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Properties of Empty Fruit Bunches Eco-Composite Boards from *Elaeis guineesis*

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Abstract

This studies investigated on the properties of eco-composite boards made from *Elaeis guineesis* empty fruit bunch. The empty fruit bunches (EFB) collected from a private *Elaeis guineesis* plantation in Selangor. The EFB refined using fiber cutter and particle crusher. Hardeners and wax added at 1% and 3% during the mixing process. Boards with densities of 700, 600 and 500 kg/m^3 produced using resin urea formaldehyde as the bonding agent at 10, 12 and 14%. The boards conditioned in a conditioning chamber set at 20±2 ℃ and 65%

relative humidity before undergoing subsequent testing. Preparation for boards and tests samples follows BS and EN Standards specifications. Maximum modulus of rupture (MOR) were 22.91 N/mm^2 and modulus of elasticity (MOE) 2059.56 N/mm^2. The internal bonding recorded at 0.98 N/mm^2, for the edge and face screw withdrawal were at 467.47 N/mm^2 and 512.37 N/mm^2 respectively. The boards with 700 kg/m^3 density and 14% resin content met the required standard with good dimensional stability. In the thermogravimetric analysis the maximum rate of decomposition for the EFB boards occurred at 380.83 ℃. The board's overall properties are influence by the density and resin content applied.

Keywords: *Elaeis guineesis*, empty fruit bunches, eco-composite boards, physical and strength properties, thermogravimetric analysis.

1. Introduction

Wood composites products have nowaday become popular in the timber industry due to the scarcity in obtaining natural timber. The demands for these commodities increases due to the shortage of the wood supply (Wahab *et al*., 2016a; 2008; Rasat *et al*., 2013a). *Elaeis guineesis* or oil palm is a valuable plantation in Malaysia. The *E. guineesis* become economically unproductive after 25-30 years and need to be replanting. Huge amount of oil palm biomass becomes available during this period. This biomass is normally left in the fields to rot. This readily resource could be used as a raw material for wood-based industry (Rasat *et al*., 2013b; 2013c; 2013d). Studies has been initiated to find suitable uses of this lignocellulose material from *E. guineesis* trunks as an alternative to replace wood in wood-based panel industry. The empty fruit bunches (EFB) is a lignocellulosic material that has potential as the natural fiber resource. EFB are available in abundance in Malaysia, converting them into composite boards can reduced pressure on wood sources in the tropical region of the world. EFB amounting to 12.4 million tons per year (fresh weight) and regularly discharged from palm oil refineries (Khalil *et al*., 2007). EFB is a poor material fuel and presents a considerable emission problem during burning. *E. guineesis* mills typically use the shell and drier part of the fiber product rather than EFB, to fuel their boilers (Abdullah & Bridgwater, 2006).

This study focused on the physical, mechanical properties, microscopy studies using Scanning Electron Microscope (SEM) on resin-fiber bonding properties and thermal properties of the boards. The information obtained in the study can help the wood industry in enhancing the utilization of the oil palm biomass.

2. Materials and Methods

The EFB were collected from an *Elaeis guineesis* plantation located in Kuala Selangor, Selangor. The materials were refined into smaller size using the mechanical cutter and crusher. A four-tier sieve shaker used to screen and remove the oversize, fines and impurities. The particles that passed through 2.0 mm sieve size and retained at 1.5 mm sieve size. The particles oven-dried at 103±2 ℃ for 24 hrs. The mass of the particles was measured to obtain targeted densities of 700, 600 and 500 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%. The mixed particles hand-felted into a wooden frame 340 x 340 mm size of a caul plate. The formed mat was pre-pressed by using the cold press machine. The forming frame removed leaving the mat on the caul plate. The mat hot-pressed under Taihei hot-press machine at temperature 165 ℃ 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 ℃ and 65% relative humidity until reaching their constant weight, before the testing procedure. Boards at densities of 700, 600 and 500 kg/m^3 and UF resin applied at 10, 12 and 14% produced in laboratory scale. All boards provided by European standards (EN standards).

2.1 Physical Properties

The studies conducted were the density, moisture content, water absorption, and thickness swelling tests of 2 and 24 hours elapsed of the EFB composite boards. The physical studies carried out in accordance to the EN 322 (European standard, 1993a), EN 323 (European standard, 1993b) and EN 317 (European standard, 1993c).

