Properties of Sandwich-Type Particleboard Panels Made from Rubberwood and Eastern Redcedar

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Abstract

The objective of this study was to determine some of the mechanical properties of sandwich-type particleboard manufactured from rubberwood (*Hevea brasilenesis*) and Eastern redcedar (*Juniperus virginiana*). A total of 36 panels with two density levels of 0.65 and 0.75 g/cm^3 were made using 10 percent urea-formaldehyde, a combination of 3 percent urea-formaldehyde and 10 percent cassava starch, and 10 percent cassava starch, respectively, as a binder. Three-layer panels with rubberwood fibers on the face layers and a mixture of 10 percent Eastern redcedar and 90 percent rubberwood particles in the core layer of the panels were manufactured. The highest modulus of elasticity, modulus of rupture, and internal bond strength values of 2,990, 34.72, and 1.09 MPa, respectively, were found for those panels made with 10 percent urea-formaldehyde having a density of 0.75 g/cm^3. Panels made with 10 percent starch did not have satisfactory mechanical properties and dimensional stability according to Japanese Industrial Standards. However, it seems that a mixture of a low percentage of urea-formaldehyde resin with cassava starch would be a viable alternative binder to manufacture particleboard with acceptable mechanical properties and enhanced surface quality.

Particleboard and fiberboard have been two main composite panels widely manufactured since 1986 in Thailand. Rubberwood (*Hevea brasiliensis*) is the most commonly used raw material to produce wood-based composites in Thailand (Falvey 2000, Krukanont and Prasertsan 2004). Rubberwood originated from the Amazon forest in Brazil and was first introduced to Southeast Asia in the mid-1800s (Hong and Sim 1994, Yusoff 1994). Lumber from rubberwood has been produced on a rather small scale in the past but recently has become much more common in planting as a cash crop in Thailand. At the end of a life cycle of 25 to 30 years for latex production, logs were used as a fuel source in the past. However, rubberwood, with excellent mechanical and physical properties has become an important raw material for the furniture and composite panel industries in Southeast Asian countries, including Thailand. Waste material from furniture and lumber production, together with low-quality small logs, also makes up the main raw material for particleboard and fiberboard manufacture in Thailand (Falvey 2000).

Eastern redcedar (*Juniperus virginiana* L.) is considered an invasive species, as it adapts well to the different soil types and climate conditions in the Great Plains of the United States (Adams 1987, Bidwell et al. 2000). It has been determined that Eastern redcedar spreads at the rate of around 50 trees per acre per year in the prairie land of Kansas (Hiziroglu 2002, Hiziroglu et al. 2002). This spread rate is estimated at approximately 121,000 ha/y in Oklahoma (Bidwell et al. 2000). It is a fact that the encroachment of redcedar is creating a significant ecological problem to farmers in the form of depletion of groundwater and risk of wildfires. Currently, there is no effective and efficient use of small Eastern redcedar trees. Prescribed

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burning and manufacturing mulch are common practices to eliminate this invasive species, although various types of experimental studies have been carried out to manufacture panel products from chipped low-quality whole trees (Hiziroglu et al. 2002).

Formaldehyde-based adhesives, such as urea-formaldehyde and phenol-formaldehyde resin, are the most commonly used adhesives in the wood composite industry in many countries (Roffael 1993). Its fast curing, clear color, and low cost are some of the main advantages of urea-formaldehyde resin (Marutzky 1989). However, one important disadvantage of phenolic-based adhesives is formaldehyde emission from manufactured panels. Even though urea-formaldehyde is the least expensive binder as compared with other adhesives used in wood composite manufacture, it still makes up almost 60 percent of overall production costs (Maloney 1993). Particleboard is generally overlaid with thin laminates or solid wood veneer to manufacture cabinets and furniture units. Formaldehyde emission of particleboard can still be an important problem, depending on the different manufacturing parameters and the chemistry of the adhesive. It has been known for many years that formaldehyde emission causes eye, nose, and respiratory irritation for sensitive people (Roffael 1993). The World Health Organization has classified formaldehyde, which is also used in many other building products, a carcinogen. Most irritation due to formaldehyde emission starts at 0.1 to 0.2 parts per million (ppm). Amounts above 0.3 ppm would be characterized by watery eyes and nose and throat irritation. On average, formaldehyde emission from a typical particleboard is about 0.2 ppm. The California Air Resources Board (CARB) set an emissions standard for particleboard of 0.18 ppm effective January 1, 2009 (Salthammer et al. 2010). On January 1, 2011, the standard was lowered to 0.09 ppm. CARB estimates that the average emission from particleboard will be very close to 0.06 ppm.

