Advances in Environmental Biology, 9(23) October 2015, Pages: 352-360

AENSI Journals

Advances in Environmental Biology

ISSN-1995-0756 EISSN-1998-1066

Journal home page: http://www.aensiweb.com/AEB/

Measurement on Properties of Empty Fruit Bunch Oil Palm Composite Boards at Different Density and Resin Contents

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ARTICLE INFO

Article history:
Received 28 September 2015
Accepted 30 October 2015
Available online 24 November 2015

Keywords:
Oil palm, empty fruit bunch, composite boards, physical, mechanical strength, thermal stability.

ABSTRACT

Background: The objective of this study is to measures on the properties of composite boards made from oil palm empty fruit bunch (OPEFB) at different density and resin contents. The oil palm empty fruit bunches were obtained from an oil palm plantation and refined using fibre cutter and particle crusher. Hardeners and wax added at 1% and 3% during the mixing process. Boards of densities 500, 600 and 700 kg m^{-3} produced with resin urea formaldehyde at 10, 12 and 14% respectively. The boards stored in a conditioning chamber set at 20±2°C and 65% relative humidity before undergoing subsequent testing. The testing procedure followed the EN Standard of specifications. The results indicated increases across the board physical and mechanical properties. The highest modulus of rupture (MOR) and modulus of elasticity (MOE) value achieved in this study were 22.91 N mm^{-2} and 2059.56 N mm^{-2}. The highest value for internal bonding (IB) was 0.98 N mm^{-2}, for edge and face screw withdrawal the IB were 467.47 N mm^{-2} and 512.37 N mm^{-2}. Boards with 700 kg m^{-3} density and 14% resin contents met the requirement in accordance to the established standard. Board with 500 k gm^{-3} density and 10% resin content observed microscopy showe voids in some of the resin-fibre bonding areas at the cross-section of the board. This suggested that moisture somehow penetrated into the board via the open spaces and attacked the linkages existed causing in the low property. Thermogravimetric analysis conducted in the thermal stability of the boards showed maximum rate of decomposition for the OPEFB boards at 380.83°C. In conclusion, the board's density and resin content applied influenced on the boards overall properties.

To Cite This Article: Razak Wahab, Mohd Sukhairi Mat Rasat, Mohammed Abdus Salam, Janshah Moktar, Mazlan Mohamed and Siti Marlia Mohd Don., Measurement on Properties of Empty Fruit Bunch Oil Palm Composite Boards at Different Density and Resin Contents. ***Adv. Environ. Biol., 9(23),*** *352-360, 2015*

INTRODUCTION

Wood composite products such as thick laminates for glued laminated beams, thin veneers for plywood, strands for strand board, flakes for flake board, particles for particleboard and fibres for fibreboard has nowadays become popular in the wood industry. The demands for these products have increases due to the scarcity of the wood supply [1], [2], [3]. Oil palm is an important plantation and by far the largest crop in Malaysia. The oil palm trees become economically unproductive after 25-30 years and needs to be replanted. A Huge amount of oil palm biomass becomes available during this period. This biomass is usually left to rot in the fields. This readily available renewable resource could be used as a raw material for wood-based industry [4], [5]. Extensive study has been done to find suitability of lignocellulose material from oil palm trunks to replace wood in wood-based panel industry. The il palm empty fruit bunch (OPEFB) is one of the oil palm biomass materials. OPEFB is amounting to 12.4 million tonnes per year (fresh weight) and regularly discharged from palm oil refineries [6]. It is a lignocellulosic material and has potential as the natural fibre resource. The moisture content of fresh OPEFB is very high, about over 60% on a wet OPEFB 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 the shell and drier part of the fibre product stream, rather than OPEFB, to fuel their

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boilers [7]. As OPEFB is readily available and abundance in Malaysia, converting them into composite boards can be a way to resolve the scarcity of wood sources in the tropical region of the world where the plants grow.

