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Effects of Resin Content on Mechanical and Physical Properties of Treated Kenaf Particleboard

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ABSTRACT

Kenaf whole stems were obtained from kenaf plantation located in Chendor, Cherating, Pahang. The stems were cut into small particles with sizes ranging between 0.5 mm to 2.0 mm. Kenaf particles were treated using 2 % NaOH solution. Phenol formaldehyde (PF) adhesive was used to bind the kenaf particles together with resin contents of 8 and 10 %. The objectives of this study were to evaluate the effect of resin content on mechanical and physical properties of treated kenaf particleboard. The boards were cut and tested according to the Malaysian Standard (MS1787:2004) for furniture grade particleboards for use in humid condition. Results showed that the values of modulus of rupture, modulus of elasticity and internal bonding strength increased with an increase in resin content, while thickness swelling and water absorption increased with a decrease in resin content. Kenaf board treated with sodium hydroxide gave the highest value of bending strength and internal bonding strength compared to untreated particleboard which acted as a control board. Although all boards did not achieve the minimum standard values requirement according to the Malaysian standard, kenaf has been proven to have a great potential as raw materials in the particleboard industry. Further studies are needed to improve its properties particularly for exterior applications.

Keywords: particleboard; kenaf particles; alkali treatment; phenol formaldehyde; sodium hydroxide.

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INTRODUCTION

In fulfilling lifestyle demands, the furniture industry continues to expand due to the increase in human population and urbanization. Furniture industry mostly depends on solid wood as a raw material in furniture manufacturing. However, due to the shortage of solid wood, composite panels such as particleboard has been introduced to minimize the use of solid wood. Although particleboard is a viable solution in utilizing wood resources efficiently, it is still using solid wood as the main material. In Malaysia, sources to manufacture particleboard have been mainly from off-cuts and other sawmilling residues of hardwood and rubber wood species for decades. However, hardwood and rubber wood resources are depleting as a consequence of the cultivation of oil palm plant [1]. Therefore, fast-growing species and non-woody plants have been explored and studied by numerous researchers as a new raw material in particleboard manufacturing [2,3].

Non-wood fibers are chosen due to their availability and sustainability. Additionally, non-wood fibers are also low cost, low density, high specific strength, good mechanical properties, non-abrasive, eco-friendly and biodegradable. Non-wood fibers are mostly from fast growing plants species that can achieve maturity and can be harvested in just a few months or a year. Examples of non-wood fibers are kenaf, cotton, kapok, flax, jute, hemp, ramie, sisal, abaca, henequen, coir, corn stalk, wheat straw, rice straw, rice husk, sugarcane bagasse, pineapple leaf, banana pseudostems, coconut stem, oil palm trunk (OPT), oil palm frond (OPF), empty fruit bunch (EFB) and bamboo [4]. Numerous studies have been done on the use of non-wood fibers as raw materials in particleboard manufacturing. Juliana and Paridah [5] evaluated the basic properties of kenaf particles as raw materials for particleboard. It was found that the density of kenaf stem was much denser compared to the core and can also be processed into fine particles that is suitable for making particleboards.

Kenaf (*Hibiscus cannabinus L.*) is a non-wood fiber crop that comes from Africa [6]. Kenaf is a fast-growing species and was introduced to Malaysia bio-composite industry by the National Kenaf and Tobacco Board (NKTB). Kenaf plant has a single, straight and branchless stalk. It can achieve a height of three to five meters and harvested in four to five months [7,8]. The whole kenaf stem can be divided into two parts namely bast fiber and woody inner core. The inner core fibers consist of 60 to 75 % of kenaf stalk, while the outer bast fibers contributes 25 to 40 % based on oven dry weight. These two fibers differ in its morphology structure and chemical composition [9]. These proportions demonstrate that kenaf core are most abundant in the kenaf stem than the bast fiber. The kenaf core is light and porous having bulk density of 0.10 to 0.20 gcm^{-3}. It contains a higher lignin content and less cellulose compared to the bast fiber. Bast fiber contains over 44.4 % cellulose, 21.1 % lignin, 2.7 % extractives and 4.6 % ash [6,10-12].

