Asian Journal of Applied Sciences (ISSN: 2321 – 0893)
Volume 03 – Issue 04, August 2015

The Selected Properties of Hybrid Particleboard Made from Oil Palm Empty Fruit Bunch (EFB) and Merpauh (*Irvingla Malayanan* Olive) Sawdust Wastes

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ABSTRACT---*The physical and mechanical properties of particleboard made from Merpauh (Irvingla malayana olive) and empty fruit bunch (EFB) wastes mixture was investigated in relation to the fibre diameter and mixture ratio. The EFB and Merpauh particles with diameter of less than 1 mm and more than 1 mm were prepared and they were mixed with ratios of 40:60, 60:40, 80:20, 100:0 separately. The particleboard sized of 340mm x 340mm x 12mm was prepared with a target density of 750 Kg/m^3 contained 12% urea formaldehyde (UF) resin, 3% hardener and 1% wax. The water absorption, thickness swelling, modulus of rupture, modulus of elasticity and internal bond were tested in according to JIS (Japanese Industrial Standard): 5908. The results showed that the thickness swelling and modulus of elasticity of any mixture (EFB/wood) or homogenous EFB particleboards were not met a minimum requirement of JIS 5908: 2003 standard. In contrast, only modulus of rupture and internal bonding (thin particle) met a minimum standard.*

Keywords--- Empty fruit bunch, merpauh, particleboard, hybrid, JIS 5908

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1. INTRODUCTION

Malaysian wood based panel industries especially particleboard and medium density fiberboard are relied on Rubber wood as a main material for their production for more than 2 decades; due to its abundantly supply from plantation. However, the supply of Rubber wood was declined as a consequence to decline of Rubber tree plantation area from 1.4 million ha in 2001 to 1 million ha in 2009. This is mainly due to low latex price in global market [1]. Many Rubber tree plantations were converted to a more profitable Oil palm plantation. This can be observed by the growth of oil palm plantation from only 1.7 million ha in 1990 to 4.8 million ha in 2013, and Malaysia government is targeting for 5.8 million ha by 2020. The annual availability of oil palm stem for trunk, frond and empty fruit bunches (EFB) was estimated to be around 13.6 million logs based on 100,000 ha of replanting each year [2].

The oil palm trunk had many weaknesses such as low strength, durability, dimensional stability and machining properties [2]. Conversion of low quality oil palm biomass into composites is a priority solution and its development was reported in many studies [3][4][5][6][7]. Amongst them, only oil palm plywood was successfully commercialised. The oil palm veneer found to be only suitable as a core layer integrated with face and back layers of tropical hardwood veneer; due to its soft structure and fibrous. The technology to manufacture particleboard and medium density fiberboard is hindrance by a hygroscopic nature of oil palm biomass.

Conversion the oil palm EFB and Merpauh sawdust to biomass energy would solve this abundantly waste problem for a short term, but generating power through combustion would pollute the air quality in a long term. In contrast, conversion of oil palm EFB to a green composite would remain the green status of oil palm plantation with its 25 years of replanting program policy.

The objective of this study is to investigate the physical and mechanical properties of hybrid particleboard made from oil palm EFB and Merpauh sawdust.

2. MATERIALS AND METHOD

2.1 Material

The fresh oil palm Empty fruit bunch (EFB) bundle was obtained from Seri Ulu Langat Palm oil mill Sdn Bhd, in Dengkil Selangor. The length of the EFB particles were 5 – 15 cm and its initial moisture content (MC) was ranged from 14% - 15 %. The Merpauh (*Irvingla malayana* olive Meerpa) sawdust was obtained from BJ Timber Trading, Serdang, Selangor.

2.2 Processing of EFB Fibre and manufacturing of particleboard

The EFB bunch was steamed and was pressured to separate the bunch from its fruit. The EFB and Merpauh particles were crushed by a crushing machine to obtain a thin (less than 1 mm) and thick (more than 1 mm) particles. The mixture of EFB and Merpauh particles with ratios of 40:60, 60:40, 80:20 and 100:0 were prepared for manufacturing the particleboard sized of 340mm x 340mm x 12mm with a target density of 750 Kg/m^3, for both particle diameter. The 12% of urea formaldehyde (UF-E1, Malayan Adhesive Corporation) resin, 3 % hardener, and 1 % wax (Aquawax 88, Emulco Sdn. Bhd.) were sprayed and blended for 5 minutes. The specification of the EI-urea formaldehyde resin and wax was listed in Table 1. The furnish mat was manually formed using a jig and cold press was applied by ballasted the mat with 70 kg square cement block for 5 minutes. Cold press aimed to reduce thickness and increased the density of the furnish before hot press. The cold press was also aimed to remove air between the particle and resin. The furnish was hot pressed at 160ºC and pressurized at 10 bar - 30 bar for 7 minutes. The hot press aimed to compress the material to the required thickness and to heat cures the resin to form the bonds that give the panel a specific properties and strength. All the particleboards were conditioned in a conditioning room at RH 65± 5% relative humidity (RH), 20±2 ºC for 7 days.