The objective of the current study is to measure the properties of composite boards made from OPEFB. The measurement will focus on the physical and mechanical properties, a study on resin-fibre bonding properties through scanning electron microscopy (SEM) and measurement on the thermal properties of the boards. The information obtained in the study can help the wood industry in enhancing the utilisation of the oil palm biomass.

MATERIALS AND METHODS

The OPEFB samples obtained from an oil palm plantation located in Kuala Selangor, Selangor. The materials were refined into smaller size using fibre 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 chosen in this study. The particles were then oven-dried at 103±2°C for 24 hrs. The mass of the particles was measured to obtain targeted densities of 500, 600 and 700 kg m^{-3}. They mixed with the urea-formaldehyde (UF) resin in a mixing drum. Three (3) levels of resin content applied to the boards' production at 10, 12 and 14% level.

The mixed particles were hand-felted into a wooden frame 340 mm x 340 mm size of a caul plate. The formed mat was pre-pressed by using the 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 the duration of 6 minutes. Four metal bars of 12 mm thickness used in the hot-pressing process. The boards produced were then cooled and cut into standard testing size. The testing samples stored in a conditioning chamber conditioned at 20±2°C and 65% relative humidity until reaching their constant weight, prior for the testing procedure. Boards at densities of 500, 600 and 700 kgm^{-3} and UF resin application at 10, 12 and 14% produced in laboratory scale. All boards produced in accordance to British [8] and European Standards [9], [10], [11], [12], [13], [14].

Physical studies:

The physical studies measurement conducted were the density of the OPEFB composite boards, the moisture content of the boards manufactured, water absorption and thickness swelling tests of 2 and 24 hours elapsed. Physical studies conducted in accordance to the standard of EN 322 [12], EN323 [13], EN 317 [11].

Mechanical studies:

The mechanical measurement carried out including the static bending test including modulus of rupture (MOR) and modulus of elasticity (MOE), internal bonding test and screw withdrawal test (edge and face). All the tests were done by using the universal testing machine in according to the standard of EN 310 [9] and EN 325 [14]. Screw hold strength of the OPEFB composite boards tested according to the standard of BS 5669 [8].

Scanning Electron Microscopy:

The microscopy study conducted to study the structure of the boards of 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 SEM located at the Pulp and Paper Laboratory, FRIM, Kepong. Clean cut sample with a dimension of 1cm x 1 cm x 1 cm used. The SEM equipment connected with a computer for image storage and processing.

Thermo Gravimetric Analysis:

Thermogravimetric analysis (TGA) 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) 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 of the material in comparative studies. Thermal analysis was carried out with a computerised TA Instrument SDT-Q600 thermogravimetric analyser. Samples (5.5±0.2 mg) placed in alumina crucibles and the TGA performed under 100 ml min^{-1} nitrogen with a heating rate of 10°C min^{-1}.

RESULTS AND DISCUSSION

Physical Properties:

The physical properties discussed throughout this study, including the density of the OPEFB composite boards manufactured, moisture content, thickness swelling and water absorption at 2 and 24 hours elapsed time. Table 1 shows the density properties of the OPEFB composite boards. Boards' at density 500 kg m^{-3} with 10%

