

Properties of Composite Boards Properties from *Elaeis guineensis* Empty Fruit Bunch

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Abstract: This study focussed on composite boards made from *Elaeis guineensis* empty fruit bunches (EFB). The EFB supplied by a smallholder oil palm planter in Kuala Krai, Kelantan. The fibre cutter and crusher were used in turning the EFB into smaller size particles. They were screened with four-tier sieve shaker used to remove the oversize particles and impurities present. Hardeners and wax added during the mixing process at 1% and 3%. Boards of three (3) different densities were produced using urea-formaldehyde as the bonding agent. The boards produced later conditioned in a chamber set at 20±2°C and 65% relative humidity. The testing procedure set by EN Standards and specifications were followed. The tests results showed the EFB composite boards possessed excellent physical and mechanical properties. The MOR, MOE and internal bonding of the boards were 22.91 N/mm², 2059.56 N/mm² and 0.98 N/mm². The internal bonding for both edge and face screw withdrawal were 467.47 N/mm² and 512.37 N/mm² respectively. Boards with 700 g/cm³ density and 14% resin content met all the requirement needed according to standard exercised. Scanning electron microscope images of low-performance boards showed the resin and fibre in the board interacted closely, but voids appeared at the cross-section suggesting moisture penetrated the board via the open spaces and attacked the linkages existed, thus cause the board to have a low property. The thermal stability of the boards manufactured studied using the Thermogravimetric Analysis.

Keywords: Empty fruit bunch, composite boards, physical and mechanical strength, thermogravimetric analysis.

INTRODUCTION

Wood products such as large timbers or lumber commonly used in solid forms. However, due to rapid deforestation, the ever-increasing demand and increases in pricing make the application of solid wood no longer possible. The new composite product started with the glued laminated beams from thick laminates, plywood from veneers, strand board from strands, flakeboard from flakes, particleboard from particles and fiberboard from fibres, has become popular due to the scarcity in obtaining wood supply [1][2].

Oil palm is the largest and essential 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. Research has been conducted in determining the most suitable part of the oil palm biomass that can produce renewable lignocelluloses material for the bio-

composite industry. Empty fruit bunch (EFB) is one of the oil palm biomass materials that are found in abundance in Malaysia. The 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 normally use the shells and drier part of the natural fibre to produce steam to fuel their boilers [3]. As EFB is readily available and abundance in Malaysia, The EFB available on the average of 12.4 million ton/year from the plantations and oil palm mills can be converting into composite boards to resolve the scarcity of wood sources [4].

The current studies focus on properties of composite boards made from EFB of oil palm trees. The objectives of the studies were to determine and study (i) the physical and mechanical properties, (ii) the bonding properties of the EFB composite boards, and (iii) the thermal properties, of the particle board made from EFB.

MATERIALS AND METHODS

The EFB samples were supplied by a smallholder oil palm planter in Kuala Krai, Kelantan. The fibre cutter and crusher were used in turning the EFB into smaller sizes. They were screened with four-tier sieve shaker used to remove the oversize and impurities present. The particles that passed through a 2.0 mm sieve size and retained at 1.5 mm sieve size were used in this study. The particles were then oven-dried at $103\pm 2^\circ\text{C}$ for 24 hrs. The mass of the particles was measured to obtain targeted densities of 500, 600 and 700 kg/m^3 . They were mixed with UF resin at three (3) levels of resin content; 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 mats were cold pressed. The forming frame removed leaving the mat on the caul plate. The mats then pressed under a hot-press machine at temperature 165°C for 6 minutes. The boards produced were then cooled and cut into standard testing size. The testing samples were stored in a conditioning chamber conditioned at $20\pm 2^\circ\text{C}$ and 65% relative humidity until reaching their constant weight, before the testing procedure. All boards were produced in accordance EN Standard 1993 [5].

Physical Studies

The physical properties studies such as the density moisture content, water absorption and the 2 and 24 hours elapsed thickness swelling tests of the EFB composite boards. All studies were conducted by Standard EN 322: 1993 [6], Standard EN 223: 1993 [7] and Standard EN 317: 1993 [8].

Mechanical Studies

The determination of the mechanical studies carried out includes the static bending test for the MOR and MOE, internal bonding tests and screw withdrawal tests for the edge and the face. All the tests were done by using Universal Testing Machine in according to the Standards EN 310: 1993 [5] and EN 325: 2012 [9]. Screw hold strength of the EFB boards was tested according to Standard BS 5669: 1989 [11].