All the physical and mechanical properties of particleboard were tested according to [8]. The conditioned particleboard were trimmed and cut into a smaller specimen for testing as shown in Table 2.

Table 1: The specification of E1-urea formaldehyde (UF) resin and Aquawax 88

Properties	E1- UF	Aquawax 88
ph	8.25 (at 30 °C)	9.34 (at 25 °C)
Viscosity in poise	1.4	314
Specific gravity	1.202 (at 30 °C)	0.915 (at 25 °C)
Percentage of Free formaldehyde	0.53	-
Percentage of non-volatile content @105 °C	51.2	58.3

Table 2: Type of testing and the specimen dimensions

Type of Testing	Size (mm)
Static Bending	230 x 50 x 12
Water Absorption	50 x 50 x 12
Internal Bonding	50 x 50 x 12
Moisture Content	100 x 100 x 12
Thickness Swelling	50 x 50 x 12

2.3 Physical and mechanical tests

2.3.1 Water Absorption

This test was intended to assess the extent of changes and the rate of water absorption after 24 hour submerged period. The specimens were oven dried, weighed and submerged in 3 cm under the water. The specimens were taken out, wiped with a tissue paper and reweighed.

The water absorption was calculated according to the following equation:

$$Water\ absorption\ (WA) = \frac{M2 - M1}{M1} X \quad 100$$

Where: M1 is weight of specimen before immersion (g) and M2 is weight of specimen after immersion (g)

2.3.2 Thickness swelling

The thickness swelling aimed to measure the dimensional changes due to the water absorption. The thickness at the centre of specimen was measured to the nearest of 0.01 mm by using a micrometer before and after submerged in water.

The thickness swelling due to water absorption was calculated as the following equation:

$$Thickness\ swelling\ (TS) = \frac{T2 - T1}{T1} X \quad 100$$

Where: T1 is thickness before water absorption (mm), T2 is thickness after absorption (mm).

2.3.3 Density

The density was obtained by measuring oven dried weight and volume of the specimen. The density was calculated using the following equation:

$$Density\ (DN, \mathrm{Kg/m^3}) = \frac{M}{V}$$

Where: M is weight of the test piece (kg) and V is volume of the test piece (kg)

2.3.4 Moisture content

The specimen was weighed, oven dried at 103±2 °C for 24 hours, cooled in silica gel and reweighed. The moisture content was measured as the following equation:

$$Moisture\ Content\ (MC) = \frac{M1 - M0}{M0} X \quad 100$$

Where: M0 is mass (g) after drying to constant weight at 103±2ºC and M1 is mass (g) before drying.

2.4 Static Bending

The static bending test was measured using INSTRON universal testing machine. Specimen sized of 25mm X 25mm X 200mm (*r x t x l*) was used in this study and the distance between the supporting roller was 150mm. The speed rate of 8.0 mm/min speed was applied at the center of the span until the failure occurred. The maximum load of the specimen was recorded. The MoR and MoE were calculated using the following equation:

$$Modulus\ of\ rupture\ (MoR) = \frac{3PL}{2bt}$$

Where: MOR is modulus of rapture (N/mm^2), P is Maximum load (N), L is Span between center of support (mm), b is width of the specimen (mm), t is thickness of the specimen (m).

$$Modulus\ of\ elasticity\ (MoE) = \frac{\Delta PL^3}{4bd^3\Delta s}$$

Where: MOE is modulus of elasticity (N/mm^2), L is span between centers of support (mm), ΔP is Increment in load on the straight line portion of the load deflection curve (N), b is Width of the specimen (mm), d is Thickness of the specimen (mm), Δs is increment in deflection corresponding to ΔP increment in load (mm).

