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Surface Wettability and Colour Change of Betung Bamboo Strands Treated with 1% NaOH under Various Immersing Times

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Abstract: Bamboo was a material with enormous potential to be used as raw material for various purposes. This material has good properties for structural purposes such as buildings and furniture or converted to a composite product such as bamboo oriented strand board (BOSB). This study was aimed to determine the wettability properties and the colour change of *Dendrocalamus asper* bamboo strands after alkali immersing treatment with 1% NaOH solution. The treatments were carried out for 1, 2, and 3 hours, respectively. The wettability of surfaces is quantified by computing the value of the K parameter or the contact angle change rate constant. Meanwhile, the colour change parameter of bamboo strands was quantified by portable colour difference meter CDX – 105 to determine the brightness intensity of a combination of red–green and blue-yellow. The results show that the wettability properties of bamboo strands were getting better after the treatments. On the other hand, the bamboo strands' colour was darker due to the alkali immersion treatment. The optimum duration of alkali immersing treatment with 1% NaOH was 2 hours.

Keywords: *betung bamboo, wettability properties, colour change, bamboo surface, alkali treatment*

Introduction

Bamboo was a material with enormous potential to be used as raw material for various purposes [1]. According to [2], Indonesia's forest product commodity in the form of bamboo has a very high total productivity in 2020, which was 11,303,317 stems. Bamboo has been in use for many years, and this material has good properties for structural purposes such as buildings and furniture. As a material, bamboo has several disadvantages such as high variations in physical properties in each part, limited diameter, and susceptible to attack by deterioration organisms. Thus, instead of using bamboo as single materials, it is highly recommended to use bamboo as filler in composites materials such as Oriented Strand Board (OSB) [3]–[6].

Oriented strand board (OSB) was a composite board product made of laminated strands of wood arranged in opposite directions between each layer [7]. Along with the decline in natural wood production, efforts to substitute wood with other materials with the same or even superior characteristics continue to be carried out. Bamboo was one of many materials which could use as a substitute for OSB manufacture [3], [5], [8]–[11].

Bamboo Oriented Strand Board (BOSB) has several advantages compared to OSB made of wood [3], [5], [8], [12]. These advantages include better physical properties, better mechanical properties, and ease of obtaining and preparing raw materials [5], [13]. The process of making strands or strands of bamboo is easier to do because naturally, the characteristics of bamboo stems are easy to split [2], [4], [5].

BOSB has been extensively researched and developed to find composite products with the best characteristics. There have been many treatments on bamboo strands to improve the quality of BOSB products. Several treatments that have been carried out previously were steam treatment, shelling ratio modification, and rinsing treatment using polar and non-polar solutions [4]–[6], [12], [14]–[18] Based on the treatment of bamboo strands that have been reported, there was a significant improvement in the quality of BOSB products. The improvement of BOSB properties was caused by the reduction of extractives in the bamboo strand [15], [16], [18]. Adhesive penetration increases due to reduction of the extravies of the bamboo strand [19], [20].This phenomenon caused the better glueing process so that improved BOSB properties [3], [19], [21]–[23].

Good glueing quality will correlate to the firmness of the board and its strength value [19]. The penetration of adhesive liquid influenced the adhesive quality of BOSB into the bamboo strand. It was reported that alkaline treatment of bamboo strands increased the penetration of phenol-formaldehyde (PF) adhesive into bamboo strands [15], [16], [18]. In another study, alkaline treatment of the substrate was also reported to reduce the moisture content of the fibre, improve the morphology of the fibre, and increase the compatibility between fibre and composite matrix [24]. Adhesive penetration correlates with wettability properties. Several studies reported that wettability improvement of biocomposite material due to chemical treatment had a significant effect on enhancement of physical and mechanical properties of the biocomposite end product [25], [26]. On the other hand, colour change of the filler due to treatment was one of the observable properties to evaluate the effect of the treatment [27]. However, there is no scientific report about wettability and colour change due to alkali-immersed treatment on the bamboo strand. Therefore, the objectives of this study were to evaluate wettability and colour change in the betung bamboo strand due to alkali-immersed treatment.

Method

Materials

Four-year-old betung bamboo (*Dendrocalamus asper*) was harvested in Sukabumi, West Java, Indonesia. The density of bamboo culm is 0.57 g/cm^3. The mechanical method was used to obtain the bamboo strands. This research used bamboo strands whose length, width, and thickness of 70, 25, and 0.8 mm, respectively. Furthermore, PF resin was used as a polymeric resin for the wettability test.