Scanning Electron Microscopy

The Scanning Electron Microscope located in FRIM was used in studying the structure of the EFB boards to determine the interaction between resin UF and EFB particles. Clean cut samples of size 1 cm x 1 cm x 1 cm were used. The SEM equipment is connected to a computer for image storage and processing.

Thermogravimetric Analysis (TGA)

The thermogravimetric analysis was used to measure the thermal stability of the EFB boards. Thermal analysis was carried out with a computerized TA Instrument SDT-Q600 thermogravimetric analyzer. Samples ($5.5\pm 0.2\text{ mg}$) were placed in alumina crucibles. TGA was performed under 100 ml min^{-1} nitrogen with a heating rate of 10°C/min . The weight change with temperature was measured and used to infer the moments of change during the heating. The temperature at which the rate of maximum degradation occurs was taken as an indicator of the stability to the material in comparative studies [12].

RESULTS AND DISCUSSION

Physical Properties

Table 1 shows the The moisture content and thickness swelling (TS) at different density and resin content for 2 and 24 hours time elapsed of EFB composite boards. The targeted boards of 500 kg/m^3 with 10%, 12 and 14% resin contents possessed density of 506.29 kg/m^3 , 506.90 kg/m^3 and 517.60 kg/m^3 respectively. Targetted board 600 kg/cm^3 with 10%, 12% and 14% resin contents possessed density of 598.65 kg/cm^3 , 608.90 kg/cm^3 and 620.05 kg/cm^3 . Targetted boards of 700 kg/cm^3 having actual densities of 704.03 kg/cm^3 , 714.72 kg/cm^3 and 723.89 kg/cm^3 for 10%, 12% and 14% resin contents.

The MC values were 6.64% for the 10% resin content, 6.72% for the 12% resin content and 7.12% for the 14% resin content. The 500 kg/cm^3 density boards possessed MC value of 6.89%, 7.15% and 8.48% for 10%, 12% and 14% resin contents respectively. Boards of 600 kg/m^3 have MC of 6.04% for 10% resin content, 6.83% for 12% resin content and 6.48% for 14% resin content.

The EFB boards of targeted densities 500, 600 and 700 kg/cm^3 possessed a particular trend at the 2- and 24-hours thickness swelling where the rate of the board swelled decreased as the amount of resin applied increased. The 500 kg/cm^3 density boards with 10% resin content 10% possess high rate of thickness swelling at 35.10% for the 2-hours time elapsed. Low value at 16.34% obtained for the 2-hours thickness swelling for boards with 700 kg/m^3 density with resin content 14%. The highest value of 41.11% obtained for 24-hours time elapsed in the thickness swelling for the boards of 500 kg/m^3 with resin content 10%. Boards at density 700 kg/cm^3 with 14% resin content 14% possessed the lowest thickness swelling at 12.99% for the 24-hour elapse time.

Chemical components in the resin applied capable of cross-linking with the hydroxyl group in the

boards fibre. This reduced the hygroscopicity level of the boards. The monomer, the polymerisation 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 may affect the hygroscopic expansion [13]. The existence of the void found in low-density EFB boards may provide spaces that enhance high water absorption [14]. The high porous structure of the board allows penetration of water into the board and increases water uptake causes

the board to swell and causes a rise of thickness swelling [15].

Table 2 shows the water absorption of EFB boards at different density and resin content. The EFB boards at densities of 500, 600 and 700 kg/m³ possessed the same trend for both the 2-, and 24-hours elapse. The rate of the water absorbed board absorbed decreases as the amount of resin applied increases.

Table 1: The moisture content and thickness swelling (TS) at different density and resin content for 2- and 24-hours time elapsed of EFB composite boards

Board density (kg/m ³)	Resin content (%)	Moisture content (%)	Density (kg/m ³)	TS (%)	
				Two 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)

Table 2: The water absorption (WA) at different density and resin contents for 2- and 24-hours time elapsed of EFB composite boards

Board density (kg/cm ³)	Resin content (%)	WA (%)	
		Two 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)

Boards of density 500 kg/m³ with resin content 10% possess a higher rate of 139.02% in the 2-hours water absorption. The lowest of 40.71% recorded by the 700 kg/m³ density board at resin content 14%. The absorption rate of 206.77% in 24-hours attained by the board 500 kg/m³ density with 10% resin content. The lowest value of 59.62% in 24-hours water absorption recorded by board 700 kg/m³ of resin 14%. The increase in EFB boards density enhanced the thickness swelling and decreases water absorption [16]. More water absorption occurred in high density boards compared to the those with low density. The adhesion strength of the board decreases once dwell inside the water increases,. The increment in the adhesion ratio

resulted in low thickness swelling and water absorption as the high adhesive ratio equals more adhesive amount applied, resulting in enhances the resin bonding strength of the materials.

