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RESEARCH ARTICLE

PROPERTIES OF *HIBISCUS CANNABINUS* AND *ELAEIS GUINEESIS* FROND FIBERS ECO-COMPOSITE BOARDS

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ABSTRACT

This paper investigated the bio-resources characteristics of composite boards manufactured from kenaf bast and oil palm fronds fibers. These two fibers mixed thoroughly and bonded together with resin urea formaldehyde at specified fibers ratios. The evaluations of the physical and strength characteristics made by the European Standards. Assessment of the physical characteristics includes the density, water absorption, thickness swelling and wettability. The strength characteristics assessment comprises of static bending for modulus of elasticity and modulus of rupture, besides internal bonding of the boards, revealed the enhanced values after increasing the resin content. The morphological studies were conducted using micrographs' structures obtained from the scanning electron microscopy used in determining the distribution of the fibers and resin in the boards. The hybrid (*Hibiscus* and *Elaeis*) biocomposite board, highlighted the excellent physical and strength characteristics.

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INTRODUCTION

Future supply of bio-resources for the composite wood-based industry will be disrupted if alternative resources not discovered. Non-timber resources and agriculture waste found in abundance in the tropical regions of the world could be utilized to solve this problem. Composites made from these resources can play a significant role in structural and non-structural applications presently dominated by timber. Bio-composite from the lignocelluloses resources has a high potential to be used as a replacement or as an alternative to the future wood, especially in the wood-based product. Utilization of these materials could also overcome the environmental issues of using the natural timbers from the forests. The natural fibers from these resources with excellent properties can be used to produce bio-composite materials. These materials are renewable and can be recyclable (Aki *et al*., 2011). *Hibiscus cannabinus* is a warm-season annual fiber crop closely related to cottoning and jute incorporated in a variety of application. The *Hibiscus cannabinus* bast fibers obtained in the stems of the plant. The fibers can be found along the entire length of the stem and are very long. *Hibiscus cannabinus* bast fiber has superior mechanical properties compared to the other parts of the plant (Aji *et al*., 2009). The *Elaeis guineesis* fronds fibers are found in abundant all the year round in the palm oil plantations in Malaysia. These fronds considered as agricultural residues not fully utilized and are left to rot in the fields. This study explored the potential of turning a mixture of *Hibiscus cannabinus* bast fiber with *Elaeis guineesis* fronds as a bio-composite board at the various ratio. It aims at evaluating the physical and strength characteristics of kenaf bast and oil palm fronds fibers composite at different mixture and resin content.

MATERIALS AND METHODS

Five-month-old *Hibiscus cannabinus* stalks obtained from the Malaysia Agriculture Research Development Institute (MARDI) station in Pasir Puteh, Kelantan. The bast fiber separated from the core using a decorticating machine. The separated bast fiber was then refined using fiber cutter. The bast fibers of 1 mm length were dried similarly as *Hibiscus cannabinus* fronds before composite preparation and the size of *Hibiscus cannabinus* bast fibers screened by shaker machine. The *Elaeis guineesis* fronds collected from a private plantation in Hulu Selangor, Malaysia. The fronds collected from trees aged between 8-10 years. The fronds put into drum chipper and then further cut using knife ring flakes to get particles of acceptable length. The particles from the fronds were screened resulting in 0.8 mm fibers size which later dried in an oven at 60°C to reduce the moisture content up to 5% before composite fabrication. The *Hibiscus cannabinus* bast and *Elaeis guineesis* fronds fibers mixed at ratio 100:0, 70:30, 50:50, 30:70 and 0:100 of *Hibiscus* to *Elaeis* respectively. The mixed fibers then added with resin urea formaldehyde using a blender machine at 10%, 12%, and 14% contents. The mixtures blended for 5 minutes in a blender to ensure evenly mixed. The KBF and OPF later removed from the mixer and scattered in a square-shaped former with the dimension of 340 x 340 mm, placed on a cool plate covered with a Teflon fiber sheet. The furnish of mixed *Hibiscus* bast and *Elaeis* fronds fiber with resin were then pre-pressed at 35 kg/cm² pressure and hot-pressed into 12 mm thickness at 165°C for 6 min. The fibers boards then left to cool off for the resin to cure. Boards with density 700 kg/m³ produced. Three replicates were prepared for each ratio of *Hibiscus* and *Elaeis*, at respective resin contents.

