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Properties of Oil Palm frond and Kenaf Bast Bio-composites Boards.

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ABSTRACT

Properties of bio-composite boards made from mixture of fibers from oil palm fronds (OPF), and kenaf bast fibers (KBF) at five different ratios were investigated. Urea formaldehyde resin at 10%, 12%, and 14% was used in bonding the mixtures together. The micrographs' structures obtained through scanning electron microscopy were used in determining the distribution of the resin in the boards. The EFB and kenaf bast fibers were mixed at ratios of 100:0, 70:30, 50:50, 30:70, 0:100 (OPF: KBF). All testing, specimen size and shape were done in accordance with the European EN Standards. Testing on the physical properties included moisture content, water absorption and thickness swelling, density and contact angle and mechanical testing included static bending for MOE, MOR, and internal bonding of the boards revealed the enhanced values after increasing the resin content. The overall results showed that boards of 100% OPF with 14% of resin content exhibited the highest properties compared to the other boards. It was found that mixture of different fibers can be good combination for fabrication of new candidates.

Keywords: Oil palm fronds, kenaf bast, urea formaldehyde, bio-composite boards, physical, mechanical properties.

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INTRODUCTION

The demand for timber is increasing with the increase in the world population. This can be satisfied, either by felling or harvested more trees, and ultimately increased the pressure to consume more natural resources. To overcome this problem, new sources of the natural resources are needed to be found. One of the most attractive alternatives is to use agricultural residues, which are found in abundant annually. Agricultural residues once converted into boards will become an excellent alternative source to replace wood and wood fiber.

The utilization of renewable resources is one of the major solutions for the Malaysia to overcome the environmental issues. The research carried out in recent times about natural fibres and agricultural residue which abundantly accessible is responsible for new polymer science and engineering research for a sustainable technology. Natural fibres provide with interesting properties of the final bio-composite, especially those related to the protection of the environment such as their capacity to be recyclable, renewable raw material, and less abrasive and harmful behavior [1].

One of the most widely used natural fibers which was successfully incorporated in variety of application is kenaf fiber. Kenaf (Hibiscus cannabinus L) is a warm-season annual fiber crop closely related to cottoning and jute. Historically, kenaf has been used as a cordage crop to produce twine, rope and sackcloth. Various new applications for kenaf including paper products, building materials, absorbents animals feed. Kenaf bast fibers are found in the stems of the plant providing the plant its strength. Usually, they run across the entire length from the stem and are therefore, very long.

Bio-composites from the lignocelluloses resources have a high potential to be used as replacement or as an alternative for the future wood especially in wood-based product. The composites made from the agriculture residues are eco-friendly and can be utilized for non-structural and light structural purposes was used in this study was oil palm fronds. Kenaf bast fibers were used in this study as addition to the lignocellulosic bio-composite. Kenaf as the renewable resources and abundantly accessible natural fibers is responsible for the future research. The combination of the agro waste oil palm fronds and natural fibers kenaf bast fibers as a bio-composite board are the potential candidates to replace lumber due to the extinction of the lumber. The kenaf plant is an annual plant that can harvest 2 to 3 times a year. It can grow to reach 3 to 4 m within 4 to 5 months. The kenaf plant has three layers consisting of bast, core and pith. Kenaf bast fiber has been reported to have superior mechanical properties compared to the other parts of the plant [2].

The current research explored the potential of turning the mixed of an oil palm frond with kenaf bast fiber as a bio-composite boards. The aims of this study were: i) To evaluate the physical, mechanical properties of oil palm fronds and kenaf bast fiber composite and to compare the mechanical properties' lumber made from oil palm fronds and kenaf bast fiber at different resin content, ii) To study the morphological structure of composite lumber by using Scanning Electron Microscope (SEM),

MATERIALS AND METHODS

Materials

The sample of Oil Palm Fronds was collected from Felda Kemahang, Tanah Merah, Kelantan, Malaysia. The fronds from oil palm trees aged between 8-10 years were selected. The five month old kenaf stalks were collected from MARDI Telong, Pasir Puteh, Kelantan. Kenaf bast was separated from core using decorticating machine.