resin content level had an average density of 506.29 kg m^{-3}, 12% resin content with 506.9 kg m^{-3} and 14% resin content at 517.6 kg m^{-3}. Board 600 kg m^{-3} with 10% resin content level had an average density of 598.65 kg m^{-3}, 12% resin content with 608.9 kg m^{-3} and 14% resin content at 620.05 kg m^{-3}. Average density of the board 700 kg m^{-3} is 704.03 kg m^{-3} (10% resin content), 714.72 kg m^{-3} (12% resin content) and 723.89 kg m^{-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 kg m^{-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 kgm^{-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 composite boards manufactured obtained from thickness swelling analysis. Time elapsed of 2 and 24 hours thickness swelling analysis was carried out, and percentage of increment of thickness were then calculated. Boards at densities of 500, 600 and 700 kg m^{-3} had a particular trend of 2 and 24 hours thickness swelling where the rate of the board got swelled decreased as the amount of resin applied increase. The boards at 500 kg m^{-3} at resin content 10% had the highest rate of thickness swelling for 2 hours' time elapsed (35.1%). The lowest value of 2 hours thickness swelling given by the board 700 kg m^{-3} with resin content 14% (16.34%). The highest value for 24 hours, thickness swelling was attained by the board 500 k gm^{-3} with resin content 10% (41.11%). The boards at 700 kg m^{-3} with resin content 14% had the lowest 24 hours thickness swelling (12.99%).

Table 1: Density of OPEFB composite boards and values for thickness swelling at different density and resin content for 2 and 24 hours time elapsed.

Board density (kg m^{-3})	Resin content (%)	Moisture content (%)	Density (kg m^{-3})	Thickness swelling (%)	
				2 hrs.	24 hrs.
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)

Standard deviations are shown in the bracket.

Some chemical components in resin applied are capable of cross-linked with the hydroxyl group of the fibre, hence reducing the hygroscopicity of the boards. Hygroscopic expansion can be affected 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 [15]. According to the theory of voids over the volume of the board, the greater existence of the void that can mostly found in low-density particleboard than high-density particle board may provide spaces, which encourage higher water absorption [16]. 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 that at the same time, causes the board to swell and subsequently causes a rise of thickness swelling [17].

Water absorption property of the OPEFB composite boards manufactured obtained from water absorption analysis. Time elapsed of 2 and 24 hours water absorption analyses were carried out. Table 2 shows the water absorption of OPEFB composite boards at different density and resin content. Boards at densities of 500, 600 and 700 k gm^{-3} showed the same trend of 2 and 24-hour water abortion where the rate of the board absorbed water decreases as the amount of resin applied increases.

Boards at density 500 k gm^{-3} with resin content 10% had the highest rate of 2-hour water absorption (139.02%) while the lowest (40.71%) given by the 700 k gm^{-3} board density of resin content 14%. The highest rate of 24 hours water absorption was attained by the board at density 500 kg m^{-3} with resin content 10% (206.77%). Meanwhile, the lowest value of 24 hours water absorption (59.62%) was given by the board 700 kgm^{-3} with the application of resin 14%. The increase in the board density resulted in a better thickness swelling performance and decreased water absorption of the boards [18]. 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.

The behaviour of the boards in swelling remained deficient even after increases in the boards' density and doses of adhesive [19]. The density increases of the boards significantly improved mechanical properties and water resistance of the boards [20], [21]. Based on the same volume of the 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 [20], [21]. Moreover, higher density board 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 composite board.

Table 2: Water absorption of OPEFB composite boards at different density and resin contents for 2 and 24 hours time elapsed.

Board density (kgm^{-3})	Resin content (%)	Water absorption (%)	
		2 hrs.	24 hrs.
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)

Standard deviations are shown in the bracket.

Mechanical Properties:

The mechanical properties discussed here were the static bending strength (MOR and MOE), internal bonding and screw withdrawal property at edge and face side with the sample. The procedure of testing executed as outlined in standards of EN 310 [10] and EN 325 [14].