2.4.1 Internal Bond

The internal bond test aimed to test the strength in tension perpendicular to the plane of the board and the test was conducted using INSTRON universal testing machine. Both surface of the specimens were applied with epoxy resin and attached to the metal block. The metal block were pulled in an opposite directions until the specimen was failure and the maximum load was recorded.

Internal bond strength was calculated using the following equation:

$$Internal\ bond\ (IB) = \frac{P'}{bl}$$

Where: IB is internal bond (N/mm^2), P' is Maximum load (N) at the time of failing force, b is width of the test pieces (mm), I is length of test pieces (mm).

All the data from the tests were statistically analysed for the analysis of variance (ANOVA) and Waller Duncan using SPSS version 13.

3. RESULTS AND DISCUSSION

3.1 Physical properties

3.1.2. The density

Generally, the density of a substance is defined as the ratio of its mass and volume; and is expressed as kilogram per cubic meter [9]. The density, water absorption (WA), modulus of rupture (MoR) and modulus of elasticity (MoE) were not significantly different with particle diameter (Table 3). The averages were 707.20 kg/m^3 and 692.14 kg/m^3 , 91.03% and 88.87%, 12.39 MPa and 13.1 MPa, 1108.12 MPa and 1023.68 MPa for both particle diameters (< 1 mm and > 1 mm) respectively. In contrast, the moisture content was significantly higher in particleboard made from a thin particle (9.53 %) than a thick particle (8.86 %). Particleboard made from a thick particle (28.04%) had a significantly higher thickness swelling than those of thin particle (22.59%), most probably due to its larger lumen diameter which allowed more water accommodation. The internal bond was significantly higher in particleboard made from a thin particle (0.20 MPa) than those of thick particle (0.08 MPa).

Table 3: Summary of ANOVA on the physical and mechanical properties.

Properties	Particle diameter		DF	F	Significance
	< 1mm	>1mm			
Density (Kg/m^3)	707.2 (43.6)	692.1 (38.2)	1	1.67	0.20^{Ns}
Moisture content (%)	9.53(1.27)	8.86 (1.37)	1	3.16	0.08*
Water absorption (%)	91.03 (13.62)	88.87 (9.52)	1	0.41	0.53^{Ns}
Thickness swelling (%)	22.59 (4.37)	28.04 (4.57)	1	17.84	0.00***
Modulus of Rupture (MPa)	12.39 (3.81)	13.1 (6.33)	1	0.22	0.64^{Ns}
Modulus of elasticity (MPa)	1108.1 (222.7)	1023.7(335.0)	1	0.75	0.38^{Ns}
Internal bonding (MPa)	0.20 (0.12)	0.08(0.05)	1	18.63	0.00***

Ns is not significant at P>0.1, * is significant at P<0.1, *** is significant at P<0.01, DF is degree of freedom, F is F ratio

The averages density of particleboard made from thin particle were not significantly different with ratios of 40:60 (713.34 kg/m^3), 60:40 (716.52 kg/m^3) and 80:20 (737.94 kg/m^3). Particleboard made from 100 % EFB had a significantly lowest density (661.02 kg/m^3). In contrast, the averages density of particleboard made from thick particle were not significantly different with the ratios, ranging from 680.72 kg/m^3 to 711 kg/m^3 (Table 4). All the density was closed to the target density and within the acceptable range according to [8].

3.1.3 Moisture content

The averages moisture content of particleboard made from a thin particle was not significantly different with the ratios of 40:60, 60:40 and 80:20 ranging from 10.15% to 10.31%. The lowest moisture content (7.51%) was obtained in 100 % EFB particleboard (Table 4). The averages moisture content was also not significantly different for 40:60 (9.49%), 60:40 (9.51%), and 80:20 (9.73%) ratios in particleboard made from a thick particle. The lowest moisture content was obtained in particleboard made from a thick particle contained 100% EFB. Overall, all the moisture contents were within the acceptable range according to [8] (5% to 13%); regardless of particle diameter and mixture ratio.

3.1.4 Water absorption

The averages water absorption was not significantly different for the ratios of 40:60 (81.50%), 60:40 (84.48%) and 80:20 (90.71%); in particleboard made from a thin particle (Table 4). The particleboard made from 100% EFB (107.41 %) had significantly highest water absorption. The averages water absorption was not significantly different with the ratios in particleboard made from a thick particle, ranging from 86.36% to 93.31%. For comparison, the particleboard made from oil palm fibre (diameter less than 1 mm) from bark, leaves, frond, and core part of trunk with phenol formaldehyde and density of 800 Kg/m^3 had a water absorption ranged from 58% to 70% [10].