Physical Properties

Density: The density tests carried out according to ISO 3131 (1975). Board test samples were cut into (5 cm x 5 cm x 0.5 cm) and conditioned at 20°C and relative humidity of 65%. The boards then placed in an oven at temperature 105°C±2 for 24 hrs. until constant weight attained. The boards then placed in a desiccator for 15 min. and reweighed.

Water Absorption: This test was conducted to study the dimensional stability of the boards. Tests carried out according to standard EN 317 (1993). The boards then immersed in water and weighed after 24 hrs.

Thickness Swelling: This test was carried out by BS EN 317 (1993). The depth in the center of a sample board measured with a digital micrometer to the nearest 0.48 mm. The board weighted then immersed in water of 20°C±1 horizontally about 3 cm below the water surface for 24 hrs. before reweight. The dimensional board stability, water absorption and thickness swelling calculated after immersing the samples board in the water at 20 °C for 24 hrs. (BS EN 317, 1993).

Wettability: The wettability test carried out with water using the contact angle analysis (walinder & Strom 2001). The methods of contact angle determination were done based on research conducted by Wahab *et al*. (2013) and Sulaiman *et al*. (2008). Images of the droplets were recorded using a fixed video camera. The water of 10µl was dropped manually using micropipette onto the surface of the board. The pictures of the droplet were recorded using a video camera for 60 seconds. Five replicate used in this study.

Strength Characteristics

Static Bending: Static bending carried out according to standard BS EN 310 (1993). The static bending conducted with a load of 10 mm/min. The boards of size 50 mm x 290 mm x 150 mm were used.

Internal Bonding: Internal bonding was carried out according to standard BS EN 319 (1993). Boards test adhered to the mould blocks and then placed in the testing machine. The load applied vertically to the board face with the loading speed at 2 mm/min. The maximum load measured at the time of failing force breaking a load of perpendicular tensile strength to the board.

Testing Procedures: Testing samples conditioned in a conditioning chamber set at temperature 20±2°C and relative humidity 65±5% for three days. The strength tests carried were static bending for MOE and MOR and internal bonding[31]. The tests carried out using an Instron Universal Testing Machine.

Microscopic study: Microscopic study and analysis conducted using a scanning electron microscopy (SEM) at the 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, substrate and the penetrated board. Sample with size of 1 cm (length) x 1 cm (width) were used. The samples cleaned from any contaminants and dried in an oven at 105°C. The samples then coated with gold approximately 20 nm thick using sputter coating POLARON 515. The SEM machine connected to a computer for image storage and processing. The images taken viewed according to the desired angle for the clearer picture selected based on preference for evaluation. The procedure used by Wahab *et al*. (2005 & 2002) adopted.

RESULT AND DISCUSSION

Physical Properties

Table 1 shows the results of the density, water absorption, thickness swelling and wettability.

Density: Table 1 gives the density of all samples tested. The highest density obtained was 715.32 kg/m^3 and the lowest 681.19 kg/m^3 found in samples with ration 30:70 (*Hibiscus* BF to *Elaeis* F) and 100% KBF respectively with resin content 14%. Decreasing in density occurred due to the variation in the number of the vascular bundles with fiber cell and fewer parenchymatous tissues (Haslet, 1990). The strength characteristics of the boards significantly correlated to density. It reported that these properties commonly found in all types of materials (Haygreen & Bowyer, 1996). The strength characteristics of boards have a close relationship with its density (Desh, 1981). An increase in density increases the strength characteristics of the boards, including bending strength.

Water Absorption: The results of the water absorption tests show that the water absorption decreased with the increase in resin content (see Table 1). The results indicated that the chemical components in the resin are capable of cross-link with the hydroxyl group of oil palm fronds and kenaf bast fibers, hence reducing the hygroscopic expansion. The type of resin, the polymerization rates, the cross-linking, the fibers pore sizes, and bond strength used also contributed to such effects. Water absorption of the boards presents a serious concern, especially for their indoor and outdoor applications. For a given composite from the different ratios of *Hibiscus* bast and *Elaeis* fronds fibers, the water absorption characteristic depends upon the content below the fibers, fiber orientation, temperature, the area of the exposed surface, the permeability of fibers, void content, and the hydrophilic of the individual components.

