PROPERTIES OF PARTICLEBOARD WITH OIL PALM TRUNK AS CORE LAYER IN COMPARISON TO THREE-LAYER RUBBERWOOD PARTICLEBOARD

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ABSTRACT

Compaction ratio is highly dependent on the density of the wood materials used in the production of particleboard. Lower density wood materials will produce particleboard with higher compaction ratio and is believed to give better properties. The objective of this study was to evaluate the properties of three-layer particleboard made from rubberwood and oil palm trunk with different bulk density as the core layer, while the rubberwood fine particles served as surface layers for both types of particleboard. This study also investigated the effect of shelling ratios on the mechanical and physical properties of the three-layer particleboard. Melamine-fortified urea formaldehyde (UF) resin was used as the binder. The modulus of rupture (MOR), internal bond strength (IB) and thickness swelling (TS) of the particleboards were evaluated based on the Japanese Industrial Standard for particleboard (JIS A 5908:2003). The results showed that both species and shelling ratios are variables that influenced the mechanical and physical properties of the particleboard. Despite its lower compaction ratio, particleboard made from rubberwood alone had better strength properties and dimensional stability than particleboard made from a mixture of rubberwood and oil palm trunk.

Keywords: oil palm trunk, rubberwood, shelling ratio, compaction ratio, slenderness ratio.

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INTRODUCTION

Rubberwood [*Hevea brasiliensis* (Willd. ex. Adr. de Juss) Muell. Arg] is a major raw material for particleboard production and manufacturing in Malaysia (H'ng *et al*., 2012). But, rubberwood is facing depletion as the total area planted with rubber has been decreasing (Ratnasingam *et al*., 2011). Shortage of rubberwood forces the manufacturers to find alternative raw materials for the particleboard production. The manufacturers are shifting their attention to oil palm.

According to the Malaysian Palm Oil Board (2012), oil palm (*Elaeis guineensis* Jacq.) plantation makes up 77% of the agricultural land in Malaysia. In other words, the oil palm plantations cover about 15% of the total land area of Malaysia. In 2013, due to the newly planted areas in Sarawak, the total oil palm planted areas in Malaysia reached 5.23 million hectares, an increase of 3.0% against 5.08 million hectares recorded in the previous year (MPOB, 2013). As the world second largest producer of palm oil, Malaysia produced 18.79 million tonnes

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of crude palm oil in 2012 on 5 million hectares of land (Ahmad, 2013). Nevertheless, crude palm oil (CPO) and its economic co-products constitute only 10% of the crop, leaving the rest of the biomass as waste. Annually, the oil palm industry generates a substantial amount of at least 30 million tonnes of underutilised residues in the form of trunks, fronds, and empty fruit bunches (Khalil *et al*., 2006). In terms of environmental and socio-economic aspects, it will be beneficial to fully utilise these wastes.

Oil palm contains lignocellulosic materials (Akmar and Kennedy, 2001) which are suitable for producing value-added composite panels. For example, fibres from empty fruit bunches have been used to produce particleboards (Zaidon *et al*., 2007). Due to the high percentage of soft parenchyma tissues in the central region, only the outer part of the oil palm trunk is used in the production of lumber (Loh *et al*., 2011). However, only approximately 30% of the stem radius (outer part) could be used as lumber, the other 70% (inner part) is waste (Bakar *et al*., 2006). These values show that the trunk itself has a great potential to be a source of alternative raw material for particleboard manufacture. Nonetheless, oil palm trunk has not yet been used effectively in particleboard fabrication (Thanate *et al*., 2006) compared to rubberwood which have been studied by a number of researchers (H'ng *et al*., 2011). Hence, the knowledge on the properties of particleboard made from oil palm trunk is still very scarce.

Oil palm trunk has a lower density than rubberwood; this can promote a better compaction ratio for the particleboard. Compaction ratio is calculated by dividing the density of the board by the density of the wood materials. Theoretically, the lower the density of wood materials, the higher is the compaction ratio. Particleboard with higher compaction ratio has been recorded to have better strength properties (Vital *et al*., 1974). To find out the validity of the theory, a study was conducted to compare the properties of particleboard made from rubberwood and oil palm trunk particles in terms of compaction ratio and the slenderness ratio.