Alkali Immersing Treatment

Bamboo was converted into strands with a target strand dimension (70 × 25 × 0.5) mm^3. The strands were air-dried for one week until the moisture content (MC) was below 12% and kept the strands from mould. The strands were then immersed in 1% NaOH solution for 1 hour, 2 hours, and 3 hours, respectively. After immersing in 1% NaOH solution, the strands were air-dried for one week and oven-dried at 60-80 °C for three days to achieve MC below 5%.

Wettability Test

The dynamic contact angle of PF was performed by a video measuring system using a high-speed camera. A bamboo strand was placed on the top of the table in front of the camera. About 0.02 ml PF liquid was dropped on the strand surfaces. Continous images were captured for 170s to determine the dynamic contact angle (θ). The video was cut into separated individual images at the intervals of 10 s to produce a total of 18 data videos using gom players software. Then the contact angle was measured using image-j 1.46 software with drop-snakes plugin analysis and then averaged.

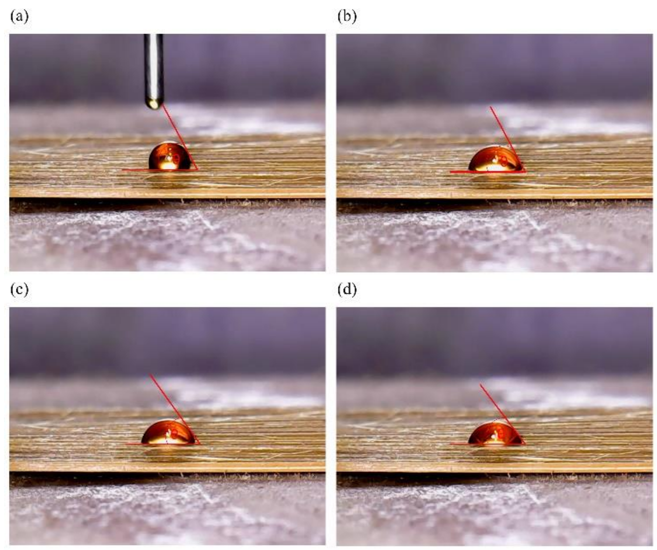

Figure 1. Appearances of PF contact angle to bamboo strand surfaces: (a) Contact angle at 0s; (b) contact angle at the 50 s; (c) contact angle at 100 s; (d) contact angle at 170 s.

$$\theta = \frac{\theta i.\theta e}{\theta i+(\theta e-\theta i)exp\left[K\left(\frac{\theta e}{\theta e-\theta i}\right)t\right]} \quad \textbf{(1)}$$

Equation 1 is used to calculate the equilibrium contact angle (θ_e) and the constant of contact angle change rate

(K). θ_i is the contact angle at 0 second. The PROC NLIN program from SAS did the statistic analysis.

Colour Parameter Analysis

Alkali immersing treatment may influence the colour change of the bamboo surface as it indicates the hydrolysis of structural and amorphous components of the bamboo strand. The quantification of colour change was done by portable colour difference meter CDX – 105 to determine the brightness intensity of a combination of red–green and blue-yellow. Equation 2 is used to compute the change in color intensity.

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad \textbf{(2)}$$

ΔE is the color intensity change, ΔL is the brightness change, Δa is the color difference of red-green, and Δb is the color difference of yellow blue. The value of $\Delta L, \Delta a, \Delta b$ were obtained from equipment.

Results And Discussion

Figure 2 shows the value of contact angle decreasing as function of time. The highest contact angle was on the untreated bamboo strand at 0 seconds with a value of 92.962˚, and the lowest was on the bamboo strand with 1% NaOH immersion for 3 hours at 170 seconds with a value of 63.425˚. Overall measurements of the contact angle values that have been carried out showed a decreasing trend from the highest on the control bamboo strand to the lowest on the bamboo strand with 1% NaOH immersion treatment. The decrease in the contact angle value indicated that the wettability properties of the substrate were getting better [14]. Good wettability quality, indicated by a slight contact angle, correlates with a material easily wetted by a liquid and vice versa [28].

Alkali treatment with NaOH to the organic material reduced the number of extractives, degraded hemicellulose, and degraded lignin [15], [29]. So that immersing treatment with 1% NaOH decreased the contact angle value. This phenomenon is caused by the structural components of the material being more porous so that it was easier for liquids to penetrate the material.

Phenol formaldehyde (PF), which was dropped onto the bamboo strand's surface, would spread and penetrate the strand until constant (θe). The highest average θe value was found in untreated bamboo strands with a value of 74,248˚ and the lowest in bamboo strands with 1% NaOH immersion treatment for 2 hours, which was 62,771˚. The smaller θe value indicates the better wettability quality [30]. In this case, the most optimal wettability was in the bamboo strand with 1% NaOH immersion treatment for 2 hours.