MOR indicates the ability of a specimen to withstand transverse (bending) forces perpendicular to its longitudinal axis [22]. The results of MOR obtained compared with rubber wood. MOR analysis was exercised by using the universal testing machine, where the rectangular shape sample of OPEFB board (290 mm x 50 mm x 12 mm) placed flat on the supports as the load applied. Results of MOR obtained compared with rubber wood. Table 3 presents MOR of the OPEFB composite board at density 500, 600 and 700 kg m^{-3}. It noted that resistance to rupture increase with the increasing of board density and resin content. Board 700 kg m^{-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 kg m^{-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 kg m^{-3} gives an increasing trend from 10% (10.2 N mm^{-2}) to 12% (10.26 N mm^{-2}) and 14% (12.77 N mm^{-2}) resin content. The OPEFB boards at density 700 kg m^{-3} with 12 and 14% resin contents passed the minimum requirement for MOR (14 N mm^{-2}) for general use's type according to the standard of EN 312-3 [10]. Compared with a convenient board made from rubber wood [23], the MOR value of OPEFB composite board 700 kg m^{-3} with 14% had a quite identical property (22.91 to 22.8 N mm^{-2}).

MOE is related to the stiffness of a board, and the higher the MOE, the higher the stiffness. The boards tend to be brittle when the MOE value is high and tends to be ductile or flexible when the value is low [24], [25]. MOE analysis was done by using the universal testing machine. Placed flat on supports, the MOE values were obtained as the constant load applied to the testing OPEFB composite boards. The values MOE obtained compared with rubber wood. MOE of OPEFB boards manufactured presented in Table 3. The highest value of MOE was attained by the board at density 700 kg m^{-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 kg m^{-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. MOE value of the board 600 kgm^{-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 OPEFB boards at density 700 kg m^{-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 standard of EN 312-3 [10] but exceeded the required values. The maximum MOE value of the OPEFB composite boards manufactured in this study was 2059.56 N mm^{-2}. This value is slightly lower than the MOE of rubber wood (2381 N mm^{-2}).

Internal Bonding (IB) test was conducted to determine the interfacial bonding strength between fibres in the boards. The test was undergone by using the universal testing machine, where the top and bottom of OPEFB composite boards were glued on metal blocks slotted into the testing assembly. It was clear from Table 4 that the OPEFB composite boards 700 kg m^{-3} with 14% resin content give 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 kg m^{-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. IB value of the panel 600 kg m^{-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. OPEFB composite boards 700 kg m^{-3} with 10, 12 and 14% resin contents were passed the minimum requirement value of the general type of board (0.4 N mm^{-2}). However, the IB values obtained from the OPEFB composite boards were slightly lower than of rubber wood (1.3 N mm^{-2}). The lower IB values found from; the lower density boards 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-fibre bonding [26]. 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 [27].

Table 3: Modulus of rupture (MOR) and modulus of elasticity (MOE) of OPEFB composite boards at different density and resin content.

Board density (k gm^{-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 Rubber wood		14.0 22.8*	1800 2381*

*Paridah *et al.* (2010), and the standard deviations are shown in the bracket.

Platen temperature was found to influences the internal bonding results of the composite boards. Internal bonding of UF resin composite board significantly improved with the increase in the platen temperature. The Higher temperature of the platen promotes higher cross-linking and curing of the resin. During pressing process, the temperature at a board's core is the lowest compared with the surface. Corrected platen temperature has to be applied to ensure that the core reaches a sufficiently high temperature to allow the resin to cure. Application of wax can result in lower internal bonding. This is due to the differences in chemical bonding between UF resin and particles. The wax interferes with UF resin when hydrogen bonds formed [28].

The edge screw withdrawal test was 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 the test sample and placed in a stirrup attached to the load. Results of edge screw withdrawal property obtained as the load was applied in a pulling action. Table 4 presents the results of the edge screw withdrawal of OPEFB composite boards produced. The highest value of edge screw withdrawal was given by the boards at 700 k gm^{-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 kg m^{-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 kg m^{-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 OPEFB composite boards at 700 kg m^{-3} with 10, 12 and 14% resin content results met the minimum requirement for edge screw withdrawal property according to BS 5669 [8]. They exceeded the 360 N mm^{-2} value that used as the guided standard.

Table 4: Internal bonding of OPEFB composite boards at different density and resin content.