MATERIALS AND METHODS

Rubberwood [*Hevea brasiliensis* (Willd. ex. Adr. de Juss) Muell. Arg] particles were obtained from a commercial plant located in Gemas, Negeri Sembilan, Malaysia. The rubberwood particles consisted of core flakes and fine particles. The oil palm trunk core particles were collected from felled oil palm which were later chipped into the required size. The classification of the particle dimensions is shown in *Table 1*. The particles were kept in plastic bags, and stored in the conditioning room with relative humidity of 65% ± 5% and temperature of 20°C ± 2°C. This is to stabilise the moisture content (MC) of these particles before the production of particleboard.

TABLE 1. CLASSIFICATION OF PARTICLES

Range of particle dimensions	Surface (mm)	Core (mm)	
		Rubberwood	Oil palm trunk
Length	0.5-1.0	10.0-30.0	20.0-40.0
Width	1.0-2.0	2.0-4.0	2.0-4.0
Thickness	0.3-0.5	0.2-0.4	0.2-0.3

Table 2 shows the bulk density (BD) of particles used in this study. The bulk density of particles was measured by the cylinder method. A certain weight of wood particles (mass) was measured and put into a graduated cylinder half-filled with water. The increase in the volume of water was recorded. The final density of the particles was obtained by dividing the mass with the volume. The average bulk density of rubberwood fine particles is 620 kg m^{-3} and core particles, 560 kg m^{-3}. The average density of the oil palm trunk particles is 440 kg m^{-3}. This density was then used to determine the compaction ratio of the particleboard produced in this study.

TABLE 2. AVERAGE BULK DENSITY OF RUBBERWOOD AND OIL PALM TRUNK PARTICLES

Particles type	Average density (kg m^{-3})
Rubberwood fine particles	620
Rubberwood core particles	560
Oil palm trunk core particles	440

The slenderness ratio (SR) and surface area per unit weight of the particles used in the core and surface layers were calculated by the simple equation taken from Moslemi (1974) as shown in Equations (1), (2) and (3). The principal dimensional elements of particles of distinct geometry are length (l), width (w) and thickness (t).

$$\text{Slenderness ratio,} \quad s = l \,/\, t \qquad (1)$$

The surface area per unit weight can be calculated. Weight of a flake is calculated as follows:

$$\text{Weight of flake,} \quad W = vg = wltg \qquad (2)$$

where, v = volume
g = density
l = length
t = thickness
w = width

The particles surface area, *a*, is calculated as follows:

Particle surface area, $a = 2(tl + wl + tw)$ (3)

Five different shelling ratios were used to manufacture two types of three-layer particleboard, *i.e*. rubberwood fine particles as surface layers + oil palm trunk coarse particles as core layer (denoted as mixed particleboard), and rubberwood fine particles as surface layers + rubberwood coarse particles as core layer (denoted as rubberwood particleboard). Shelling ratio is a parameter related to the amount of particles used for surface layers compared to the entire board. For example, shelling ratio of 20% means that the board consist of 20% surface particles and 80% core particles. The shelling ratios of 30%, 40%, 50%, 60% and 70% were used in this study. The details of the parameters are shown in *Table 3*.

Melamine-fortified urea formaldehyde (UF) resin was applied, and particleboard was pressed for 270 s at 180°C. The resin dosages for core and surface was 7% and 10% (based on particles oven-dry weight), respectively. Three-layer particleboards with dimensions of 340 mm length x 340 mm width x 12 mm thickness were fabricated. The targeted density of the board was 680 kg m^{-3}. A total of 30 particleboards were produced, with three boards for each ratio. For each type, five test samples were used for evaluation of the physical and mechanical properties.

Following the JIS A 5908 (Japanese Industrial Standard), the test samples were kept in the conditioning room with the relative humidity of 65 ± 5% and the temperature of 20 ± 2°C until a constant weight was reached. This was achieved when the changes of sample mass for two consecutive weighing at 24 hr interval were less than 0.1%. Properties such as thickness swelling (TS), modulus of rupture (MOR) and internal bond strength (IB) were evaluated based on JIS A 5908.

