Properties of Single Layer Particleboard from Oil Palm Trunk Particles

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ABSTRACT

Single layer or homogeneous particleboard was produced using oil palm trunk particles. Oil palm trunk was supplied by MPOB, Bangi. The trunk bark was removed using a headrig and then cut into smaller blocks and flaked using a disc flaker to produce strand-like particles. These strands were then passed through a dust extractor to reduce them into particles. This study determined the mechanical and physical properties of single layer particleboard from unscreened OPT particles using 7%, 9% and 11% phenol formaldehyde (PF) resin. The target board densities were 500 kg/m^3, 600 kg/m^3 and 700 kg/m^3, respectively, with board thickness of 12 mm and 19 mm. From the results, it shows that the increasing resin contents and board densities increased the mechanical properties and improved the physical properties of the particleboard, respectively. Thicker boards increased the mechanical properties of MOR and MOE and improved the physical properties of the particleboard. Generally, the effects of resin content, board densities and board thickness greatly influenced the mechanical and physical properties of the particleboard made from oil palm trunk particles.

Keywords: *mechanical properties, physical properties, single layer particleboard, oil palm trunk*

Introduction

The oil palm tree (*Elaeis guineensis*) is one of the most important commercial crops supplying palm oil for household and commercial consumption. Commercial cultivation was started in 1917 and has positioned Malaysia as the leading nation in palm oil production and exporter (Gurmit, 1995; Mohd Nasir, 2003). The huge production of palm oil consists of only about 10 percent of the total biomass of the tree and the remainder consists of a large amount of lignocellulosic materials in form of empty fruit bunches (EFB), oil palm fronds (OPF) and oil palm trunk (OPT) (Mohd Nasir, 2003). Therefore, to achieve a zero-waste strategy in the Malaysia palm oil industry, research and development activities are also focused on the utilization of oil palm biomass. The oil palm biomass has great potential to be converted into high value-added and useful income-generating products. This strategy will also introduce to the market a new alternative or supplementary lignocellulosic source in addition to rubberwood. In this study, the feasibility of using OPTs as a suitable raw material for manufacturing single layer particleboard was investigated.

Some of the typical applications for particleboard include; floor underlayment, housing, cabinets, stair treads, shelving, table tops, furniture, vanities, speakers, sliding doors, lock blocks, interior signs, displays, table tennis, pool tables and electronic game consoles (Nemli & Çolakogˇlu, 2005). Recently, the demand for particleboard has continued to increase for housing construction and furniture manufacturing. Zhongli et al. (2007) stated in 1999, approximately

85% of interior type particleboard was consumed worldwide as core stock for various furniture and cabinet application. Malaysian particleboard industry was speedy expanded year by year. Malaysian Timber Council (2009) has been reported that the export of the particleboard to USA, Taiwan, Japan, Korea and Singapore was increased 83% from 2003 until 2007. This situation gave huge opportunity to particleboard industry still remain as the dominant raw material supplier for global furniture industries in near future.

Nemli & Aydin (2007) reported many researchers have been done on the utilization of various of annual plants, agricultural residues, bark, and branch wood from many different regions of the world: wheat straws, rice husks, groundnut shells, bamboo waste of tea leaves, bagasse, cotton, hemp, jute stalks, sunflower stalks, maize husk, cab, kiwi, wine pruning, durian peel, coconut coir, flax shiv, corn pith, castor stalks, miscanthus, steam-treated rice industry residues, mimosa bark, *Pinus radiata*, ponderosa and tanoak bark; decayed and branch woods. Due to the availability of OPT from plantation is qualified in terms of its stem volume. Considering that the economic life of an oil palm is about 25-30 years, many of the oil palm stands are now due for replanting. Estimations made by Noraini et al. (1999) projected that the availability of OPT and OPF would reach peaks of 5.76 million and 55.9 million tonnes in the years 2015 and 2020, respectively. According to Kamarudin et al. (1997), Malaysia provided about 13.2 million tonnes of oil palm biomass, and Jalani et al. (2002) expected the total planted hectare of oil palm in Malaysia would increase to reach 5.10 million hectares in 2020. Recent figures have indicated that oil palm plantation areas in Malaysia have expanded from 3.5 million hectares in 2001 to 4.3 million hectares in 2007 (Malaysia Oil Palm Board, 2009). Therefore, OPT has great potential to be used as raw material for manufacturing particleboard, which is the focus of this study.

