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Strength Properties of Mixed Cocopeat Fibres and Merawan Siput Jantan (*Hopea Odorata spp*.) Bonded with Partial Rubber Latex Adhesive and Nano- SiO_2 in Particleboard Manufacturing

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Abstract. The main purpose of this study is to determine the potential strength properties of Cocopeat fibres and Merawan Siput Jantan species as a raw material for particleboard manufacturing. The biomass can be well managed if particleboard can be manufactured from these raw materials. The 2% of Nano Silicon dioxide (SiO_2) was added as an additive to rubber latex binder. The ratio of 20% cocopeat fibres and 80% Merawan Siput Jantan (*Hopea Odorata*) were used for particleboard manufacturing in this study. An experiment was designed of a total of 36 boards with nine (9) different parameters. The physical testing, mechanical testing, adhesive properties, formaldehyde emission, and scanning electron microscopic (SEM) were used to evaluate the properties of the particleboards based on EN 310, EN 319, JIS A 5908, and JIS A 1460. The thickness swelling (TS) results were showed that all values were less than 150%. However, the water absorption (WA) value for all particleboard samples was found higher up to 200%. The best performance for mechanical properties was found in the particleboard samples made from 100 % Merawan Siput Jantan when bonded with Urea Formaldehyde (UF) and passed the minimum requirement for internal bonding (IB) test (0.60 N/mm^2) as stated in EN 319, 1993. The particleboard samples also showed a comparable internal bonding value with 593.60 N/mm^2 when a rubber latex was added with 2% Nano-SiO2 used as a binder. However, none of the samples were passed the bending strength test requirement, as stated in the standards. The adhesive properties testing also revealed that rubber latex was categorized as an acid when a pH value of approximately 4.17 and high viscosity was also found in the rubber latex adhesive. The SEM images also showed that many void volumes appeared in the particleboard samples and Nano silicon dioxide (SiO_2) saves significant effects on the formaldehyde emission (F.E.) test. In conclusion, cocopeat fibres and Merawan Siput Jantan can be used as potential raw materials for particleboard manufacturing, especially as a non-structural product.

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INTRODUCTION

Particleboard is one of the conventional wood-based composite materials commercially used in furniture making [1]. Particleboard was produced from lignocellulose materials commonly bonded with Urea Formaldehyde (U.F.) under specific heat and pressure [2]. The demand for this board keeps increasing and approximately ranged from 2 % to 5 % every year [2, 3].

Depleting and declining in wood resources continuously had encouraged the researchers to use biomass in particleboard fabrication that could be solved formaldehyde emission (F.E.) released in the environment [4, 5]. The cocopeat fibres were originated from the coconut husks, which have a long structure, and were removed from the coir fibres pith. It is primarily utilized in building construction as fire-resistant, insulation, and an acoustic panel [6].

Natural rubber latex has been widely explored and used as an alternative for synthetic glue. It has a milky brown colour, slightly viscous latex suspension, good moisture, mould resistance, and free toxicity [7]. Meanwhile, the nano silicon dioxide (SiO_2) was considered a microscopic piece with less than 100 nm and had a large surface area [8]. A previous study reported that cement board containing 3% Nano-SiO^2, when mixed with milled reed or bagasse particles, had successfully enhanced and reduced a hydration temperature and setting time [9]. The lower loading levels ranged from 1% to 3% of nanoparticles had a positive effect on strength properties. However, a higher loading percentage may cause a higher impact on thickness swelling properties [10].

Hopea odorata or Merawan Siput Jantan is a species in the family of Dipterocarpaceae and commonly live along the banks of streams or damp areas up to 600 m altitudes. It was characterized as a medium-sized to a large evergreen tree with a large crown growing up to 45 m tall, bole straight, cylindrical, branchless to 25 m, with a diameter of up to 4.5 m or more and prominent buttresses, bark surface scaly, grey to dark brown and leaves ovate-lanceolate [11]. Merawan Siput Jantan also has been listed as one of the species that can be planted as forest plantations for timber production in Malaysia since it is fast growing in Malaysia [12]. The timber was used for light to medium construction work, such as flooring for pedestrian traffic, light industrial floors, and joinery purposes [12]. This species also can be used for solid wood furniture, building construction, doors, flooring, decking, staircases, wall paneling, joinery, cabinetwork, and interior paneling [13].