The trends of the boards in swelling remained deficient even after the increases in the density of the EFB boards and the doses of adhesive [17]. Increasing in density of the boards significantly improved mechanical properties and water resistance of the boards [18]. 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 (Zheng et al., [18]. High-density boards with less void volume result in better

water resistance. A similar finding also recorded by Izyan *et al.*, [19].

Mechanical Properties

The procedure for mechanical testing was executed as outlined in Standards EN 310: 1993 [5] and EN 325: 2012 [9]. The MOR indicates the ability of a specimen to withstand transverse (bending) forces perpendicular to its longitudinal axis [20]. The testing conducted using the universal testing machine, where the samples of the EFB boards placed flat on the supports as the load applied. Results of MOR obtained were compared with rubberwood. Table 3 presents MOR of the EFB boards at various densities. The resistance to rupture increases with the increasing in the density of the board and resin content. Board with density 700 kg/m³ with 14% resin content recorded the highest MOR value of 22.91 N/mm² followed by the board made with resin content 12% at 18.97 N/mm² with the same density. The low value of MOR at 6.37 N/mm² recorded attained by the 500 kg/m³ with 10% resin content followed by 12% and 14% resin content at 6.75 N/mm². The boards at density 600 kg/m³ showed an increasing trend from 10% at 10.20 N/mm² to 12% at

10.26 N/mm² and 14% at 12.77 N/mm² resin content respectively. The minimum requirement for MOR at 14.0 N/mm² for general uses type of board according to Standard EN 312-3 [21] were attained for the EFB boards with 700 kg/cm³ density with 12 and 14% resin contents. Compared with composite boards the from rubberwood [22], the MOR value of EFB boards ranged from 22.91 to 22.8 N/mm².

High stiffness properties normally resulted in higher MOE values. Boards with low MOE tend to be ductile or flexible and brittle when the MOE value is high [23][24]. Testing for MOE analysis was done using the universal testing machine. The results on MOE tested of the EFB boards were presented in Table 3. High MOE recorded for boards with 700 kg/m³ density with 14% resin content at 2059.56 N/mm², followed at 1683.93 N/mm² and 1063.43 N/mm² by boards with 12% and 10% resin contents respectively. Boards at a density at 500 kg/cm³ with 10% resin content possessed low value MOE at 385.64 N/mm² followed by 419.43 N/mm² and 447.44 N/mm² at 10%, 12% and 14% resin contents. The MOE of board at density 600 kg/m³ increases from 673.82 N/mm² to 773.37 N/mm² and 1006.78 N/mm² with resin at 10%, 12% and 14% respectively.

Table 3: The modulus of rupture (MOR) and modulus of elasticity (MOE) at different density and the resin content of EFB composite boards

Board density (kg/m 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

The 700 kg/m³ density EFB composite boards with MOE 1800 N/mm² at 14% resin content not only met the minimum requirement but exceeded the required values for general uses type of board [21]. The maximum MOE at 2059.56 N/mm² obtained for the EFB boards was slightly lower than MOE of rubberwood (2381 N/mm²).

High IB value at 0.98 N/mm² followed by IB at 0.77 N/mm² with 12% resin content of the same board density (see Table 7) obtained that the EFB boards 700 kg/m³ with 14% resin content. Low in IB recorded for boards at 500 kg/m³, 0.18 N/mm², 0.19 N/mm² and 0.23 N/mm² at 10%, 12% and 14% resin contents

respectively. IB value of boards at density 600 kg/m³ increase from 0.28 N/mm², 0.31 N/mm² and 0.36 N/mm² at 10%, 12% and 14% resin contents. The minimum requirement of 0.40 N/mm² for general type of boards were met by the EFB boards of 700 kg/m³ density with all the 10%, 12% and 14% resin contents. The values were slightly lower than the rubberwood boards IB. These are expected as the EFB boards possessed more voids.. The voids directly caused inefficiency of the inter-fibre bonding [25]. 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 [26].

The platen temperature affects the internal bonding of the boards. The internal bonding in the UF resin boards improved significantly with the increase of the platen temperature. The high temperature of the platen promotes higher cross-linking and curing of the resin. During the pressing process, the temperature remain low at a center of the boards compared with the surface. Correct platen temperature needed to be apply to ensure sufficiently high temperature at the core in allowing the resin to cure. Applying wax can lower internal bonding of the EFB boards due to the differences in chemical bonding between UF resin and particles. The wax interferences with UF resin when hydrogen bonds are formed [27].