The objective of this study is to use of the OPT as a raw material for laboratory-made single-layer particleboard and to test the mechanical and physical properties of panels to determine if they have required levels of properties for general uses. In addition, the effects of resin content, board densities and board thickness on the mechanical and physical properties of particleboard made from unscreened OPT particles were investigated.

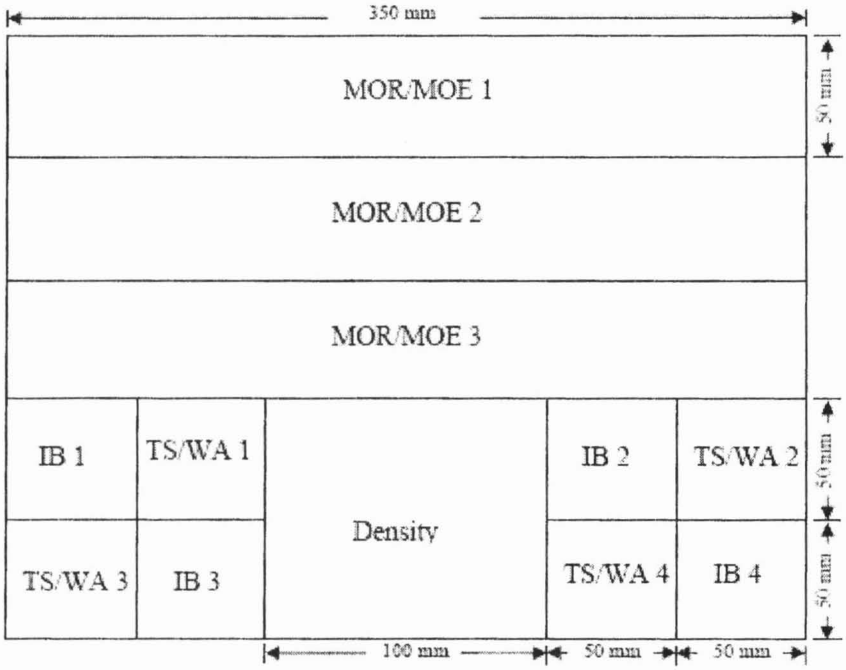
Materials and Methods

Single layer particleboard was produced using OPT particles .The OPT is about 25-years old was supplied by Malaysian Palm Oil Board (MPOB), Bangi. The trunk bark was removed using a headrig and then cut into smaller blocks and flaked using a disc flaker to produce strand-like particles. These strands were then passed through a dust extractor to reduce them into particles. The particles were dried less than 5% moisture content in an oven dryer. Phenol formaldehyde (PF) resin (PL-60M, 40.5% solid content) was used as the adhesives for making the particleboards. PF was obtained from Malayan Adhesives Company (Shah Alam, Selangor). Particles were blended with PF resin with three parameters of resin contents were 7%, 9% and 11% respectively for each panel manufacture. A total of 36 panels with lengths of 350 mm, widths of 350 mm, and thickness of 12 mm and 19 mm were made for the experiments. The target densities were 500kg/m^3, 600kg/m^3 and 700kg/m^3. The mat was cold-pressed at 1000 psi for about 1 minute to consolidate it before hot pressing. The cold press was applied to reduce the danger of disturbance of the graded structure while transferred to the hot press. Hand-formed mats were pressed at a temperature of 165 °C with three stages of pressure i.e. 1800 psi for 180 seconds, 1200 psi for 120 seconds and 800 psi for 60 seconds. After pressing, particleboards were conditioned at a temperature of 20 °C and 65% relative humidity.

