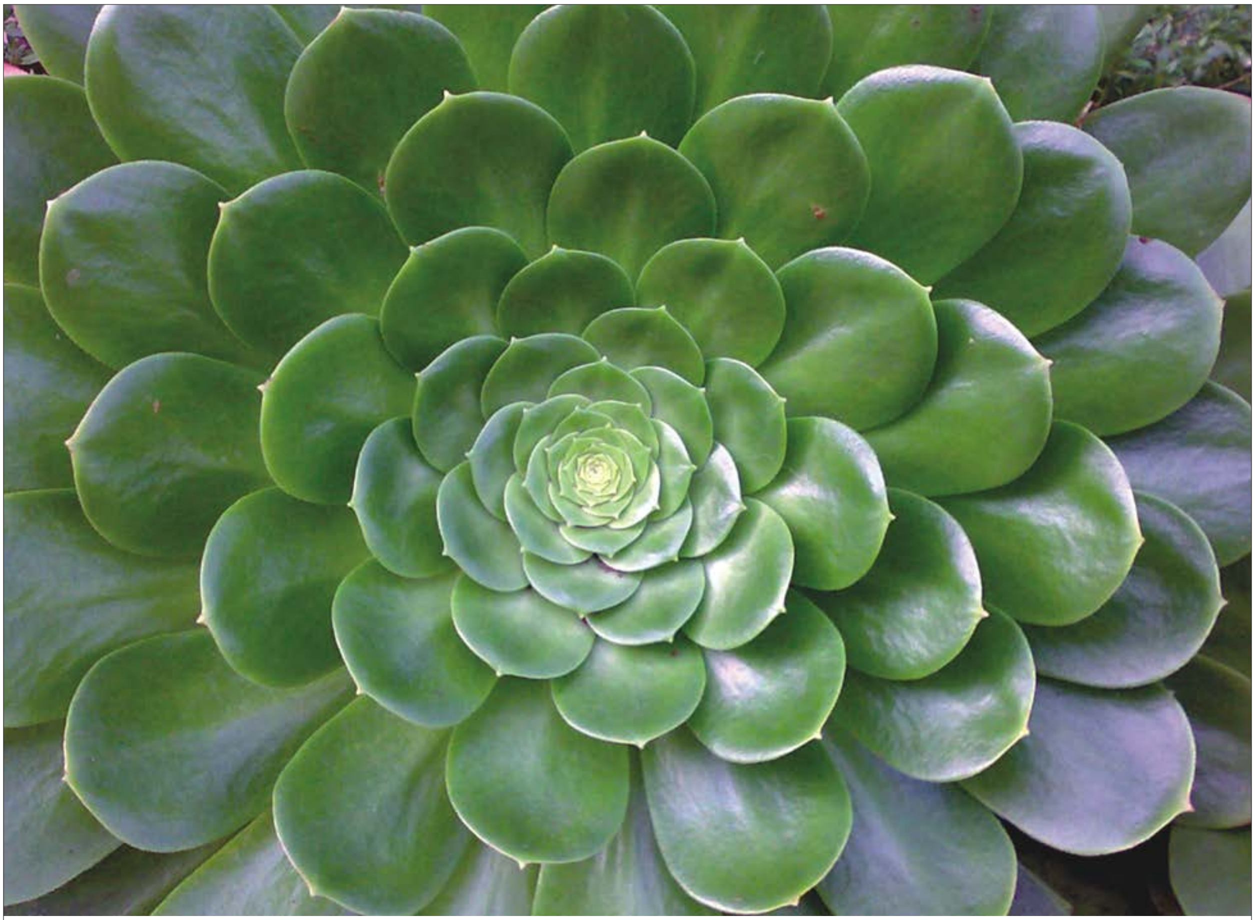

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Properties of Empty Fruit Bunch Oil Palm (*Elaeis guineesis*) Composite Boards at Different Densities and Resin Contents

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ABSTRACT

Properties of composite boards made from oil palm Empty Fruit Bunch (EFB) at different density and resin content were investigated. The EFB was refined using fiber cutter and particle's crusher. Hardeners and wax were added at 1 and 3% during the mixing process. Boards of densities 500, 600 and 700 kg m^{-3} were produced with resin urea formaldehyde at 10, 12 and 14%, respectively. The boards were stored in a conditioning chamber set at 20±2°C and 65% relative humidity before undergoing subsequent testing. Testing procedure was done in accordance with EN Standard and specifications. The results indicated increases across the board physical and mechanical properties. The highest MOR and MOE value achieved in this study were 22.91 and 2059.56 N mm^{-2}. Highest value for internal bonding was 0.98 N mm^{-2}, meanwhile for edge and face screw withdrawal, 467.47 and 512.37 N mm^{-2}. Boards with 700 g cm^{-3} density and 14% resin content met all the requirement needed according to standard exercised. Board with the lowest performance was observed using microscopy machine to study the resin-fiber bonding property. Resin and fiber in the board intacted closely but there were voids appeared at the cross-section of the board 500 g cm^{-3} density with 10% resin content, suggesting moisture had penetrated into the board via the open spaces and attacked the linkages existed, thus cause the board to have a low property. Thermogravimetric analysis was done to study the thermal stability of the boards manufactured. The maximum rate of decomposition for the OPEFB boards occurred at 380.83°C.

