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Properties of Biocomposite Mixture of Oil Palm Frond and Kenaf Bast Fibers.

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ABSTRACT

The physical and mechanical properties of biocomposite from a mixture of oil palm fronds (OPF), and kenaf bast fibers (KBF) fibers investigated. Urea formaldehyde resin used in cementing the mixtures together. The OPF and KBF were mixed at five (5) different ratio. Testing for the physical and mechanical properties made by the European EN Standards. Testing on the physical properties includes the density, water absorption, thickness swelling and wettability. Mechanical testing includes static bending for MOE and MOR, the internal bonding strength of the boards, revealed the enhanced values after increasing the resin content. The overall results showed that boards with 100% OPF and 50:50% (OPF: KBF) at 14% of resin material exhibited the overall quality in properties.
Keywords: Bio-composite boards, physical properties, water absorption, dimensional stability, mechanical properties.

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INTRODUCTION

Continue decline of natural resources requires the use of non-wood materials in the wood industry. Utilization of the natural resources is an answer to overcome the environmental issues of using the native timbers from the forests. Research on natural resources and agricultural residue fibers leads to new polymer science and engineering research for sustainable technology. Natural resources fibers provided unusual properties in the manufacturing of bio-composite. These materials are renewable raw material, recyclable, less abrasive and harmful behavior and considered environmental friendly [1],[2].

Kenaf fibers are one of the most widely used natural fibers that can successfully incorporate in a variety of application. Kenaf (Hibiscus cannabinus L.) is a warm-season annual fiber crop closely related to cottoning and jute. It 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 found in the stems of the plant providing strength for them. The oil palm fronds fibers found in abundant all the year round in the palm oil plantations in Malaysia are considered an agricultural residues not fully utilized. Bio-composite from these resources has a high potential to used as an alternative to the wood [3]. These composite are eco-friendly and can utilize for non-structural and light structural purposes. 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 of kenaf bast as a composite board are the potential candidates to replace lumber due to the extinction of them. Kenaf bast fiber have superior mechanical properties compared to the other parts of the plant [1]. The current research explored the potential of turning the mixed of oil palm fronds with kenaf bast fiber as a bio-composite boards. The aims of this studies were to evaluate the physical and mechanical properties of oil palm fronds and kenaf bast fiber composite and to correlate these properties' composite at different resin content and mixture.

MATERIALS AND METHODS

Materials

The oil palm fronds collected from an oil palm plantation in Tanah Merah, Kelantan, Malaysia. The fronds collected from oil palm trees aged between 8-10 years. While, the five-month-old kenaf stalks obtained from Malaysia Agriculture Research Development Institute (MARDI) station in Pasir Puteh, Kelantan.

Methods

The OPF placed into drum chipper and cut using knife ring flakes to get acceptable particles length. The particles screened for 0.8 mm size fibers then dried in an oven at 60°C to reduce the moisture content to 5% before composite fabrication. Kenaf bast fiber 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 fibers screened by shaker machine. The oil palm fronds and kenaf bast fibers mixed at a ratio of 100:0, 70:30, 50:50, 30:70 and 0:100, respectively. The mixed fibers added with urea formaldehyde using a blender machine with a loading percentage of 10%, 12%, and 14%. The fibers and the resin were mixed in the blender for about 5 minutes to ensure they are evenly mixed. The OPF and KBF removed from the mixer and scattered in a square-shaped former with the dimension of 340 x 340 mm, which first placed on a cauls plate covered with a Teflon fiber sheet. The furnish of mixed oil palm fronds and kenaf bast fiber with resin was pre-pressed at the pressure of 35 kg/cm^2 and subsequently pressed in the hot press machine to 12 mm thickness at a temperature 165°C for 6 minutes. The fibers then left to cool down for resin curing. Boards with density 700 kg/m^3 produced.

Physical Properties

Density: The test carried out according to EN 323:1993 [4]. Board test specimens cut into (5 x 5 x 0.48 cm). The test piece conditioned to a constant mass in a conditioning chamber set at a relative humidity of 65% and temp. of 20°C. The samples then placed in an oven at temp. 105°C±2 for 24 hrs until attained constant. They then placed in a desiccator for 15 min. and weighed.

Water Absorption: This test was conducted to study the dimensional stability of the boards. Tests carried out according to EN 317:1993 [6]. The samples (W_1) immersed in the water and weighed after 24 hours (W_2).

Thickness Swelling: This test carried out according to BS EN 317:1993 [5]. The depth at the center of a test measured to the nearest 0.48 mm with the digital micrometer. It was immersed in water of 20°C±1 horizontally about 3 cm below the water surface for 24 hrs then reweight. The dimensional stability of the board determined with water absorption and thickness swelling tests. The water absorption and thickness swelling ability calculated after immersing the samples in the water at 20°C for 24 hrs [6].