Test samples were cut from the particleboards (Figure 1) and the following properties were determined in accordance with appropriate BS EN standards: modulus of rupture (MOR) and modulus of elasticity (MOE) (BS EN 310, 1993), internal bond strength (IB) (BS EN 319, 1993), and thickness swelling and water absorption (TS/WA) (BS EN 317, 1993). All specimens were conditioned to equilibrium at a temperature of 20 °C and 65% relative humidity. Seventy-two specimens of each density board were used for the physical and mechanical properties.

Data for each test were statistically analyzed. Analysis of variance (ANOVA) and *t*-test were used to test ($\alpha = 0.05$) for significant difference between factors and levels. When the ANOVA indicated a significant difference among factors and levels, a comparison of the means was done employing Duncan and Waller-Duncan tests to identify which groups were significantly different from other groups at a 95% confidence level. Table 1 displays the experimental design of the study.

Figure 1. Cutting pattern for sample testing (BS EN326-1, 1994)



Results and Discussion

Average values of mechanical properties (modulus of rupture, modulus of elasticity, and internal bonding) and physical properties (thickness swelling and water absorption) are given in Table 3. The minimum requirement for mechanical properties of particleboard panels for general uses and furniture manufacturing as based on BS EN standards are 14, 1900, and 0.5 Mpa for modulus of rupture, modulus of elasticity, and internal bonding, respectively (BS EN 310, 1993 and BS EN 319, 1993). Meanwhile, the minimum requirements for thickness swelling and water absorption of particleboard are12% and 20% for 24 hours immersion in water, respectively (BS EN 317, 1993). According to the test results, some of the particleboards were passed the standard and the rest were failed. However, internal bonding properties for all boards were met the standard. The results showed that the maximum strength of single-layer particleboard made from OPT particles were 32.24, 3511.54 and 3.11 MPa whereas the minimum strength were 7.74, 1125.14 and 0.58 MPa for those modulus of rupture, modulus of elasticity, and internal bonding, respectively. On the other hand, panels did not satisfy the thickness-swelling requirement for general uses. This is due to not using water repellent agents in particleboard manufacturing. Moreover, the anatomical structure due to the parenchyma tissue which covered the vascular bundles may influence the ability to absorb water. According to Lim and Khoo (1986), an increasing moisture content in OPT is effected by the distribution of the parenchymatous cells which retain more moisture than vascular bundles. Based on the results, the highest thickness swelling and water absorption were 28.07% and 113.69%, respectively meanwhile the lowest thickness swelling and water absorption were 8.19% and 35.11%, respectively. However, actual densities (507, 586 and 699 kg/m^3) of single-layer particleboard still in range to those target densities (500, 600 and 700 kg/m^3). It can be said that the actual densities of the boards are acceptable for this study.

Table 1. Experimental design

Board density (kg/m^3)	Resin content (%)	Board thickness	Number of board	MOR/MOE sample	IB sample	TS/WA sample
500	7	12	2	4	4	4
		19	2	4	4	4
	9	12	2	4	4	4
		19	2	4	4	4
	11	12	2	4	4	4
		19	2	4	4	4
600	7	12	2	4	4	4
		19	2	4	4	4
	9	12	2	4	4	4
		19	2	4	4	4
	11	12	2	4	4	4
		19	2	4	4	4
700	7	12	2	4	4	4
		19	2	4	4	4
	9	12	2	4	4	4
		19	2	4	4	4
	11	12	2	4	4	4
		19	2	4	4	4

Table 2. The physical and mechanical properties of the single-layer particleboard from OPT