A possible solution to the emission problems caused by using formaldehyde-based adhesives would be to manufacture panel products with organic-based adhesives. Various studies have investigated the properties of wood-based panels made using modified starch–based and soybean binders (Pan et al. 2006, Liu and Li 2007). Some attempts have also been made to evaluate properties of particleboard samples made without using any adhesives (Hashim et al. 2012). The main disadvantage of the binderless board is the long press time required to activate chemicals from the raw material as a substitute for adhesive, resulting in higher production costs (Hashim et al. 2012).

Cassava (*Manihot esculenta*), also called tapioca, is a woody shrub native to South America and extensively planted as an annual crop in many tropical countries, including Thailand. It is the third-largest carbohydrate-based food source, having edible, starchy roots. Starch from cassava has been used as a binder in the manufacture of experimental particleboard, and it has been found that the dimensional stability of the panels needs to be improved. Different characteristics of particleboard and fiberboard made from rubberwood and Eastern redcedar have been studied previously (Hong and Sim 1994, Hiziroglu et al. 2002). However, there is very little or no information on the physical and mechanical properties of sandwich-type panels with a combination of these two wood species using both urea-formaldehyde resin and cassava starch as a potential green binder. Therefore, the objective of this work was to manufacture three-layer panels from rubberwood and Eastern redcedar raw materials using both urea-formaldehyde resin and cassava starch and a mixture of both. It is expected that data from this study would give some background information on the properties of such panels so that both underutilized species would have some potential to be used as raw materials for value-added panel application.

Materials and Methods

Chips of rubberwood and Eastern redcedar were reduced to particles using a laboratory-type hammermill. The particles were dried to 3 percent moisture content in an oven. Rubberwood chips were also disintegrated in a defibrator using a pressure of 0.85 MPa and a temperature of 165°C for 3 minutes for the face layers of the panels. The defibrated fibers were also dried to 3 percent moisture content in an oven. Raw materials were mixed with 10 percent urea-formaldehyde resin, 10 percent cassava starch, and a mixture of 3 percent urea-formaldehyde and 10 percent cassava starch as a binder individually in a rotating drum equipped with a pressurized spray gun. Three-layer sandwich-type panels having 25 percent rubberwood fibers on each face layer and a 50 percent mixture of 85 percent rubberwood and 15 percent redcedar particles were formed in a Plexiglas box. A total of 18 panels with two target density levels of 0.65 and 0.75 g/cm^3 were compressed with a computer-controlled press using a pressure of 5.2 MPa at a temperature of 160°C for 5 minutes to a target thickness of 1.0 cm. Figure 1 illustrates the panel configurations of the samples. Specimens were conditioned in a climate-controlled room at a temperature of 20°C and a relative humidity of 65 percent for approximately 10 days before bending, internal bond (IB) strength, dimensional stability, and surface roughness tests were carried out. Modulus of elasticity (MOE) and modulus of rupture (MOR) of the samples were determined on an Instron Testing Machine Model-22, 550-R, equipped with a 2,500-kg load cell. Five specimens from each panel were cut for each type of test stated above. Thickness swelling (TS) of the panels was also evaluated after 2 hours of water soaking. Mechanical and dimensional stability tests were carried out according to Japanese Industrial Standard (JIS) A-5908 (JIS 1995). Formaldehyde emission of the panels was also determined using the perforator method based on the European Committee for Standardization (EN 1993) procedure.

Surface roughness of the panels was measured on TS samples prior to being soaked in water. Five measurements were taken from each sample with a tracing span of 12 mm using a Hommel T-500 stylus unit. Two roughness parameters—average roughness (R_a) and mean peak-to-

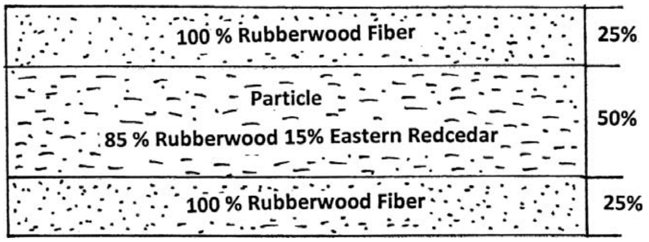

Figure 1.—Configuration of the samples.