The data were analysed using Statistical Package for the Social Sciences (SPSS) procedure for the analysis of variance (ANOVA) at 95% confident level ($P \leq 0.05$). The two main variables were the species (two levels) and the shelling ratios (five levels). Pearson's correlation was performed to measure of the strength of the association between the two variables.

RESULTS AND DISCUSSION

Table 4 summarises the ANOVA of the dependent (TS, MOR and IB) and independent (shelling ratio and species) variables for the study. From the ANOVA results, there was a highly significant effect of both shelling ratio and species on the physical and mechanical properties of the particleboard.

The distribution of TS values for both types of particleboard is as shown in *Figure 1*. The TS of the particleboards ranged from 14% to 32%; the maximum allowable TS is 12% (dash line) according to JIS A 5908. The particleboard with a higher ratio of surface particles (higher shelling ratio) significantly had better TS compared to the particleboard with higher ratio of core particles (lower shelling ratio). Thin particles filled the voids and promoted the connection between particles, and hence improved the thickness swelling (Lum *et al*., 2014). Rubberwood particleboards significantly had better dimensional stability than mixed particleboard. Oil palm is lighter than rubberwood. For this reason, oil palm occupies a greater volume than the same

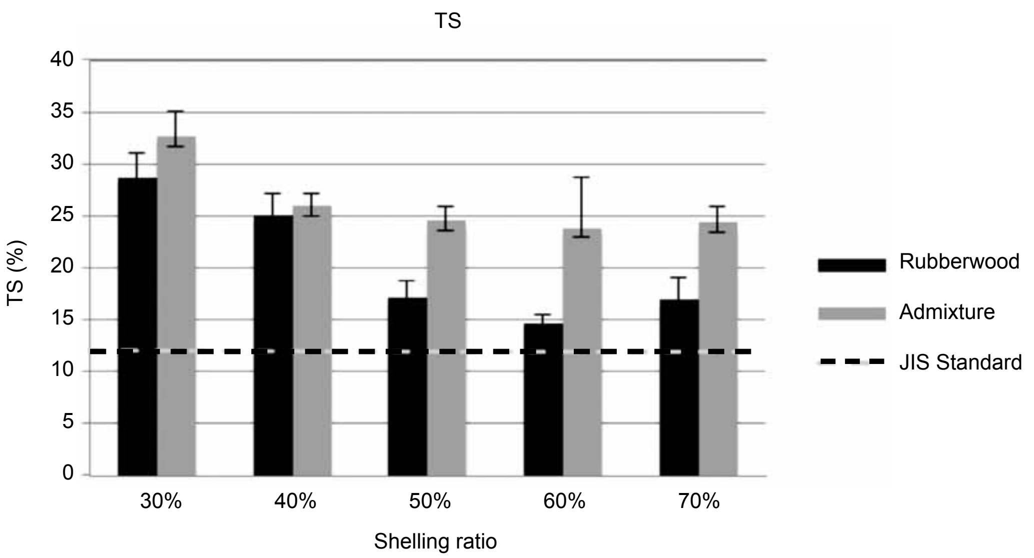

Figure 1. Average thickness swelling (TS) values for both types of particleboard made with different shelling ratios.

TABLE 3. TWO TYPES OF PARTICLEBOARD MADE WITH FIVE DIFFERENT SHELLING RATIOS

	Surface layer (top) (%)	Core layer (middle) (%)	Surface layer (bottom) (%)
	Rubberwood fine particles	Oil palm trunk coarse particles	Rubberwood fine particles
O30	15	70	15
O40	20	60	20
O50	25	50	25
O60	30	40	30
O70	35	30	35
	Rubberwood fine particles	Rubberwood coarse particles	Rubberwood fine particles
R30	15	70	15
R40	20	60	20
R50	25	50	25
R60	30	40	30
R70	35	30	35

