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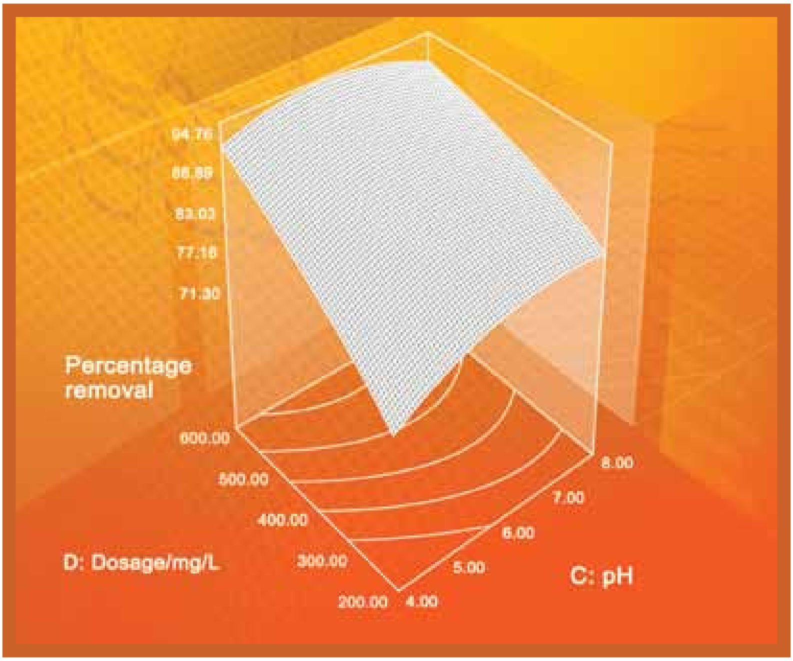

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Effects of Particle Sizes, Resin Content and Board Densities on the Properties of Phenol Formaldehyde Particleboard from Oil Palm Trunk Particles

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ABSTRACT

Twenty five year old oil palm trunk supplied by MPOB, Bangi, Selangor, was converted into strands using a disk flaker and into particles using a dust extractor. Particleboard was produced using phenolic resin at 7, 9 and 11 % compositions based on particle weight used. Particle size varied from 1.0-2.0 mm and the board density varied from 500-700 kg m^{-3}. No significant improvement in MOR, MOE and IB was observed when the particle size was increased from 1.0 to 2.0 mm. However, with larger particle size the water absorption and thickness swelling properties improved. Increasing the resin content from 7-11 % significantly increases the mechanical properties and improves the water absorption and thickness swelling properties. Increasing the board density results in an increase in MOR, MOE and IB and a significant increase in the water absorption and thickness swelling properties. Particleboard with a high board density and resin content of more than 9 % met the minimum British Standard requirements.

Keywords: *Oil palm trunk particles, particleboard properties, resin content, board density, particle size*

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Introduction

Particleboard is one of the oldest composites to be produced and still remains the world's dominant furniture panel and is also used predominately in structural applications. In Malaysia, the most common species used to make particleboard is rubberwood. However the demand for rubberwood is high, especially for solid wood furniture and medium density fiberboard. Due to such high demand, rubberwood resources are now insufficient to satisfy the demand hence there is a real need to source other species to supplement its shortage.

The utilization of oil palm trunk particles as a raw material could solve this problem. On an oil palm plantation, palm trees of 25 years and above are cut down and replaced through replanting. The problem faced by the plantation sector is how to manage the oil palm trunks after cutting them down. If the oil palm trunks are burnt, it will increase air pollution. To reduce palm oil trunk waste, new uses must be found to maximize the utilization of the palm oil trunks. Palm oil trunks could be used to satisfy the demand for raw material in the particleboard industry and thus solve the raw material supply scarcity and provide an opportunity to maximize the use palm oil trees. The objectives of this study are to determine the properties of particleboard constructed from palm oil trunk particles and to study the effect of particle size, resin content and board density on the particleboard properties.

Materials and Methods

Raw Material Preparation

The 25 year old oil palm trunk used in this study was supplied by MPOB, Bangi, Selangor. The bark was removed using a band saw and the trunk was cut into 8 inche long blocks and fed into a Disc Flaker to produce the long strands. The strands were then fed into a dust extractor to reduce the strands into smaller particles. After air drying for about one week, the particles were separated into particle sizes of 1.0 mm and 2.0 mm. The separated particles were then oven dried in an oven for 48 hours at 80 °C to attain a moisture content of about 5 % of dry particle weight. The bulk density of the remaining particles was determined and recorded.