Preparation of Oil Palm Frond Particles

The obtained OPF, was put into drum chipper and then further cut using knife ring flaker in order to obtain particles of acceptable length. The particles of Oil Palm Frond were screened to get 0.8 mm size particlesand were dried in an oven at 60°C in order to reduce the moisture content up to 5% prior to composite fabrication.

Preparation of Kenaf Bast Fibres

Kenaf bast fiber was separated from the core using kenaf decorticating machine. The separated kenaf bast fiber was then refined using fiber cutter. The kenaf bast fibers of 1 mm length were dried similarly as OPF before composite preparation and the size of kenaf bast fiber was screened by shaker machine..

Resin Addition Process

The Oil Palm Frond particles and Kenaf bast fibers were mixed with each other at different ratio. The ratio were (OPF:KBF 100:0), (OPF:KBF 70:30), (OPF:KBF 50:50), (OPF:KBF 30:70), (OPF:KBF 0:100),respectively.

The mixed particles were then mixed with the resins separately using blender machine, with loading percentage of 10%, 12% and 14% of Urea Formaldehyde resin. The particles and the resin were mixed approximately in the blender for 5 minutes to ensure that the particles are evenly mixed with the resin.

Composite fabrication

After the mixing process, the Oil Palm Frond and kenaf bast fiber were removed from the mixer and were scattered in a square-shaped former with the dimension of 340 x 340 mm, which was first placed on a cauls plate covered covered with a Teflon fibre sheet. The furnish of mixed Oil Palm Frond and Kenaf bast fiber particles with resin was pre-pressed at the pressure of 35 kg/cm² and subsequently pressed in the hot press machine model Taihei to 12 mm thickness at a temperature 165 °C for 6 minutes. Then, the particleboards were exposed to the surrounding to cool them down and encourage curing of the resin. The targeted board density 700 kg/m^3 were produced. Three replicates were prepared for each ratio of mixed Oil Palm Frond particles and Kenaf bast fibres and resin content. The description of the particleboards is summarized in Table 1.

Table 1: The description of the particleboards

Raw Material	Oil Palm Frond Particles size 0.8 mm and Kenaf bast fibres.
Targeted board density	700 kg/m^3
Board size	(340 x 340 x 12) mm
Adhesive	10 %, 12% and 14% of Urea Formaldehyde resin content
Pressing temperature	165 °C
Pressing time	6 minutes

Determination of Mechanical and Physical Properties of Board

Testing Procedures

All samples were kept in a conditioning room which was set at a temperature of 20 ±2°C and 65 ±5 % RH for 3 days prior to the testing. The conditioning was to ensure that the resin in the particleboard have cured uniformly. The mechanical tests carried out for the samples were bending strength tests (MOR, MOE) [3], internal bond (IB) [3]. The tests were carried out using Instron Universal Testing Machine Model 4204. The dimensional stability of the board was also determines with water absorption and thickness and swelling tests. The water absorption, thickness and swelling ability were calculated after immersing the samples in the water at 20° C for 24 hours [3].

Bending Test

Bending test was carried out according to BS EN 310:1993 [3] using an Instron machine model 4204. Bending test was conducted with a concentrated load of 10mm/min. The specimen size for bending test was 50 x 290 mm with effective span of 150 mm.

Internal Bond Strength

Internal bonding strength test was carried out according to BS EN 319:1993 [4] using an Instron Machine model 4204 same as bending strength. A sample test was adhered to the IB blocks and then placed to the machine. Tension load was applied vertically to the board face, with the tension loading speed at 2mm/min. The maximum load (P') was measured at the time of failing force (breaking load of perpendicular tensile strength to the board).

Density

The test was carried out according to EN 323:1993 [5]. Board test specimens were cut into (5 cm x 5 cm x 0.48 cm). The test piece was square in shape and conditioned to a constant mass in an atmosphere of a relative humidity of 65% and a temperature of 20 °C. The samples were placed in an oven at temperature 105 °C±2 for 24 hours or until the weight become constant. After 24 hours, the samples were placed in a desiccator for 15 minutes and weighed. These steps were repeated until the constant weight was obtained.