2.2 Mechanical Properties

The studies carried out including the static bending for modulus of rupture (MOR) and modulus of elasticity (MOE), internal bonding test and the screw withdrawal test (edge and face). All tests conducted using the universal testing machine in according to the standard of EN 310 (European standard, 1993d) and EN 325 (European standard, 2012).

Screw hold strength of the composite boards tested according to the standard of BS 5669 (British standard, 1989). The edge screw withdrawal test conducted to evaluate the screw holding strength at the edge sections of the boards. A screw inserted upright into the holes at the edge side of the test sample and placed in a stirrup attached to the load. The edge screw withdrawal property obtained as the load applied to a pulling action.

2.3 Thermogravimetric Analysis

Thermogravimetric analysis (TGA) used to measure the thermal stability of the boards. The weight changed with temperature measured and used to infer the moments of change during the heating. Temperature occurred when the boards started to degrade are taken as an indicator of the stability of the material (Soom *et al.*, 2006). TGA was carried out with a digital TA Instrument SDT-Q600 thermogravimetric analyzer. Samples (5.5±0.2 mg) placed in alumina crucibles. TGA performed under 100 mlmin^{-1} nitrogen with a heating rate of 10 ℃ min^{-1}.

3. Results and Discussion

3.1 Physical Properties

Table 1 shows the density and thickness swelling of the EFB composite boards. Boards' at density 500 kg/m^3 with 10% resin content level had an average density of 506.29 k/gm^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 k/gm^3. Average density of the board 700 kg/m^3 is 704.03 kg/m^3 with 10% resin, 714.72 kgm^{-3} with 12% resin, and 723.89 k/gm^3 with 14% resin. The boards at density 500 kg/m^3 possess MC value of 6.89% at 10% resin, 7.15% at 12% resin, and 8.48% at 14% resin. Boards at 600 kg/m^3 has MC of 6.04% at 10% resin, 6.83% at 12% resin, and 6.48% at 14% resin. The board's density of 700 possesses MC at 6.64% with 10% resin, 6.72% with 12% resin, and 7.12% with 14% resin.

The thickness swelling properties of the EFB composite boards manufactured obtained from the thickness swelling analysis. Time elapsed of 2 and 24 hours thickness swelling analysis was carried out, and percentage of increment of thickness then calculated. Boards with densities of 700, 600 and 500 kg/m^3 possess a particular trend of 2 and 24 hours thickness swelling where the swelling decreases as the amount of resin applied increases. The boards at 500 kg/m^3 at resin content 10% had the highest rate of thickness swelling for 2 hours' time elapsed at 35.1%. The lowest value of 2 hours thickness swelling given by the board 700 kg/m^3 with resin content 14% at 16.34%. The highest value for 24 hours, thickness swelling was attained by the board 500 kg/m^3 with resin content 10% at 41.11%. The boards at 700 kg/m^3 with resin content 14% had the lowest 24 hours thickness swelling at 12.99%.

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

Board density (kg/m^3)	Resin content (%)	Moisture content (%)	Density (kg/m^3)	Thickness swelling (%)	
				2 h	24 h
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)
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)
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)

Standard deviations shown in bracket.

Some chemical components in the resin applied capable of cross-linking with the hydroxyl group of the fiber reducing the hygroscopicity of the boards. Hygroscopic expansion can be affected by various factors of the resin, polymerization rates, cross-linking, and pore-size of the polymer network, bond strength, interaction between polymer and water, the filler and the resin-filler interface (Wong et al., 1999). 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 boards than high-density boards may provide spaces that increase water absorption (Loh et al., 2010). In the low-density board, the highly porous structure allows penetration of water into the board and increases the water uptake resulting in high water absorption, causes the board to swell and gives rise in thickness swelling (Wong et al., 1999).

