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MECHANICAL AND PHYSICAL PROPERTIES OF OIL PALM TRUNK CORE PARTICLEBOARD BONDED WITH DIFFERENT UF RESINS

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ABSTRACT

Rapid price increases and reduction in the supply of rubberwood has forced the particleboard manufacturers to look for new alternative raw materials. The production of particleboard from other wood species will be a good solution to the problem of depleting wood supplies. The objective of this study was to evaluate the properties of particleboard made from rubberwood and oil palm trunk pressed at different temperatures and times compared to particleboards made from single species. Two types of UF resins (E1 resin and SE0 resin) were applied in this study. The effect of surface-to-core ratio was also examined in this study. The modulus of rupture, internal bond strength and thickness swelling of the boards were evaluated based on the Japanese Industrial Standard for particleboard (JIS A 5908:2003). After evaluation, the panels produced are a potential substitute to the panels made from pure rubberwood.

Keywords: thickness swelling, mechanical properties, physical properties, oil palm trunk, urea formaldehyde resin, rubberwood.

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INTRODUCTION

Rubberwood is a very important material for the Malaysian furniture industry. Traditionally, rubberwood has been the main raw material used for particleboard production as it is a favourable medium-density hardwood and is of a natural light colour (Balsiger *et al.*, 2000). Rubberwood serves as a substitute for certain tropical hardwoods that now risk depletion. As the growth of the rubber trees is relatively rapid, and as they are comparatively inexpensive to cultivate they represent an economically sustainable resource that can be a viable alternative to the increasingly rare tropical timbers. During the 1970s and 1980s, the supply of rubber as a raw material was in abundance, and this could be attributed to the success of particleboard in the wood-based industry in Malaysia (Rahman, 2002). However, since oil palm provides a higher rate of return than rubber and requires a lower labour input, concerns related to the long-term sustainability of the entire rubber and rubberwood-based furniture industry arise from the conversion of rubber plantations to oil palm.

As the supply of rubberwood for particleboard production is fast declining, the use of oil palm trunk as a source of raw material for particleboard processing becomes an interesting alternative. Oil palm trunks can be considered as a substitute for rubberwood due to the increasing land area of oil palm plantations in Malaysia. The oil palm trunk is a lignocellulosic material rich in carbohydrates in the form of starch and sugar and contains cellulose, hemicelluloses and lignin (Murai *et al.*, 2009). It is abundant as waste material in replanting sites in Malaysia as well as in many parts of South-east Asia (Sreekala *et al.*, 1997). Large quantities of these waste

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materials are not utilised. At least 30 million tonnes of residues in the form of trunks, fronds, empty fruit bunches and leaves are generated by the oil palm industry every year (Sumathi *et al*., 2008). These residues can be effectively utilised to produce value-added composite panels similar to rubberwood.

However, research findings related to the properties of particleboards produced by oil palm trunk are scarce. The suitability of oil palm trunks as materials to produce particleboard is still under investigation. In addition, the application of mixed wood species for particleboard production is not common in Peninsular Malaysia (Loh *et al*., 2010). As such, a study was conducted to compare the properties of particleboard made from rubberwood and oil palm particles. In this study, the oil palm particles were only used as core layers, while the surface layers were stuck to rubberwood particles.

As pressing temperature is one of the most important manufacturing parameters that influences board properties, this study therefore evaluated the properties of particleboard made from mixed species pressed at different temperatures and times which were compared to particleboards made from single species. The physical and mechanical properties of the panels, including modulus of rupture (MOR), internal bond (IB) strength and thickness swelling (TS) were also evaluated.

MATERIALS AND METHODS

Rubberwood (*Hevea brasiliensis*) particles were obtained from a commercial particleboard plant located in Negeri Sembilan, Malaysia, while the oil palm particles were obtained from the fell off oil palm trunk. The oil palm trunks were chipped to the desired particle sizes. Both types of particles were dried to 3% moisture content prior to the particleboard fabrication. The dried rubberwood particles were used as surface layers, while the oil palm particles were used as core layer.

Low formaldehyde to urea ratio (F/U), urea formaldehyde [Super E0 (SE0)], RD 100 and E1 UF resin, RD110 from NorseChem Resins Sdn Bhd were used in the study. The solid content of these resins ranged from 60%-65%. The wax applied was in the form of emulsion with 60% solid content that was obtained from a commercial particleboard plant. Ammonium chloride (NH_4Cl) with 25% solid content was used as a hardener.

Three layered boards were fabricated from an admixture of rubberwood and oil palm particles by using both E1 and SE0 resins. The oil palm particles were used as a core layer. Panels of 340 mm long x 340 mm wide x 12 mm thick at a targeted density of 680 kg m^{-3} were made with both types of UF resins with a solid content range from 60%-65%. A resin dosage of 7% and 10% for core and surface layer was selected respectively for both types of the UF resins. The 1% hardener used in the glue mix for the surface layer, while 3.8% was used in the glue mix for the core layer for each panel.