TABLE 4. SIGNIFICANT PROBABILITIES FOR STUDIED VARIABLES AND INTERACTION

Source of variation	TS		MOR		IB	
	F-value	Pr>F	F-value	Pr>F	F-value	Pr>F
Shelling ratio	36.145	0.000**	8.392	0.000**	5.682	0.000**
Species	69.565	0.000**	224.543	0.000**	106.561	0.000**
SR* species	4.505	0.004**	0.451	0.771^{ns}	0.49	0.743^{ns}

Note: * Significant at $p \leq 0.05$; ** significant at $p \leq 0.01$; ^{ns} not significant.
TS: thickness swelling, MOR: modulus of rupture, IB: internal bond strength.

weight of similar particles from rubberwood. Rubberwood particleboard contained lower wood per unit volume with the ensuing swelling partially extended into interparticle voids which resulted in less TS.

The distribution of MOR values for both types of particleboard is as shown in *Figure 2*. Particleboard made from rubberwood alone achieved the minimum bending strength (13.00 Nmm^{-2}) according to JIS A 5908. Mixed particleboard showed lower bending strength compared to rubberwood particleboard. From *Figure 2*, mixed particleboard made with 30% shelling ratio failed to meet the JIS requirement. The particleboard with a higher ratio of fine particles significantly had higher MOR compared to the particleboard with higher ratio of core particles. These results are in agreement with the findings of Lum *et al*., (2014). Higher MOR may be caused by the higher density of particleboard produced due to a high degree of compression during pressing related to the high pressure level and the amount of thin particles (Nemli *et al*., 2004).

The distribution of IB values for both types of particleboard is as shown in *Figure 3*. All the particleboards fabricated were able to achieve the minimum internal bond (0.2 Nmm^{-2}) requirement according to JIS 5908. Generally, rubberwood particleboard had higher IB than mixed particleboard. These results were in agreement with the findings of Lee *et al*. (2014). Ashori and Nourbakhsh (2008) stated that low density wood species will gave poor internal bonding strength compared to a higher density wood. The presence of lower density oil palm particles in the core layer caused a significant reduction of IB strength.

Pearson's correlation was performed to measure the strength of the association between the two variables. *Table 5* shows the Pearson's correlation coefficient between shelling ratio and properties of particleboards. For rubberwood particlebord, a strong negative correlation was found between shelling ratio and TS. TS value decreased as the shelling ratio increased from 30% to 70%. For MOR and IB, a strong positive correlation was observed which indicated that the MOR and IB values increased with increasing surface ratios.

For the mixed particleboards, there was a strong positive correlation between shelling ratio and

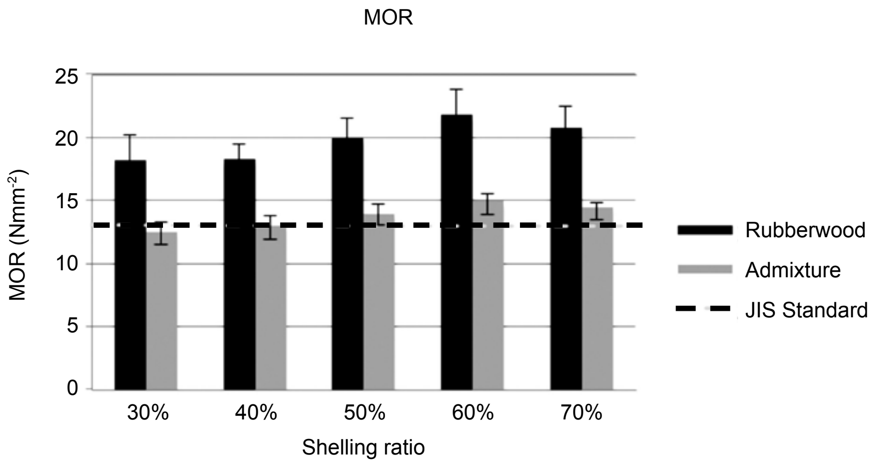

Figure 2. Average modulus of rupture (MOR) values for both types of particleboard made with different shelling ratios.