Board thickness (mm)	Resin Content (%)	Density (kg/m³)		MOR (MPa)	MOE (MPa)	IB (MPa)	TS (%)	WA (%)
		Target	Actual					
12	7	500	524.28	8.17	1152.06	0.97	28.07	113.69
	9		553.38	7.74	1125.14	1.17	27.56	93.34
	11		476.81	7.97	1265.34	1.31	19.13	95.43
	7	600	568.03	11.71	1774.85	1.87	34.44	92.18
	9		570.17	11.30	1724.30	2.13	25.55	78.52
	11		569.20	14.69	2003.05	2.64	16.25	62.21
	7	700	698.58	19.45	2524.16	1.54	26.91	63.94
	9		670.69	19.68	2675.70	2.98	22.97	66.39
	11		671.25	20.27	2657.42	3.11	16.18	51.62
19	7	500	500.81	9.09	1214.52	0.58	22.57	87.42
	9		499.74	9.78	1275.75	0.77	17.20	87.68
	11		488.61	10.90	1359.29	0.71	13.52	72.70
	7	600	601.21	17.93	2116.92	0.92	19.54	60.36
	9		619.42	17.93	2154.44	1.30	13.74	60.21
	11		589.50	18.10	2214.30	1.18	11.35	50.05
	7	700	686.92	30.43	3511.54	1.70	19.03	46.85
	9		719.33	32.24	3423.31	1.87	8.77	35.11
	11		749.48	26.46	3134.06	2.39	8.19	39.57
BS EN				**>14.00**	**>1900**	**>0.5**	**<12**	**<45**

Notes: MOR- modulus of rupture MOE-modulus of elasticity IB-internal bonding
TS-thickness swelling WA-water absorption

Table 3 shows the statistical analyses of variance towards mechanical and physical properties of single-layer particleboard from OPT at different board thicknesses, board densities and resin contents. The results indicated that they were significantly different ($p \leq 0.01$) for all board properties except at different resin content, it shows that the significant effect on IB, TS and WA but not significant on MOR and MOE. Generally, statistical differences were significantly influenced the interaction between source of variation toward mechanical and physical properties. However, there were no significant difference on interaction between BT x

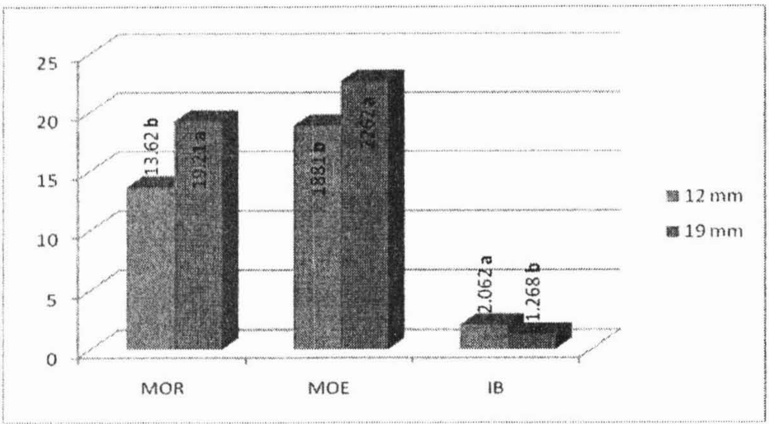
BD for WA, interaction between BT x RC and BD x RC for MOE, and interaction between BT x BD x RC for those MOR, MOE and IB, respectively.