Board density (kg m^{-3})	Resin content (%)	Internal bonding (N mm^{-2})	Screw Withdrawal "edgewise" (N mm^{-2})	Screw Withdrawal "flatwise" (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 Rubber wood		0.40 1.30*	360.0	

*Paridah *et al*. (2010), and the standard deviations shown in the bracket.

The face screw withdrawal test conducted to evaluate the screw holding strength on the face sections of the boards "edgewise" and "flatwise". A screw was inserted upright into the holes in the face side of the test sample and placed in a stirrup attached to the load. The results of edge screw withdrawal property obtained as the load was applied in a pulling action. Table 4 presents face screw withdrawal of the OPEFB composite boards manufactured. Boards of 700 kg m^{-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 a density of 500 kg m^{-3} with 10% (193.42 N mm^{-2}) resin content followed by 12% (244.5 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 kg m^{-3} increases from 10% (305.4 N mm^{-2}) resin content to 12% (314.6 N mm^{-2}) and 14% (321.62 N mm^{-2}) resin content. Higher particle loading to strengthens the boards as well as 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 [3], [29].

Microscopy studies:

The samples from the composite boards were randomly selected for observations of their structure especially the occurrence of the fibres compression, binder-fibre compatibility and void's occurrence. The boards sample at a density of 500 kg m^{-3} with UF resin content level 10% (board with the lowest physical and mechanical properties) taken for the micrographic studies. Figures 1 and 2 shows the micrographs of a cross-section of OPEFB composite board with resin content level 10% at 100 x and 500 x magnification. Figure 1 shows the occurrences of fibres compression in the OPEFB composite boards. The compression of fibres occurred during the pressing stage at different applied pressure and temperatures. OPEFB fibres in the boards' profile were forced to shrink to a specified thickness resulting in the compressed structure of the fibres. This resulted in the reduction of lumen void spaces and thus, increase the density of the board produced [29]. Figure 2 shows that there is a good compatibility between OPEFB fibre and UF resin in the particle board manufactured. The fibres touch one to the others closely, and no UF resin was observed clumped. This affect the result on the mechanical properties especially on the MOR and MOE properties of the board [30]. As the load was applied perpendicular to the OPEFB composite board surface, it creates compression stress on the top side on the board that 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, OPEFB fibre's acts through a medium of the load transfer [23]. However, there are some voids appear in the board's profile. The existence of voids in the EFB composite board profile reveals that there were empty spaces or gaps occurred at a certain area on the board, which might lead to the higher water absorption. The voids created more surfaces of OPEFB fibre to be exposed to the surrounding humidity [15]. The void's occurrence can be reduced by using or mixing smaller sizes of particles in the board manufacturing [31]. Boards with the smoother surface will be able to produce, and the tiny particles will not go wasted.

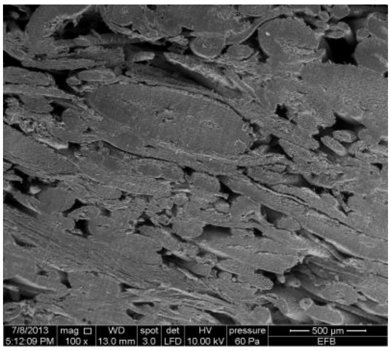

Fig. 1: Micrographs of a cross section at density 500 k gm^{-3} ^{OP}EFB composite boards with resin content 10% at 100x magnification.

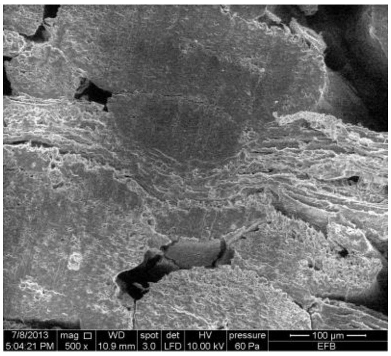

Fig. 2: Micrographs of a cross section at density 500 k gm^{-3} OPEFB composite boards with resin content 10% at 500x magnification.