Kenaf plant has a promising use in the particleboard industry. However, there are limited studies on the use of kenaf plant for exterior purpose. In order to improve the durability for exterior exposure, phenol formaldehyde (PF) resin was used. Phenol formaldehyde resin is extensively used in the production of wood-based panels for exterior applications. Kenaf particles were treated with sodium hydroxide (NaOH) to improve glue bonding between particles. Several studies on resin content in particleboard have also been documented. Previous research investigated the effect of resin content on the mechanical and physical properties of kenaf core particleboard. In the study, three percentages of PF resin loadings were used which were 7, 9 and 11 %. The results indicated that resin content influenced the increase in physical and mechanical properties of kenaf particleboard [13].

This study aimed to investigate the effects of resin content and chemical treatments using NaOH on mechanical and physical properties of kenaf particleboard and to determine the suitability of treated particles from kenaf stalk for exterior type particleboard.

MATERIALS AND METHODS

Raw materials

Kenaf from variety 36, also known as V36 was obtained from a kenaf plantation located in Chendor, Cherating, Pahang. Matured green kenaf at age of 4 months old with a range of height between 2 to 2.5 m were chosen. Phenol formaldehyde adhesive was used as a binder with resin contents of

8 and 10 %, which was obtained from Malayan Adhesive and Chemical (MAC) Sdn. Bhd. located in Shah Alam, Selangor. Sodium hydroxide (NaOH) at a concentration of 2 % that was used to treat the kenaf particles which was obtained from Syarikat Saintifik Jaya in Glenmarie, Shah Alam, Selangor. 20 g of NaOH pallets were diluted in 1000 ml distilled water to obtain 2 % NaOH solutions.

Preparation of raw material and composite board

The green kenaf stalks underwent air drying process to reduce its moisture content. It took a month for the kenaf stalk to fully dry. The dried kenaf stalks were cut into shorter length using a machete and were placed in a hammer mill machine to produce kenaf particles at sizes ranging between 0.5 to 2.0 mm.

The kenaf particles were soaked in 2 % NaOH solution for 30 minutes and then oven dried until the particles reached below 5 % of moisture content. This was to ensure all the water inside the particles dried up. Kenaf particles were poured into a mixer machine to mix and blend the particles with resins. After blending, the particles were spread evenly in a mould with size of 400 mm × 400 mm × 15 mm to form a particleboard mat with target density of 650 kg/m^3. The mats were placed in a hot-press machine with a temperature of 170 °C for seven minutes to obtain the final thickness and to cure the resins. After cooling, the boards were cut into sizes in accordance with the Malaysian Standard for Wood-Based Panels – Part 2: Sampling and Cutting of Test Pieces [14] to obtain the desired length and width.

Mechanical properties tests

Bending test is used to measure the value of modulus of elasticity (MOE) and modulus of rupture (MOR). MOE value measures the resistance to bending related to stiffness of a beam while MOR is the measurement of the rate of rupture pieces of the particleboard specimen. The load was applied at the middle of the specimen until it deflected at cross-head speed rate of 10 mm/min. According to the Malaysian Standard for Wood Based Panels-Particleboards-Specification [15], the minimum requirements value for MOE and MOR are 2000 MPa and 14 MPa, respectively, for furniture grade particleboards for use in humid conditions (PF2). The calculations to obtain values of MOE and MOR based on the Malaysian Standard [16] are shown in Equation (1) and (2) respectively.

$$\text{MOE} = \frac{1}{4} \text{ x } \frac{F_{pl} \times L^3}{bd^3 \times \Delta} \tag{1}$$

where;

L	=	Span between supports (mm)
F_{pl}	=	Maximum force at proportional limit (N)
b	=	Width (mm)
d	=	Depth (mm)
Δ	=	Deformation (mm)

$$\text{MOR} = \frac{3}{2} \text{ x } \frac{F_{max} \times L}{b \times d^2} \tag{2}$$

where;