The results of edge screw withdrawal on EFB composite boards highlighted in Table 4 presents the results of the edge screw withdrawal produced. High value of edge screw withdrawal recorded by the boards at 700 kg/m³ at 467.47 N/mm², 440.67 N/mm² and 412.27 N/mm² with 14%, 12 and 10% resin contents. Low value of edge screw withdrawal obtained from boards at 500 kg/m³ at 168.18 N/mm², 178.82 N/mm² and 189.93 N/mm² with 10%, 12 and 14% resin

contents respectively. The edge screw withdrawal value for boards at 600 kg/m³ were 232.72 N/mm², 239.08 N/mm² and 302.13 N/mm² increases from 10% to 12% and 14% resin contents. The EFB boards with density 700 kg/cm³ at 10%, 12% and 14% resin contents met the minimum requirement for edge screw withdrawal property according to BS 5669:1989 [11].

Results of the edge screw withdrawal tabulated in Table 4 presents face screw withdrawal of the EFB boards manufactured. The boards of 700 kg/cm³ with 14% resin content gives the highest values at 512.37 N/mm², 511.23 N/mm² and 459.72 N/mm² at 10%, 12% and 14% resin contents. The lowest value obtained by boards having a density of 500 kg/cm³ with 10% (193.42 N/mm²) resin content followed by 12% (244.50 N/mm²) and 14% (268.38 N/mm²) resin contents of the same density boards. The face screw withdrawal of the boards with 600 kg/m³ increases from the 10% (305.40 N/mm²) to 12% (314.60 N/mm²) and 14% (321.62 N/mm²) resin content. Higher particle loading tends to strengthen the boards with the increase in densities further assists the boards to hold the screw better [15][2].

Table 4: Internal bonding (IB) of EFB composite boards at different density and resin content.

Board density (kg/m 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

Microscopy Studies

Samples from both EFB composite and UF resin boards were randomly selected for the microscopy studies. Observations of their structure especially the occurrence of the fibers compression, binder-fiber compatibility and void's occurrence were given preferences. The boards with 500 kg/m³ density UF with 10% resin content level were selected for the micrographic studies. Figures 1 and 2 show the micrographs of the cross-section of EFB composite board with resin content level 10% at 100x and 500x magnification. The occurrence of fibers compression occurred in the EFB boards (Figure 1). The fibers compression most probably occurred during the pressing stage at different applied pressure and

temperatures. The fibers in EFB boards were forced to shrink to a specified thickness resulted in the compressed structure of the fibres. This reduced in the lumen void spaces and increase the density of the board produced [28]. There is good compatibility between EFB fibre and UF resin in the particle board manufactured (see Figure. 2). The fibers touch one other closely, and no clumped observed in the UF resin boards. This affected the result on the mechanical properties especially on the MOR and MOE properties of the board [29]. The perpendicular applied load to the EFB board surface creates compression stress on the top side that transforms into tension stress in the bottom side of the EFB boards exceeding the middle portion. The load stresses transferred from one particle to another particle in the EFB fiber's that acts through a

medium of the load transfer [22]. The existence of voids showed the existence of gaps occurred at certain parts on the EFB boards that lead to high water absorption. The voids created more parts of EFB fiber exposed to the surrounding moisture [13]. This can be minimized by using smaller sizes of particles in the manufactured boards [30].

Thermal Properties

Computerised TA Instruments SDT-Q600 TGA was used in analysing the thermal properties of the EFB composite boards. The TGA analysed conducted under 100 ml/min nitrogen gas for a 10°C/ min heating rate. The result of the thermal properties analysis on EFB boards were showed in Figure 3. The decomposition occurred at 100.46°C (at the first peak) and continued

to the second peak at 204.81°C and completed at the third peak (380.83°C). The degradation of UF resin composite boards occurred at 99.93°C (at the first peak), continued at 168.45°C (second peak) and completed at third peak (389.26°C). The loss of UF resin in weight recorded high at third peak at 58.48%, followed by the second peak at 9.39% and the first peak at 8.43% (see Table 4). The final decomposition of the EFB composite boards is lower than of the UF resin at 389.26°C to 380.83°C. This indicates the presence of

cellulose fibres from the EFB gives influences to significant effect on thermal stability of the EFB boards. Disturbance in the original crystal lattice of the composite by the EFB boards could probably be the results of this occurrence [31].