Recently, there are still fewer studies on cocopeat fibres and Merawan Siput Jantan as a raw material for particleboard manufacturing. Therefore, the main objective of this study is to explore the potential properties of cocopeat fibres when mixed with Merawan Siput Jantan and rubber latex as a partial wood adhesive for particleboard manufacturing. The effectiveness of nano silicon dioxide (SiO_2) in particleboard binder was also evaluated in this study.

MATERIALS AND METHODS

Raw Materials Preparation

The cocopeat fibres were procured from a local company located at Kota Marudu, Sabah. Merawan Siput Jantan (*Hopea odorata*) spesies with a size of 1.0 mm was supplied by Forest Research Institute Malaysia (FRIM), Kepong, Malaysia. In this study, the cocopeat fibres were cut into 2 cm or 20 mm using a table saw machine to get a similar length of fibres. However, getting a similar size as wood particles was quite difficult if the fibres were too short when handling a table saw. The rubber latex was mixed with 20% of UF. Meanwhile, 100% of UF was used as control samples. Urea Formaldehyde (UF) was procured from Sepanggar Chemical Sdn Bhd, Kota Kinabalu, Sabah, with a solid content of 50.5%. Nano silicon dioxide (SiO_2) with 20 nm size was bought from China.

Particleboard Fabrication

The experimental particleboards were produced based on a target density of 0.70 $g/cm^{3,}$ each panel with the dimension of 32 cm x 32 cm x 0.8 cm. A total of 36 board samples were produced based on nine (9) parameters such as: (1) 20% cocopeat fibres: 80% Merawan Siput Jantan mixed with 100% UF (sample A); (2) 20% cocopeat fibres: 80% Merawan Siput Jantan bonded with 20% rubber latex: 80% UF (sample B); (3) 20% cocopeat fibres: 80% Merawan Siput Jantan bonded with 20% rubber latex: 80% UF: 2% nano silicon doxide (SiO2) (sample C); (4) 100%

cocopeat fibres with 100% UF (sample D); (5) 100% cocopeat fibres bonded with 20% rubber latex: 80% UF (sample E); (6) 100% cocopeat fibres bonded with 20% rubber latex: 80% UF: 2% nano silicon doxide (SiO2) (sample F); (7) 100% Merawan Siput Jantan mixed with 100% UF (sample G); (8) 100% Merawan Siput Jantan bonded with 20% rubber latex: 80% UF (sample H) and (9) 100% Merawan Siput Jantan bonded with 20% rubber latex: 80% UF: 2% nano silicon doxide (SiO2) (sample I). Higher cocopeat fibres up to 30% in the preliminary study had caused a low physical properties performance. Therefore, in this study, the 80:20 ratios were set up in particleboard manufacturing. The wood particles and cocopeat fibres were dried at 5 % moisture content (MC), with 12% of MC as targeted in the final boards. Approximately 14 % of resin level was set up based on their particle weight. The previous work [14] was used between 10% to 15% resin level when handling the coconut fibres and bio-adhesives in particleboard fabrication. The particleboard manufacturing process was started with wood particles and cocopeat fibres preparation by manually sorting and the sieving process of raw materials. All the materials were mixed with the binder with 1% of Ammonium chloride (w/w) and nano - SiO_2 in the container and evenly mixed for about 5 minutes. Then, the mixture was poured into the steel mould to form a mat. Finally, the particleboard mat was compressed with a cold press machine within 2 minutes, and the hot press at 5 MPa with a temperature was set up at 165 °C for 5 min before further testing and evaluations.

Particleboard Testing and Evaluations

Particleboards were cut into three samples for each parameter and underwent physical tests such as thickness swelling (TS) and water absorption (WA). The physical testing was conducted based on JIS standard A 5908 (2003) [15]. The accuracy level of these tests was set up to 0.01mm and 0.01g for dimensions and weight, respectively. The samples were then soaked in distilled water for 24 h.