Key words: Empty fruit bunch, composite boards, physical and mechanical strength, thermogravimetric analysis

INTRODUCTION

Wood products such as large timbers or lumber were commonly used in solid forms. However, due to rapid deforestation, the ever increasing demand and increasing in prices make the application of solid wood no longer possible. New composite product started with very thick laminates for glued laminated beams, thin veneers for plywood, strands for strand board, flakes for flake board, particles for particle board and finally, fibers for fiber board has becoming popular due to scarcity of the wood supply (Rowell, 2005; Wahab *et al*., 2008).

Oil palm is the largest and important plantation crop in Malaysia. The oil palm trees generally could last between 25-30 years before the next replantation needs to be done. With this replantation cycle, the huge amount of available biomass is available and not being fully utilized and normally left to rot naturally. This readily available renewable resource could be used as a raw material for wood based industry. Extensive study has been done to find suitability of lignocellulose material from oil palm trunks to replace wood in wood based panel industry. Empty Fruit Bunch (EFB) is one of the oil palm biomass material. The EFB amounting to 12.4 million t $year^{-1}$ (fresh weight) and regularly discharged from oil palm refineries (Abdul Khalil *et al*., 2006). It is a lignocellulosic material and has potential as the natural fibre resource. Moisture content of fresh EFB is very high, about over 60% on a wet EFB basis. It is a poor fuel without drying and presents a considerable emission problem such that its burning is discouraged. Palm oil mills, therefore, typically use shell and drier part of the fiber product stream, rather than EFB, to fuel their boilers (Abdullah and Bridgwater, 2006). As EFB is readily available and abundance in Malaysia, converting them into composite boards can be a way to resolve the scarcity of wood sources.

The current studies focus on properties of composite boards made from EFB of oil palm trees. The objectives of the studies were to: (1) Physical and mechanical properties, (2) Study on resin-fiber bonding properties through SEM and (3) Thermal properties of the particle board made from EFB.

MATERIALS AND METHODS

The EFB samples were obtained from an oil palm plantation located in Kuala Selangor, Selangor. The materials were refined into smaller size using fiber cutter and crusher were screened with four-tier sieve shaker to remove the oversize, fines and impurities. The particles that passed through 2.0 mm sieve size and retained at 1.5 mm sieve size were chosen in this study. The particles were then oven-dried at 103±2°C for 24 h. The mass of the particles were measured to obtain targeted densities of 500, 600 and 700 kg m^{-3}. They were mixed with UF resin in a mixing drum. Three levels of resin content were applied to the boards' production; 10, 12 and 14% level. The mixed particles were hand-felted into a wooden frame 340×340 mm size of a caul plate. The formed mat was pre-pressed by using cold press. After that, the forming frame was removed leaving the mat itself on the caul plate. The mat was hot-pressed under Taihei hot-press machine at temperature 165°C to duration of 6 min. Four metal bars of 12 mm thickness were used in the hot-pressing process. The boards produced were then cooled and cut into standard testing size. The testing samples were stored in a conditioning chamber conditioned at 20±2°C and 65% relative humidity until reaching their constant weight, prior for testing procedure. Boards at densities of 500, 600 and 700 g cm^{-3} and UF resin application at 10, 12 and 14% were produced in laboratory scale. All boards were produced in accordance Europeans Standards EN 1993.

Physical studies: The physical studies conducted were the density of composite boards made from the oil palm EFB, moisture content of the boards manufactured, water absorption and thickness swelling tests of 2 and 24 h elapsed. Physical studies were conducted in accordance to European Standards EN 322 (1993), EN 323 (1993), EN 317 (1993) and EN 319 (1993).

Mechanical studies: The mechanical studies carried out including the static bending test (MOR and MOE), internal bonding test and screw withdrawal test (edge and face). All the tests were done by using Universal Testing Machine (UTM) in according to the European Standards EN 310 (1993) and EN 325 (2012). Screw hold strength of the EFB boards was tested according to British Standard BS 5669 (1989).

Scanning electron microscopy: The microscopy study were conducted in order to study the structure of the boards in relation to the physical, mechanical and thermal properties. The boards were viewed in a cross-cut direction to see the interaction between resin UF and EFB particles. This was done using the FEI Quanta 200 scanning electron microscope located at the Pulp and Paper Laboratory, FRIM, Kepong. Clean cut sample with a dimension of 1×1×1 cm was used. The SEM equipment is connected with a computer for image storage and processing.

Thermogravimetric analysis: Thermo gravimetric analysis is a method used to measure the thermal stability of the boards. The weight change with temperature was measured and used to infer the moments of change during the heating. The rate of change (a derivative) is often preferred since it clearly marks the point of maximum change in the degradation of the material. The temperature at which the rate of maximum degradation occurs may be taken as an indicator of the stability to the material in comparative studies (Soom *et al*., 2006). Thermal analysis was carried out with a computerized TA Instrument SDT-Q600 thermogravimetric analyzer. Samples (5.5±0.2 mg) were placed in alumina crucibles. TGA was performed under 100 mL min^{-1} nitrogen with a heating rate of 10°C min^{-1}.