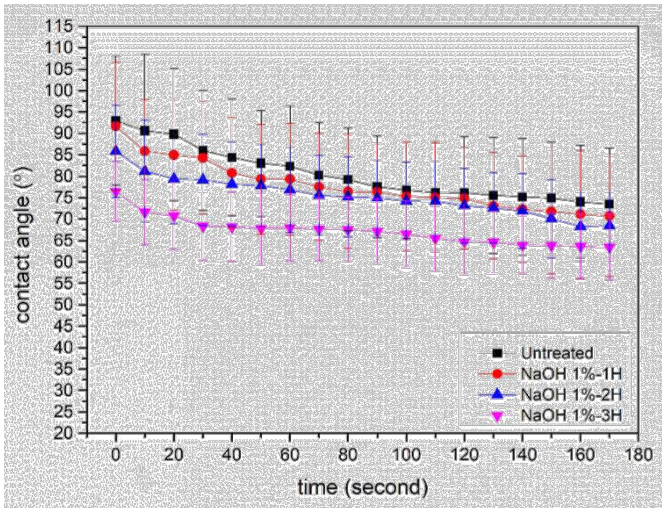

Figure 2 Measurement of PF contact angle to bamboo strand surfaces after 1% NaOH immersing treatment at 1, 2 , and 3 hours, respectively, as a function of time

Table 1 shows the contact angle, equilibrium contact angle, and K-values. The K-value measured the surface wettability property to indicate the wetting rate of the liquid on the surface. A high K-value indicated that the substrate was easier to spread by liquid [31]. The K-value of bamboo strands treated with 1% NaOH solution immersion for 2 hours had the highest K-value of 0.005 (Table 3), which indicated that bamboo strands had better wettability than other treatments. Meanwhile, in the immersion treatment with 1% NaOH solution for 3 hours, the K-value decreased again. The longer immersion time with alkali solution increased the contact angle and tend to decrease the wettability properties due to the degradation of structural components in the crystalline regions [32], [33]. This phenomenon showed that the optimal limit for 1% NaOH treatment was for 2 hours of immersion.

Table 1. Equilibrium contact angle values and K-values of bamboo strands

Treatment	Time	θi	θϵ	*K* (L/s)
Untreated	-	92.962	74.248	0.004
NaOH 1%	1 hour	91.675	71.420	0.004
	2 hours	85.839	62.771	0.005
	3 hours	76.456	63.796	0.004

Alkali immersing treatment with 1% NaOH for 1, 2, and 3 hours tends to decrease the value of the PF contact angle on bamboo strands. The decrease in the contact angle value shows that the bamboo strand was experiencing a better wettability process. Previously reported in [15], [16], alkali treatment at various concentrations caused hemicellulose and extractives degradation in bamboo strands. This phenomenon increased the ability of bamboo strands to absorb liquid due to the reduced components of extractives and hemicellulose, which inhibit the liquid binding process. The report of [34] supported this phenomenon; NaOH solution could swell the cellulose structure even at room temperature conditions. The previous research showed that alkali pretreatment using $Ca(OH)_2$ solution removed amorphous substances such as lignin, hydrolyzing the acetyl groups of hemicelluloses and reducing steric hindrance, thus enhancing cellulose digestibility even at low temperatures [34].

In another interesting study, alkali immersing treatment caused hydrolysis process in raw cellulose fibre of bamboo. This process aimed to degrade the lignin component and remove the amorphous regions. It creates a rough bamboo fibre surface, activates hydroxyl groups and improves the fibre tensile strength [35]. A rough bamboo fibre surface will create a higher surface roughness. A higher surface roughness will produce higher surface hydrophilicity that produces perfect wetting (high K-value) with lower contacts angle [36], [37]. Alkali treatment increased fibre tensile strength, which improved bamboo strands' physical and mechanical properties [34]. The wettability properties tend to improve permanently due to the alkali immersion treatment. This phenomenon was caused by the degradation of low weight molecular components such as hemicellulose and extractives in the alkali-treated bamboo strands [33], [38]. Based on the results obtained, the treatment of immersing bamboo strands with 1% NaOH solution might improve the internal bonding quality, improve hygroscopicity, and improve the ability of bamboo strands to absorb liquid. It might produce a better quality of BOSB products.