Water Absorption

Water absorption test was done to study dimensional stability. The test was carried out according to BS EN 317:1993 [6]. The samples (W_1) were immersed in the water and weighed after 24 hours (W_2).

Thickness Swelling

Thickness swelling test was carried out also according to BS EN 317:1993 [6]. The thickness in the centre of a test was measured to the nearest 0.48 mm with the digimatic micrometer. It was immersed in water of 20 °C±1 horizontally about 3 cm below the water surface for 24 hours then reweight.

Scanning Electron Microscopy

Microscopy study was carried out using Scanning Electron Microscopy (SEM) at Forest Research Institute Malaysia, Kepong, Selangor. The samples were viewed in a cross-cut direction to see the adhesive line which is the interaction between adhesive and substrate and penetration through the particle board. Clean cut sample with dimensions of 1 cm length x 1 cm width was used. Initially, the samples were dried in the oven at 105° C and were cleaned from any contaminants. The samples were then coated using sputter coating POLARON 515 with gold approximately 20 nm thick. The SEM equipment is connected with a computer for image storage and processing. The image of the sample was viewed according to the desired angle for clearer view using computer and images were selected based on preference for evaluation.

Wettability

Contact angles were measured to study the wetting characteristics of solid materials [7]. Therefore, contact angle analysis was used to determine the wettability of particle board surface in this study. Wettability test was carried out using water. The method of contact angle determination was done based on the previous study by Sulaiman et al., (2008)[8] and Razak et al., (2013)[9]. A video camera was used to record the image of droplets. 10µl of the water was dropped manually using micropipette onto the surface of the particle board. The image of the droplet was recorded using a video camera for 60 second. 5 replicate were used in the determination of contact angle for each liquid.

RESULT AND DISSCUSION

Physical Properties

Density

The highest and lowest value of density 715.32 kg/m^3 and 681.19 kg/m^3, was found in samples (OPF:KBF 70:30) and (OPF:KBF 0:100), respectively with 14% resin loading. The mean value of density of samples is given in Table 2.

Density is expressions of how much substance is present in given volume, whilst density of the board is a ratio of dry weight of board to its volume [10]. The density decreases in the oil palm fronds occurred due to its population of the vascular bundle where the oil palm frond has a more vascular bundle with fibre cell and fewer parenchymatous tissues [11]. Most mechanical properties of particle board are closely correlated to density. It reported that these properties are commonly found in all types of materials [12]. The strength properties of wood have a close relationship with its density [13]. Increment of density value absolutely increases most of the mechanical properties of wood, including bending strength.

Table 2: Density board of Oil Palm Frond and Kenaf bast fiber Composite

Resin content (%)	Density every ratio (%)				
	100:0 (OPF:KBF)	70:30 (OPF:KBF)	50:50 (OPF:KBF)	30:70 (OPF:KBF)	0:100 (OPF:KBF)
10	684.72	706.28	688.83	715.18	678.96
12	687.34	687.43	700.83	674.49	677.35
14	685.01	715.32	704.74	704.99	681.19

Thickness Swelling

Results of thickness swelling are given in Table 3. The thickness swelling was measured by calculating the difference between the thicknesses of the sample before, and after it is soaked in the water for 24 hours. It was found that the result of thickness swelling decreased with increasing the resin contents. The highest thickness swelling 45.35% at ratio 30:70 (OPF : KBF) at 10% resin content, followed by 100:0 (Kenaf : OPF) also at 10% of resin content 41.73%. While the lowest thickness and swelling were 100:0 (OPF : Kenaf) at 14% of resin content 22.44%.

Table 3: Thickness swelling of Oil Palm Frond and Kenaf bast fibe Composite

Resin content (%)	Thickness swelling every ratio (%)				
	100:0 (OPF: KBF)	70:30 (OPF: KBF)	50:50 (OPF: KBF)	30:70 (OPF: KBF)	0:100 (OPF: KBF)
10	33.55	41.40	39.38	45.35	41.73
12	28.95	35.55	37.86	41.13	37.05
14	22.44	34.52	25.35	30.55	30.97

Thickness swelling of the particleboard is proportional to water absorption. When the water absorption is high, the thickness swelling will be also high. This can be attributed to swelling of the fiber inside the fabricated particleboard. Thickness swelling generally will occur due to the swelling of the fibers itself when soaked in the water for 24 hours.