RESULT AND DISCUSSION

Physical properties: The physical properties discussed throughout this study, including the density of the EFB composite boards manufactured, moisture content, thickness swelling and water absorption at 2 and 24 h elapsed time.

Table 1 shows the density properties of the EFB boards. Boards 500 g cm^{-3} with 10% resin content level had an average density of 506.29 g cm^{-3}, 12% resin content with 506.90 g cm^{-3} and 14% resin content at 517.60 g cm^{-3}. Board 600 g cm^{-3} with 10% resin content level had an average density of 598.65 g cm^{-3}, 12% resin content with 608.90 g cm^{-3} and 14% resin content at 620.05 g cm^{-3}. Average density of the board 700 g cm^{-3} is 704.03 g cm^{-3} (10% resin content), 714.72 g cm^{-3} (12% resin content) and 723.89 g cm^{-3} (14% resin content).

Moisture Content (MC) analysis was done and calculated by dividing the mass loss after oven drying and was presented in percentage. Boards at density 500 g cm^{-3} had an average MC value of 6.89% (10% resin content), 7.15% (12% resin content) and 8.48% (14% resin content). Boards at 600 g cm^{-3} had the average MC value of 6.04% (10% resin content), 6.83% (12% resin content) and 6.48% (14% resin content). The MC values were 6.64% (10% resin content), 6.72% (12% resin content) and 7.12% (14% resin content).

Thickness swelling properties of the EFB particle board manufactured was obtained from thickness swelling analysis. Time elapsed of 2 and 24 h thickness swelling analysis was carried out and percentage of increment of thickness was then calculated.

Table 1: Density of empty fruit bunch boards and values for thickness swelling at different density and resin content for 2 and 24 h time elapsed

				TS (%)	
Board density (g cm^{-3})	Resin content (%)	Moisture content (%)	Density (g cm^{-3})	2 h	24 h
500	10	6.89 (0.42)	506.29 (31.27)	35.10 (2.75)	41.11 (2.86)
	12	7.15 (0.43)	506.90 (25.54)	26.44 (3.42)	38.25 (2.61)
	14	8.48 (0.26)	517.60 (14.25)	24.90 (0.63)	26.69 (1.18)
600	10	6.04 (0.72)	598.65 (14.43)	24.04 (2.56)	25.46 (1.50)
	12	6.83 (0.81)	608.90 (27.31)	23.01 (0.68)	24.41 (1.84)
	14	6.48 (1.16)	620.05 (25.19)	20.90 (1.73)	21.41 (2.78)
700	10	6.64 (0.29)	704.03 (31.91)	19.18 (0.43)	21.37 (0.54)
	12	6.72 (0.46)	714.72 (7.21)	17.46 (1.20)	16.88 (0.43)
	14	7.12 (0.30)	723.89 (17.47)	16.34 (0.19)	12.99 (2.50)

TS: Thickness swelling

Generally, boards at densities of 500, 600 and 700 g cm^{-3} had a particular trend of 2 and 24 h thickness swelling where the rate of the board got swelled is decreased as the amount of resin applied increase. The boards at 500 g cm^{-3} at resin content 10% had the highest rate of thickness swelling for 2 h time elapsed (35.10%). The lowest value of two-hour thickness swelling was given by the board 700 g cm^{-3} with resin content 14% (16.34%). The highest value for 24 h, thickness swelling was attained by the board 500 g cm^{-3} with resin content 10% (41.11%). The boards at 700 g cm^{-3} with resin content 14% had the lowest 24 h thickness swelling (12.99%).

Some chemical components in resin applied are capable of cross-linked with the hydroxyl group of the fiber, hence reducing the hygroscopicity of the boards. Hygroscopic expansion can be effected by various factors of the resin such as a monomer, the polymerization rates, the cross-linking and pore-size of the polymer network, the bond strength, the interaction between polymer and water, the filler and the resin-filler interface (Wei *et al*., 2011). According to the theory of voids over volume of board, greater existence of the void which can mostly be found in low density particle board than high density particle board may provide spaces, which encourage higher water absorption (Loh *et al*., 2010). In the low density board, the highly porous structure on the board allows penetration of water into the board and increases the water uptake resulting in high-water absorption which at the same time, causes the board to swell and subsequently causes a rise of thickness swelling (Wong *et al*., 1999).

Water absorption property of the EFB boards manufactured were obtained from water absorption analysis. Time elapsed of 2 and 24 h water absorption analyses were carried out. Table 2 shows the water absorption of EFB boards at different density and resin content. Boards at 500, 600 and 700 g cm^{-3} had the same trend of 2 and 24 h water abortion where the rate of the board absorbed water decreases as the amount of resin applied increases.