Board Manufacture

Homogenous particleboard was manufactured using phenol formaldehyde resin provided by a local resin company and formulated to commercial standard. The resin specifications are given in Table 1.

Table 1: Specifications of Phenol-Formaldhyde Resin

Property	
Viscosity at 30 °C	0.59 p
pH	12.73
Density at 30 °C	1.187 gcm^{-3}
Solid Content	40.6 %

Particleboards used in this study were produced using particles of size 1.0 mm and 2.0 mm, resin contents of 7, 9 and 11 % and target board densities of 500, 600 and 700 kg m^{-3}. For board manufacture, a weighted amount of particles based on the board density was placed in a HiTech particle glue mixer and sprayed with phenolic resin. The resin was sprayed as a fine mist at an air pressure of about 2.0 MPa to obtain an even distribution of resin over the oil palm particles. After spraying, the particles were then manually laid in a wooden mould over a 35 × 35 cm caul plate and then pre-pressed at 3.5 MPa for 30 seconds. The wooden frame was removed and two 12 mm metal stops were placed near the sides of the consolidated mat before another caul plate was laid on top of it. The consolidated mat was then finally pressed to the required thickness of 12 mm at 165 °C for 6 minutes. The maximum pressure at the metal stops was set at 120 Pascal. A total of two boards were produced for each formulation.

Sample Cutting and Conditioning

All the boards produced were cut according to a cutting plan in order to obtain a random selection of samples from the manufactured board (350 × 350 mm). The sizes of the tests samples are presented in Table 2.

The cut samples were left in a conditioning room with a relative humidity of 65 ± 5 %, a moisture content of below 10 % and at 20 ± 2°C, in accordance with the British Standard Method (BS EN: 1993).

Table 2: Tests Samples Sizes

Property	Sample sizes	No. of test pieces/board
Modulus of rupture	320 × 50 mm	3
Internal bond	50 × 50 mm	5
Thickness swelling	50 × 50 mm	5
Water absorption	50 × 50 mm	5

Board Evaluation

Samples were tested for their mechanical properties namely; modulus of rupture (MOR), modulus of elasticity (MOE) [1], internal bond (IB) [2], dimensional stability [3], water absorption (WA) and thickness swelling (TS). These mechanical tests were conducted using an Instron Universal Testing Machine, Model 4204. The test results were then compared with the mean quality values stated by the British Standards [4].

Results and Discussions

Bulk Density and Particle Analysis

The particle bulk density of the unseparated particles was determined using a 1000ml beaker. The bulk density indicates the suitability of the palm oil particles for use in board manufacture. The particles have a bulk density of 87.05g/l, which implies that a greater quantity of particles would be required to produce particleboard. Using particles with this comparatively low bulk density would decrease the resin spread per unit area and hence the lighter particles would occupy a higher volume at the same weight [5]. Particle size analysis is a necessity in determining the particle size distribution, the mean thickness and particle size to be used in the wood composite. This analysis was performed using an established procedure to estimate the particle geometry of wood in the manufacture of particleboard and particle cement board [6]. The average thickness and length of an oil palm trunk particle is 0.79 and 3.18 mm, respectively.

Mechanical and Physical Properties of Homogenous Particleboard

Table 3 presents the mechanical and physical properties of the oil palm particleboard according to particle size, resin content and board density.

From Table 3, particleboards made from 1 mm particles with 11 % RC at a target density of 700 kg m^{-3} exhibited the highest MOR (11.89 MPa), MOE (1889 MPa) and IB (2.61 MPa) values, and the lowest WA (63.43 %) and TS (10.34 %) values. Among the particleboards having a board density of 500 kg m^{-3}, those composed of 11 % RC, had the highest MOR (21.20 MPa), MOE (3003 MPa) and IB (3.13 MPa) values, and the lowest WA (41.90 %) and TS (10.06 %) values. For boards made at a target density of 600 kg m^{-3}, boards with 11 % RC had the highest value of MOR (21.20 MPa), MOE (3003 MPa), IB (3.13 MPa) while the least value for WA (41.90 %) and TS (10.06 %). Among the particleboard made with 1 mm particles with a target board density of 700 kg m^{-3}, particleboards with a resin content of 11 % showed the highest value of