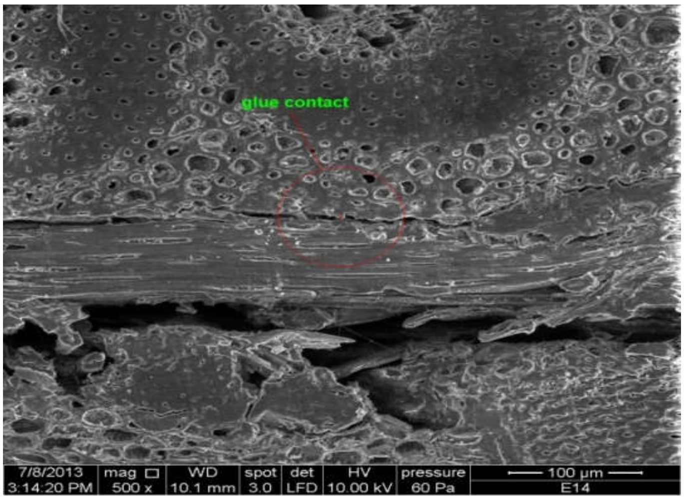

Fig. 1. Structure of kenaf bast and oil palm fronds fibers composite board at 500 x magnification

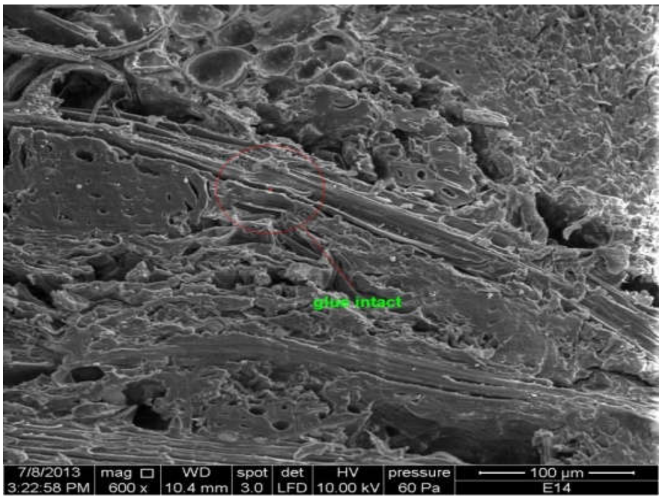

Fig. 2. Glue intact between kenaf bast and oil palm fronds fibers composite board at 600 x magnification

The result of the water absorption on the composites of the *Hibiscus* bast and *Elaeis* fronds fibers showed the highest water absorption was 128.94% at ratio 100:0 (BF to *Elaeis* F) at 10% of resin content. The lowest was 72.03% at 100% *Elaeis* F with 14% of resin content. This result shows that boards with 100% *Hibiscus* bast fibers absorb more water in the short run than the boards of 100% of *Elaeis* fronds. The increases of water absorbed in the boards with 100% of *Hibiscus* bast fiber showed rapid moisture penetration into the composite boards. This result can be attributed to the penetrability of water and capillary action that becomes active as water passed into the interface by swelling of *Hibiscus* bast fiber (Mazuki *et al*., 2011). Water absorption is a condition when the fiber expands due to the incorporation of moisture and water. Water absorption experiments conducted because the intake of water can cause changes in shape, debonding, or loss of strength in products regularly exposed to moisture (Wahab *et al*., 2017; 2015a; Tserki *et al*., 2006). The cells mainly the parenchyma behaves like a sponge and can quickly absorb moisture (Paridah & Anis, 2008; Wahab *et al*., 2009). For the fiber cells, the water uptake is dependent on fiber content (Tajvidi et al., 2006). The larger the particles or fibers size, the higher the water absorption. This study shows that the boards, especially with a high ratio of *Hibiscus* bast fibers absorb more water in the short run. *Hibiscus* bast fiber boards absorb water through the fibers, and matrix plus water also existed in the voids of the composite.