L	=	Span between supports (mm)
F_{max}	=	Maximum load (N)
b	=	Width (mm)
d	=	Depth (mm)

Internal bond test is used to determine the strength of the particle by determining the bonding between particles. An Instron universal testing machine was used to test the internal bonding (IB) between particles by pulling the upper and bottom parts of the specimen until it cracked. The minimum requirement values according to the Malaysian Standard [15] for IB is 0.45 MPa. The calculations to obtain values of IB are shown in Equation (3).

$$\text{IB} = \frac{F_{max}}{L \times W} \tag{3}$$

where;

L	=	Length (mm)
W	=	Width (mm)
F_{max}	=	Maximum load (N)

Physical properties tests

The dimensional stability of the board was determined through water absorption (WA) and thickness swelling (TS) tests. The WA and TS tests indicate how much the particleboard absorbed water and identify the durability of particleboard to water. Thickness measurement and weight of the samples were taken after submerged in tap water for 2 hours and 24 hours. According to Malaysian specifications [15], the maximum requirement for thickness swelling is 15 % and the values that exceed this threshold are considered not meeting the requirement. The calculations to obtain values of WA and TS based on the Malaysian Standard [17] are shown in Equation (4) and (5) respectively.

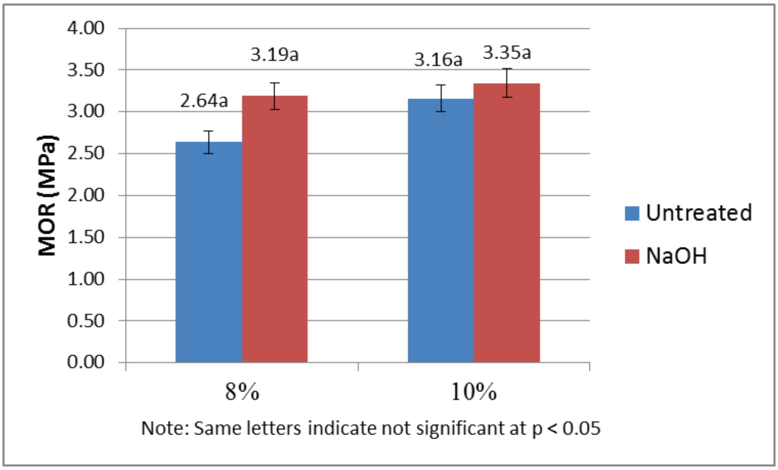
$$\text{WA (\%)} = \frac{weight\ after - weight\ before}{weight\ before} \times 100 \tag{4}$$

$$\text{TS (\%)} = \frac{thickness\ after - thickness\ before}{thickness\ before} \times 100 \tag{5}$$

RESULTS AND DISCUSSION

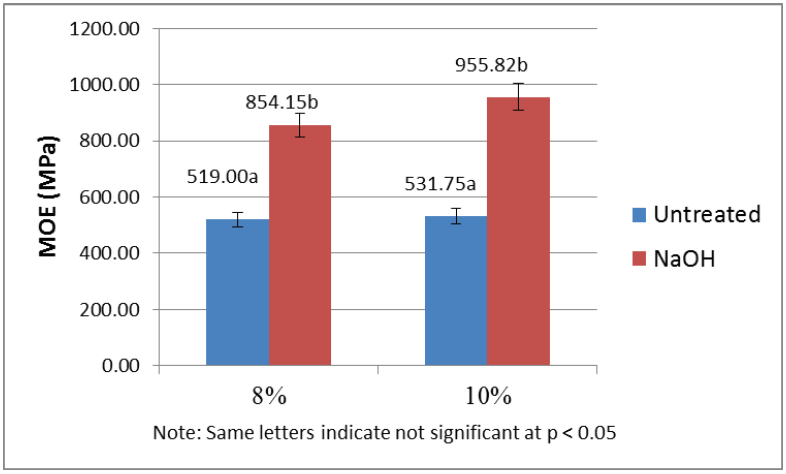
Effect of resin content on mechanical properties