The percentage of absorption was depended on microstructure, where higher percentage may probably be caused by variation of compactness and voids in particleboard itself [11]. Other factor was that the urea resin was susceptible to hydrolytic degradation in presence of moisture; and this could be the reason for poor water resistance in particleboard [12]. This can be explained by week compatibility between the particle surface and the adhesion which lead to the formation of voids structure within the composite and this facilitates water absorption [13].

Table 4: The averages physical properties of particleboard made from different ratio.

Properties	Ratio	Particle diameter	
		< 1 mm	>1mm
Density (Kg/m^3)	40:60	713.3^a (21.1)	680.7^a (25.7)
	60:40	716.5^b (24.5)	690.1^a (52.1)
	80:20	737.9^b (20.1)	711.1^a (30.0)
	100:0	661.0^a (55.1)	686.6^a (42.6)
Moisture content	40:60	10.31^b (0.67)	9.49^b (0.39)
	60:40	10.15^b (0.25)	9.51^b (0.25)
	80:20	10.16^b (0.47)	9.73^b (0.58)
	100:0	7.51^a (0.30)	6.70^a (0.77)
Water absorption	40:60	81.50^a (6.18)	88.30^a (9.75)
	60:40	84.48^a (7.15)	93.31^a (10.50)
	80:20	90.71^a (14.26)	87.51^a (6.71)
	100:0	107.41^b (10.71)	86.36^a (11.49)
Thickness swelling	40:60	18.11^a (1.43)	29.05^b (3.35)
	60:40	23.10^b (2.12)	23.72^a (6.96)
	80:20	23.85^b (3.43)	29.13^b (2.15)
	100:0	25.28^b (5.89)	30.27^b (0.86)

Values in the parentheses are standard deviation. Mean followed by the same letter(s) in the same column are not significantly different at the 0.05 probability level according to the Waller-Duncan Test.

3.1.5 Thickness swelling

The averages thickness swelling was not significantly different for the ratios of 40:60 (18.11%), 60:40 (23.10%) and 80:20 (23.85%) in particleboard made from a thin particle (Table 4). In contrast, the averages thickness swelling was not significantly different for the 40:60 (29.05%), 80:20 (29.13%) and 100:0(30.27%) ratios in particleboard made from a thick particle. The lowest thickness swelling of particleboard made from thick particle was obtained in 60:40 (23.72%) ratio. However, all the thickness swelling either particle diameter or its ratio was not met a minimum requirement according to [8]. The oil palm particleboard made of 8% urea formaldehyde, 1 % wax and target density of 600 kg/m3 had a thickness swelling of 41.3% [14]. A similar particleboard specification but with a target density of 500 kg/m3 using a thick particle (>1 mm) gave a thickness swelling of 12.31%. The thickness swelling of particleboard made from bark, leave, frond, middle and core parts of oil palm trunk with phenol formaldehyde at density of 800 Kg/m^3 were ranged from 14% to 22 % [10]. The thickness swelling of binderless oil palm particleboard from strand diameter of 3 to 5 cm (density of 800 Kg/m^3) was 41.6%, while it was 45% for a fine particle [15]. The thickness swelling of binder less oil palm particleboard made from particle less than 1 mm blended with 10% polyhydroxyalkanoates and density of 800 Kg/m^3 was 13.55% [16].

3.2 Mechanical properties

3.2.1 Static bending

Static bending is an important mechanical property, because in most structures wood is subjected to loads which cause it to bend [17].

3.2.1.1 Modulus of rupture

The averages MoR were significantly different with ratio in particleboard made from both thin and thick particles. The averages MoR were not significantly different for 40:60 (12.05 MPa) and 100:0 (12.88 MPa) in particleboard made from thin particle; but the highest and lowest were obtained in 80:20 (15.17 MPa) and 60:40 (9.48 MPa) ratios (Table 5).

Table 5: The averages mechanical properties of particleboard made from different ratio.