The effect of surface-to-core ratio (S:C) on the mechanical and physical properties of particleboard were studied. Five different surface-to-core ratios which are 30% surface:70% core (3:7); 40% surface:60% core (4:6); 50% surface:50% core (5:5); 60% surface:40% core (6:4) and 70% surface:30% core (7:3) based on dry particle weight, were selected as the parameters for the particleboard fabrication process.

To examine the effect of pressing temperature and time on the particleboard, particleboard made with both resins were pressed under three different pressing temperature levels (170°C, 180°C and 190°C). For every temperature level, the particleboards were pressed for 210 s, 270 s and 330 s, respectively. Three layered boards were fabricated with a s:c of 60% surface and 40% core. *Table 1* shows the experimental parameters for the study. A set of pure rubberwood particleboards using RD100 resin was made under the same pressing temperature and time for comparison purpose. All the panels were pressed with 100 bar pressure.

After pressing, the boards were conditioned for seven days at a temperature of 20°C±2°C and relative humidity of 65%±5% prior to physical and mechanical properties determination. Properties of the panels such as bending strength, TS and IB strength were tested according to JIS A 5908.

All data were statistically analysed by using one-way ANOVA analysis and the mean of each value was compared by using the Tukey test to determine the differences between treatment levels.

RESULTS AND DISCUSSION

Effect of Surface-to-core Ratio (S:C) to Mechanical and Physical Properties

Tables 2 and *3* show the results of tested particleboard made with both types of UF resins. The MOR for E1 resin and SE0 resin ranged from 13.81 N mm^{-2} to 16.04 N mm^{-2} and 7.48 N mm^{-2} to 12.02 N mm^{-2}, respectively. Particleboard bonded with E1 resin achieved the minimum requirement of bending strength (13.00 N mm^{-2}) according to JIS A 5908:2003, while the particleboard made with SE0 failed to meet JIS requirement. All the particleboards fabricated achieved the minimum internal bond (0.2 N mm^{-2}) requirement according to JIS A 5908:2003. TS of all the particleboards ranged from 16.04% to 32.71% where the maximum TS allowed is 12% according to JIS A 5908:2003. However, heat treatment of 180°C

TABLE 1. EXPERIMENTAL PARAMETERS FOR THE STUDY

Resin type	Panels	Pressing temperature (°C)	Pressing time (s)
E1	E1	170	210
	E2		270
	E3		330
	E4	180	210
	E5		270
	E6		330
	E7	190	210
	E8		270
	E9		330
SE0	S1	170	210
	S2		270
	S3		330
	S4	180	210
	S5		270
	S6		330
	S7	190	210
	S8		270
	S9		330

TABLE 2. MECHANICAL PROPERTIES AND THICKNESS SWELLING OF E1 PARTICLEBOARD

Treatment	MOR (N mm^{-2})	IB (N mm^{-2})	TS (%)
E3:7	13.81(2.78)[a]	0.87 (0.14)[a]	29.35 (1.95)[b]
E4:6	14.52 (3.19)[a]	0.99 (0.32)[a]	19.92 (2.32)[a]
E5:5	14.74 (1.48)[a]	1.07 (0.34)[a]	19.67 (2.21)[a]
E6:4	15.51 (1.18)[a]	1.32 (0.23)[a]	18.57 (1.46)[a]
E7:3	16.04 (3.56)[a]	1.49 (0.28)[a]	16.04 (0.88)[a]

Note: *Within the same column, means values followed by different letters are significantly different at $P<0.05$.
**Values in parentheses are standard deviations.
***MOR: modulus of rupture, IB: internal bond strength, TS: thickness swelling.

can help to reduce the TS of particleboards to meet the required standard besides increasing the board durability against termite attacks (H'ng *et al*., 2012; Lee *et al*., 2013).

In general, no significant differences were detected for the different S:C ratios. However, the lowest s:c ratio of E3:7 and S3:7 had a higher TS value than the other ratios. Higher core particles used would result in higher TS values. Nemli (2003) suggested that increasing the S:C ratio improves the physical and mechanical properties of the particleboard. The particleboard with a higher ratio of surface particles has better TS compared to the particleboard with a higher ratio of core particles. Wood dust addition of about 10% to particles improved TS. The dust and thin particles filled the holes and increased the connection between the particles. For this reason, wood dust usage decreased TS (Nemli, 2003; Lum *et al*., 2014).

The particleboard with a higher ratio of fine particles significantly had a higher MOR compared to the particleboard with a higher ratio of core particles. The decreasing static bending and modulus of elasticity may be due to the small dimensions of the wood dust (Kolman, 1975). Nemli *et al.* (2004) found that particleboards produced with a higher surface ratio had higher density values than those of the panels produced with lower surface ratios. This may be due to a high degree of compression during pressing, which may be related to the high pressure level and amount of thin particles.