Two different resin contents were used in this study to evaluate its effect on mechanical properties of kenaf particleboard. The strength performance of kenaf particleboard was determined through conducting bending and internal bond tests. Figures 1 and 2 show the effect of resin content on MOR and MOE in bending test. There was no significant difference on MOR values for both 8 and 10 % resin contents. In Figure 2, there was a significant difference between untreated and treated particles on MOE, however, there was no significant difference between 8 and 10 % resin contents. As can be seen in Figures 1 and 2, the values of MOR and MOE increased as the resin content increased from 8 to 10 % for all untreated and treated boards. The value of MOR at 8 % resin content was 2.64 MPa (untreated) and 3.19 MPa (NaOH) while at 10 % resin content the value of MOR showed an increase with 3.16 MPa (untreated) and 3.35 MPa (NaOH). The value of MOE at 10 % resin content was 531.75 MPa for untreated and 955.82 MPa for NaOH treatment. Meanwhile, the value of MOE at 8 % resin content was 519.00 MPa for untreated and 854.15 MPa for treated board using NaOH. This indicates that the addition of more resin into the board improves the mechanical properties of particleboard, through enhancing the bonding between the particles [18]. Previous studies from Ogola *et al.* [19] and Ayrilmis *et al.* [20] also indicated the same relationship in which as the resin content increased, the value of bending strength and internal bond strength also increased. Higher resin content also means more resin is available to cover all the surfaces of particles [21]. On the other hand, low resin content causes low bonding between the wood particles and the resins, thus, resulting in low MOR and MOE values of particleboard. This is due to the characteristics of kenaf core fiber which has open porous cells that absorb resin and other liquids easily. Therefore, a low amount of bast in particleboard reduces the ability to absorb the resin. This resulted in inadequate amount of resin to be spread evenly to cover all the particles surfaces [22]. The quantity of resin used was an important factor to indicate the strength properties of particleboard.



*"a" is simply used in statistical analysis to show that the mean values are not significantly different.

Figure 1: Effect of resin content on MOR in bending test



*"b" is simply used in statistical analysis to show that the mean values are not significantly different.

Figure 2: Effect of resin content on MOE in bending test

Figure 3 shows the effect of resin content on IB. There was no significant difference in IB values at 8 and 10 % resin contents. As expected, a higher resin content resulted in higher IB strength. A 10 % resin content showed an increase in IB value for the untreated and treated particleboards. Treated particleboard using NaOH produced the highest IB strength at 10 % resin content, which was 0.16 MPa. Untreated particleboard at 10 % resin content gave a higher value compared to 8 % resin content with 0.05 MPa and 0.03 MPa for 10 and 8 %, respectively. A higher quantity of adhesive produced better distribution on the particle surfaces, thus, increased the internal bonding strength. A high resin content gives sufficient resin to create bonding with particles and thus, allows more adhesive to penetrate into the wood particles [23]. Additionally, kenaf particleboard that contains kenaf core and kenaf bast fiber can also affect the distribution of resin content, which directly affect the internal bonding performance. Kenaf core has a great absorption property whereas kenaf bast fiber absorb less resin which is insufficient to cover the fiber surface [22]. Hence, a low amount of resin produces weaker interfacial bonding between fibers in the particleboard resulting in a low internal bonding strength.