Table 3: Analysis of variance on mechanical and physical properties of single-layer particleboard from OPT

Source of variation	DF	MOR	MOE	IB	TS	WA
Board thickness (BT)	1	148.309**	61.449**	65.492**	377.806**	302.615**
Board density (BD)	2	375.383**	419.270**	81.812**	29.488**	444.603**
Resin content (RC)	2	0.165ns	0.468ns	18.566**	178.300**	62.244**
BT x BD	2	23.757**	14.023**	4.943*	4.850*	0.465ns
BT x RC	2	3.213*	1.693ns	3.464*	13.228**	6.047**
BD x RC	4	2.712*	1.632ns	3.315*	3.995**	3.097*
BT x BD x RC	4	2.125ns	0.945ns	2.401ns	4.998**	10.896**

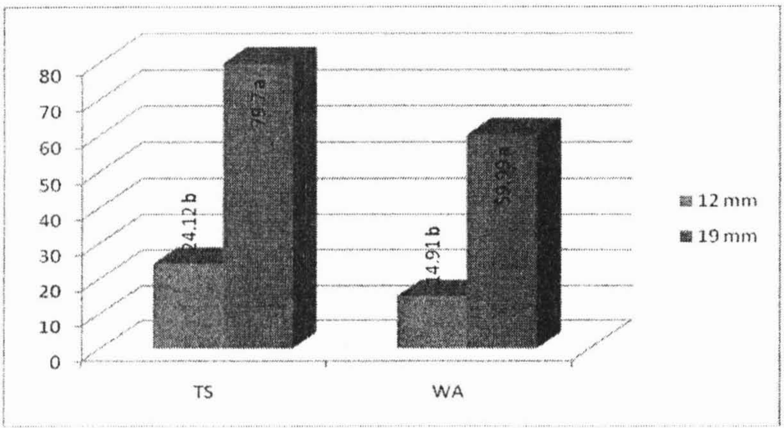
Notes: ns- not significant $p<0.05$ *- significant at $p \leq 0.05$ **-significant at $p \leq 0.01$ DF-degree of freedom
MOR -modulus of rupture MOE-modulus of elasticity IB-internal bonding TS-thickness swelling
WA-water Absorption

The thickness of the boards increased the MOR and MOE but decreased the IB strength, significantly ($p \leq 0.01$). The MOR and MOE of 19 mm board thickness (19.21 and 2262.84 MPa) were superior as compare to 12 mm board thickness (13.62 and 1881.08 MPa), respectively. Meanwhile, the IB of 12 mm board thickness (2.06 MPa) was higher than the 19 mm board thickness (1.27 MPa). This finding is due to lower resin binder used for 19 mm board thickness as compare to the 12 mm board thickness. Therefore, resin content used in particleboard manufacturing should appropriate with the increment of the board thickness to achieve the good adhesion between particles. However, IB strength of the board in this study still agreed with the minimum requirement of the general uses standard. The board thickness decreased the TS and WA, significantly ($p \leq 0.01$). The effect of board thickness did not satisfy the thickness swelling and water absorption requirements for general uses. This is due to the ability of the thicker board to resist the uptake of water, as a result it difficult the penetration of the water into the board. On the other hand, the thickness swelling and water absorption values (14.91 and 59.99% for 19 mm thickness) of the particleboard made from OPT particles were close the required level of panels for general uses. Figure 2 and Figure 3 illustrate the effects of board thickness of single-layer particleboard from OPT particles on the mechanical and physical properties.



Note: Means with the same letter are not significantly different at $p < 0.05$

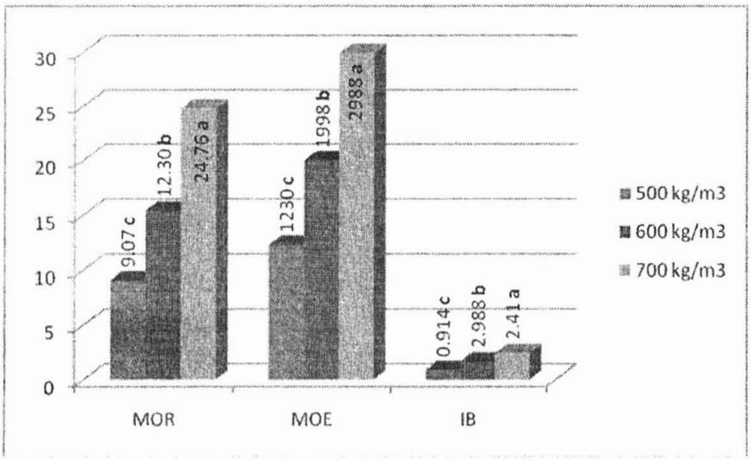
Figure 2. The effect of board thickness on mechanical properties