Boards of 500 g cm^{-3} with resin content 10% had the highest rate of two-hour water absorption (139.02%) whilst the lowest (40.71%) was given by the 700 g cm^{-3} board density of resin content 14%. The highest rate of 24 h water absorption was attained by the board 500 g cm^{-3} with resin content 10% (206.77%). Meanwhile, the lowest value of 24 h water absorption (59.62%) was given by the board 700 g cm^{-3} with the application of resin 14%. The increase in particle board density resulted in a better thickness swelling performance and decreased water absorption of the boards (Guler and Buyuksari, 2011). The boards with higher density can absorb more water than the boards with lower density. If the dwell inside the water increases, the adhesion strength of the board decreases, resulting in the increase in thickness. The increment in the adhesion ratio resulted in a lower thickness swelling and water absorption for the produced boards as the high adhesive ratio equals more adhesive amount applied, resulting in enhances the resin bonding strength of the materials.

Table 2: Water absorption of EFB composite boards at different density and resin contents for 2 and 24 h time elapsed

		WA (%)	
Board density (g cm^{-3})	Resin content (%)	2 h	24 h
500	10	139.02 (5.71)	206.77 (10.71)
	12	119.20 (3.06)	140.81 (3.93)
	14	113.26 (7.59)	138.29 (2.55)
600	10	92.50 (7.38)	127.48 (6.16)
	12	82.78 (5.95)	108.58 (2.05)
	14	79.84 (5.23)	96.95 (3.45)
700	10	64.24 (3.32)	91.22 (2.56)
	12	44.27 (3.09)	69.12 (5.24)
	14	40.71 (3.75)	59.62 (3.71)

WA: Water absorption

The behavior of the boards in swelling still remained deficient even after increases in the boards density and doses of adhesive (Garay *et al*., 2009). The density increases of the boards significantly improved mechanical properties and water resistance of the boards (Zheng *et al*., 2005). Zheng *et al*. (2005) suggested that, based on the same volume of board, the higher density boards had a large contact surface area between particles, making the adhesive function more effectively, as compared to the lower density particle board. Moreover, higher-density boards has less void volume, which results in a better water resistance. Although the higher-density corresponds to higher quality, it also means higher cost and weight of finished particle board. Similar finding was also observed by Khalid *et al*. (2010) in their studies on the chemical changes in 15 year-old cultivated *Acacia* hybrid oil-heat treated at 180, 200 and 220°C.

Mechanical properties: The mechanical properties discussed here were the bending strength (MOR and MOE), internal bonding and screw withdrawal property at edge and face side with the sample. The procedure of testing was executed as outlined in European Standards EN 310: 1993 and EN 325: 2012.

MOR indicates the ability of a specimen to withstand transverse (bending) forces perpendicular to its longitudinal axis (Jacobs and Kliduff, 1994). The results of MOR obtained were compared with rubber wood. The MOR analysis was exercised by using universal testing machine, where the rectangular shape sample of EFB particle board (290×50×12 mm) was placed flat on the supports as load applied. Results of MOR obtained were compared with rubber wood. Table 3 presents MOR of the EFB particle board at density 500, 600 and 700 g cm^{-3}. It can be noted that resistance to rupture increase with the increasing of board density and resin content. Board 700 g cm^{-3} with 14% resin content, had the highest MOR value (22.91 N mm^{-2}) followed by the board made with resin content 12% (18.97 N mm^{-2}) resin content of the same board density. The lowest value of MOR was attained by the board of 500 g cm^{-3} with 10% resin content (6.07 N mm^{-2}) followed by 12% (6.37 N mm^{-2}) and 14% (6.75 N mm^{-2}) resin content. Meanwhile, board of 600 g cm^{-3} gives an increasing trend from 10% (10.20 N mm^{-2}) to 12% (10.26 N mm^{-2}) and 14% (12.77 N mm^{-2}) resin content. The EFB boards 700 g cm^{-3} with 12 and 14% resin content passed the minimum requirement for MOR (14.0 N mm^{-2}) for general use's type of board according to European Standard EN 312-3 (1996). Compared with convenient particle board made from rubber wood (Paridah *et al*., 2010), the MOR value of EFB particle board 700 g cm^{-3} with 14% had a quite identical property (22.91-22.8 N mm^{-2}).

The MOE is related to the stiffness of a board and the higher the MOE the higher the stiffness. Generally, boards tend to be brittle when the MOE value is high and tends to be ductile or flexible

Table 3: Modulus of rupture and modulus of elasticity of empty fruit bunch composite boards at different density and resin content

Board density (g cm^{-3})	Resin content (%)	MOR (N mm^{-2})	MOE (N mm^{-2})
500	10	6.07 (1.54)	385.64 (108.02)
	12	6.37 (0.88)	419.43 (88.55)
	14	6.75 (1.47)	447.44 (134.29)
600	10	10.20 (0.79)	673.82 (55.64)
	12	10.26 (3.07)	773.37 (156.73)
	14	12.77 (3.37)	1006.78 (231.94)
700	10	11.03 (3.33)	1063.43 (348.71)
	12	18.97 (3.09)	1683.93 (255.10)
	14	22.91 (3.81)	2059.56 (285.01)
EN 312-3		14.0	1800
Rubberwood		22.8*	2381*