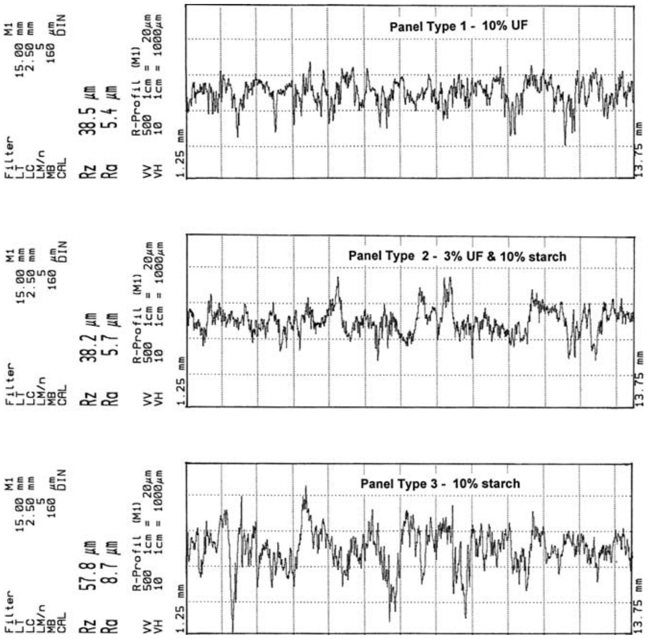

Figure 2.—Typical roughness profiles of the samples.

valley height (R_z)—were used to evaluate the surface quality of the samples. Definitions and specifications of these parameters have been discussed in past studies (American National Standards Institute [ANSI] 1985, Mummery 1993, Hiziroglu 1996). Figure 2 illustrates typical surface profiles of the samples.

Results and Discussion

Table 1 displays the physical and mechanical properties of the samples made from rubberwood and Eastern redcedar raw material. The highest MOE and MOR values of 2,990 and 34.72 MPa, respectively, were found for the panels having a density of 0.75 g/cm^3 made with 10 percent urea-formaldehyde as a binder. Panels with 0.65 g/cm^3 made using 10 percent cassava starch resulted in the lowest corresponding values of 746 and 3.81 MPa, respectively. It appears that panels having only starch as a binder resulted in relatively lower bending characteristics than those samples made using urea-formaldehyde resin. The MOE of starch-bonded panels with a density of 0.75 g/cm^3 was 1,358 MPa, as shown in Figure 3. The value of 13.03 MPa is the minimum requirement for MOR of interior-grade particleboard panels for general use according to JIS A-5908 (JIS 1995; Fig. 4). Panels made with only 10 percent cassava starch at both density levels did not meet such a standard. However, other panels, including having a combination of 3 percent urea-formaldehyde resin and 10 percent cassava starch as a binder, satisfied JIS requirements regarding their bending properties.

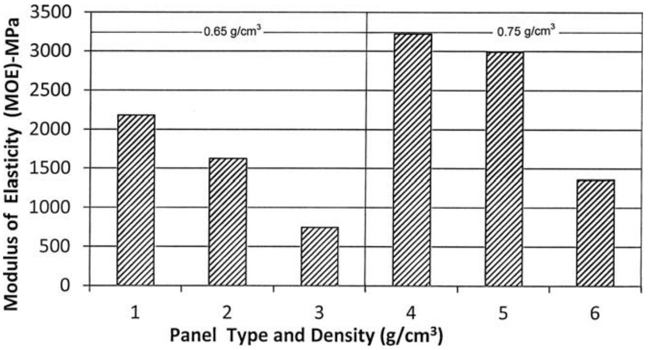

Figure 3.—Modulus of elasticity values of the samples.1 and 4 = 10 percent urea-formaldehyde; 2 and 5 = 3 percent urea-formaldehyde plus 10 percent starch; 3 and 6 = 10 percent starch.