Water absorption property of the EFB composite boards manufactured obtained from water absorption analysis. Time elapsed of 2 and 24 hours water absorption studies tested. The water absorption of EFB composite boards at different density, and resin content was shown in Table 2. Boards of 700, 600 and 500 kg/m^3 densities 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 kg/m^3 with resin content 10% had the highest rate of 2-hour water absorption at 139.02% while the lowest at 40.71% given by the 700 kg/m^3 board density of resin content 14%. The highest rate of 24 hours water absorption attained by the board at 500 kg/m^3 density with resin content 10% at 206.77%. The lowest value at 24 hours water intake at 59.62% obtained by the board 700 kg/m^3 with 14% resin. The increase in the board density resulted in a better thickness swelling performance and decreased water absorption of the boards (Wahab *et al*. 2016c; Rasat *et al*. 2013e; Guler & Büyüksarı, 2011). The boards with high density absorbed more water than those with low density. The adhesion strength of the board decreases when the dwell inside the water increases, resulting in the increase in the thickness of the boards. The increment in the adhesion ratio resulted in low thickness swelling and water absorption for the boards. The swelled boards remained deficient even after the increases in the boards' density and adhesive (Wahab *et al*., 2016a; Garay *et al*., 2009). Increases in the density of the boards significantly improved the strength and water resistance (Zheng *et al*., 2005). The high-density boards possess large contact surface area between particles, making the adhesive function more efficiently compared to the lower density particle board (Zheng *et al*., 2005). The boards with higher density have less void volume, resulting in better water resistance. Although boards with high density normally correspond to high quality, it also means higher cost and weight of the finished composite board. Khalid *et al.* (2015) made a similar observation in their studies in the evaluation of layering effects and adhesive rates on laminated compressed composite panels from oil palm.

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

Board density (kg/m^3)	Resin content (%)	Water absorption (%) 2 hrs.	Water absorption (%) 24 hrs.
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)
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)
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)

Standard deviations shown in bracket.

3.2 Mechanical Properties

Sample of EFB board of size 290 x 50 x 12 mm placed flat on the supports as the load applied using a universal testing machine. The results on the MOR obtained were compared with rubber wood. Table 3 presents MOR of the EFB composite board at density 700, 600 and 500 kg/m^3. The resistance to rupture increase with the increasing of board density and resin content. Board with 700 kg/m^3 with 14% resin possess the highest MOR at 22.91 N/mm^2 followed by the board made with a resin content of 12% at 18.97 N/mm^2 resin with the same density. Lower MOR attained by the boards with density 500 kg/m^3 with 10% resin content at 6.07 N/mm^2 followed by 12% at 6.37 N/mm^2) and 14% at 6.75 N/mm^2 resin content. The boards of 600 kg/m^3 gives an increasing trend from 10% at 10.2 N/mm^2 to 12% at 10.26 N/mm^2 and 14% at 12.77 N/mm^2 resin content. The EFB boards at density 700 kg/m^3 with 12 and 14% resin contents passed the minimum requirement for MOR at 14 N/mm^2 for general use's type according to the standard of EN 312-3 (European standard, 1996). Compared with a convenient board made from rubber wood (Paridah *et al*., 2010), the MOR value of EFB composite board 700 kg/m^3 with 14% had a quite identical property at 22.91 to 22.8 N/mm^2.

The MOE is related to the stiffness of the board, where the higher MOE meant the greater the stiffness. The boards tend to be brittle when the MOE is too high and tends to be ductile or flexible when the value is small (Wahab *et al*., 2016b; 2013; Rasat *et al*., 2011; Yang *et al*., 2003). MOE of EFB boards presented in Table 3. The highest value of MOE attained by the board at density 700 kg/m^3 with 14% resin content at 2059.56 N/mm^2 followed by 12% at 1683.93 N/mm^2 and 10% at 1063.43 N/mm^2 resin of the same density of the board. Boards at density 500 kg/m^3 with 10% at 385.64 N/mm^2 resin has low MOE followed by 12% at 419.43 N/mm^2 and 14% at 447.44 N/mm^2 resin of the same density. MOE value of the board 600 kg/m^3 is an increase from 10% at 673.82 N/mm^2 to 12% at 773.37 N/mm^2 and 14% at 1006.78 N/mm^2 resin content. The EFB boards at density 700 kg/m^3 with 14% resin content not only met the minimum requirement for MOE at 1800 N/mm^2 for general use's type of board according to the standard of EN 312-3 but exceeded the required values. The maximum MOE value of the EFB composite boards manufactured in this study at 2059.56 N/mm^2. This value is just slightly lower than the MOE of rubber wood at 2381 N/mm^2.

Table 3: MOR and MOE of EFB boards at different density and resin content.