The highly porous structure in the oil palm fronds and kenaf composite board allows water to uptake resulting in high-water absorption which at the same time, causes the board to swell and subsequently causes a rise of thickness swelling.

Water Absorption

The water absorption results revealed that the water absorption decreased with the increased resin content. The results of water absorption test are summarized in Table 4. The obtained results are corroborated by the fact that chemical components in the resin are capable of cross-link with the hydroxyl group of oil palm fronds and kenaf fibers. Hence, reducing the hygroscopic expansion. The other factors which contribute to such effects are tyoe of resin such as the monomer, the polymerization rates, the cross-linking and pore sizes of the fibres and bond strength.

Water absorption of the composite is actually a serious concern, especially for their potential indoor and outdoor applications. For a given composite from the different ratios of oil palm frond and kenaf bast fibers, the water absorption characteristic depends upon the content below the fiber, fiber orientation, temperature, area of the exposed surface, permeability of fibers, void content, and the hydrophilic of the individual components.

Table 4: Water absorption of Oil Palm Frond and Kenaf bast fiber Composite

Resin content (%)	Water absorption every ratio (%)				
	100:0 (OPF: KBF)	70:30 (OPF: KBF)	50:50 (OPF: KBF)	30:70 (OPF: KBF	0:100 (OPF: KBF)
10	93.66	124.60	105.60	119.30	128.94
12	80.27	95.61	99.82	112.86	123.11
14	72.03	86.91	82.25	92.28	103.18

From the result of mean value of water absorption of oil palm fronds and kenaf bast fibres composite showed that the highest water absorption was 128.94% at 100:0 (OPF: KBF) at 10% of resin content. While the lowest was at ratio 100:0 (OPF : KBF) at 14% of resin content 72.03%. This shown that 100% of kenaf composite absorb more water in the short run than 100% of oil palm fronds. The increasing of water absorption in the 100% of kenaf fiber's board, showed with the rapid moisture penetration into the composite materials. The pattern can be attributed to the penetrability of water and capillary action, which becomes active as water penetrates into the interface via void induced by swelling of kenaf fibers [14].

Water absorption is a condition when the fiber swells due to the absorption of moisture and water. Water absorption experiments were conducted because the absorption of water can cause changes in shape, debonding, or loss of strength in products regularly exposed to moisture [15]. For a given particleboard, the water absorption characteristic depends upon the content below the fiber, fiber orientation, temperature, area of the exposed surface, and permeability of fibers, void content, and the hydrophilicity of the individual components [16].

The parenchyma behaves like sponge and can easily absorb moisture [17]. The fibers size plays an important role in the water absorption [15]. Thus the effect of fiber length on water uptake is dependent on fibre content. This can be explained in two ways: larger fibers lead to a greater hydrophilic exposed surface, and poor adhesion between wood particles and the matrix generates void spaces among the wood particles. An increasing in moisture makes the ability fiber to absorb or desorb moisture should be considered when evaluating the suitability of fiber for various applications [18][19]. In this, test showed that composite from kenaf absorbs more water in the short run as expected kenafas natural fibers. Bastfiber composites absorb water in the fibers, and matrix and water also existed in the voids of the composite.

Contact Angle and Wettability

The measured contact angles are shown in Table 5. A significant different was found between the contact angles of every ratio of oil palm fronds and kenaf bast fibers composite boards with the different ratios. The highest contact angle was at ratio 70:30 (OPF : KBF) at 14% of resin content was 73.91° compared with 50:50 (OPF : KBF) at 10% resin content which give the lowest value of contact angle 47.23°. If the contact angle is less than 90° the liquid is said to be non-wetting. It is clear from the results that ratio of 70:30 (OPF : KBF) at 14% resin content increased wettability than the others' ratios.