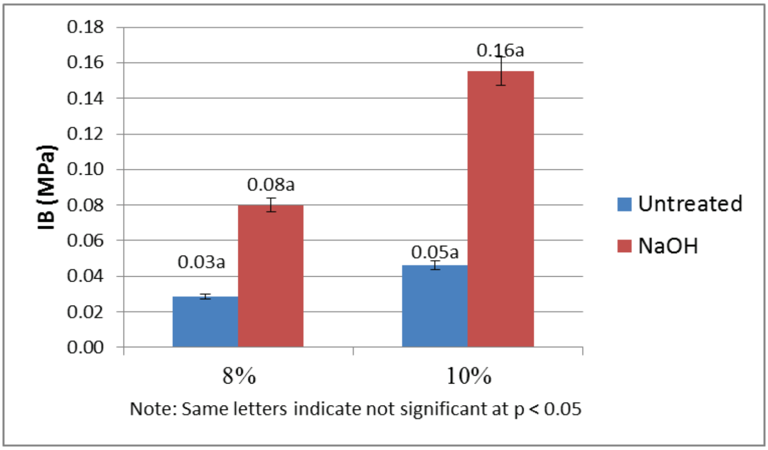


Figure 3: Effect of resin content on internal bonding test

Effect of resin content on physical properties

The amount of resins used also affected the physical properties of the particleboard. 8 and 10 % resin contents were used to evaluate TS and WA percentage after 24 hours of soaking in water. Figure 4 and Figure 5 show the effect of resin content on TS and WA performance of the kenaf particleboards. There was no significant difference effect on TS, however, there was a significant difference for WA between resin contents. The values of both TS and WA were decreased as the resin content increased from 8 to 10 %. The 8 % resin content boards showed the highest percentage of TS and WA for treated and untreated boards. The values of TS and WA at 8 % resin content were 109.81 and 253.77 % for untreated and 66.57 and 170.88 % for treated boards, respectively. The best dimensional stability results were produced by treated boards with 10 % resin content, which was 57.28 % for TS and 144.21 % for WA, followed by untreated boards with 86.39 % in TS and 251.55 % in WA. As the resin content increased, the contact areas were also increased, and this induces better adhesion of resin between particles [18]. A previous study by Pan *et al.* [24], stated that TA, and WA significantly decreased with the increased of resin content, thus will lead to better performance of board towards water resistant. A higher resin content will reduce the TS and WA values because there is an adequate amount of resin to hold the particles and produces better bonding. Allowing the resin to penetrate the wood particles reduces the amount of water absorbed into the board [23]. Thickness swelling is also related to the IB of the board. The higher IB strength, the lower the amount of water absorbed into the board, thus reducing the TS behaviour of the particleboard. The boards with 10 % resin content showed higher values of IB strength, therefore, gave the lowest thickness swelling values than the boards with 8 % resin content. The low IB strength from 8 % resin content showed that the particle was not bonded well with the resin and failed to prevent the water from penetrating into the board due to the increased in TS. Lower values of TS indicate better dimensional stability of the board [25].

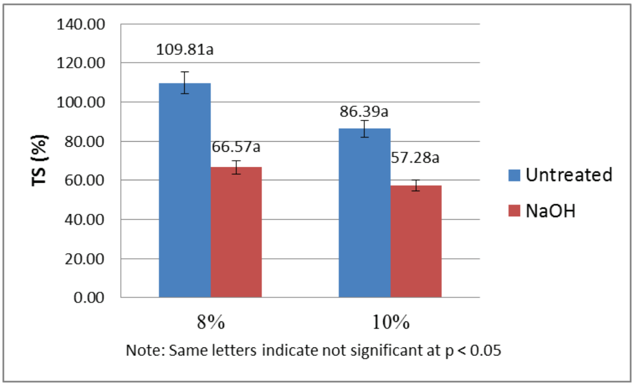


Figure 4: Effect of resin content on thickness swelling

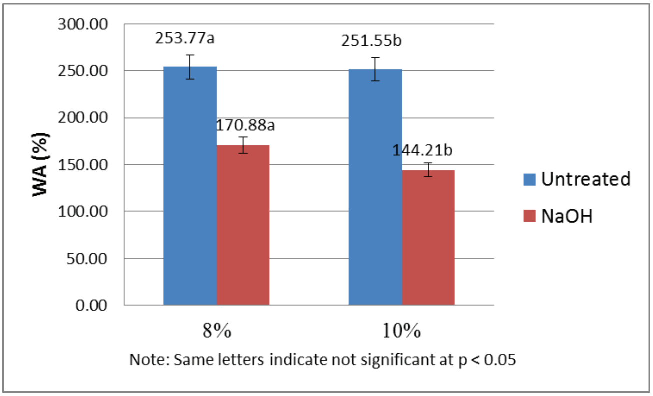
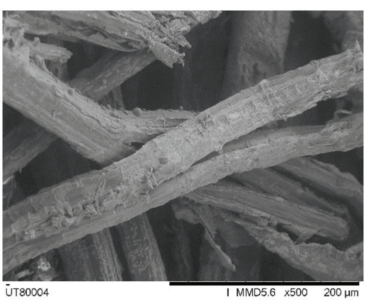