Table 3: Mechanical and Physical Properties of Homogenous Particleboard

PS (mm)	RC (%)	DEN (Kg/m³)		MOR (MPa)	MOE (MPa)	IB (MPa)	WA (%)	TS (%)
		Target	Actual					
1	7	500	492	7.44	1326	1.41	82.43	18.24
1	9	500	495	10.65	1722	2.22	76.81	14.33
1	11	500	498	11.89	1889	2.61	63.43	10.34
1	7	600	625	12.26	2403	2.18	56.58	23.24
1	9	600	609	18.17	2695	2.53	47.28	15.63
1	11	600	619	21.20	3003	3.13	41.90	10.06
1	7	700	682	13.67	2425	2.01	49.19	23.67
1	9	700	664	17.65	2715	3.31	41.81	11.84
1	11	700	694	22.20	3543	3.80	30.79	9.27
2	7	500	477	8.78	1602	1.74	68.22	16.70
2	9	500	496	10.91	1811	2.08	59.74	14.42
2	11	500	533	13.76	1987	2.27	47.20	11.1
2	7	600	602	12.85	2099	2.23	49.30	16.07
2	9	600	623	16.85	2467	3.01	33.53	9.74
2	11	600	605	22.53	2804	3.21	28.86	9.28
2	7	700	697	15.85	2336	2.20	40.53	17.54
2	9	700	725	18.68	2719	3.05	30.91	11.20
2	11	700	713	23.11	3206	3.28	19.48	6.36
BS EN	312:2003			>15.00	>2050	>0.45	n.a	<14

Notes: PS – Particle size, RC – Resin content, DEN – Board density, MOR – Modulus of Rupture, MOE – Modulus of Elasticity, IB – Internal Bonding, TS – Thickness Swelling and WA – Water Absorption, n.a – not available

MOR (22.20 MPa), MOE (3543MPa), IB (3.80MPa) and lowest in WA (30.79 %) and TS (9.27 %).

For particleboards made from 2.0 mm particles, boards with a target density of 500 kg m^{-3} had the lowest value for MOR (8.78 MPa), MOE (1602 MPa), IB (1.74 MPa), highest value for WA (68.22 %) and TS (16.70 %). The highest value for boards made at 500 kg m^{-3} was shown by boards made with 11 % RC with highest value of MOR (13.76 MPa), MOE 1987 MPa), IB (2.27 MPa), and lowest value in WA (47.20 %) and TS (11.10 %). In general, boards made from 1.0 mm and 2.0 mm particles composed of more than 9 % RC and with a target board density higher than 500 kg m^{-3} are able to attain and surpass the minimum requirements of British Standards for general boards.

Statistical Significance

Table 4 presents the ANOVA results on the effect of PS, RC and DEN on particleboard properties. Particle Size (PS) has an effective insignificant effect on MOR, MOE and IB, but does effect Water Absorption (WA) and Thickness Swelling (TS). The Resin Content (RC) has a significant effect on all board properties. Board DENsity (DEN) significantly effects all the board properties. The interaction of PS*RC indicates that only TS is significantly affected. MOE is significant in the interaction of PS*DEN, and RC*DEN shows significant effects on MOR, MOE and TS. The interaction effect of PS*RC*DEN shows comparatively insignificant effects on all the board properties.

Table 4: Summary of ANOVA Analysis on the Effects of Particle Size, Resin Content and Board Density on Board Mechanical and Physical Properties

Source	df	MOR	MOE	IB	WA	TS
PS	1	3.77ns	1.84ns	0.49ns	64.39*	29.60*
RC	2	81.10*	52.26*	20.42*	49.53*	105.04*
DEN	2	111.70*	139.63*	22.09*	132.81*	3.78*
PS* RC	2	0.97ns	0.38ns	0.57ns	0.97ns	4.61*
PS* DEN	2	0.60ns	4.45*	0.66ns	0.80ns	2.30ns
RC* DEN	4	2.97*	3.06*	0.68ns	0.20ns	2.94*
PS*RC* DEN	4	0.29ns	0.60ns	1.86ns	0.22ns	1.99ns

Notes: *F – values are significant at $p < 0.05$, and ns – not significant df – Degree of Freedom, MOE – Modulus of Elasticity, MOR – Modulus of Rupture, IB – Internal Bonding, TS – Thickness Swelling and WA – Water Absorption

Effect of Particle Size

Figure 1 shows the effects of varying PS on the mechanical properties. There is a small increment in MOR (6 %), whereas there are small decrements in MOE and IB, 3.2 % and 0.61 %, respectively, with increasing PS. Higher MOR values are usually observed with larger particle size, because there is a higher quantity of resin available per unit area due to a lower surface area per particle [5, 7]. Larger particles provide surface areas which are better at distributing the stress than smaller particles. Internal bonds are unaffected by an increase in particle size. Brumbaugh [8] states that a greater degree of discontinuous planes reduces the tendency to develop areas of failure, therefore increasing particle size can reduce this ability, because more gaps are present between particles, thereby introducing fewer discontinuous planes.