Table 7: Correlation coefficient between the physical and mechanical properties of EFB composite boards at different density and resin content

	D	RCT	MC	DEN	2HWA	24WA	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

Note: * = p ≤ 0.05, ** = p ≤ 0.01, ^{ns} = not significant, RCT= resin content, MC= moisture content, DEN= density, 2HWA= 2 hours water absorption, 24WA= 24 hours water absorption, 2HTS= 2 hours thickness swell, 24TS= 24 hours thickness swell, MOR= Modulus of rupture, MOE= Modulus of elasticity, IB= Internal bonding, SWE= Edge screw withdrawal, SWF= Face screw withdrawal.

The degradation process of the EFB and UF resin boards started by the depolymerisation of the molecular structure and the dehydration of tested boards and later, the slow releases of formaldehyde present in the UF resin [30][32]. The process resumed by the cleave of linkages that occurred in the EFB 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. This is the stage where the cellulose, hemicellulose, and lignin began to decomposes. The thermal degradation of polymer blocks of biomass occurred at the second peak. Hemicellulose and lignin degraded first [12][4]. These were due to their less rigid molecular structure compared to the cellulose. Upon the introduction of oxygen (3rd peak), combustion occurred, and the final weight loss infers the amount of carbon in the

composite. Table 8 showed the carbon contents of the boards at 58.48% (UF resin boards) and 66.65% (EFB composite boards).

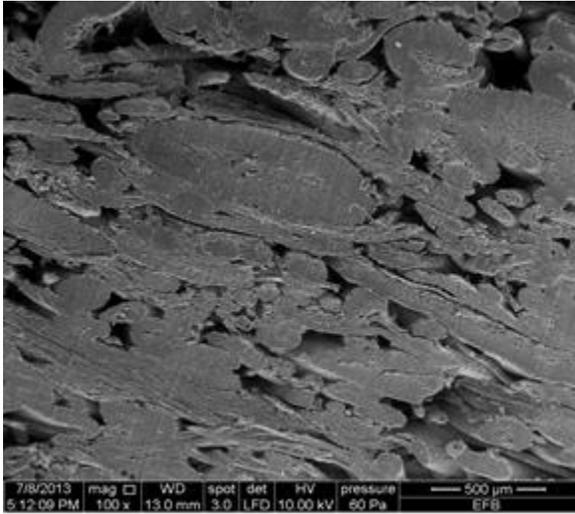


Figure 1: The x-section of the 500 kg/m³ EFB composite boards with resin content 10% (Magnification at 100x)

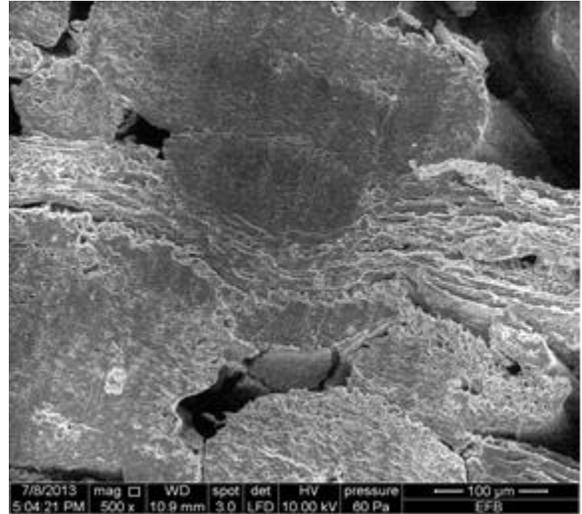


Figure 2: The x-section of 500 kg/m³ EFB composite boards with resin content 10% (Magnification at 500x)

Table 8: Thermogravimetric analysis (TGA) weight loss (%) with temperature for UF resin and EFB composite boards

		First peak	Second peak	Third 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