Mechanical properties tests such as modulus of elasticity (MOE), modulus of rupture (MOR), and internal bonding strength (IB) were evaluated based on BS EN 310 and BS EN 319 (1993) standards, respectively [16,17]. The tests were conducted at FRIM, Kepong Malaysia, using a universal testing machine with a crosshead speed of 10 mm/min for the bending test and 2 mm / min for the internal bonding test. Three (3) and eight (8) replicates were used for bending strength tests and internal bonding tests, respectively.

Formaldehyde emission release test from particleboard samples was evaluated based on the Japanese Industrial Standard JIS A 1460 [18] and professionally conducted by FRIM laboratory staff. Each board with a 30 cm x 30 cm x 0.8 cm size sample was prepared for this test.

The solid content was conducted based on the previous work [19], pH was performed by using an electronic pH meter [20]. The viscosity test was conducted using a Brookfield LVT Analog Viscometer with a spindle size no.2 at few notations per minute (RPM), with 200 ml of rubber latex samples.

Morphology analysis was conducted at Archaeology Lab, Universiti Sains Malaysia (USM). The samples were cut into 5 cm x 5 cm x 0.8 cm. The thin layer of gold was coated on the samples before being evaluated using a scanning electron microscope (Model F.E.I./Model Quante FEG 650). The penetration of wood adhesive into raw materials and the appearance of Nano silicon dioxide (SiO_2) were observed. All samples in this study were analyzed using SPSS software for windows version 21 [21].

RESULTS AND DISCUSSION

Physical and Mechanical Properties

The physical properties such as thickness swelling (TS) and water absorption (WA) result findings were presented in Table 1. The TS within 24 h had obtained the ranged values from 5 % to 133 %. The lower values were found in sample D, which acquired a value of 5.07 %, followed by sample E with a value of 5.74 %. Both samples were successfully passed the minimum requirements (< 12%) as stated in the JIS standard. The highest value was found in samples A, which obtained a value of 132.99% even though it was bonded with 100% UF. Nano silicon dioxide had shown no significant difference from all samples, either with or without rubber latex. However, the rubber latex significantly affected the T.S. properties that successfully prevented the water into the particleboard. A similar trend was also found in WA values as presented in Table 1, where all the board samples had obtained the higher values ranged from 75 % to 211%. As expected, samples with cocopeat fibers showed higher values than the samples without these fibres, ranging from 188 % to 211 % (samples E, F, and D). Higher water holding capacity in cocopeat fibres [22] thus influenced the higher results in water absorption. All the board samples of Merawan Siput Jantan species seem to give a lower value in WA, which were obtained below 100%. The rubber latex particleboard mixing with UF appears to significant reduce the water uptake to the samples, especially for samples E and H. However, adding 2 % of nano silicon dioxide (SiO_2) did not give any advantages in physical properties except in mixed particleboard samples (C). The statistical analysis also proved that all samples were not significant with $p < 0.05$.

TABLE 1. The Physical and Mechanical Properties of Particleboard

Samples	Thickness Swelling (T.S.) (24 h)	Water Absorption (W.A.) (24 h)	Modulus of Elasticity (MOE) (N/mm^2)	Modulus of Rupture (MOR) (N/mm^2)	Internal Bonding (I.B.) (N/mm^2)
A	132.99 (16.65)^{d}	81.84 (4.09)^{a}	702.90 (426.62)^{c}	5.92 (3.55)^{d}	0.22 (0.06)^{c}
B	106.11 (5.25)^{c}	132.37 (18.76)^{c}	296.80 (131.79)^{b}	2.38 (0.95)^{a,b}	0.15 (0.06)^{b}
C	132.70 (6.85)^{d}	121.61 (26.06)^{b,c}	593.60 (200.99)^{c}	5.01 (2.14)^{d}	0.20 (0.09)^{b,c}
D	5.07 (2.79)^{a}	210.26 (16.51)^{d}	170.10 (112.58)^{a,b}	2.66 (1.23)^{a,b}	0.003 (0.002)^{a}
E	5.74 (1.80)^{a}	188.97 (41.27)^{d}	84.30 (45.82)^{a}	2.44 (0.91)^{a,b}	0.059 (0.08)^{a}
F	59.77 (11.73)^{b}	191.43 (23.19)^{d}	44.50 (29.93)^{a}	1.13 (0.55)^{a}	0.013 (0.01)^{a}
G	131.20 (5.46)^{d}	75.72 (10.90)^{a}	719.30 (235.95)^{c}	4.61 (1.95)^{c,d}	0.60 (0.12)^{d}
H	100.64 (5.91)^{c}	75.45 (10.90)^{a}	742.50 (132.59)^{c}	4.38 (1.13)^{c,d}	0.15 (0.05)^{b}
I	125.45 (5.49)^{d}	98.24 (6.63)^{a,b}	670.90 (115.48)^{c}	3.34 (0.59)^{b,c}	0.16 (0.08)^{b,c}