TABLE 3. MECHANICAL PROPERTIES AND THICKNESS SWELLING OF SE0 PARTICLEBOARD

Treatment	MOR (N mm^{-2})	IB (N mm^{-2})	TS (%)
S3:7	7.48 (2.22)^{a}	0.53 (0.22)^{a}	32.71 (2.02)^{b}
S4:6	9.78 (1.14)^{a}	0.61 (0.33)^{a}	26.05 (2.15)^{a}
S5:5	10.56 (1.57)^{ab}	0.69 (0.28)^{a}	24.59 (2.28)^{a}
S6:4	11.76 (1.31)^{ab}	0.72 (0.39)^{a}	23.88 (2.27)^{a}
S7:3	12.02 (1.92)^{b}	0.78 (0.15)^{a}	24.42 (1.44)^{a}

Note: *Within the same column, means values followed by different letters are significantly different at P<0.05.
**Values in parentheses are standard deviations.
***MOR: modulus of rupture, IB: internal bond strength, TS: thickness swelling.

Effect of Pressing Time and Temperature to Mechanical and Physical Properties

Tables 4 and *5* show the mechanical properties and TS of the panels manufactured with different pressing temperatures and time. The Japanese Industrial Standard JIS A 5908:2003 required minimum MOR and IB values of 13.00 N mm^{-2} and 0.2 N mm^{-2}, respectively. All of the panels made with E1 resin met the requirement of the JIS standard for the IB strength. Some of the panels bonded with SE0 resin failed to meet MOR requirements. The requirements for TS according to JIS A 5908:2003 must not exceed 12%, all the panels produced failed to comply with JIS A 5908. H'ng *et al*. (2011) stated that all the properties of the particleboard produced with pure urea formaldehyde resin complied with JIS A 5908 except for TS. The panels made with E1 resin have better TS than the panels made with SE0 resin. The poor TS performance by low F/U ratio resin may be due to the existing amino methylene linkages in resins, as the resins are not resistant to the water. As the F/U ratio reduces, the resin is more susceptible to moisture and undergoes decomposition with the effect of water absorption of particles (Jackh, 1993).

Table 6 shows the MOR, IB strength and TS of pure rubberwood panels bonded with SE0 resin. As shown in *Table 6*, the particleboards produced from pure rubberwood have slightly better MOR and TS than the particleboards produced from the admixture of oil palm and rubberwood. The properties of particleboards made with rubberwood and the oil palm trunk showed a totally different pattern compared to the particleboards made with pure rubberwood.

The particleboard made with rubberwood alone has better MOR properties than the particleboard made with rubberwood and oil palm trunk. For a particleboard made with rubberwood alone, the highest MOR was obtained when the board was pressed for 270 s, with three different pressing temperatures. Under the same pressing temperature, the MOR values increased initially when the board was pressed from 210 s to 270 s, and then degraded when the pressing time increased to 330 s. This phenomenon suggests that 270 s is ideal for the resin to fully cure, while any extension of the pressing time causes the resin to overcure and begin to degrade. Ashori and Nourbakhsh (2008) found that the mechanical properties of particleboard, pressed at 160°C, were degraded when the press time increased from 300 s to 360 s. On the other hand, the particleboard made with rubberwood and oil palm trunk showed more or less the same pattern as the boards made with homogenous species, except that its best MOR value was recorded when it was pressed at 190°C. This may have been caused by the heat transfer in the core layer of rubberwood, which was more rapid than oil palm trunk (Moslemi, 1974), and which caused a delay in the resin curing time in the particleboard made with rubberwood and oil palm trunk.

For the particleboard made with rubberwood alone, the IB values increased initially and decreased along with the prolonged pressing time. Nevertheless, the IB values of the particleboard made with rubberwood and the oil palm trunk showed a completely different pattern. The IB values increased continuously and reached its peak when the temperature of 190°C for 270 s was applied.