*Paridah *et al*. (2010), MOR: Modules of repture, MOE: Modulus of elasticity when the value is low (Yang *et al*., 2003; Rasat *et al*., 2011). The MOE analysis was done by using universal testing machine. Placed flat on supports, the MOE values were obtained as the constant load were applied to the testing EFB boards. The values MOE obtained were compared with rubber wood. The MOE of EFB boards manufactured was presented in Table 3. The highest value of MOE was attained by the board at density 700 g cm^{-3} with 14% resin content (2059.56 N mm^{-2}) followed by 12% (1683.93 N mm^{-2}) and 10% (1063.43 N mm^{-2}) resin content of the same density of the board. Boards at density 500 g cm^{-3} with 10% (385.64 N mm^{-2}) resin content gives the lowest value of MOE followed by 12% (419.43 N mm^{-2}) and 14% (447.44 N mm^{-2}) resin content of the same density of the board. The MOE value of the board 600 g cm^{-3} is an increase from 10% (673.82 N mm^{-2}) to 12% (773.37 N mm^{-2}) and 14% (1006.78 N mm^{-2}) resin content.

The EFB composite boards at density 700 g cm^{-3} with 14% resin content not only met the minimum requirement for MOE (1800 N mm^{-2}) for general use's type of board according to the European Standard EN 312-3 (1996) but exceeded the required values. The maximum MOE value of the EFB boards manufactured in this study was 2059.56 N mm^{-2}, slightly lower than MOE of rubber wood (2381 N mm^{-2}).

The Internal Bonding (IB) test was conducted to determine the interfacial bonding strength between fibre in the boards. The test was undergone by using universal testing machine, where the top and bottom of EFB boards were glued on metal blocks slotted into the testing assembly. It was clear from Table 4 that the EFB boards 700 g cm^{-3} with 14% resin content gives the highest IB value (0.98 N mm^{-2}) followed by 12% (0.77 N mm^{-2}) resin content of the same board density. The lowest value of IB was reported by the boards at 500 g cm^{-3} with 10% (0.18 N mm^{-2}) followed by 12% (0.19 N mm^{-2}) and 14% (0.23 N mm^{-2}) resin content of the same board density. The IB value of the panel 600 g cm^{-3} increase from 10% (0.28 N mm^{-2}) to 12% (0.31 N mm^{-2}) and 14% (0.36 N mm^{-2}) resin content. The EFB boards 700 g cm^{-3} with 10, 12 and 14% resin contents were passed the minimum requirement value of general type of board (0.40 N mm^{-2}). However, the IB values obtained from the EFB boards were slightly lower than of rubber woods' (1.3 N mm^{-2}). The lower mean IB values found from the lower density boards were expected due to the existence of more voids in the boards compared to the higher-density boards. Poor packing will lead to most of the inter particle spaces remaining as voids. The voids directly caused inefficiency of the inter-fiber bonding (Ashori and Nourbaksh, 2008). For fine and mixed particles, the chance of tighter packing and closer contact between the particles is greater, which may positively contribute to the boards (Gupta *et al*., 2011).

The platen temperature was found to affect on the internal bonding results of the composite boards. Internal bonding of UF-resin particle board significantly improved with the increase in the

Table 4: Internal bonding of empty fruit bunch composite boards at different density and resin content

Board density (g cm^{-3})	Resin content (%)	IB (N mm^{-2})	SWE (N mm^{-2})	SWF (N mm^{-2})
500	10	0.18 (0.04)	168.18 (23.56)	193.42 (29.58)
	12	0.19 (0.02)	178.82 (39.51)	244.50 (50.53)
	14	0.23 (0.03)	189.93 (20.05)	268.38 (48.04)
600	10	0.28 (0.07)	232.72 (20.19)	305.40 (24.23)
	12	0.31 (0.08)	239.08 (25.01)	314.60 (34.51)
	14	0.36 (0.17)	302.13 (41.53)	321.62 (32.27)
700	10	0.54 (0.06)	412.27 (38.10)	459.72 (42.45)
	12	0.77 (0.12)	440.67 (35.38)	511.23 (32.45)
	14	0.98 (0.08)	467.47 (46.18)	512.37 (87.26)
EN 312-3		0.40	360.0	
Rubberwood		1.30*		

*Paridah *et al*. (2010), IB: Internal bonding, SWE: Edge screw with drawal, SWF: Face screw with drawal platen temperature. Higher temperature of the platen promotes higher cross-linking and curing of the resin. During pressing process, temperature at a board's core is the lowest compared with the surface. Correct platen temperature has to be applied to ensure that the core reaches a sufficient high temperature to allow the resin to cure. Application of wax can results in lower internal bonding. This might due to the differences in chemical bonding between UF resin and particles. The wax interferes with UF resin when hydrogen bonds are formed (Papadopoulos, 2006).