Wettability: The contact angle analysis was used to determine the wettability of board surface [7]. Wettability test was carried out using water. The method of contact angle determination conducted based on studies by Sulaiman et al. [8] and Wahab et al., [9]. Ten (10) µl of water dropped manually using micropipette onto the surface of the board. The pictures of the droplet were recorded using a video camera for 60 seconds.

Mechanical Properties

Static Bending: Static bending carried out according to EN 310:1993 [5]. Static bending conducted with a load of 10 mm/min. The specimen size used for bending test has a dimension of 50 x 290 x 150 mm.

Internal Bonding: Internal bonding carried out according to EN 319:1993 [10]. A sample test adhered to the internal bonding blocks and placed in the machine. Tension load applied vertically to the board face, with the tension loading speed at 2mm/min. The maximum load (P') measured at the time of failing force.

Testing Procedures: All samples placed in a conditioning chamber and set at temp. 20±2°C and RH 65±5% for three days before testing. The mechanical tests carried out on the samples were static bending for MOE and MOR [5] and internal bonding [5]. The tests carried using an Instron Universal Testing Machine Model 4204.

RESULTS AND DISCUSSION

Physical Properties

The results of the physical properties studies which include the density, water absorption, thickness swelling and wettability shown in Table 1.

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 (see Table 1). The mean values of the density for samples given in Table 1. Density expressed how much substance present in the given volume while the density of the board is a ratio of dry weight of board to its volume [11]. The mechanical properties of the composite boards closely correlated to density [12]. The increment in the density value increases the mechanical properties of wood.

Water Absorption

The water absorption results revealed that the water absorption decreased with the increased in resin content. The results of the water absorption test summarized in Table 1. 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 bast fibers, hence reducing the hygroscopic expansion. The other factors that contribute to such effects are the type of resin such as the monomer, the polymerization rates, the cross-linking and pore sizes of the fibers and bond strength. Water absorption of the composite is a serious concern, especially for their potential indoor and outdoor applications. For a given composite of different ratio OPF and KBF, the water absorption characteristic depends upon the content of the fiber, fiber orientation, temperature, the area of the exposed surface, the permeability of fibers, void content, and the hydrophilic of the individual components [13].

The water absorption of oil palm fronds and kenaf bast fibers composite shows the highest value of 128.94% in ratio 0:100 (OPF: KBF) at 10% of resin content. The lowest obtained 72.03% at ratio 100:0 (OPF: KBF) at 14% of resin content. This show that 100% of kenaf bast fibers absorbed more water in the short run than 100% of oil palm fronds composite. The increasing of water absorption in the 100% of kenaf bast fiber's board showed the rapid moisture penetration into the composite materials. The penetrability of water and capillary action becomes active when moisture penetrates into the interface via void-induced by swelling [14].

The absorption of water can cause changes in shape, debonding, or the loss of strength in products exposed to moisture [15]. For a given particleboard, the water absorption characteristic depends upon the content below the fiber, fiber orientation, temperature, the area of the exposed surface, and permeability of fibers, void content, and the hydrophilicity of the individual components [16]. Increases in the ability of the fiber to absorb or desorb moisture should consider when evaluating the suitability of the composite boards for various applications [17]. This study showed that the composite boards absorb more water in the short run.

Thickness Swelling

The results of thickness swelling given 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 hours. It found that the result of thickness swelling decreased with increasing the resin contents. The highest thickness swelling is 45.35% at ratio 30:70 (OPF: KBF) at 10% resin content, followed by 0:100 (OPF: KBF) also at 10% of resin content 41.73%. While the lowest thickness swelling was at ratio 100:0 (OPF: KBF) at 14% of resin content 22.44%. Thickness swelling of the composite board is proportional to water absorption. When the water absorption is high, the thickness swelling will also be great. This attribute to swelling of the fiber inside the fabricated composite board. 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 of the oil palm fronds and the kenaf bast fibers composite board allows more water uptake, causing the board to swell and subsequently a rise in thickness swelling.

Wettability

The measured contact angles shown in Table 1. A different significant found between the contact angles of every ratio of oil palm fronds and kenaf bast fibers composite boards with the different ratio. 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 that gives 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. Wettability 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 [18]. Wettability is an essential property of wood adhesion [19]. The phenomenon of wetting or non-wetting of a solid by a liquid is a better understanding of studying known as the contact angle [20]. Wetting on surface occurs when the contact angle approaches zero [21]. The liquid spreads spontaneously or entirely on the surface of the solids [22]. Therefore, the liquid wetting processes include information about the contact angle formation, spreading and penetration [23]. 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 the composite board. Previous work has shown that after the modification of fibers, its contact angles decreased [24]. This relates to the theory of contact angle measurements, which predicts that if the values of contact angles are small, the liquid will spread or wet well while high values indicate poor wetting. The composite boards at ratio 70:30 (OPF: KBF) possess more reduced wettability than the others' ratios. The high contact angle is necessary to decrease the ability of particle surface to absorb water during used and reduced the probability of composite board to damage because of water absorption such as swelling. There is a linear relationship between surface wettability and glue bond strength in most tropical wood species [25].