Note: Values with the same letter are not significantly different at $p < 0.05$.

The values of MOE, MOR, and IB obtained in this study were presented in Table 1. The overall observation in this study showed that all samples did not meet the minimum requirement as stated in EN 310 and EN 319 (1993) standards for general purpose (P1) or humid condition (P3) of particleboard properties. The best performance of MOE was found in samples H (742. 50 N/mm^2), followed by sample G (719.30 N/mm^2). However, samples A (702.90 N/mm2) and C (593.60 N/mm^2) also showed a comparable strength property. As expected, the lowest value of MOE was found in sample F, with 44.50 N/mm^2. The addition of 2 % of nano silicon dioxide (SiO^2) had successfully enhanced the mechanical strength in sample C.

The overall MOR values were found to obtain a comparable strength property for all samples. All samples bonded with U.F. had shown excellent results compared to the samples bonded with bio-adhesives. The addition of 2 % nano silicon dioxide (SiO_2) was only significant to sample C compared to sample B that only obtained a value of 2.38 N/mm^2. The lowest performance was found in sample F, which was acquired a value of 1.13 N/mm^2. However, overall results for MOE did not meet the minimum requirement as stated in EN 310 standard. The cocopeat fibres seem to give an advantage in MOR performance when mixed with 80 % Merawan Siput Jantan species, especially in samples A and C. Duncan multiple range tests (DMRT) also showed that there were no significantly different for all samples involved in this study.

The highest I.B. value was obtained from sample G, which was 0.60 N/mm^2. This board had passed the minimum requirement for P1 and P3 types mentioned in EN 319 (1993). Merawan Siput Jantan species had successfully enhanced the bonding properties of particleboard. The lowest IB values were found in all samples made from 100% of cocopeat fibres, samples D, E, and F, with 0.003 N/mm^2, 0.059 N/mm^2 0.013 N/mm^2, respectively. The statistical analysis also revealed that only sample G had a significant difference at $p < 0.05$ compared to others. The addition of 2% nano silicon dioxide (SiO^2) was only effective in sample C. This may be due to the nanomaterial type and size that will affect the strength properties of the board's panel [10].

TABLE 2. The Adhesive Properties of Particleboard

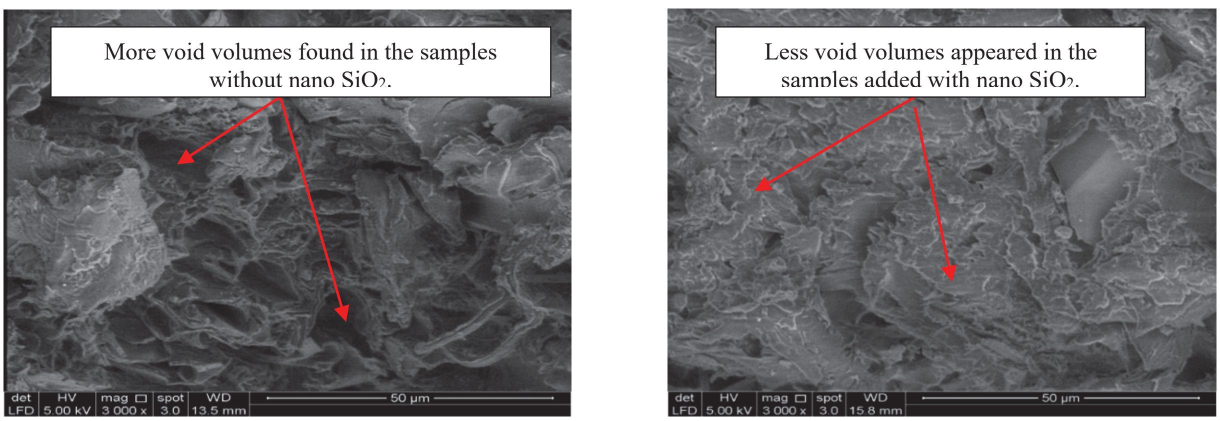
Samples	**Adhesive Properties**		
	pH	**Solid Content (%)**	**Viscosity (cP) # Spindle 2**
Commercial Rubber Latex	4.17 (0.04)	46.51 (4.02)	14800

