Insitute 1985, Mummery 1993, Hiziroglu 1996, Hiziroglu et al. 2004).

Results and Discussion

Results of mechanical and physical tests of the samples are presented in Table 2. The average MOE and MOR values of 2,359 and 26.58 MPa were found for the samples made with 10 percent starch and 3 percent UF having a density of 0.80 g/cm^3. These values are only 9.1 and 14.7 percent lower that those of panel type B, control samples made with 10 percent adhesive with the same density level. Both values decreased with decreasing density of the same type of panels. Panels with 0.65 and 0.80 g/cm^3 density levels made with 10 percent starch had 22.7 and 49.4 percent lower MOE values than those manufactured with UF. Bending properties of wood composites generally are directly related to their density level with a linear relationship. In a previous study, rubberwood MDF samples bonded with 10 percent UF had MOR and MOE values of 21.49 and 1,897 MPa, respectively (Yusoff 1994). The highest MOR value of 28.40 MPa was found for the control sample type A. Panels made with only 3 percent UF resin and 10 percent starch had 6.40 percent lower MOR values than those of the control samples. It appears that using a low percentage of formaldehyde-based adhesive did not have any substantial effect on their bending properties. On the other hand, panels having only starch as a binder resulted in significantly lower MOE and MOR values than those of other samples at 95 percent confidence level based on *t* tests, as shown Figures 1 and 2.

Test results revealed that three types of the samples, panel types A, B, and F, satisfied MOE requirements of 2,000 MPa for MDF panels for general use based on JIS Standard A-5908 (JIS 1995). On the other hand, all panels with the

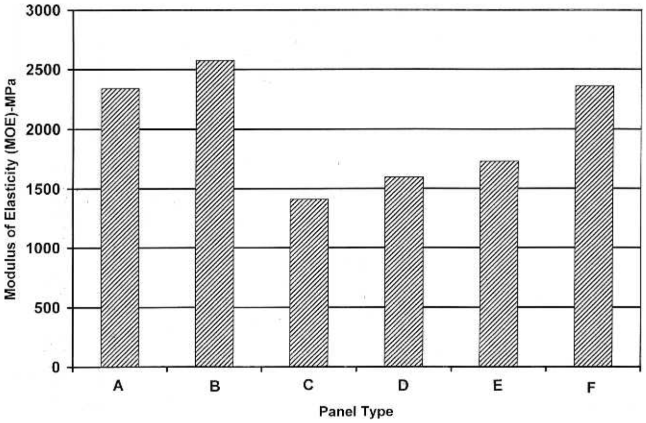

Figure 1.—Modulus of elasticity of the panels.

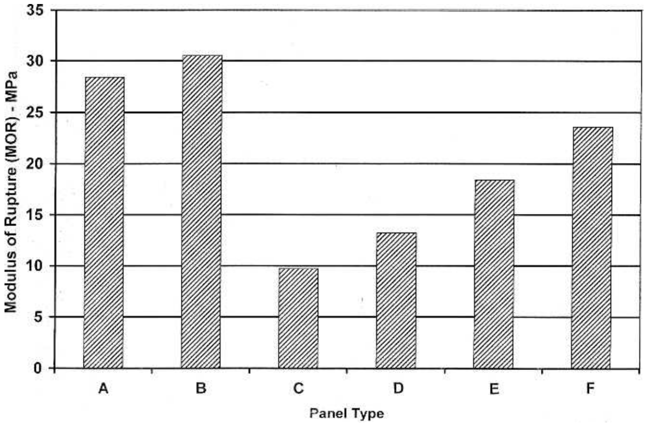

Figure 2.—Modulus of rupture of the panel.

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 (%)	WA (%)	Hardness (kg)	FE (mg/100 g)	Roughness parameters (µm)		
									R_a	R_z	$R_{\max}$
A	0.65	2,340 (376.7)	28.40 (2.86)	0.80 (0.10)	11.30 (0.10)	40.0 (5.34)	890 (137)	38.0 (2.1)	4.20 (0.28)	29.40 (2.65)	49.60 (5.15)
B	0.80	2,574 (369.3)	30.51 (2.98)	1.01 (0.12)	12.80 (1.71)	54.7 (4.60)	912 (129.50)	39.0 (3.1)	4.13 (0.36)	30.11 (2.33)	50.32 (5.08)
C	0.65	1,409 (201.4)	9.78 (10.0)	0.07 (0.01)	128 (14.9)	213 (20.13)	635 (85.0)	0.37 (0.01)	6.12 (0.60)	39.31 (2.51)	54.50 (5.55)
D	0.80	1,597 (237.9)	13.23 (1.48)	0.11 (0.01)	118 (14.5)	279 (28.30)	881 (132.1)	0.39 (0.02)	5.30 (0.41)	36.82 (3.01)	40.81 (4.44)
E	0.65	1,729 (228.2)	18.41 (2.00)	0.41 (0.05)	31 (4.40)	99 (8.90)	750 (102.7)	19.0 (1.23)	7.49 (0.73)	38.33 (2.64)	43.62 (4.27)
F	0.80	2,359 (349.1)	26.58 (3.48)	0.73 (0.09)	40 (5.36)	128 (10.8)	850 (84.4)	20.0 (1.89)	5.21 (0.54)	25.34 (1.89)	36.53 (4.09)