Note: Means with the same letter are not significantly different at $p < 0.05$

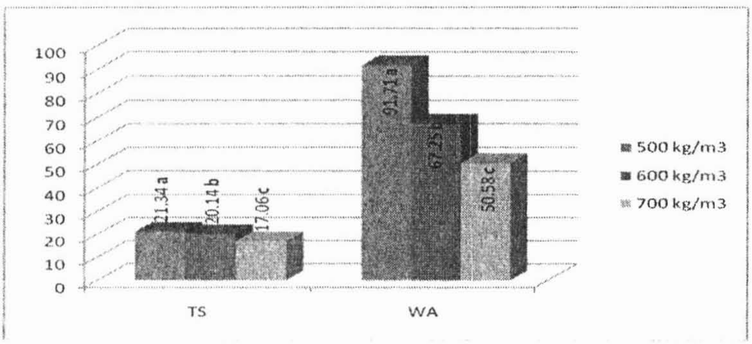
Figure 3. The effect of board thickness on physical properties

The effects of board density towards mechanical properties were significantly different at $p \leq 0.01$, as the density of the board increased the MOR, MOE and IB also increased. Jamaludin (2006) reported that the increase in strength properties may possibly is connected with higher compaction ratio at higher density. In addition Moslemi (1974) stated that the strength and the dimensional properties of the particleboard are straight related by the board density. According to the results the mechanical properties at different board densities were accepted the minimum requirement of general uses except at density 500 kg/m^3 for both MOR (9.07 MPa) and MOE (1230.21 MPa). The effect of board density significantly influenced the physical properties of the boards ($p \leq 0.01$). This must be attributed to the compressed relative amount at upper density which leads lower TS and WA properties due to congested gap among the particles. This situation might be avoiding the absorption of the water to enter into the OPT particles. Based on standards, particleboard should have a maximum TS value of 12% and WA value of 45% (for 24 hours immersion). Average TS of the specimens ranged from 17.06 to 21.34% whereas average WA of the specimens ranged from 50.58 to 91.71% for 24 hours immersion. Therefore, boards did not promise the thickness swelling and water absorption requirements for general uses. The effects of board density on the mechanical and physical properties are revealed in Figure 4 and Figure 5.



Note: Means with the same letter are not significantly different at $p< 0.05$

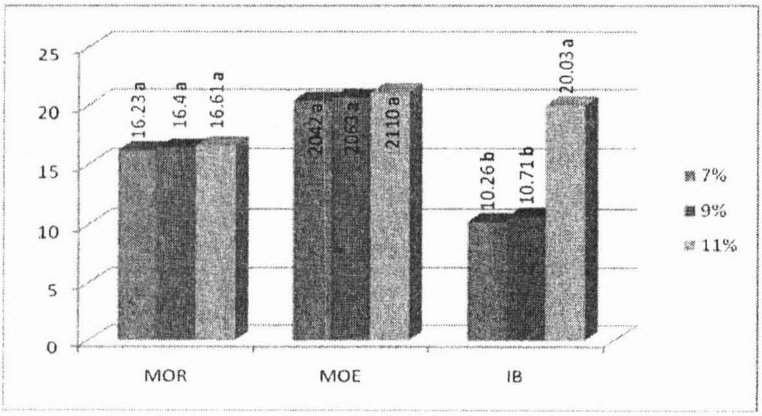
Figure 4. The effect of board density on mechanical properties