Thickness Swelling: The results of the tests on thickness swelling are shown in Table 1. The thickness swelling measured by calculating the difference between the thicknesses of the sample before, and after soaked in water for 24 hrs. The thickness swelling of the boards decreased with increase in the resin contents. The highest thickness swelling occurred at 45.35% with ratio 70:30 (*Hibiscus* to *Elaeis*) and 10% resin content, followed by 100% *Hibiscus* also at 10% of resin content 41.73%. The lowest thickness swelling was 22.44% at 100% OPF at 14% of resin content. The thickness swelling of the composite board is proportional to the water absorption. The porous structure of the *Hibiscus* bast and *Elaeis* fronds fibers board allows water uptake resulting in high-water absorption that at the same time, causes the board to swell and subsequently causes a rise in thickness swelling.

Wettability: The measurement for the contact angles shown in Table 1. A significant difference 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 30:70 (*Hibiscus* and *Elaeis*) at 14% of resin content was 73.91° compared to the 50:50 (*Hibiscus* and *Elaeis*) with 10% resin content that gives low value in contact angle 47.23°. The results of the boards at ratio 30:70 (*Hibiscus* and *Elaeis*) with 14% resin content increased wettability than others ratios. Previous works have shown that after the modification of fibers, its contact angles decreased (Wu & Dzenis, 2006). The boards at a ratio of 30:70 (*Hibiscus* and *Elaeis*) have poor wettability compared to the others' ratios. The higher contact angle is essential in reducing the ability of the boards surface to absorb water and reduced the probability of board to get damage. Boards bonded with resin urea formaldehyde shows a linear relationship between the surface wettability and glue strength (Wahab *et al*., 2017b).. Boards with lower the contact angle have better wettability and thus will improve their gluing properties.

Strength Characteristics: The strength characteristics of the *Hibiscus* and *Elaeis* composite boards summarized in Table 2. Three characteristics made namely the modulus of elasticity (MOE), modulus of rupture (MOR) of the static bending and internal bonding.

Static Bending for Modulus of Elasticity (MOE): The MOE is the quantified a material's elastic that is recoverable resistance to deformation under load. It is solely a material property, and stiffness depends both on the contents and the size of the beam. Large and small beams of similar material would have similar MOEs but different stiffness. The MOE calculated from the stress-strain curve as the change in stress causing a corresponding change in strain. Based on results showed in Table 2, the MOE results of the composites from oil palm fronds and kenaf bast fibers were gradually increasing from 10% to 14% of resin content. The highest MOE was 3029.13 MPa for board ratio 30:70 (*Hibiscus* to *Elaeis*) at 14% of resin content. The MOE for boards with 10% resin 100% *Elaeis*, 30:70 (*Hibiscus* to *Elaeis*), and 50:50 (*Hibiscus* to *Elaeis*) are 2279.25, 1927.97 and 1754.45 MPa respectively. The addition of resin to the board increases the MOE which makes the board stiffer. The results tallied with the previous studies (Rasat *et al.,* 2014; 2011; James *et al*., 1999).

EN 310 standard (1993). The MOR indicates the ability of a specimen to withstand a transverse (bending) force perpendicular to its longitudinal axis, MOR results from the

Table 1. Density, water absorption, thickness swelling and wettability of *Hibiscus* and *Elaeis* fronds fibers composite boards

Physical properties	Resin content	Ratios of KBF to OPF				
		100:0	70:30	50:50	30:70	0:100
	10%	678.96	715.18	688.83	706.28	684.72
Density (kg/m^3)	12%	677.35	674.49	700.83	687.43	687.34
	14%	681.19	704.99	704.74	715.32	685.01
Water	10%	128.94	119.30	105.60	124.60	93.66
Absorption (%)	12%	123.11	112.86	99.82	95.61	80.27
	14%	103.18	92.28	82.25	86.91	72.03
Thickness	10%	41.73	45.35	39.38	41.40	33.55
swelling (%)	12%	37.05	41.13	37.86	35.55	28.95
	14%	30.97	30.55	25.35	34.52	22.44
	10%	63.43	56.31	47.23	65.83	55.08
Wettability (°)	12%	64.32	57.65	64.88	68.75	57.99
	14%	66.80	65.77	68.75	73.91	72.82