It seems that having 15 percent Eastern redcedar particles in the core layer of the panels did not have any adverse influence on either the MOE or the MOR values of the panels. Both the MOE and the MOR values of the samples made with two density levels showed a significant difference at the 95 percent confidence level based on the *t* test. It is a well-known fact that bending properties of wood composites are strongly related to their density (Maloney 1993). Such a finding was also supported by IB strength characteristics of the samples having a density of 0.65 g/cm^3, which resulted in lower IB values, as can be seen in Figure 5. Starch-bonded samples had an average IB value of 0.13 MPa. However, when 3 percent urea-formaldehyde was added along with 10 percent starch, it was increased by 50 percent, to 0.27 MPa. It is clear that using only starch did not produce panels with acceptable mechanical properties. Average TS of the samples after 2 hours of water soaking and water absorption ranged from 21.09 to 164.39 percent and from 77.09 to 256.46 percent, respectively. Panels manufactured using starch as a binder had extremely low dimensional stability, as illustrated in

Table 1.—Test results of the samples.[a]

Panel type	Binder type	Density (g/cm^3)	MOE (MPa)	MOR (MPa)	IB (MPa)	TS (%)	WA (%)	Roughness parameters (µm)		Formaldehyde emission (per 100 g)
								R_a	R_z	
1	10% UF	0.65	2,183 (15.1)	23.50 (10.2)	0.98 (14.1)	21.09 (11.9)	77.09 (10.4)	5.15 (8.9)	39.56 (6.8)	20
2	3% UF+10% starch	0.65	1,625 (14.9)	13.59 (10.9)	0.29 (13.2)	41.58 (11.6)	118.82 (15.3)	6.05 (7.7)	45.75 (8.3)	10
3	10% starch	0.65	746 (13.2)	3.81 (11.1)	0.20 (12.4)	157.04 (11.9)	278.79 (15.9)	8.93 (10.1)	60.53 (7.6)	0
4	10% UF	0.75	2,990 (14.7)	34.72 (12.2)	1.09 (13.5)	23.35 (12.0)	69.34 (9.1)	5.02 (10.9)	38.91 (8.1)	20
5	3% UF+10% starch	0.75	2,320 (14.8)	20.71 (12.8)	0.25 (12.9)	48.20 (12.8)	94.31 (12.2)	5.63 (9.7)	44.83 (6.3)	10
6	10% starch	0.75	1,358 (14.4)	8.67 (10.1)	0.07 (11.7)	164.39 (14.2)	256.46 (15.6)	9.03 (9.9)	59.59 (7.6)	0

[a] MOE = modulus of elasticity; MOR = modulus of rupture; IB = internal bond; TS = thickness swelling; WA = water absorption; R_a = average roughness; R_z = mean peak-to-valley height; UF = urea-formaldehyde. Numbers in parentheses are coefficients of variation values.

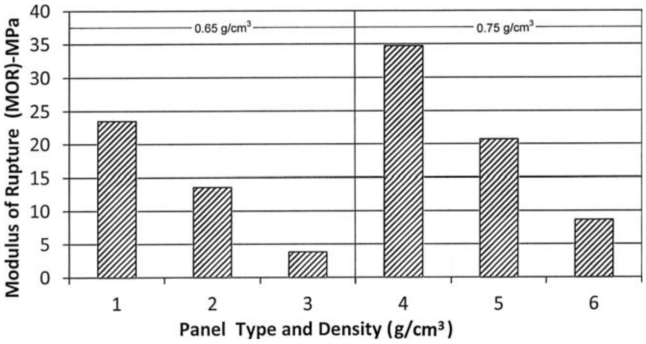

Figure 4.—Modulus of rupture values of the samples. 1 and 4 = 10 percent urea-formaldehyde; 2 and 5 = 3 percent urea-formaldehyde plus 10 percent starch; 3 and 6 = 10 percent starch.

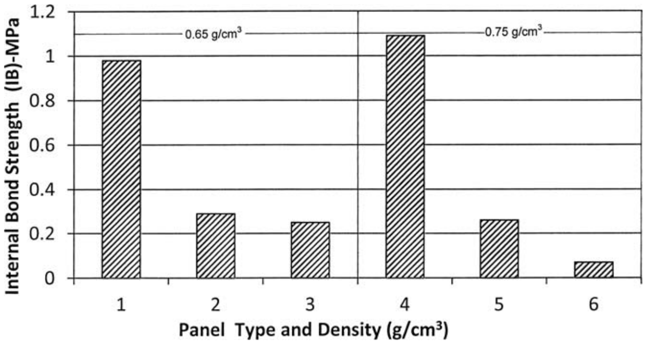

Figure 5.—Internal bond strength values of the samples. 1 and 4 = 10 percent urea-formaldehyde; 2 and 5 = 3 percent urea-formaldehyde plus 10 percent starch; 3 and 6 = 10 percent starch.