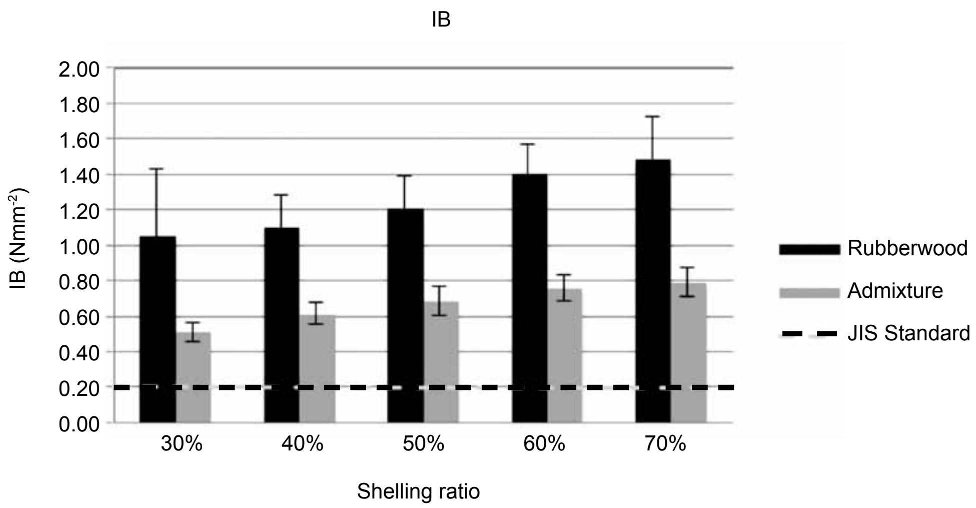

Figure 3. Average internal bond strength (IB) values for both types of particleboard made with different shelling ratios.

TABLE 5. PEARSON'S CORRELATION COEFFICIENT BETWEEN SHELLING RATIO AND PARTICLEBOARD PROPERTIES

	Ratio	TS	MOR	IB
Rubberwood alone	Pearson correlation	-0.839**	0.564**	0.559**
	Sig. (2-tailed)	0.000	0.003	0.004
Rubberwood-oil palm trunk	Pearson correlation	-0.641**	0.759**	0.819**
	Sig. (2-tailed)	0.001	0.003	0.000

Note: * Significant at $p \leq 0.05$; ** significant at $p \leq 0.01$; ^{ns} not significant.
TS: thickness swelling, MOR: modulus of rupture, IB: internal bond strength.

MOR. This means that changes in MOR are strongly correlated with changes in shelling ratio. In this case, the MOR value increased with decreasing ratios of the core particles. Negative correlation also occurred between shelling ratio and TS. A strong positive relationship between shelling ratio and IB was also observed. This means that changes in IB value are strongly correlated with changes in surface and core ratio.

The overall density of the particle mixtures is calculated and listed in *Table 6*. The compaction ratio was calculated based on the density of the board produced and the density of particle mixtures (Hse, 1975). *Table 7* exhibits the compaction ratio for both types of particleboards. From the results, lower compaction ratio was observed in rubberwood particleboard compared to mixed particleboard. This is because the density of rubberwood core particles was higher than the oil palm trunk core particles. As the compaction ratio is determined by dividing the density of the board with the density of the wood materials, a higher density wood material will result in a lower compaction ratio. Heebink and Lehmann (1977) found that the compaction ratio is indirectly proportional to the species density used in the particleboard fabrication. Based on *Figure 2*, particleboard made with shelling ratio of 60% had the highest MOR value. This is due to the particleboard made with this ratio produced the highest compaction ratio (1.20 and 1.25, respectively). Vital *et al.* (1974) found that particleboards from four exotic hardwoods had higher MOR values as the compaction ratio increased from 1.2 to 1.6. They concluded that with the increasing compaction ratio, the bending strength increases as well. Wang and Winistorfer (2001) also reported that the compaction ratio plays an important role in affecting the bending strength. Nevertheless, mixed particleboard with higher compaction ratio did not show better strength properties compared to rubberwood particleboard. This is because oil palm trunk has lower density which causes a high volume per unit weight of oil palm trunk occupying in the core layer. This excessive unit volume inhibited the board from obtaining an adequate compaction ratio in limited pressing time. Hence, although the compaction ratio obtained was higher than rubberwood particleboard, it did not reflect its due strength.