Table 5: Contact angle of Oil Palm Frond and Kenaf bast fiber Composite

Resin content (%)	Contact angle every ratio (°)				
	100:0 (OPF:KBF)	70:30 (OPF:KBF)	50:50 (OPF:KBF)	30:70 (OPF:KBF)	0:100 (OPF:KBF
10	55.08	65.83	47.23	56.31	63.43
12	57.99	68.75	64.88	57.65	64.32
14	72.82	73.91	68.75	65.77	66.80

Wettability is defined as a condition on a surface that determines how fast a liquid will wet and spread over the surface or whether it will repel and not spread over the surface (USDA. 1999)[20]. Wettability is an essential property in wood adhesion [21]. The phenomenon of wetting or non-wetting of a solid by a liquid is better understanding by studying what is known as the contact angle [22].

Wetting on surface occurs when the contact angle approaches zero [23]. The liquid spreads spontaneously or completely on the surface of the solids [24]. Therefore, the liquid wetting processes include information about the contact angle formation, spreading and penetration [25]. By referring to the contact angle in the wetting process, it could be defined as the angle between the edges of drop water and the surface of particle board.

Previous work has shown that after the modification of fibres, its contact angles decreased [26]. The above results can be related with the theory of contact angle measurements, which predicts that if the values of contact angles are low, the liquid will spread or wet well while high values indicate poor wetting. This mean that 70:30 (OPF : Kenaf) have a poorer wettability than the others' ratios.

The higher contact angle is important to reduce the ability of particle surface to absorb water during used and reduced the probability of particleboard to damage because of water absorption such as swelling. In tropical wood glued with UF resin shows linear relationship between surface wettability and glue bond strength [27][28]. The lower the contact angle, the better wettability will improve the gluing properties.

Mechanical properties of particleboard

The results on the mechanical properties of the bio-composites of OPF and KBF are summarized in Tables 6 and 7. These include the modulus of elasticity (MOE) and modulus of rupture (MOR) of the strength bending strengths.

Modulus of Rupture

It is clearly observed the value of MOR increased through increasing the resin content. The results revealed that biocomposites with 14% of resin content have the MOR as compared with the other composites with different resin content. In addition, the ratio 100% Oil palm frond possessed the highest value to each resin content value. According to the obtained results bending strength test, which is summarized in Table 6 for MOR, the average values of the 10% resin content for ratio 100% oil palm frond, 70:30 and 50:50 are 14.38, 9.75, and 13.95 MPa, respectively. In addition, the average value MOR for 14% of resin content 21.38, 17.33 and 19.95 MPa for 100% oil palm frond, 70:30 and 50:50 ratio group respectively. The mean MOR value to the resin content 12% of urea formaldehyde at ratio 50:50 surpassed the minimum value of the EN 310:1996 standard.

Table 6: Modulus of rupture of Oil Palm Frond and Kenaf bast fiber composite

Resin content (%)	MOR every ratio (MPa)				
	100:0 (OPF:KBF)	70:30 (OPF: KBF)	50:50 (OPF:KBF)	30:70 (OPF:KBF)	0:100 (OPF:KBF)
10	14.38	9.75	13.79	4.06	8.46
12	20.82	13.30	18.47	15.97	9.78
14	21.38	17.33	19.95	18.93	11.390

Since the MOR indicates the ability of a specimen to withstand a transverse (bending) force perpendicular to its longitudinal axis, MOR results from the composite at higher resin contents are able to withstand such force. The amount of resin plays an important role in improving the MOR value across the composites' board. Adhesive can effectively transfer and distribute stresses, thereby increasing the strength and stiffness of the composite. Urea formaldehyde has higher solids content, thus, the penetration of high viscosity urea formaldehyde resin probably would break the cell walls of the compressed oil palm frond and kenaf bast fiber composite boards [29]. This action would make it impossible for the fiber and matrix to withstand greater loads. As reported earlier the parenchyma behaves like sponge and can easily absorb moisture [17]. Therefore, the composite from oil palm frond and kenaf bast fiber board can easily absorb urea formaldehyde resin. It is can be assumed that the urea formaldehyde resin enhanced the strength of MOR of the resulted composites.