Higher TS of particleboard made from rubberwood and oil palm trunk was expected, and was probably due to oil palm being more hygroscopic compared to rubberwood (Sulaiman *et al*., 2009). The TS values of the particleboard made with rubberwood alone started to increase when subjected to longer press time (330 s) and

TABLE 4. MECHANICAL PROPERTIES AND THICKNESS SWELLING OF PANELS MADE WITH E1 RESIN

Type	MOR ($N\ mm^{-2}$)	IB ($N\ mm^{-2}$)	TS (%)
E1	13.50 (3.31)[a]	0.98 (0.24)[a]	17.15 (3.09)[ab]
E2	13.81 (1.80)[a]	1.02 (0.22)[a]	18.57 (1.35)[b]
E3	14.89 (0.98)[a]	1.04 (0.22)[a]	16.57 (1.39)[ab]
E4	15.38 (0.61)[a]	1.22 (0.54)[a]	15.89 (2.04)[ab]
E5	16.95 (1.62)[a]	1.07 (0.35)[a]	15.63 (0.55)[ab]
E6	15.65 (1.06)[a]	1.36 (0.51)[a]	15.36 (0.33)[ab]
E7	15.30 (4.13)[a]	1.01 (0.16)[a]	14.98 (1.37)[a]
E8	17.49 (3.48)[a]	1.30 (0.31)[a]	14.98 (1.37)[a]
E9	14.94 (3.48)[a]	1.33 (0.35)[a]	14.48 (1.49)[a]

Note: *Within the same column, means values followed by different letters are significantly different at P<0.05.
**Values in parentheses are standard deviations.
***MOR: modulus of rupture, IB: internal bond strength, TS: thickness swelling.

TABLE 5. MECHANICAL PROPERTIES AND THICKNESS SWELLING OF PANELS MADE WITH SE0 RESIN

Type	MOR ($N\ mm^{-2}$)	IB ($N\ mm^{-2}$)	TS (%)
S1	8.43 (1.49)[b]	0.53 (0.13)[b]	23.74 (3.86)[b]
S2	10.60 (1.91)[ab]	0.73 (0.31)[ab]	23.89 (5.25)[b]
S3	11.88 (1.60)[ab]	0.99 (0.33)[a]	21.88 (2.35)[ab]
S4	13.83 (2.06)[a]	0.79 (0.22)[ab]	20.76 (4.42)[ab]
S5	14.13 (2.90)[a]	1.13 (0.47)[a]	19.21 (1.48)[ab]
S6	14.17 (2.67)[a]	1.20 (0.29)[a]	17.35 (1.13)[ab]
S7	13.13 (3.28)[a]	0.79 (0.26)[ab]	16.01 (1.90)[ab]
S8	14.32 (0.92)[a]	0.95 (0.27)[a]	14.71 (0.53)[a]
S9	12.82 (1.39)[a]	0.68 (0.16)[ab]	16.97 (2.36)[ab]

Note: *Within the same column, means values followed by different letters are significantly different at P<0.05.
**Values in parentheses are standard deviations.
***MOR: modulus of rupture, IB: internal bond strength, TS: thickness swelling.

higher temperature (190°C). This suggested that the strength loss was due to resin overcure. However, particleboards made with rubberwood and oil palm trunks showed better TS values when pressed at a higher temperature (190°C). In this study, oil palm trunk particles had higher particles surface areas, thus requiring a greater pressing temperature or time to ensure better particle-particle contact.

CONCLUSION

The S:C ratio exerted considerable influence on the particleboards produced with both resins. Pressing time and temperature also are extremely important parameters in particleboard manufacturing and have to be carefully controlled without subjecting the board surface to a high and degradative temperature. Generally, particleboards made with rubberwood particles alone have better properties than particleboards made with rubberwood and oil palm trunk. Nevertheless, particleboards produced by the combination of rubberwood and oil palm trunk still can be considered as a potential solution to replace the particleboard made with pure rubberwood, on condition that the processing parameters mentioned above are manipulated carefully.

TABLE 6. MECHANICAL PROPERTIES AND THICKNESS SWELLING OF PANELS MADE OF 100% RUBBERWOOD USING SE0 RESIN

Type	MOR (N mm^{-2})	IB (N mm^{-2})	TS (%)
1	12.19 (0.60)^{b}	0.83 (0.16)^{ab}	16.91 (2.08)^{ab}
2	15.69 (1.39)^{a}	0.94 (0.26)^{a}	16.69 (1.67)^{ab}
3	14.76 (0.92)^{ab}	0.52 (0.06)^{b}	17.84 (2.06)^{ab}
4	13.32 (0.56)^{ab}	0.87 (0.22)^{a}	16.68 (1.37)^{ab}
5	17.63 (0.96)^{a}	1.20 (0.33)^{a}	14.49 (2.03)^{a}
6	13.77 (0.19)^{ab}	0.61 (0.11)^{b}	16.30 (1.98)^{ab}
7	14.87 (0.97)^{ab}	0.62 (0.13)^{b}	19.99 (1.08)^{bc}
8	16.48 (2.12)^{a}	0.98 (0.21)^{a}	18.72 (1.77)^{ab}
9	12.75 (0.87)^{b}	0.84 (0.14)^{ab}	23.43 (4.63)^{c}

Note: *Within the same column, means values followed by different letters are significantly different at $P<0.05$.
**Values in parentheses are standard deviations.
***MOR: modulus of rupture, IB: internal bond strength, TS: thickness swelling.

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