Note: Means with the same letter are not significantly different at $p< 0.05$

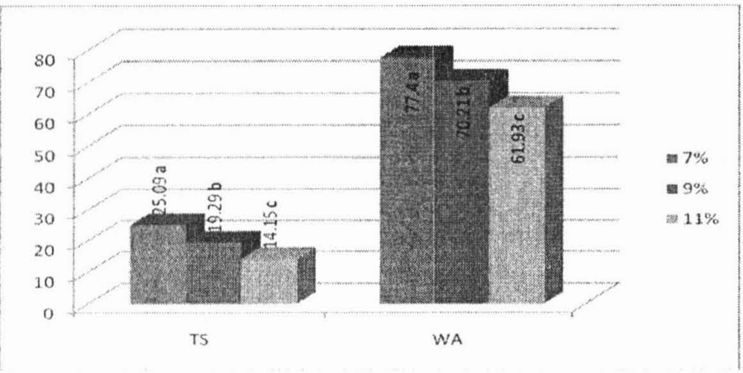
Figure 5. The effect of board density on physical properties

Significant differences were determined between IB strength, TS and WA values of the panels manufactured from OPT particles at different resin content ($p \leq 0.01$) meanwhile there no significant differences were determined between MOR and MOE. The effect of resin content on mechanical properties of particleboard were achieved the standard however they did not passed the standard for physical properties requirement. According to the results, all the mechanical properties increase with an increasing of the resin content. Average MOR of the specimens ranged from 16.23 to 16.61 MPa, average MOE of the specimens ranged from 2042.35 to 2110.39 MPa and average IB of the specimens ranged from 1.26 to 2.03 MPa. Comparable finding on the strength properties-resin contents relationship were also reported by other studies on wood (Moslemi, 1974), empty fruit bunches (Shaikh et al., 1993) and bamboo (Rahim & Jamaludin, 1992; Jamaludin, 2006). The results of dimensional stability indicated that the additional of resin content from 7 to 9% decreased the TS (about 44%) and WA (about 20%) properties. This could due to the board with greater resin improve the coverage of particles thus the water not easy to penetrate into the board. Furthermore, Rahim & Jamaludin (1992) obtain that an increasing of resin content will increase the contact areas of the particles and this turn contribute to better adhesion between particles. On the other study, Buyuksari et al. (in press 2010) suggested that the high values in TS and WA may be related to the fact that no wax or other hydrophobic substance was used during particleboard manufacture. He reviewed other studies that heat-treatment, adding water-repellent chemicals such as paraffin (wax), use of phenolic resins, coating of the particleboard surfaces and acetylating of particles can improve the water repellency of the panels. Figure 6 and Figure 7 displays the effect of resin content on mechanical and physical properties of single-layer particleboard made from OPT particles.



Note: Means with the same letter are not significantly different at $p < 0.05$

Figure 6. The effect of resin content on mechanical properties



Note: Means with the same letter are not significantly different at $p < 0.05$

Figure 7. The effect of resin content on physical properties

Conclusions

This study investigated the feasibility of using OPT in the manufacture of single-layer particleboard. The results show that it is possible to produce particleboards using unscreened OPT particle while using phenol formaldehyde as an adhesive. The effects of board thickness, board density and resin content improved mechanical properties and reached the minimum requirement of the general uses. Conversely, they decreased the physical properties of the boards. This is because the characteristics of the oil palm stem as a monocot tree having the parenchyma tissue where make their physical properties is easy to absorb water. By adding water repellant agent such as wax emulsion could be recover the limitation of the material. Thus, it recommended that the OPT is to be considered as an alternative to wood material in manufacture of particleboard used in indoor environmental due to lower thickness swelling, water absorption and formaldehyde emission.

Acknowledgements

The authors gratefully acknowledge the material support of the Malaysian Palm Oil Board (MPOB) Bangi, Selangor. Further acknowledgement goes to Dana Kecemerlangan Research Fund of Research Management Unit, Universiti Teknologi MARA Pahang for the funding and the laboratory equipment used in the panel manufacture and testing of the panels.

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