Modulus of Elasticity

The modulus of elasticity is the quantifies a material's elastic that is recoverable resistance to deformation under load. MOE is solely a material property and stiffness depends both on the material and the size of the beam. Large and small beams of similar material would have similar MOEs but different stiffness. The MOE can be calculated from the stress-strain curve as the change in stress causing a corresponding change in strain.

Table 7: Modulus of elasticity of Oil Palm Frond and Kenaf bast fiber composite.

Resin content (%)	MOE at every ratio (MPa)				
	100:0 (OPF:KBF)	70:30 (OPF: KBF)	50:50 (OPF:KBF)	30:70 (OPF:KBF)	0:100 (OPF:KBF)
10	2279.25	1927.97	1754.45	1198.88	1452.32
12	2567.11	2176.43	2215.23	2449.45	1547.46
14	2809.74	3029.13	2803.32	2663.27	1896.58

Based on results showed in the Table 7, the MOE results of the composites from oil palm frond and kenaf bast fiber were gradually increasing from 10% to 14% resin content. The highest average value of MOE is 3029.13 MPa for ratio 70:30. The average value of MOE for 10% resin content of 100:0, 70:30, and 50:50 are 2279.25, 1927.97 and 1754.45 MPa respectively. This indicates that the addition of resin into the board has increased MOE or makes the board to be more brittle. The results were found tallied with to the previous studies [30].

Internal Bond (IB) Strength

Internal bonding (IB) test was conducted to determine the interfacial bonding strength between fibres in the boards. The results in the table showed that the resins' content has significantly affected the mean IB values of the boards. The IB values increased with the increasing resin content from 10% to 14%. The values were better when loading of the resin content was increased. In general, mean IB values for ratio 100:0, 30:70, and 50:50 at 10% resin content were 0.73, 0.41, and 0.36 respectively. While at 14% resin content of IB at ratios 100:0, 30:70, and 50:50 were 0.83, 0.6 and 0.61 respectively.

The result indicated that higher amount of resin encourages stronger interfacial bonding between fibres in the boards, thus prolong the ability for the boards to withstand the pulling force created through the test. By comparing the ratios, it was seen that board manufactured at 100% of OPF was superior in internal bonding (IB) strength, exceeding that 30:70 and 50:50. The lower mean IB value found at 100% kenaf is expected due to the surface chemical properties of fibrillar fines rich in extractives and lignin that influenced the absorption, adhesion and strength properties and finally interrupt the bonding properties for the boards [31].

Table 8: Internal bond strength of Oil Palm Frond and Kenaf bast fiber composite

Resin content (%)	IB Strength at every ratio (MPa)				
	100:0 (OPF:KBF)	70:30 (Kenaf:KBF)	50:50 (OPF:KBF	30:70 (OPF:KBF)	0:100 (OPF:KBF)
10	0.73	0.19	0.36	0.30	0.34
12	0.78	0.41	0.43	0.41	0.34
14	0.83	0.54	0.61	0.60	0.40

Weak bonding between particles and very low internal bonding strength within particle board arises when fibers are cut into small particles, some of the particles cannot be split and they maintain a tubular shape, which prevents resin from reaching internal surfaces of the fibres [32]. Almost all the failures observed IB specimens originated from the board which has kenaf bast fiber were located. Some of the cure resins were seen retained on the fiber surfaces, indicating insufficient penetration of the resin. The lack of inter-fiber bonding was responsible for the low IB strength in all boards comprising kenaf bast.

Corelation between Physical and Mechanical Properties of OPF and Kenaf Bast Fiber

Correlation between physical and mechanical properties of the oil palm fronds and kenaf bast fibers composite is presented in Tables 9 and 10. There was a correlation between physical properties, moisture content, density, water absorption, thickness and swelling and contact angle of oil palm fronds and kenaf bast fibers with different ratios and difference resin content.