[a] Values are means with standard deviations in parentheses. MOE = modulus of elasticity; MOR = modulus of rupture; IB = internal bond strength; TS = thickness swelling; WA = water absorption; FE = formaldehyde emission; R_a = average roughness; R_z = mean peak-to-valley height; and $R_{\max}$ = maximum roughness.

exception of panel type C met the MOR requirement of 13.0 MPa called for in the JIS standards (JIS 1995).

IB strength values of the samples made with only starch were significantly lower than those made with a combination of starch and UF. Both panel types C and D had very low IB strength values of 0.07 and 0.11 MPa, which were significantly lower than those stated in the JIS standards, as illustrated in Figure 3. This could be related to the substantial amount of sugar content in rubberwood fiber. The sugar content is combined with starch as the binder, possibly creating a nonuniform bonding between the fibers, and thus influencing proper cure of the resin in the press and resulting in low IB strength values (Yamamoto et al. 2006). Panel types C and D did not meet the minimum IB requirement of 0.15 MPa listed in JIS. Such panels with low IB values may have poor performance for different fastening applications.

Panel type B had the highest average hardness value of 912 kg, while the lowest hardness value was found for panel type C at 635 kg with a density of 0.65 g/cm^3 as shown in Figure 4. Hardness values of the specimens did not show any significant difference from each other as a function of resin content. However, panels with a density of 0.65 g/cm^3 had significantly lower hardness values than those with a density of 0.80 g/cm^3. It is a well-known fact that surface density of the panels is a major parameter influencing hardness of the sample.

Based on the formaldehyde test results, sample types A and B had formaldehyde emission values of 38 and 39 mg/100 g, respectively. Corresponding values for the samples made with 3 percent UF were found to be 19 and 20 mg/100 g.

It appears that using only 3 percent UF in the panels reduced their formaldehyde emission substantially. Average formaldehyde emission value of panels E and F was 19.5 mg/100 g, which is much less than the limit of E2 emission class (Roffael 1993).

Average TS and WA of the samples as a result of 2 hours of soaking ranged from 40 to 139 percent and 99 and 279 percent, respectively. Panels manufactured with only starch had very poor TS and WA characteristics regardless of their density levels. Starch, which is a hygroscopic substance, adversely affected dimensional stability of the samples. None of the panels, with the exception of the control sample, satisfied required TS and WA values stated in JIS standards. This negative aspect of the sample could be addressed in future studies by using more wax. Also heat treatment or chemical treatment of the raw material should improve their dimensional stability as a result of the starch used as the binder (Fig. 5).

Surface characteristics of the samples were analyzed based on their R_a, R_z, and $R_{\max}$ values. As shown in Table 2 and Figure 6, panel types did not show any significant

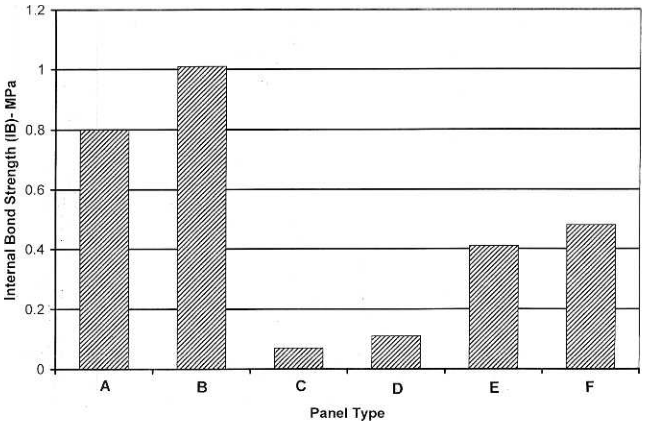

Figure 3.—Internal bond strength of the panels.