Board density (kg/m^3)	Resin content (%)	MOR (N/mm^2)	MOE (N/mm^2)
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)
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)
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)

Rubber wood	22.8*	
		2381*
EN 312-3 specification	14.0	
		1800

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

It was evident from Table 4 that the EFB composite boards 700 kg/m^3 with 14% resin content give the highest IB value at 0.98 N/mm^2 followed by 12% at 0.77 N/mm^2 resin of the same board density. The lowest value of IB was reported by the boards at 500 k/gm^3 with 10% at 0.18 N/mm^2 followed by 12% at 0.19 N/mm^2 and 14% at 0.23 N/mm^2 resin content of the same board density. IB value of the panel 600 kg/m^3 increase from 10% at 0.28 N/mm^2 to 12% at 0.31 N/mm^2 and 14% at 0.36 N/mm^2 resin content. EFB 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 at 0.4 N/mm^2. The IB values obtained from the EFB composite boards were slightly lower than of rubber wood at 1.3 N/mm^2. The boards with low density possess low IB due to the existence of more voids in it. Poor boards preparation will lead to most of the inter-particle spaces remaining as voids. The voids directly caused inefficiency of the inter-fiber bonding (Ashori & Nourbakhsh, 2008).

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 to 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. The differences in chemical bonding between UF resin and particles and the wax interferes with the UF resin when hydrogen bonds formed (Papadopoulos, 2007).

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

Board density (kg/m^3)	Resin content (%)	Internal bonding (N/mm^2)	SWe (N/mm^2)	SWf (N/mm^2)
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)
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)
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)
EN 312-3		0.40	360.0	
Rubber wood		1.30*		

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

Table 4 showed the results of the edge screw withdrawal tests on EFB composite boards. The boards at density 700 k/gm^3 with 14% resin gives the highest value at 467.47 N/mm^2, followed by 440.67 N/mm^2 with 12% and 412.27 N/mm^2 with 10% resin of the same density boards. The lowest value of edge screw withdrawal was given by the board at 500 kg/m^3 with 10% resin was 168.18 N/mm^2 content followed by 12% at 178.82 N/mm^2 and 14% resin at 189.93 N/mm^2 of the same boards' density. The edge screw withdrawal value for boards at 600 kg/m^3 increases from 10% at 232.72 N/mm^2 to 12% at 239.08 N/mm^2 and 14% resin at 302.13 N/mm^2. The EFB composite boards at 700 kg/m^3 with 10, 12 and 14% resin met the minimum requirement for edge screw withdrawal according to BS 5669 (British standard, 1989). They exceeded the 360 N/mm^2 value that used as the standard.

The face screw withdrawal of the EFB composite boards are shown in Table 4. Boards of 700 kg/m^3 with 14% resin content gives the highest values in the screw withdrawal at 512.37 N/mm^2 followed by 12% at 511.23 N/mm^2 and 14% resin at 459.72 N/mm^2 of the same density boards. The lowest value was obtained by boards having a density of 500 kg/m^3 with 10% at 193.42 N/mm^2 resin content followed by 12% at 244.5 N/mm^2 and 14% resin at 268.38 N/mm^2 of the same density boards. Face screw withdrawal of the boards with 600 kg/m^3 increases from 10% resin at 305.4 N/mm^2 to 12% at 314.6 N/mm^2 and 14% resin at 321.62 N/mm^2. The higher particle loading was to strengthen the boards as well as increases their densities assists the boards to hold the screw better. The screw withdrawal resistance is highly associated with the board density and the particles' geometry (Wahab *et al*., 2008; 2016c; Wong *et al*., 1999).

3.3 Microscopy Studies

Samples microscopy for the study randomly selected from the EFB boards. Observations made on their structure especially the occurrence of the fibers compression, binder-fiber compatibility, and existence voids. The board's sample at a density of 500 kg/m^3 with UF resin content of 10% were taken for the micrographic studies as the boards have the lowest physical and strength properties). Figure 1 shows the micrographs of a cross-section of EFB composite board with resin content level 10% at 100x magnification. Figure 1 showed the occurrences of fibers compression in the EFB composite boards. The fibers compression occurred during the pressing stage at different applied pressure and temperatures. EFB fibers in the boards' profile were forced to shrink to a specified thickness resulting in the compressed structure of the fibers. This led to the reduction of lumen void spaces and thus, increase the density of the board produced.

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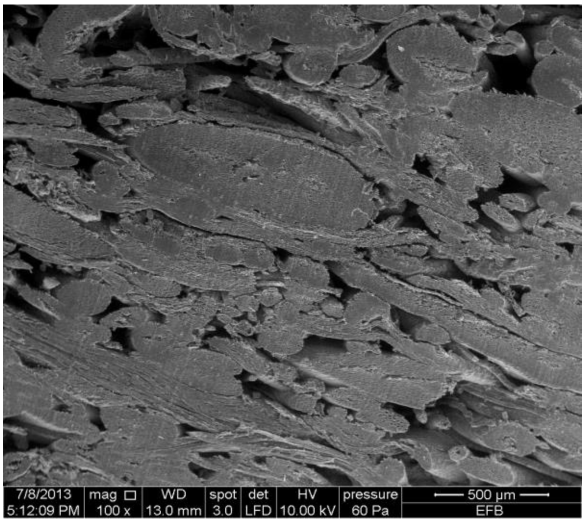

Figure 1. Micrographs of a cross section at density 500 k/gm^3 EFB composite boards with resin 10% at 100x magnification.