The results revealed that there were significant differences between physical properties and mechanical properties with the ratios of varying oil palm frond and kenaf bast fiber and resin content factors at 1% level. Based on this study, all the mechanical properties showed significant differences with ratios between oil palm fronds and kenaf bast fibers and resin content. The result shows that the physical and mechanical properties shows the significant differences with the difference of resin content. No significant different exist between physical properties of density and moisture content with the ratios of oil palm fronds and kenaf bast fibers factors in Table 9, there was no encouragement of varying of ratios to the physical properties, density and moisture content. Although, there were differences in value as the testing result for each part, which were the testing result from the ratio of oil palm fronds and kenaf bast fibers.

Table 9: ANOVA on physical and mechanical properties of OPF and KBF composite

Source of Variance	Dependent	Sum of square	Df	Mean square	F-Ratio
Ratio	MC	13.37	4	3.34	0.84^{ns}
	D	5978.64	4	1494.66	2.17^{ns}
	TS	1022.26	4	255.56	28.51**
	WA	11145.10	4	2786.29	77.76**
	CA	946.47	4	236.62	15.03**
	MOR	782.06	4	195.52	24.79**
	MOE	7.34	4	1.84	14.73**
	IB	1.75	4	0.44	60.54**
Resin Content	MC	103.04	2	51.52	12.99**
	D	17708.28	2	854.14	1.24^{ns}
	TS	1719.79	2	859.89	95.93**
	WA	9210.45	2	4605.23	128.52**
	CA	1827.39	2	913.69	58.03**
	MOR	792.78	2	396.39	50.26**
	MOE	1.05	2	5.27	42.26**
	IB	0.56	2	0.28	39.10**

Note: Total number of samples for each testing = 90, ** = significant at $p \leq 0.01$, ns = not significant, RAT = ratio, RCN = Resin Content, MC =Moisture Content, D = Density, TS = Thickness and Swelling, WA= Water Absorption, CA= Contact Angle, MOR = Modulus of Rupture, MOE = Modulus of Elasticity, IB = Internal Bonding

The correlation between the strength properties' modulus of rupture (MOR) and modulus of elasticity (MOE) for bending strength and internal bonding (IB) with difference's ratios of oil palm fronds and kenaf bast fibers and difference's resin content are presented in Table 10 too. There was a correlation between ratios with mechanical properties values. The negative correlations were obtained between ratio and MOR of bending strength, internal bonding strength.

The negative correlation between the ratio of oil palm fronds and kenaf bast fiber and resin content with mechanical properties MOR and IB indicate that the strength of composite decreased from 100% of oil palm fronds to 0% oil palm fronds. The mixing of the ratios of oil palm fronds and kenaf bast fibers influenced the mechanical properties of composite.

Table 10: Corelation Coefficient between Physical and Mechanical Properties of Oil Palm Fronds and Kenaf bast fibers composites

	RAT	RCN	MC	D	TS	WA	CA	MOR	MOE	IB
RAT	1.000	0.000^{ns}	0.086**	0.271**	0.319**	0.148**	0.208**	-0.087*	0.066^{ns}	-0.497*
RCN		1.000	-0.515*	0.039^{ns}	-0.708*	-0.634*	0.692**	0.594**	0.635**	0.441*
MC			1.000	0.040^{ns}	0.462**	0.429**	-0.299**	-0.382*	-0.431**	-0.366*
D				1.000	0.116**	0.018^{ns}	0.126**	0.064^{ns}	0.103**	-0.076^{n}
TS					1.000	0.815**	-0.437**	-0.681*	-0.593**	-0.704*
WA						1.000	-0.306**	-0.772*	-0.730**	-0.798*
CA							1.000	0.278**	0.417**	0.154*
MOR								1.000	0.807**	0.670*
MOE									1.000	0.602*
IB										1.000

Note: Total number of samples for each testing = 90, ** = significant at $p \leq 0.01$, ns = not significant, RAT = ratio, RCN = Resin Content, MC =Moisture Content, D = Density, TS = Thickness and Swelling, WA= Water Absorption, CA= Contact Angle, MOR = Modulus of Rupture, MOE = Modulus of Elasticity, IB = Internal Bonding

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The negative correlation between the ratio of oil palm fronds and kenaf bast fiber and resin content with mechanical properties MOR and IB indicate that the strength of composite decreased from 100% of oil palm fronds to 0% oil palm fronds. The mixing of the ratios of oil palm fronds and kenaf bast fibers influenced the mechanical properties of composite.