Slenderness ratio and particle surface area for the core particles were determined based on Equations (1), (2) and (3). The results are shown in *Table 8*. Although mixed particleboard obtained higher compaction ratio, better physical and mechanical properties were observed among the rubberwood particleboard. This phenomenon can be explained by higher particle surface area per unit weight of the oil palm trunk particles compared to rubberwood particles. Oil palm trunk particles used in this study were longer and thinner which can be expressed in high slenderness ratio. As the slenderness ratio is the ratio of length over thickness, thus, oil palm trunk particles had higher average slenderness ratio than rubberwood particles in this study (125 and 72.22, respectively). Slenderness ratio is directly proportional to the particle surface area, and hence higher slenderness ratio corresponds to higher particle surface area (Mulik and Fauzi, 2013). For every 100 g of oven-dried particles, oil palm trunk particles were recorded to have 1.07 m^2 surface areas versus 0.72 m^2 for rubberwood particles. In order to obtain adequate bonding, particle surface area per unit weight is an important parameter which must be considered in resin application. Particles possessing greater surface area per unit weight require a higher amount of resin for sufficient coverage compared to particles which do not possess such a high surface area for the same unit weight. In this case, the oil palm trunk particles did not acquire adequate amount of resin coverage which may retard the adequate particle-particle bonding and hence negatively affected the properties of the particleboard.

TABLE 6. OVERALL DENSITY OF WOOD PARTICLE MIXTURES

Surface ratio (%)	Density of fine particles	Core ratio (%)	Density of core particles	*Density of particles mixture
Rubberwood alone				
30	620	70	560	578
40	620	60	560	584
50	620	50	560	590
60	620	40	560	596
70	620	30	560	602
Rubberwood-oil palm trunk				
30	620	70	440	494
40	620	60	440	512
50	620	50	440	530
60	620	40	440	548
70	620	30	440	566

Note: * Density of particles mixture is calculated by (% of surface ratio x density of fine particles) + (% of core ratio x density of core particles).

TABLE 7. COMPACTION RATIO OF DIFFERENT TYPES OF PARTICLEBOARD

Board type	Density of particles mixture	Average density of board	Compaction ratio
	Rubberwood		
R30	578	676.45	1.1703
R40	584	686.13	1.1749
R50	590	703.58	1.1925
R60	596	715.71	1.2009
R70	602	716.56	1.1903
	Rubberwood + OPT		
O30	494	612.55	1.2400
O40	512	635.42	1.2411
O50	530	659.36	1.2441
O60	548	685.63	1.2511
O70	566	689.49	1.2182

Note: OPT - oil palm trunk.

TABLE 8. AVERAGE SLENDERNESS RATIO AND PARTICLE SURFACE AREA FOR RUBBERWOOD AND OIL PALM TRUNK PARTICLES

Species (core particles)	Average slenderness ratio (SR)	Particle surface area per 100 g of oven-dry particles (m^2)
Rubberwood	72.22	0.72
Oil palm trunk	125	1.07

CONCLUSION

From the study, it can be concluded that shelling ratio is an influential parameter for strength properties of particleboard. Generally, particleboard made with rubberwood alone had better strength properties and dimensional stability than particleboard made with rubberwood and oil palm trunk. The result of MOR and IB showed significant interaction with the different shelling ratio applied. Compaction ratio is believed to play an important role in mechanical and physical properties of boards. However, mixed particleboard with higher compaction did not show better strength properties compared to rubberwood particleboard. This phenomenon is due to high volume per unit weight of oil palm trunk occupying in the core layer which inhibited the board from obtaining an adequate compaction ratio in limited pressing time. Because of the high particle surface area per unit weight of the oil palm particles, higher amount of resin for sufficient coverage is required.

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