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Table 1: Density, water absorption, thickness swelling and wettability of oil palm fronds (OPF) and kenaf bast fibers (KBF) composite boards.

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

Mechanical Properties

The results on the mechanical properties of the biocomposite boards of OPF and KBF summarized in Table 2. These include the modulus of elasticity (MOE), modulus of rupture (MOR) of the static bending and internal bonding.

Static Bending: Modulus of Elasticity (MOE)

The MOE is the quantified 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 calculated from the stress-strain curve of the change in stress causing a corresponding change in strain.

Based on results showed in Table 2, the MOE of the composites boards gradually increases when the resin content changed from 10% to 14%. The highest value of MOE obtained 3029.13 MPa for ratio 70:30 (OPF: KBF) at 14% of resin content. The MOE for 10% resin content of ratio (OPF: KBF) 100:0, 70:30, and 50:50 were 2279.25, 1927.97 and 1754.45 MPa respectively. This showed that the addition of resin into the board increased MOE and thus makes the board stiffer. The results are tallied with the previous studies [2],[26].

Static Bending: Modulus of Rupture (MOR)

The MOR increased through increasing the resin content. The results revealed that bio-composites with 14% of resin material have the MOR as compared with the other composites with different resin content. Also, the ratio 100% of oil palm fronds possessed the highest value to each resin content value. According to the obtained results for static bending, summarized in Table 2 for MOR, the average values of the 10% resin content for ratios (OPF: KBF) (100:0), 70:30 and 50:50 are 14.38, 9.75, and 13.79 MPa, respectively. Also, the average value MOR for 14% of resin content are 21.38, 17.33 and 19.95 MPa for ratios (OPF:KBF) (100:0), 70:30 and 50:50 ratio group respectively. The mean MOR value for the resin content 12% of urea formaldehyde at ratio 50:50 (OPF: KBF) surpassed the minimum value of the EN 310:1996 standard [5]. 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 can withstand such force.

Internal Bonding

Internal bonding test conducted determine the interfacial bonding strength between fibers in the boards. 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. The internal bonding for ratio OPF to KBF 100:0, 30:70, 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 (OPF:KBF) 100:0, 30:70, and 50:50 were 0.83, 0.54 and 0.61 respectively.

Table 2: Modulus of elasticity (MOE), modulus of rupture (MOR) and internal bonding of oil palm fronds and kenaf bast fibers composite boards.

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

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

The result showed a higher amount of resin resulted in stronger interfacial bonding between fibers in the boards, This prolong the ability for the boards to withstand the pulling force created by the test. By comparing the ratios, the board with 100% of OPF was superior in internal bonding, exceeding the boards at ratio 30:70 and 50:50. The lower internal bonding value found at 100% KBF 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 interrupted the bonding properties of the sample as stated by Kangas and Kleen [29]. Hammer et al. [30] reported that weak bonding between particles and poor internal bonding strength within particle board arises when fibers 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 fibers. Almost all the failures observed internal bonding specimens originated from the board that has kenaf bast fibers 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 internal bonding in all boards comprising kenaf bast fibers.

Relationship between Physical and Mechanical Properties

The relationship between the physical and mechanical properties of the oil palm fronds and kenaf bast fibers composite presented in Table 3. There is a correlation between physical properties; density, water absorption, thickness swelling and the wettability of oil palm fronds and kenaf bast fibers with different ratios and resin content. The results revealed that there was a significant correlation between mostly physical and mechanical properties with a ratio of varying oil palm fronds and kenaf bast fibers and resin content factors at 99% level of significant. Based on this study, all of the physical properties showed significant correlation with ratios between oil palm fronds and kenaf bast fibers and resin content except between density and resin content, thus, there was no encouragement of varying proportions to the density. 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 3: Relationship coefficient between physical and mechanical properties of oil palm fronds and kenaf bast 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.

The result shows that the mechanical properties have significant correlations with the difference in ratio and resin content except between the MOE and ratios. There was a negative correlation between ratio with MOR and internal bonding. The negative correlations obtained between ratio and MOR of bending strength, internal bonding strength. The negative correlations between the ratio of oil palm fronds and kenaf bast fibers with mechanical properties MOR and internal bonding indicate that the strength of composite decreased from ratios (OPF: KBF) from 100:0 to 0:100. The mixing of the ratios between oil palm fronds and kenaf bast fibers influenced the mechanical properties of the composite.

CONCLUSION

The bio-composite boards at a ratio (OPF: KBF) of 100:0 and 50:50 at 14% resin exhibited superior physical and mechanical properties compared to the other boards. The boards at 100:0 (OPF: KBF) showed slightly better features to boards of 50:50 ratio.

The bio-composite boards produced from a mixture between OPF and KBF has the potential to be used as an alternative to future wood. It has properties that match some of the common tropical wood species that currently used in furniture or construction industry.

The improved properties attributed to the application of varying the content of resins and particle size of fibers used. 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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