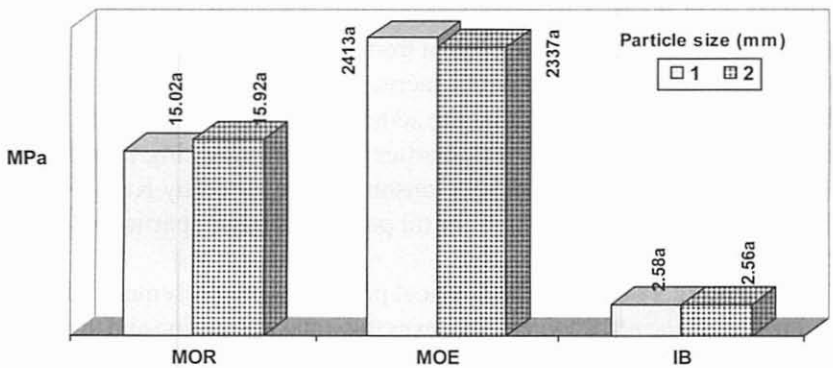

Figure 1: Effect of Particle Size on Mechanical Properties

Figure 2 presents the effects of PS on the physical properties. A larger particle size causes a significant decrease in water absorption and thickness swelling; the corresponding improvements are 23 % and 18 % for water absorption and thickness swelling, respectively. Evidently particle size is a significant factor in controlling a boards' response to water absorption and thickness swelling. Lower water absorption and thickness swelling values for larger particles may be attributed to their ability to resist the uptake of water since their surface is better covered with resin, which is hydrophobic, compared to smaller particles.

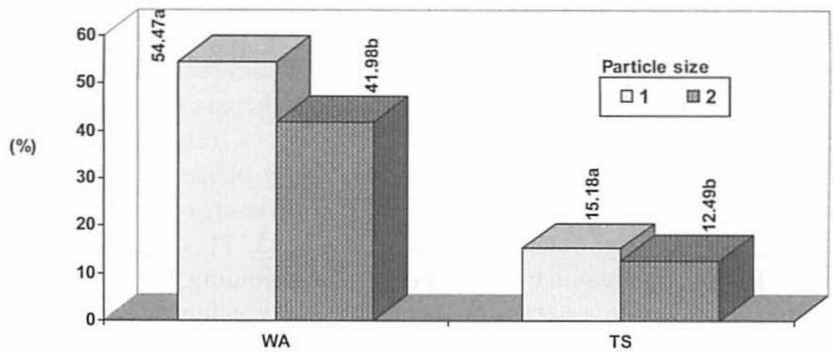

Figure 2: Effect of Particle Size on Physical Properties

Effect of Resin Content

The effect of resin content on the mechanical properties is presented in Figure 3. Increasing the resin content from 7 to 11 % significantly increases the mechanical properties; MOR increases by 62 %, MOE by 35 % and IB by 25 %. This indicates that the addition of more resin into the board improves all the mechanical properties through enhancing the bonding between particles. A similar relationship was reported by Kelly [9], for bamboo by Jamaludin [5] and for oil palm fruit bunch particleboard by Shaikh *et al.* [10].

The effects of RC on the physical properties are presented in Figure 4. Increasing the resin content improves the water absorption and thickness swelling properties significantly. As the resin content increases from 7 to

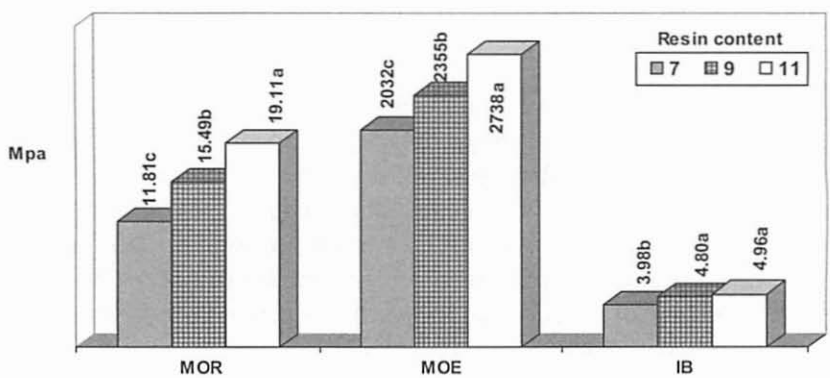

Figure 3: Effect of Resin Content on Mechanical Properties

11 %, the resistance to WA and TS improve by about 34 % and 51 %, respectively. The rationale for this is as the resin content increases the contact areas increase and this induces better adhesion between particles [11] thus culminating in better resistance to WA and TS.