The immersion treatment of bamboo strands with 1% NaOH affected the wettability properties and affected the colour of the bamboo strands. Colour change in bamboo strands was measured using the CIELab method. The colour model in the CIELab method consists of three components, namely L* as luminance, to indicate the level of brightness. A positive L value indicates a high level of brightness. Otherwise, a negative L* value means the cross-section was dark. Values a* and b* represented opposite colour dimensions, a* values represented colour dimensions from green to red and b* values represented colour dimensions from blue to yellow [39].

According to **Table 3** the colour change of betung bamboo strand due to 1% NaOH immersion treatment for 1, 2, and 3 hours has an △E value of more than 5. This phenomenon shows an apparent difference between untreated bamboo and bamboo strands with 1% NaOH immersion treatment. The L* values of bamboo strands were decreased from 71.465 to 55.019, 55.836, and 56.363, respectively (**see Table 2**). The a* and b* value shows that the bamboo strands have become reddish and yellowed. It might be caused by the extractives that accumulated on the bamboo strand's surface due to alkali immersing treatment. The extractives that came out of the wood onto the surface could affect the colour of the wood [40]. The colour appearances of the bamboo strands also look getting darker due to the alkali immersing treatments (**see Figure 3**). The high △E value supported this phenomenon (**see Table 2**) which means the bamboo strands colour were getting darker due to alkali immersing treatment. In another study, a higher △E value reflected the darker colour of the substrate after alkalization [41]. The dark colour produced by immersion with 1% NaOH was caused by the hydrolysis process in the chemical components of the betung bamboo strand. The components of lignin, hemicellulose, pectin, and wax in bamboo were hydrolyzed during alkaline treatment [42].

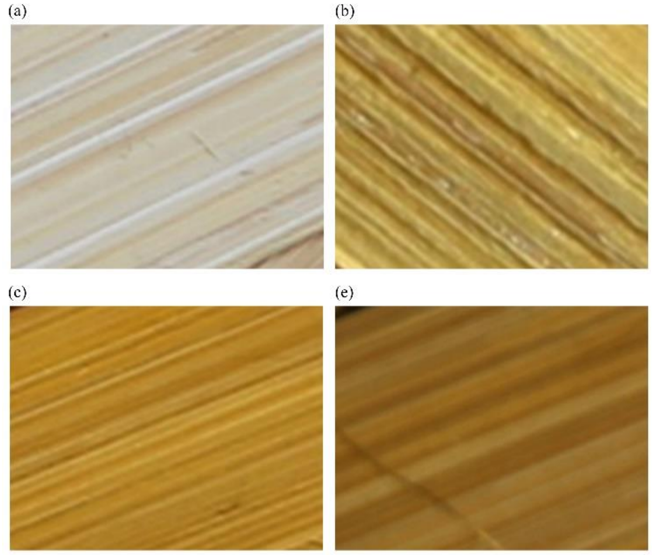

Figure 3 The colour of (a) untreated bamboo strand; (b) bamboo strand with 1% NaOH immersing treatment for 1 hour; (c) bamboo strand with 1% NaOH immersing treatment for 2 hours; (d) bamboo strand with 1% NaOH immersing treatment for 3 hours.

Table 2. Colour intensity change of untreated and treated betung bamboo strands

Treatment	Time	L*	a*	b*	△E
Untreated	-	71.465	6.019	28.741	-
NaOH 1%	1 hour	55.019	9.685	40.297	20.43163
	2 hours	55.836	9.277	39.207	19.08933
	3 hours	56.363	10.290	41.945	20.50895

Table 3. Classification of color differences value (△E) [24]

Color differeces value (△E)	Effect
0-1	No difference
1-2	Very small differences are seen by trained observers
2-3.5	Untrained observers can see small differences
3.5-5	Clear differences
>5.0	The difference is very clear

Conclusions

The effect of alkali immersing treatment of bamboo strands on the surface properties has been investigated. The wettability of surfaces is quantified by computing the value of the K parameter or the contact angle change rate constant. Bamboo that was alkali-treated with 1% NaOH for 2 hours was found to have the highest value of *K,* indicating the surface is more hydrophilic than untreated bamboo. Besides, the bamboo strands treated with 1% NaOH for a longer duration also result in a darker colour or higher value of parameter ΔE. Overall, alkali immersing treatment with 1% NaOH for 2 hours is more recommended as pretreatment in bamboo oriented strand board (BOSB). The wettability of bamboo strands after alkali immersing treatment at this condition is considered optimum to minimize the use of expensive polymer resin while maintaining the strong interaction between bamboo and resin. The optimum penetration of adhesive into bamboo strands also required the optimum wettability properties. Further physical and mechanical properties analysis of BOSB made of alkali-treated betung bamboo strands are required to formulate the optimum matrix/fibre ratio.

Conflicts of interest

There are no conflicts of interest to declare.

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