The edge screw withdrawal test were conducted to evaluate the screw holding strength on the edge sections of the boards. A screw was inserted upright into the holes in the edge side of test sample and placed in a stirrup attached to load. Results of edge screw withdrawal property were obtained as load was applied in a pulling action. Table 4 presents the results of the edge screw withdrawal of EFB composite boards produced. The highest value of edge screw withdrawal was given by the boards at 700 g cm^{-3} with 14% (467.47 N mm^{-2}) resin content followed by 12% (440.67 N mm^{-2}) and 10% (412.27 N mm^{-2}) resin content of the same density of the board. The lowest value of edge screw withdrawal was given by the board at 500 g cm^{-3} with 10% (168.18 N mm^{-2}) resin content followed by 12% (178.82 N mm^{-2}) and 14% (189.93 N mm^{-2}) resin content of the same boards density. The edge screw withdrawal value for boards at 600 g cm^{-3} increases from 10% (232.72 N mm^{-2}) to 12% (239.08 N mm^{-2}) and 14% (302.13 N mm^{-2}) resin content. The EFB boards at 700 g cm^{-3} with 10, 12 and 14% resin content results met the minimum requirement for edge screw withdrawal property according to BS 5669:1989. They exceeded the 360.0 N mm^{-2} value which was used as the guided standard.

The face screw withdrawal test conducted to evaluate the screw holding strength on the face sections of the boards. A screw was inserted upright into the holes in the face side of test sample and placed in a stirr-up attached to load. The results of edge screw withdrawal property were obtained as load was applied in a pulling action. Table 5 presents face screw withdrawal of the EFB boards manufactured. Boards of 700 g cm^{-3} with 14% resin content gives the highest values in the screw withdrawal (512.37 N mm^{-2}) followed by 12% (511.23 N mm^{-2}) and 14% (459.72 N mm^{-2}) resin content of the same density boards. The lowest value were obtained by boards having density of 500 g cm^{-3} with 10% (193.42 N mm^{-2}) resin content followed by 12% (244.50 N mm^{-2}) and 14% (268.38 N mm^{-2}) resin contents of the same density boards. Face screw withdrawal of the boards with 600 g cm^{-3} increases from 10% (305.40 N mm^{-2}) resin content to 12% (314.60 N mm^{-2}) and 14% (321.62 N mm^{-2}) resin content. Higher particle loading to strengthens the boards as well as

Table 5: Correlation coefficient between physical and mechanical properties of empty fruit bunch composite boards at different density and resin content

Correlation parameters	D	RCT	MC	DEN	2HWA	24HWA	2HTS	24TS	MOR	MOE	IB	SWE	SWF
D	1	0.0000^{ns}	-0.3279*	0.9656**	-0.7247**	-0.2250^{ns}	-0.1138^{ns}	0.0218^{ns}	0.7689**	0.8284**	0.7067**	0.9204**	0.8916**
RCT		1	0.4042**	-0.0031^{ns}	-0.4934**	-0.8027**	-0.7537**	-0.8245**	0.3448**	0.3242*	0.4774**	0.1720^{ns}	0.1651^{ns}
MC			1	-0.2795*	0.2709*	-0.4750**	-0.3366**	-0.3441**	-0.0993^{ns}	-0.1058^{ns}	-0.0972^{ns}	-0.1480^{ns}	-0.1591^{ns}
DEN				1	-0.6945**	-0.2103^{ns}	-0.1093^{ns}	0.0024^{ns}	0.7693**	0.8202**	0.7053**	0.8984**	0.8770**
2HWA					1	0.3625**	0.3191*	0.3405**	0.7504**	0.7425**	0.7800**	0.6947**	0.6460**
24WA						1	0.8353**	0.7991**	0.4359**	0.4794**	0.5283**	0.4073**	0.3835**
2HTS							1	0.7980**	0.3141*	0.3625**	0.4291**	0.3357**	0.2814*
24TS								1	0.3909**	0.3767**	0.5198**	0.1874^{ns}	0.1480^{ns}
MOR									1	0.9754**	0.8811**	0.8237**	0.7641**
MOE										1	0.8840**	0.8912**	0.8269**
IB											1	0.7711**	0.7102**
SWE												1	0.8862**
SWF													1

*: $p \leq 0.05$, *: $p \leq 0.01$, ns: Not significant, RCT: Resin content, MC: Moisture content, DEN: Density, 2HWA: 2 h water absorption, 24HWA: 24 h water absorption, 2HTS: 2 h thickness swell, 24TS: 24 h thickness swell, MOR: Modulus of rupture, MOE: Modulus of elasticity, IB: Internal bonding, SWE: Edge screw withdrawal, SWF: Face screw withdrawal

increases their densities assists the boards to hold the screw better. Screw withdrawal resistance is highly associated with the board density and the particles' geometry (Wong *et al*., 1999; Wahab *et al*., 2008).