The fibers touch one to the others closely, and no UF resin observed clumped. This affects the result of the strength properties of the MOR and MOE properties of the board. As the load applied perpendicular to the EFB board surface, it creates compression stress on the top side on the board that transforms into tension stress at the bottom after exceeding the middle portion. The load stresses transferred from one particle to another particle, which, in this case, the EFB fiber's acts through a medium of the load transfer (Paridah *et al*., 2010). However, some voids do 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 particular area on the board. This possibly leads to the higher water absorption. The presence of voids created more surfaces of EFB fiber to be exposed to the surrounding humidity. The void's occurrence can be reduced by using or mixing smaller sizes of particles in the board manufacturing.

3.4 Thermal Characteristics

Figure 3 shows the TGA result for EFB composite boards. The decomposition in EFB composite boards begun at 100.46 ℃ (1^{st} peak). It continued to the 2^{nd} peak at 204.81 ℃ and completed at the 3^{rd} peak (380.83 ℃). Figure 4 shows the degradation of UF resin initiated at 99.93 ℃ (1^{st} peak), 168.45 ℃ (2^{nd} peak) and completed at 389.26 ℃ (3^{rd} peak). Table 5 represents TGA weight loss (%) with temperature for UF resin boards. The loss of UF resin in weight was the highest at 3^{rd} peak at 58.48%, followed by the 2^{nd} peak at 9.39% and the 1^{st} peak (8.43%). The final decomposition of the EFB composite board is lower than of the UF resin at 389.26 to 380.83 ℃ indicating the presence of cellulose fibers (from EFB) significantly affecting the thermal stability of the composite boards. This probably due to the disturbance in the original crystal lattice of the composite by the EFB composite boards (Singha & Thakur 2009).

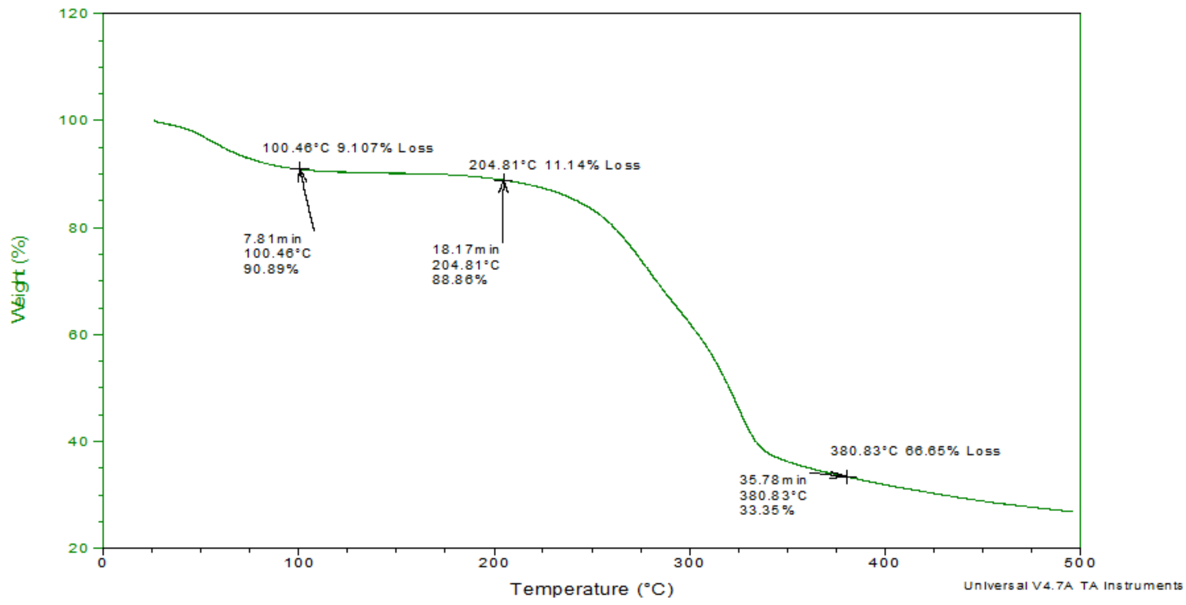

Figure 3. TGA properties of EFB composite boards.