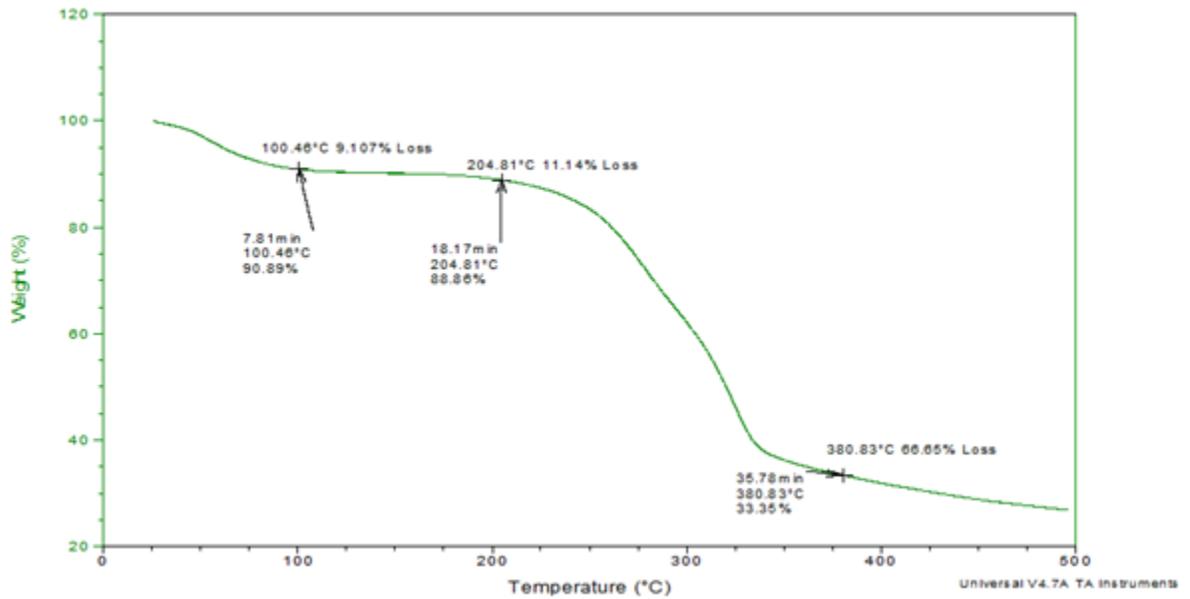


Figure 3: TGA properties of EFB composite boards.

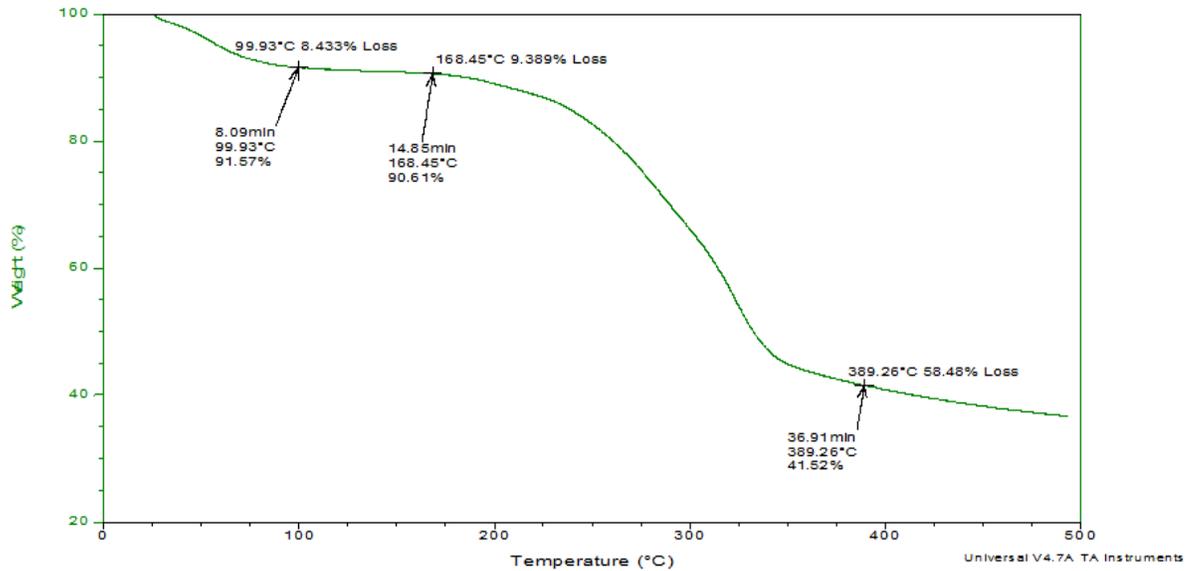


Figure 4: TGA properties of EFB composite boards with UF resin.

CONCLUSION

The properties of the EFB composites boards met the specification for the commercial usage. The density influenced the boards overall performances and the amount of resin used. The EFB composite boards produced at 700 kg/m³ density with 14% resin possessed showed excellent properties and stable dimensional stability.

The EFB composite boards produced with UF resin possessed an overall excellent thermal stability analyzed with thermogravimetric.

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