Thermal Properties:

The thermal characteristic of the OPEFB composite boards and UF resin sample analysed with computerised TA Instruments SDT-Q600 TGA. The TGA performed on 100 $mlmin^{-1}$ nitrogen gases for a heating rate 10°Cmin^{-1}. Figure 3 shows the TGA result for OPEFB composite boards. The decomposition in OPEFB composite 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). Figure 4 shows the result of the degradation of UF resin that initiated at 99.93°C (1st peak), continued at 168.45°C (2nd peak) and completed at 3rd peak (389.26°C). Table 5 represents TGA weight loss (%) with temperature for UF resin boards. The loss of UF resin in weight was the highest at third peak (58.48%), followed by the 2nd peak (9.39%) and the 1st peak (8.43%). The final decomposition of the OPEFB composite board is lower than of the UF resin (389.26 to 380.83°C) indicates that the presence of cellulose fibres (from OPEFB fibres) had a significant effect on thermal stability of the composite boards. This probably due to the disturbance in the original crystal lattice of the composite by the OPEFB composite boards [32].

Table 5: TGA weight loss (%) with temperature for OPEFB composite boards and UF resin.

		1st peak	2nd peak	3rd peak
EFB composite 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

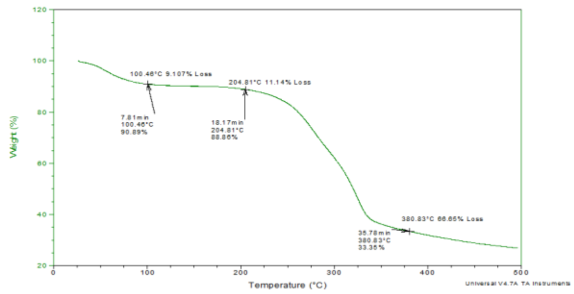

Fig. 3: TGA properties of OPEFB composite boards.

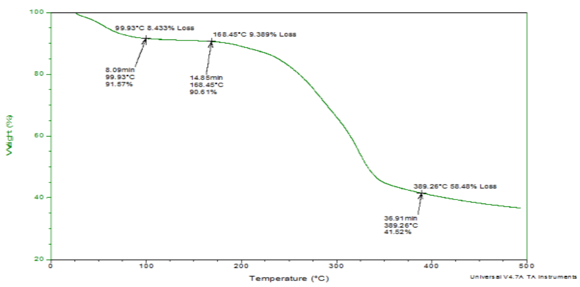

Fig. 4: TGA properties of UF resin.

The degradation of the OPEFB composite board and UF resin 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 [31], [33]. 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. The 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 [7], [34]. This is 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) and 66.65% (OPEFB composite boards) (see Table 5).

Conclusion:

The measurement on the OPEFB composite boards' properties m*et al*l requirements for commercial application. The boards' density and resin content applied influenced on the boards overall properties. The studies indicated an increase across the board physical and mechanical properties. The highest MOR and MOE value achieved in this study were 22.91 N mm^{-2} and 2059.56 N mm^{-2}. The highest value for internal bonding was 0.98 N mm^{-2}, meanwhile for edge and face screw withdrawal, 467.47 N mm^{-2} and 512.37 N mm^{-2}. The boards produced at density 700 kgm^{-3} with 14% resin content showed a good overall property with good dimensional stability. The boards with less porous structure are unlikely to swell when exposed to the wet environment. Boards produced at density 500 kg m^{-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 absorbs and traps moisture. Inter particle's bonding was thus diminished as moisture interrupts, causing low board performance. The UF resin showed higher thermal stability compared to normal boards when analysed under TGA. Thermogravimetric analysis was done to study the thermal stability of the boards manufactured. The maximum rate of decomposition for the EFB composite board sample occurred at 380.83°C, whereas the temperature of UF resin was 389.26°C, which explained that the UF resin by itself more stable than of the composite boards.

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