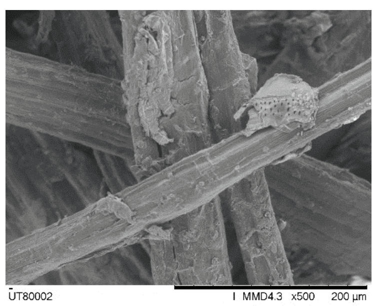
Figure 5: Effect of resin content on water absorption

Scanning Electron Microscopy (SEM) analysis

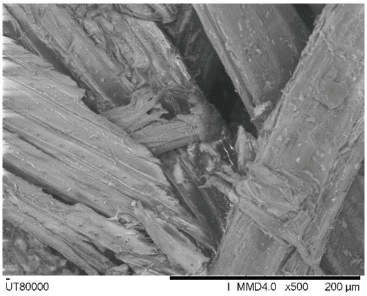
Figure 6 illustrates the effect of resin content and alkaline treatment on kenaf fiber morphology under scanning electron microscopy (SEM) at 500× magnification. Voids can be seen between fibers at 8 % resin content as shown in Figures 6(a) and 6(c). This is due to the lack of resin content that penetrates the fibers, thus, resulting in poor adhesion and causing the mechanical and physical properties of particleboard to decrease [26]. Boards at 10 % resin content are shown in Figures 6(b) and 6(d). A higher resin content leads to better performance of mechanical and physical properties of particleboard as there is adequate resin amount to evenly disperse within the particles and promotes better interlocking. Figures 6(a) and 6(b) show untreated kenaf fibers which had smooth surfaces than treated fiber. This is because untreated fiber surface was covered by lignin, hemicellulose, wax and extractives which can be removed by alkaline treatment [27]. The treated particles showed a rough and non-smooth surface on the fiber due to the removal of lignin. Surface roughness will improve the physical interaction between fiber and polymer [28]. Pits can also be seen in Figures 6(c) and 6(d) due to the reduction of extractives in kenaf fiber after the alkaline treatment. Pits are circular holes that hid under superficial layer of extractives on the fiber surface and have important function to the plant as the medium to supply water and nutrients to the leaves and roots. The presence of pits will increase the surface area, thus, resulting better bonding between particle and resins. Resins filled the pits and improved interlocking between particles [25]. From the microscopy study, it can be concluded that higher resin content and the application of alkaline treatment could improve mechanical strength and dimensional stability of particleboard.

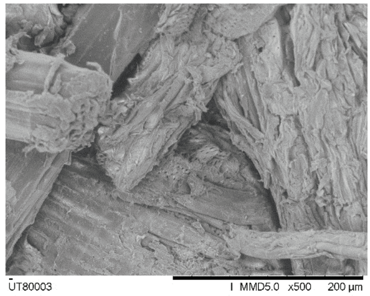


(a) Untreated with 8 % RC



(b) Untreated with 10 % RC





(c) Treated with 2 % NaOH -8 % RC **(d) Treated with 2 % NaOH -10 % RC**

Figure 6: SEM images of kenaf particleboard at 500× magnification

CONCLUSION

Resin content is an important factor that can influence the mechanical and physical properties of composite boards. Treated kenaf particleboards with target density of 650 kg/m^3 were manufactured. Results showed that MOR, MOE and IB increased with an increase in resin content while WA and TS increased with a decrease in resin content. Kenaf board treated with 2 % sodium hydroxide (NaOH) gave the highest value in bending and internal bonding strength compared to untreated kenaf particleboard. Based on statistical analysis, WA was influenced by resin content.

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