Table 2. Modulus of elasticity (MOE), modulus of rupture (MOR) and internal bonding of *Hibiscus* and *Elaeis* frond fibers composite boards

Mechanical properties	Resin content	Ratios of KBF to OPF				
		100:0	70:30	50:50	30:70	0:100
	10%	1452.32	1198.88	1754.45	1927.97	2279.25
MOE (MPa)	12%	1547.46	2449.45	2215.23	2176.43	2567.11
	14%	1896.58	2663.27	2803.32	3029.13	2809.74
	10%	8.46	4.06	13.79	9.75	14.38
MOR (MPa)	12%	9.78	15.97	18.47	13.30	20.82
	14%	11.39	18.93	19.95	17.33	21.38
	10%	0.34	0.30	0.36	0.19	0.73
IB (MPa)	12%	0.34	0.41	0.43	0.41	0.78
	14%	0.40	0.60	0.61	0.54	0.83

Note : MOE = Modulus of Elasticity, MOR = Modulus of Rupture, IB = Internal Bonding.

Table 3. Relationship coefficient between physical and strength characteristics of *Hibiscus* and *Elaeis* fronds fibers composite boards

	RT	RC	D	WA	TS	WT	MOE	MOR	IB
RT	1.000	0.000^{ns}	0.271**	0.148**	0.319**	0.208**	0.066^{ns}	-0.087**	-0.497**
RC		1.000	0.039^{ns}	-0.634**	-0.708**	0.692**	0.635**	0.594**	0.441**
D			1.000	0.018^{ns}	0.116**	0.126**	0.103**	0.064^{ns}	-0.076^{ns}
WA				1.000	0.815**	-0.437**	-0.593**	-0.681**	-0.704**
TS					1.000	-0.306**	-0.730**	-0.772**	-0.798**
WT						1.000	0.417**	0.278**	0.154**
MOE							1.000	0.807**	0.602**
MOR								1.000	0.670**
IB									1.000

Note : Total number of samples for each testing = 90, ** = significant at $p \leq 0.01$, ns = not significant, RT = Ratio, RC = Resin Content, MC = Moisture Content, D = Density, WA = Water Absorption, TS = Thickness Swelling, WA= Water Absorption, MOE = Modulus of Elasticity, MOR = Modulus of Rupture,
IB = Internal Bonding.

Static Bending for Modulus of Rupture (MOR): The MOR of the boards increased with the increasing of resin content. The composites with 14% of resin material have higher MOR as compared with the other composites with different resin content (Khalid *et al*., 2015; Wahab *et al*., 2015b). Composites with 100% of oil palm fronds have higher. The MOR for static bending (Table 2) of composites with 10% resin content with 100% *Elaeis*, at ratios 30:70 and 50:50 were 14.38, 9.75, and 13.79 MPa, respectively. The values of MOR for 14% of resin content were 21.38, 17.33 and 19.95 MPa for 100% OPF, at ratios 30:70 and 50:50 ratio group respectively. The MOR for the resin content 12% of urea formaldehyde at ratio 50:50 (*Hibiscus* to *Elaeis*) surpassed the minimum value set by BS composite at higher resin contents can withstand such force. The amount of resin plays a significant role in improving the MOR value across the composites' board. Adhesive can efficiently transfer and distribute stresses, thereby increasing the strength and stiffness of the composite. The penetration of high viscosity urea-formaldehyde resin with high solids contents would break the cell walls of the oil palm fronds and kenaf bast fibers composite boards (Abdullah, 2010). This condition makes it impossible for the fiber and matrix to withstand higher loads. The parenchyma cells behave like a sponge and can quickly absorb moisture (Paridah & Anis, 2008). The composite from *Hibiscus* and *Elaeis* fibers board can promptly absorb urea formaldehyde resin. The presence of resin urea-formaldehyde enhanced the MOR of the boards.