Microscopy studies: The samples from the composite boards were randomly selected for observations of their structure especially the occurrence of the fibers compression, binder-fiber compatibility and void's occurrence. The boards sample at density of 500 g cm^{-3} with UF resin content level 10% (board with the lowest physical and mechanical properties) was taken for the micro graphic studies. Figure 1 and 2 show the micrographs of cross-section of EFB particle board with resin content level 10% at 100 and 500× magnification. Figure 1 shows the occurance of fibers compression in the EFB boards. The compression of fibers occurred during the pressing stage at different applied pressure and temperatures. The EFB fibers in the boards' profile were forced to shrink to a specified thickness resulting in the compressed structure of the fibers. This resulted in the reduction of lumen void spaces and thus, increase the density of the board produced (Moslemi, 1974). Figure 2 shows that there is a good compatibility between EFB fibre and UF resin in the particle board manufactured. The fibers touches one to the others closely and no UF resin was observed clumped. This will affect the result on the mechanical properties especially on the MOR and MOE properties of the board (Hnin *et al*., 2011). As the load was applied perpendicular to the OPEFB board surface, it creates compression stress on the top side on the board which transforms into tension stress in the bottom after exceeding the middle portion. Load stresses are transferred from one particle to another particle, which, in this case, EFB fiber's acts through a medium of the load transfer (Paridah *et al*., 2010). However, there are some voids appear in the board's profile. The existence of voids in the EFB particle board profile reveals that there were empty spaces or gaps occurred at certain area on the board, which might lead to the higher water absorption. The voids created more surfaces of EFB fiber to be exposed to the surrounding humidity (Wei *et al*., 2011). The void's occurrence can be reduced by using or mixing smaller sizes of particles in the board manufacturing (Marashdeh *et al*., 2011). Board with smoother surface will be able to be produced and tiny particles will not go wasted.

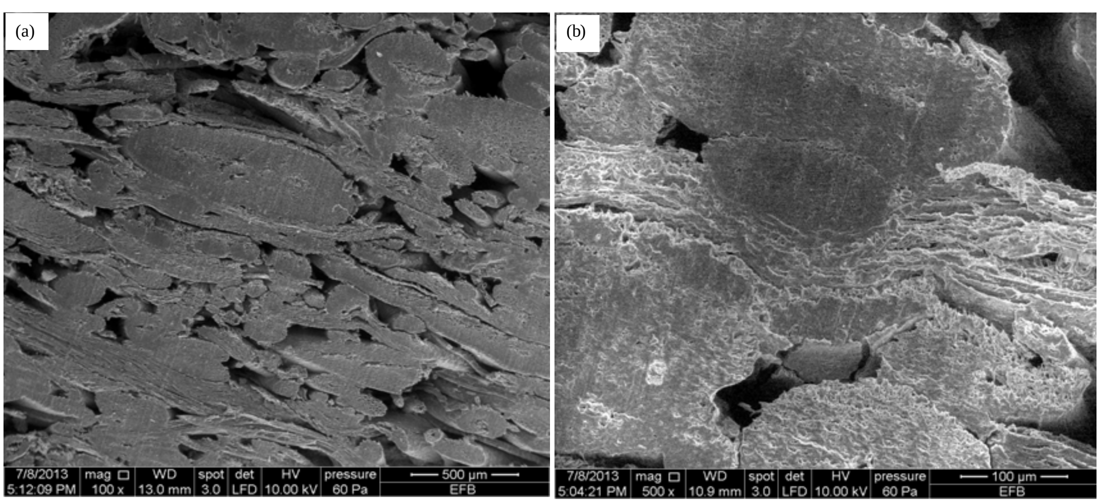

Fig. 1(a-b): Micrographs of cross section of 500 g cm^{-3} EFB composite boards with resin content 10% at (a)100× magnification and (b) 500× magnification