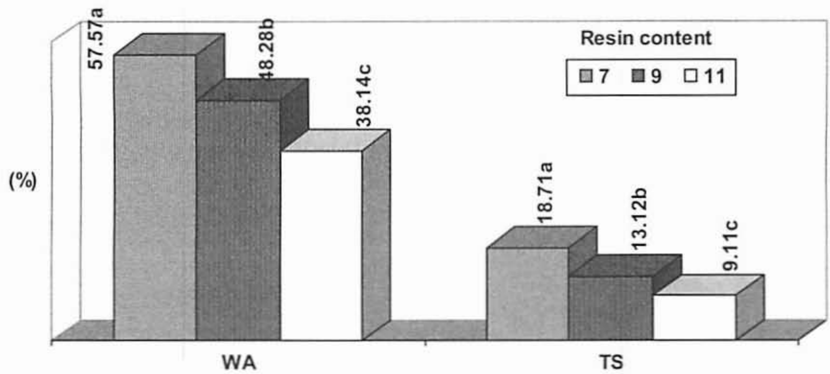

Figure 4: Effect of Resin Content on Physical Properties

Effect of Board Density

Figure 5 shows the effects of board density on the mechanical properties. As the board density increases, the MOR, MOE and IB increase significantly. The MOR, MOE and IB increase by about 75 %, 64 % and 54 %, respectively. The higher the board density, the more particles in contact with the resin, which inherently improves the mechanical

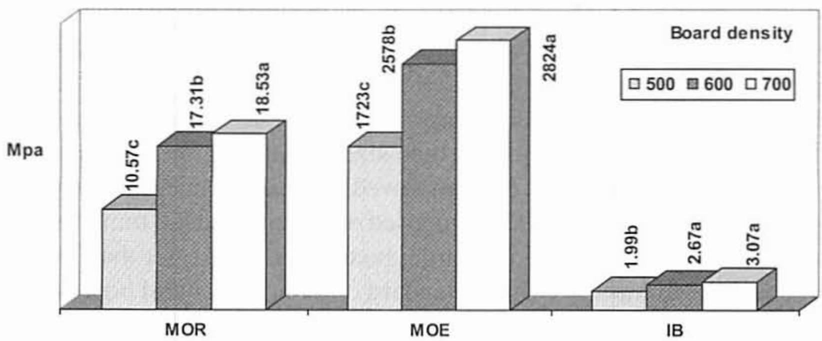

Figure 5: Effect of the Density on Mechanical Properties

properties. Moslemi [11] stated that the greater the number of particles the higher the compaction ratio thus the better the mechanical properties of the board. Shaikh [7], Shaikh *et al.* [10] and Jamaludin *et al.* [12] also reported similar findings.

Figure 6 shows the effect of board density on the physical properties of the boards. As the board density increases the WA and TS improve significantly, specifically as the board density increases from 500 to 700 kg m^{-3}, the resistance to WA and TS improved by 47 % and 12 %, respectively. Greater board densities mean higher compaction ratios and thus the creation of fewer voids during board manufacture, hence the ability to absorb water and swell is reduced.

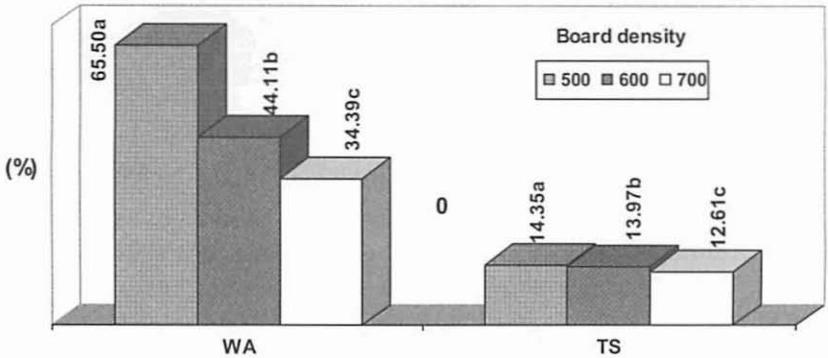

Figure 6: Effect of the Density on Physical Properties

Conclusions

According to the presented results the mechanical properties of the manufactured boards, namely MOR, MOE and IB, are independent of particle size; however water absorption and thickness swelling improves significantly with increasing particle size. Increasing the resin content and board density results in both improved board mechanical and physical properties. In general, boards composed of 1.0 mm and 2.0 mm particles with more than 9 % RC, and a target board density greater than 500 kg m^{-3} meet the minimum British Standard criteria for general boards. It is therefore fair to conclude that oil palm trunk particles are a suitable raw material to be used in the manufacture of particleboards.

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