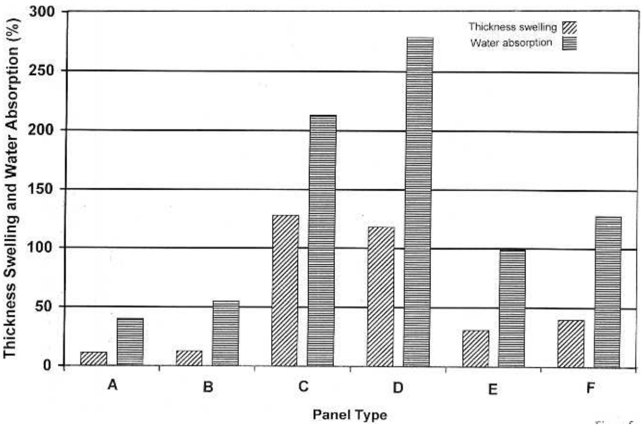

Figure 5.—Thickness swelling and water absorption of the samples.

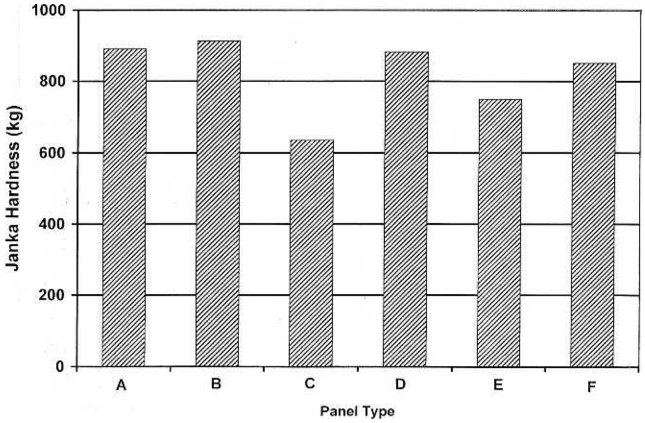

Figure 4.—Hardness values of the panels.

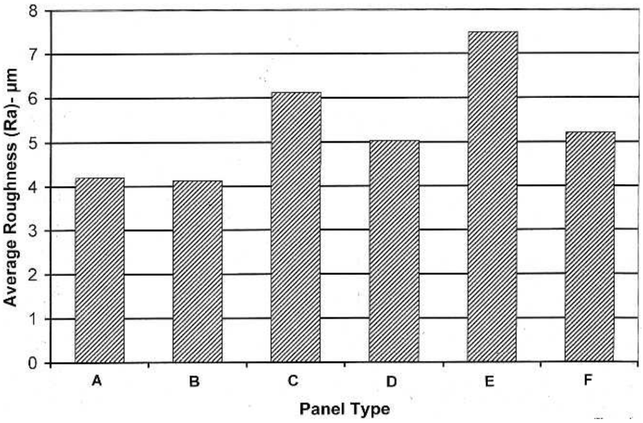

Figure 6.—Average roughness (R_a) values of the panels.

difference in their roughness values from each other at 95 percent confidence level based on *t* tests. Samples made using 100 percent starch as the binder had an average value of 5.71 µm for R_a, while the corresponding value was 6.35 µm for the panels made using a combination of starch and UF resin. Overall, samples with a density of 0.80 g/cm^3 had only several micrometers smoother surface quality than those having a density of 0.65 g/cm^3 based on R_a measurements. In a previous study, R_a and R_z values of experimental MDF panels made from bamboo and rice straw were 5.22 and 35.40 µm, respectively. Currently, there are no standards to evaluate 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 rubberwood using cassava starch and limited amounts of UF as a binder showed promising characteristics to be used as value-added products for further manufacturing steps.

Conclusions

In this work, fibers from rubberwood were used to make experimental MDF panels. The properties of most of the panels were acceptable according to the JIS standards, with the exception of IB strength. In further studies, evaluation of properties of the panels made with replacement 7 percent UF adhesive by starch should be considered. Manufacturing panels using less adhesive to satisfy E1 formaldehyde emission class and overlaying capability of the panels should also be tested in order to gather more comprehensive information about properties of such samples. Such initial data would help convert underutilized waste wood into a value-added product in Thailand.

Acknowledgments

The assistance of research associates Chaiyun Pangwong, Pitak Ha-ngam, and Somwung Chaichoom in panel manufacture is greatly appreciated. This study was funded by Kasetsart University, Royal Forest Department of Thailand, and Oklahoma State University.

Literature Cited

Akbulut, T., S. Hiziroglu, and N. Ayrilmis. 2000. Surface absorption, surface roughness, and formaldehyde emission of Turkish MDF. *Forest Prod. J*. 50(6):45–48.

American National Standards Institute. 1985. Surface texture (surface roughness, waviness, and lay) B46.1. The American Society of Mechanical Engineers, New York. 43 pp.