Internal Bonding: Internal bonding test conducted to determine the interfacial bonding strength between fibers in the boards. The results (see Table 2) shows that the resins' content has significantly affected the mean internal bonding values of the boards. The internal bonding values increased with the increasing resin content from 10 to 14%. The values were better when loading of the resin content increased. In general, mean internal bonding values for ratios (*Hibiscus* to *Elaeis*) 0:100, 70:30, and 50:50 at 10% resin content were 0.73, 0.19, and 0.36 respectively. While at 14% resin content of internal bonding at ratios (*Hibiscus* to *Elaeis*) 100:0, 30:70, and 50:50 were 0.83, 0.54 and 0.61 respectively. The result indicated that higher amount of resin encourages stronger interfacial bonding between fibers in the boards, thus prolong the ability for the boards to withstand the pulling force created by the test. By comparing the ratios, the board manufactured at 100% of OPF possessed superior in internal bonding, exceeding that 70:30 and 50:50 (*Hibiscus* to *Elaeis*). The low internal bonding found in 100% *Hibiscus* boards were expected due to the surface chemical properties of fibrillar fines-rich in extractives and lignin which influenced the absorption, adhesion and strength properties and thus interrupted the bonding properties of the boards (Kangas & Kleen, 2004; Chen, 1970). The weak bonding between fibers and very little internal bonding strength within the board arise when the fibers cut into small particles, some of the particles could not further cut, and they maintain a tubular shape, which prevents resin from reaching internal surfaces of the fibers (Hammett *et al.,* 2001). Almost all the failures observed internal bonding specimens originated from the board that has kenaf bast fibers located. Some of the cure resins seen retained on the fiber surfaces, indicating insufficient penetration of the resin. The lack of inter-fiber bonding was responsible for the low internal bonding in all boards comprising kenaf bast fibers.

The relationship between Physical and Strength Characteristics: The relationship in the composites between the physical and strength characteristics of the *Hibiscus* and *Elaeis* kenaf fronds fibers (Table 3) shows a correlation between physical properties; density, water absorption, thickness swelling and the wettability of *Hibiscus* and *Elaeis* fronds fibers with different fibers ratios and resin content. The results indicated a significant correlation between mostly physical and strength characteristics at different ratios of the kenaf bast and oil palm fronds fibers and resin content. Based on this study, the physical characteristics showed substantial correlation with ratios between kenaf bast and oil palm fronds fibers and resin content with the exception except in between density and resin content. The strength characteristics indicated a significant in the ratios and resin content (with some exception in MOE and ratios). There was a negative correlation between ratios with MOR and internal bonding. The negative correlations obtained between various mixture in the fibers ratio, MOR of bending strength and internal bonding strength indicate the strength decreased from 100% *Hibiscus* to 100% *Elaei*s. The mixing ratios between the *Hibiscus* and *Elaeis* frond fibers influenced the strength characteristics of the boards.

Microscopy Study: The structure and anatomy observation of *Hibiscus* and *Elaeis* fronds fibers boards carried out using scanning electron microscopy (SEM). The scanning electrons micrograph (SEM) of fibers contains in vascular bundles are displayed in Figures 1 and 2. Both figures showed the high porous morphology of the mixing *Hibiscus* and *Elaeis* fronds fibers that allowed the resin to be located and filled the void spaces between fibers in the composite. The strengths of *Hibiscus* and *Elaeis* fronds fibers composite boards increases with the increase in resin contents. An increase in resin retention increased in the strength of the composites. The resin applied enhanced the fibers features in the composites. This condition resulted in increasing the strength characteristics composite, Wahab *et al.* (2015a) and Mustafa *et al*. (2011) made similar observations in the empty fruit bunch of *Elaeis* composite boards.

Conclusions

The bio-composite boards at a ratio (*Hibiscus* to *Elaeis*) of 0:100 and 50:50 at 14% resin exhibited superior physical and strength characteristics compared to the other boards. The boards with 100% *Elaeis* frond fibers showed slightly better features to boards of 50:50 ratio. The composite boards made from a mixture of *Hibiscus* and *Elaeis* fibers presented good characteristics as future resources for the wood composites industry. The characteristics that they possessed are at par with some of the common tropical wood species that currently being used by the industry.

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