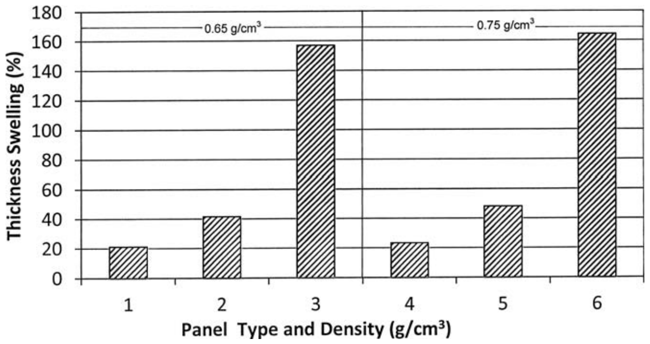

Figure 6.—Thickness swelling values of the samples. 1 and 4 = 10 percent urea-formaldehyde; 2 and 5 = 3 percent urea-formaldehyde plus 10 percent starch; 3 and 6 = 10 percent starch.

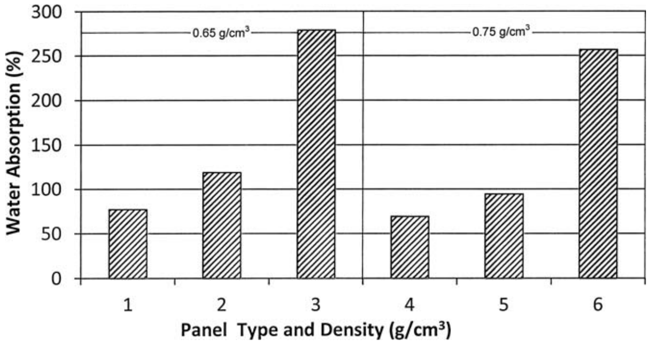

Figure 7.—Water absorption of the samples. 1 and 4 = 10 percent urea-formaldehyde; 2 and 5 = 3 percent urea-formaldehyde plus 10 percent starch; 3 and 6 = 10 percent starch.

Figures 6 and 7. The addition of 3 percent urea-formaldehyde in the panels significantly improved dimensional stability. In a previous work, it was found that TS of sandwich-type panels made with 8 percent urea-formaldehyde on the face layers and particle in the core resulted in 24.78 percent TS, which is comparable to that determined in the current work. It should be noted that only 1.5 percent wax was used in the panels; if a higher amount of wax had been used, the dimensional stability of the panels would probably have been enhanced.

As shown in Table 1, panels made with 10 percent urea-formaldehyde resin had the smoothest surface with an average R_a value of 5.08 μm followed by those made with a combination of urea-formaldehyde resin and starch as the adhesive with a value of 5.84 μm. A significant difference was found in surface roughness between these two types of samples. Using only starch as a binder adversely influenced the surface quality of the panel, resulting in higher R_a values. It appears that starch did not create a high level of densification on the face layers in contrast to those manufactured with urea-formaldehyde resin. Average roughness values of commercially manufactured Thai medium-density fiberboard ranged from 3.8 to 5.80 μm based on the finding of previous work (Hiziroglu et al. 2004). Experimental fiberboard made from bamboo and rice straw had R_a values of 5.08 μm (Hiziroglu et al. 2005). No sanding or any finishing was applied to the surface of the samples. If sanding were applied, the surface quality of the panels would be enhanced. Average formaldehyde emission values of the panels were 20 and 10 mg per 100 g for the control panels made with 10 percent urea formaldehyde and for panels made with a mixture of 3 percent urea-formaldehyde and 10 percent starch, respectively. It is clear that starch-based samples had much lower formaldehyde emission values. All these values were within the limit of the E2 emission class (Roffael 1993, Nihat and Nilgun 2002, Moubarik et al. 2010). In further studies that use wax or the application of certain treatments such as steam or heat to the raw material in addition to modifying the manufacturing parameters, the press cycle could be considered to reduce the negative effect of starch-based adhesives on overall panel characteristics.

Conclusions

Particles and fibers from rubberwood and Eastern redcedar were used to manufacture experimental sandwich-type particleboard panels. It appears that using starch as a binder reduced both mechanical and physical properties of the panels as compared with those of the control panels. As can be expected, formaldehyde emission was lower for the samples made with 3 percent urea-formaldehyde resin. Density of the panels was the main parameter influencing the mechanical properties of the samples. Using Eastern redcedar did not have any adverse effect compared with the experimental panels made from other species and cited in previous works. Using fibers on the face layer resulted in a smooth surface that would be ideal for overlaying as substrate.

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