Properties	Ratio	Particle diameter	
		< 1 mm	>1mm
Modulus of rupture (MoR)	40:60	12.05^{ab} (1.96)	9.92^{ab} (4.92)
	60:40	9.48^{b} (1.94)	7.91^{a} (3.65)
	80:20	15.17^{b} (4.06)	13.46^{b} (4.10)
	100:0	12.88^{ab} (4.78)	21.11^{c} (2.91)
Modulus of elasticity (MoE)	40:60	1149.5^{ab} (189.8)	858.1^{ab} (411.7)
	60:40	926.5^{a} (110.9)	678.4^{a} (276.5)
	80:20	1145.3^{ab} (264.1)	1120.5^{bc} (351.2)
	100:0	1211.3^{b} (232.3)	1437.8^{c} (215.2)
Internal bonding (IB)	40:60	0.21^{ab} (0.11)	0.05^{a} (0.05)
	60:40	0.18^{ab} (0.08)	0.09^{a} (0.02)
	80:20	0.13^{a} (0.10)	0.12^{a} (0.06)
	100:0	0.28^{b} (0.16)	0.09^{a} (0.05)

Values in the parentheses are standard deviation. Mean followed by the same letter(s) in the same column are not significantly different at the 0.05 probability level according to the Waller-Duncan Test.

The averages MoR were significantly increased from the ratios of 60:40 (7.91 MPa), 40:60 (9.92 MPa), 80:20 (13.46 MPa) and100:0 (21.11 MPa), in particleboard made from a thick particle. All the MoR values either particle diameter and ratio were met a minimum requirement of JIS 5908 (8 MPa), except for 60:40 ratio of particleboard made from thin particle. The oil palm particleboard made with 12 % urea formaldehyde, 1 % wax and using both thin and thick particles gave the averages MoR of 6.53 MPa and 13.02 MPa respectively [14].

3.2.1.2 Modulus of elasticity

The averages MoE were not significantly different with the ratios of 40:60 (1149.5 MPa) and 80:20 (1145.3 MPa) for particleboard made from thin particle; however the highest and lowest MoE were obtained from 60:40 (926.5 MPa) and 100:0 (1211.3 MPa) ratios (Table 5). In contrast, the averages MoE were lower for 60:40 (678.4 MPa) compared to 40:60 (858.1 MPa) ratios, but they were significantly increased to 80:20 (1120.5 MPa) and achieved a maximum value for 100:0 (1437.8 MPa) ratio in particleboard made from thick particle. Despite particleboard from 100% EFB had the highest MoE; all the MoE values ratios were not met a minimum requirement (2000 MPa) according to JIS 5908. The particleboard made from 12 % urea formaldehyde, 1 % wax and using both thin and thick particles gave MoE of 940 MPa and 1850 MPa respectively [14].

3.2.1.3 Internal Bonding (IB)

The averages IB were not significantly different between the ratios of 40:60 (0.21 MPa) and 60:40 (0.18 MPa) in particleboard made of thin particle (Table 5) In the same particle diameter, the averages IB were lowest for 80:20 (0.13 MPa) and highest for 100:0 (0.28 MPa) ratios. In contrast, the averages IB were not significantly different with the ratio in particleboard made from a thick particle ranging from 0.05 MPa to 0.12 MPa. All the IB values were met a minimum requirement (0.15 MPa) according to [8] in particleboard made from a thin particle, excepted from 80:20 ratio. In contrast, all the IB of particleboard made from a thick particle was not met a minimum requirement for [8].

The oil palm particleboard made by 12% urea formaldehyde, 1 % wax from both thin (< 1mm) and thick (>1 mm) particles gave IB of 0.42 MPa and 0.25 MPa [14]. According to [18], IB is the ability to resist pulls from the surface of the panel. It shows the degree on bonding between particles. Most failures occur between the surface and core layers. The averages IB of oil palm particleboard made from phenol formaldehyde (800 Kg/m^3) using either bark, leave, frond, middle or core parts of trunk were ranging from 0.1 MPa to 1.3 MPa [10]. The IB of binderless oil palm particleboard from strand diameter of 3 to 5 cm with density of 800 Kg/m^3 was 0.93 MPa; while fine particle had IB of 0.5 MPa [15]. The IB of binderless oil palm particleboard made from a thin particle (<1mm) blended with 10% polyhydroxyalkanoates was 1.81 MPa, while the IB of untreated board was 0.5 MPa [16].

4. CONCLUSION

The moisture content, modulus of rupture and internal bond of urea formaldehyde bonded particleboard made from a thin particle met a minimum requirement of JIS 5908. However, the thickness swelling and modulus of elasticity for either particle size or mixture ratio were not met a minimum requirement. Therefore, mixing of Merpauh (*Irvingla malayana* olive) particle to empty fruit bunch (EFB) particle was not recommended to manufacture particleboard.

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