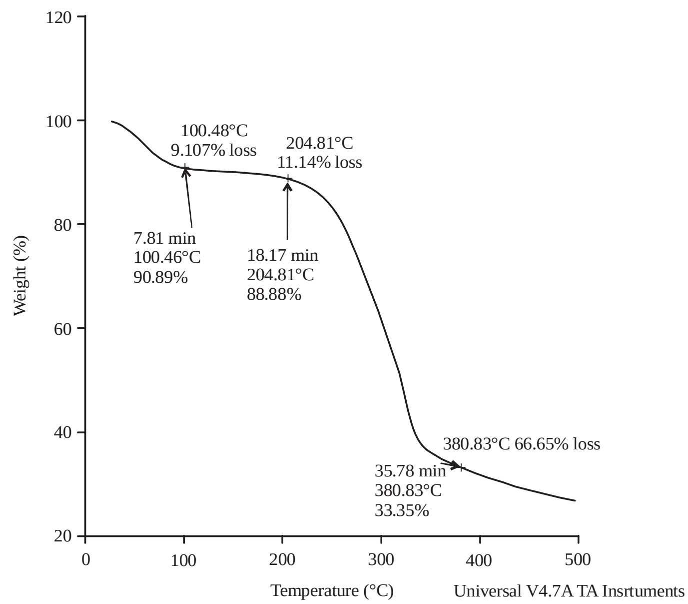

Fig. 2: TGA properties of empty fruit bunch composite boards

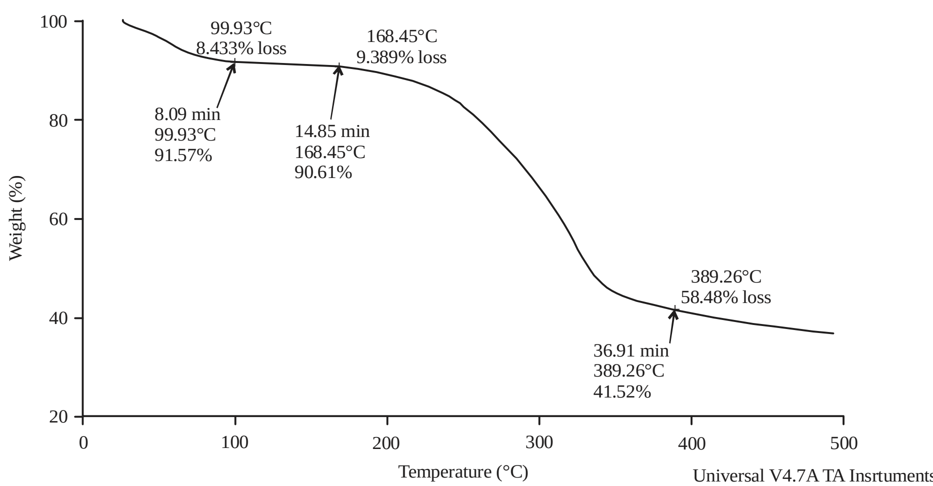

Fig. 3: TGA properties of empty fruit bunch composite boards with UF resin

Thermal properties: The thermal characteristic of the EFB composite boards and UF resin sample were analyzed with computerized TA Instruments SDT-Q600 TGA. The TGA were performed under 100 mL min^{-1} nitrogen gas for a heating rate 10°C min^{-1}. Figure 3 and show the TGA result for EFB boards. It can be seen that the decomposition in EFB boards begun at 100.46°C (1st peak). It continued to the 2nd peak at 204.81°C and completed at the 3rd peak (380.83°C). Degradation of UF resin initiated at 99.93°C (1st peak), continued at 168.45°C (2nd peak) and completed at 3rd peak (389.26°C). Table 4 represents TGA % weight loss with temperature for UF resin boards. The loss of UF resin in weight were the highest at 3rd peak (58.48%), followed by the 2nd peak (9.39%) and the 1st peak (8.43%). The final decomposition of the composite is lower than

Table 6: Thermogravimetric analysis weight loss (%) with temperature for urea-formaldehyde resin and empty fruit bunch composite boards

Parameters	1st peak	2nd peak	3rd peak
EFB boards			
Temperature (°C)	100.46	204.81	380.83
Weight loss (%)	9.12	11.14	66.65
UF resin boards			
Temperature (°C)	99.93	168.45	389.26
Weight loss (%)	8.43	9.39	58.48

EFB: Empty fruit bunch, Urea-formaldehyde

of the UF resin (389.26-380.83°C) indicates that the presence of cellulose fibers (from EFB fibers) had a significant effect on thermal stability of the composite boards. This could be probably due to the disturbance in the original crystal lattice of the composite by the EFB boards (Singha and Thakur, 2009).

Degradation of EFB and UF resin boards started by the depolymerization of molecular structure and dehydration of sample (loss of water) and later, the free formaldehyde in UF resin were slowly released (Marashdeh *et al*., 2011; Zorba *et al*., 2008). The process resumed by the cleave of linkages that occurred in the composite and UF resin. Carbon-hydrogen (C-H) bonds were broken first, followed by carbon-oxygen (C-O) bonds, carbon-carbon (C-C) bonds and hydrogen-oxygen (O-H) bonds. energy needed to break those linkages were 414 kJ mol^{-1} for -C-H bond, 356 kJ mol^{-1} for -C-O bond and 347 kJ mol^{-1} for -C-C and last but not least the O-H bond, 460 kJ mol^{-1}. This is the stage where cellulose, hemicellulose and lignin began to decompose. The thermal degradation of polymer blocks of biomass occurred at the second peak. Hemicellulose and lignin degraded earlier (BS 5669, 1989; Abdullah and Bridgwater, 2006). This might be due to their molecular structure that less rigid (amorphous) than cellulose) compared to cellulose. Finally, upon introduction of oxygen (3rd peak), combustion occurred and the final weight loss infers the amount of carbon in the composite. The carbon contents of the boards were 58.48% (UF resin boards) and 66.65% (EFB boards) (Table 6).

CONCLUSION

The EFB composite boards properties met all requirement for commercial application. The boards density and resin content applied influenced on the boards overall properties. The studies indicated an increases across the board physical and mechanical properties. The highest MOR and MOE value achieved in this study were 22.91 and 2059.56 N mm^{-2}. Highest value for internal bonding was 0.98 N mm^{-2}, meanwhile for edge and face screw withdrawal, 467.47 and 512.37 N mm^{-2}.

The boards produced at density 700 g cm^{-3} with 14% resin content showed an overall good properties with good dimensional stability. The boards with less porous structure are unlikely to swell when exposed to wet environment. Boards produced at density 500 g cm^{-3} with 10% resin content showed the lowest physical and mechanical properties. This type of board when scanned under SEM shows numerous voids structure that absorb and traps moisture. Inter particle's bonding were thus diminished as moisture interrupts, causing to low board performance.

The UF resin boards showed higher thermal stability compared to normal boards when analyzed under TGA. Thermogravimetric analysis was done to study thermal stability of the boards manufactured. The maximum rate of decomposition for the OPEFB particleboard sample occurred at 380.83°C, whereas the temperature of UF resin was 389.26°C, explaining UF resin by itself more stable than of the particle board.

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