Note: Values in parentheses consider as standard deviation (S.D.).

The pH, solid content, and viscosity values were presented in Table 2. The pH value for rubber latex used in this study was 4.17. This value was considered an acidic value. An acidic property will allow the better bonding between the binders and wood fibres [23]. Meanwhile, the solid content for rubber latex was found to be 46.51 %. The percentage of solid content generally has a significant effect on the ability of glue to form a new bonding; thus, it can improve the mechanical properties of the particleboard [24, 25]. The low solids content of the adhesive can cause the blows that occurred when the pressing pressure was released in particleboard manufacturing [26]. However, the higher solid content tends to give higher viscosity values of wood adhesives. This scenario was proven where the rubber latex showed a value of 14800 cP, considered to be highly viscous.

Formaldehyde emission for all samples had obtained the values ranged from 6.2 – 14.0 mg/L with the sample D (100% cocopeat fibres) showed the lowest value (6.2 mg/L). The addition of 2% of nano silicon dioxide (SiO2) had successfully reduced F.E. values, especially for all board samples bonded with 20% rubber latex which were obtained the values of 10.1 mg/L (sample C), 10.5 mg/L (samples F), and 9.7 mg/, L (sample I), respectively. Commercial rubber latex used as a binder in this study may have a stabilizer to avoid aging and protection from the environment, not thus affecting higher F.E. results when mixed with U.F. resin. However, all these F.E. results did not pass the minimum requirement as classified into three categories such as ≤0.3-0.4, ≤0.5-0.7, and ≤1.5-2.1 mg/L and labeled as F****, F***, F**, respectively [18]. The higher concentration in resin level up to 14% may have influenced the result findings. Factors such as the source of raw material being used in particleboard fabrication and the types of adhesive systems also influenced the findings [27].

Figures 1(a) and (b) show that all mixed particleboard samples (B and C) were low in physical and mechanical properties due to a lot of void volumes appeared in SEM imaging. The wood adhesive seems to be unsuccessfully covered to all raw materials of particleboard. Cocopeat fibres mixed with Merawan Siput Jantan may lower the penetration of wood adhesive into the particles or fibres that resulted from poor wood adhesive bonding. These findings were compared with the previous research work done by several researchers using different types of wood species [28].



(a) Mixed Particleboard bonded with UF and rubber Latex.

(b) Mixed Particleboard bonded with U.F. and rubber latex and 2% of nano silicon dioxide (SiO_2).

FIGURE 1. (a) The SEM image of the mixed particleboard bonded with UF and rubber latex (b) The mixed particleboard added with UF, rubber latex, and nano silicon dioxide (SiO_2).

CONCLUSION

In conclusion, cocopeat fibres can be considered as a partial raw material for particleboard manufacturing. However, treating the fibres before the particleboard manufacturing process still needs to be improved due to the low physical and mechanical strength. Merawan Siput Jantan (*Hopea Odorata*) acts as the main contributor to physical and mechanical strength. The mixed adhesive of U.F. and rubber latex had successfully reduced the physical properties values. In contrast, cocopeat fibres and nano silicon dioxide (SiO_2) had successfully reduced the formaldehyde and enhanced the mechanical properties, especially in the mixed particleboard. Rubber latex considers an acidic glue with lower solid content and higher viscosity. Higher void volumes appeared in SEM analysis proved that poor bonding occurred in raw materials and wood adhesive. Bio adhesives such as rubber latex should be modified with other methods to enhance the particleboard strength performance. Different resin levels and different ratios of nano silicon dioxide (SiO_2) also should be explored when mixed with natural adhesives in the future study

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