Chow, P., M. O. Bagby, and J. A. Youngquist. 1993. Furniture panels made from kenaf stalks, wood waste, and selected crop fiber residue. *In:* Proceedings of the 5th Annual International Kenaf Conference, March 3–5, 1993, Fresno, California; California State University Press, Fresno. pp. 250–255.

European Committee for Standardization. 1993. Wood based panels. Determination of formaldehyde content. EN 120. European Committee for Standardization, Brussels.

Falvey, L. 2000. Thai Agriculture. Golden Cradle of Millennia. Kasetsart University Press, Bangkok, Thailand.

Hiziroglu, S. 1996. Surface roughness analysis of wood composites: A stylus method. *Forest Prod. J*. 46(7/8):67–72.

Hiziroglu, S., S. Jarusombuti, and V. Fueangvivat. 2004. Surface characteristics of wood composites manufactured in Thailand. *J. Building Environ*. 39:1359–1364.

Hong, L. T. and H. C. Sim. 1994. Rubberwood processing and utilization. Malaysian Forest Record No. 39. Forest Research Institute of Malaysia, Kepong, Kuala Lumpur.

Japanese Industrial Standards (JIS). 1995. Particleboards. A-5908. Japanese Standards Association, Tokyo.

Kim, S. and H. J. Kim. 2005. Comparison of standard methods and gas chromatography method in determination of formaldehyde emission from MDF bonded with formaldehyde-based resin. *Bioresour. Technol*. 96:1457–1464.

Krukanont, P. and S. Prasertsan. 2004. Geographical distribution of biomass and potential sites of rubber wood fired power plants in Southern Thailand. *Biomass Bioenergy* 26:47–59.

Maloney, T. 1993. Modern Particleboard and Dry Process Fiberboard Manufacture. Miller Freeman, San Francisco.

Marutzky, R. 1989. Release of formaldehyde by wood products. *In:* Wood Adhesives—Chemistry and Technology. Vol. 2. A. Pizzi (Ed.). Marcel Dekker Inc., New York. pp. 307–387.

Moubarik, A., A. Allal, A. Pizzi, F. Charrier, and B. Charrier. 2010a. Preparation and mechanical characterization of particleboard made from maritime pine and glued with bio-adhesives based on cornstarch and tannins. *Maderas Cienc. Tecnol*. 12(3):189–197.

Moubarik, A., B. Charrier, A. Allal, F. Charrier, and A. Pizzi. 2010b. Development and optimization of a new formaldehyde-free cornstarch and tannin wood adhesive. *Eur. J. Wood Wood Prod*. 68(2):167–177.

Moubarik, A., B. Charrier, F. Charrier, A. Pizzi, and A. Allal. 2009. Evaluation of decay resistance of wood products made from borax-impregnated wood and bonded with a formaldehyde-free cornstarch and tannin adhesive. *Ann. Forest Sci*. 66(1). DOI:10.1051/forest/2008082.

Mummery, L. 1993. Surface Texture Analysis. The Handbook. Hommelwerke, Muhlhausen, Germany. 106 pp.

Nihat, S. C. and O. Nilgun. 2002. Use of organosolv lignin in phenol formaldehyde resin for particleboard production II. Particleboard production and properties. *Int. J. Adhes. Adhes*. 22:481–486.

Pichelin, F., M. Nakatanin, A. Pizzi, S. Wieland, A. Despres, and S. Rigolet. 2006. Structural beams from thick wood panels bonded industrially with formaldehyde-free tannin adhesives. *Forest Prod. J*. 56(5):31–36.

Roffael, E. 1993. Formaldehyde release from particleboard and other wood based panels. Malaysian Forest Records No. 37. Forest Research Institute of Malaysia, Kepong, Kuala Lumpur.

Yamamoto, H., E. Makita, Y. Oki, and M. Otani. 2006. Flow characteristics and gelatinization kinetics of rice starch under strong alkali conditions. *Food Hydrocoll*. 20:9–20.

Yuan, L. and L. Kaichang. 2007. Development and characterization of adhesive from soy protein for bonding wood. *Int. J. Adhes. Adhes*. 27: 59–67.

Yusoff, M. N. M. 1994. Panel products from rubberwood particleboard, blockboard and medium density fiberboard. *In:* Rubberwood Processing and Utilization. Malaysian Forest Records No. 39. L. T. Hong and H. C. Sim (Eds.). Forest Research Institute of Malaysia, Kepong, Kuala Lumpur.

Zhongli, P., A. Cathcart, and D. Wang. 2006. Properties of particleboard bond with rice bran and polymeric methylene diphenyl diisocyanate adhesives. *Ind. Crops Prod*. 23:40–45.