Scanning Electron Microscopy

Detailed investigation with regards to structural and anatomical observation of oil palm fronds and kenaf fibers composite using scanning electron microscopy (SEM) was carried out. The scanning electrons micrograph (SEM) of fibres contains in vascular bundles are displayed in Figures 1 and 2. It was observed that the parenchyma cells of oil palm fronds that function as the ground tissues make up the bulk of oil palm fronds structures and used as storage for food. Parenchyma cells of oil palm fronds were mostly in the form of spherical cell with thin-walled and brick-like in formation, but in the narrow space or area between vascular bundles. Kenaf contains three types of fibres, which are bast, core and pith.

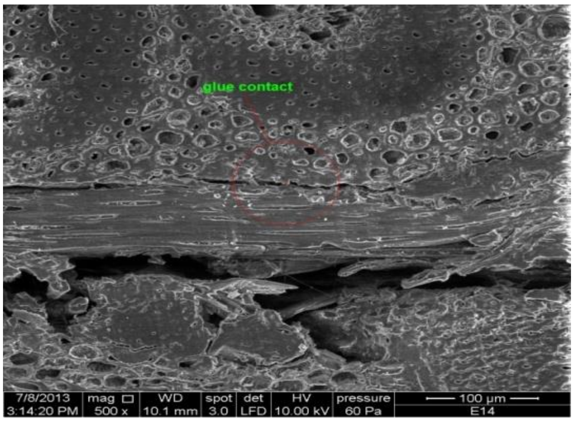

Figure 1: Structure of oil palm fronds and kenaf bast fibers composite at 500 x magnification.

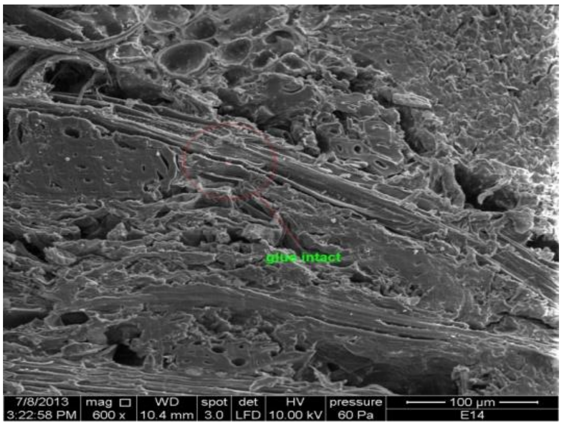

Figure 2: Glue intact between Oil Palm Fronds and Kenaf bast Fibers composite at 600 x magnification.

Both figures showed that the high porous morphology of the mixing oil palm fronds and kenaf bast fibers allowed the resin to be located and filled within the void spaces between fibers in the composite. The strengths of oil palm fronds and kenaf bast fibers composite boards were generally increased with the increasing resin contents, and it can be observed that an increasing of resin retention was resulted increasing composite strength. This is because the resin reinforcement was applied to improve the wood features of and logically accepted despite the fact that the resin penetrated through the intercellular cavities of oil palm fronds and kenaf bast fibers composite.

The tested composite shows an increase in their mechanical properties, which includes the modulus of elasticity (MOE) and modulus of rupture (MOR) in static bending strength [33][34][35]. This is attributed to the resin applied to the composites which resulting in the improved in the mechanical properties.

CONCLUSION

The bio-composite produced from mixture of oil palm fronds and kenaf bast has potential to be used as an alternative to future wood. It has properties that match some of the common tropical wood species that are currently used in furniture or construction industry. The improved properties can be attributed to application of varying the content of resins and particle size of fibers used as showed in the SEM studies. Thus these hybrid composites of different fibers can be a good new candidate for high performance economic and environment-friendly bio-composite.

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