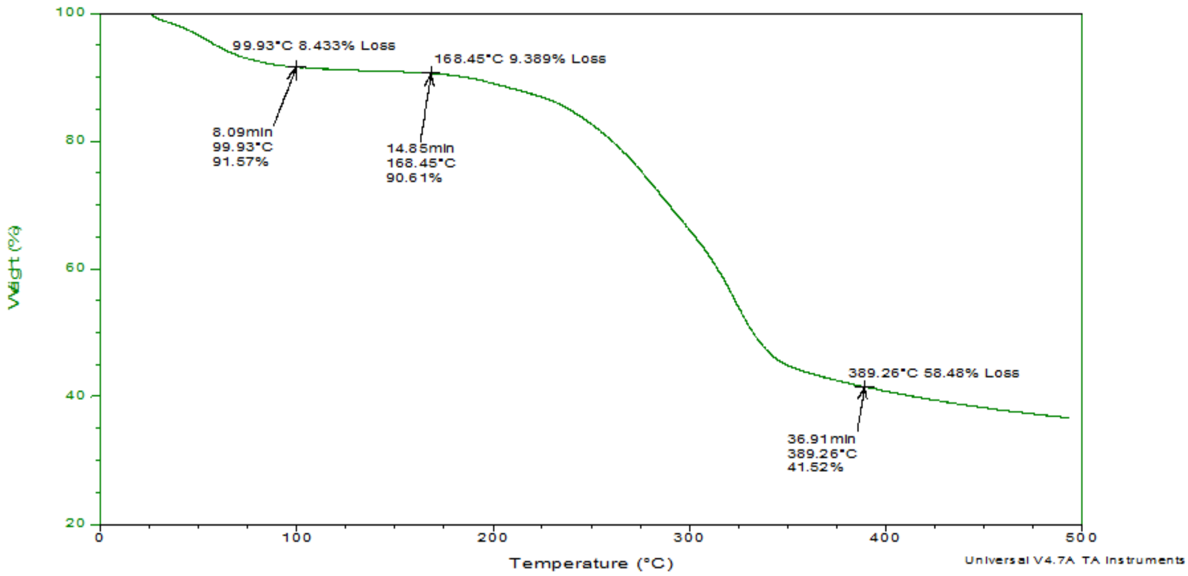

Figure 4. TGA properties of UF resin.

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

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

The degradation of the EFB boards and UF resin started by the depolymerization of molecular structure and the dehydration (loss of water). The free formaldehyde in UF resin slowly released (Zorba *et al*., 2008). The process continued by the cleave of linkages that occurred in the composite and UF resin. Carbon-hydrogen (C-H) bonds 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 for -C-H bond, 356 kJ/mol for -C-O bond and 347 kJ/mol for -C-C and last but not least the O-H bond, 460 kJ/mol. 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 (Soom *et al*., 2006; Abdullah & Bridgwater, 2006). This is due to their molecular structure that less rigid (amorphous than cellulose) compared to cellulose. The introduction of oxygen (3^{rd} peak) causes combustion to occur, and the final weight loss infers the amount of carbon in the composite. The carbon contents of the boards recorded at 58.48% for UF resin and 66.65% for EFB composite boards (see Table 5).

4. Conclusion

The EFB eco-composite boards' properties met all requirements for commercial application. The boards' density and resin content applied influenced on the board's 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 at 22.91 N/mm^2 and 2059.56 N/mm^2. The maximum value for internal bonding was at 0.98 N/mm^2. The edge and face screw withdrawal at 467.47 N/mm^2 and 512.37 N/mm^2 respectively.

The boards produced at density 700 kg/m^3 with 14% resin showed an excellent overall property with good dimensional stability. The boards are unlikely to swell with less porous structure when exposed to the wet environment.

Composite boards at 500 kg/m^3 density with 10% resin has low properties both in the physical and mechanical. The boars shows numerous voids structure that absorbs and traps moisture. Inter particle's bonding thus diminished as moisture interrupts, causing low board performance.

The UF resin showed higher thermal stability compared to regular boards when analyzed under TGA. Thermogravimetric analysis conducted to study the thermal stability of the boards manufactured. The UF resin boards were slightly more stable than of the normal composite boards.

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