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Research Paper

# Physical and Mechanical Properties of Bamboo Oriented Strand Board Prepared from Alkali-Immersed Strands

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**Abstract**

In this work, the physical and mechanical properties of bamboo oriented strand board (BOSB) prepared from alkali-immersed strands were examined. The D*endrocalamus aspe*r strands were modified with alkali treatment by immersing them in 1% sodium hydroxide solution for 1, 2, and 3 hours. Three-layers BOSBs (30 x 30 x 0.9 $cm^3$) were prepared using phenol-formaldehyde (PF) adhesive of 8% concentration and 1% paraffin. According to JIS A 5908:2003 Standard, the physical and mechanical characteristics of BOSB were evaluated (JSA, 2003). The study showed that alkali treatment improved the dimensional stability of BOSB. Immersion in 1% sodium hydroxide solutions enhanced internal bonding (IB). The longer the immersion time, the better the WA, TS, and IB values. However, alkali treatment decreased the bending strength, i.e., modulus of elasticity (MOE) and modulus of rupture (MOR). The physical and mechanical properties of all BOSBs met the commercial standard, except the BOSBs prepared from strand with alkali immersion treatment by 1% sodium hydroxide solution for 3 hours. Alkali immersion treatment of *D. asper* strands for producing BOSB for 1-2 hours was still acceptable. The results could provide an alternative method to produce high-performance oriented strand board using bamboo as the raw materials.

**Keywords**

Alkali-immersed Strands, Alkali Treatment, Bamboo Oriented Strand Board, Dimensional Stability Enhancement, Internal Bonding Improvement

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## 1. INTRODUCTION

Oriented strand board (OSB) is a wood panel commodity as a substitute for plywood. OSB is extensively used for construction and non-construction structural purposes. Wood-based OSB products have been globally produced and marketed due to their price competitiveness, uniformity, versatility, workability, and good mechanical properties (Akrami et al., 2014; Dumitrascu et al., 2020; Nuryawan et al., 2018; Zhuang et al., 2022). However, besides their excellence, wood-based OSBs still lack dimensional stability and did not meet the CSA 0437.0 standard (Nuryawan et al., 2018; Zhuang et al., 2022).

Several approaches have been conducted to enhance the dimensional stability of OSB. Changing the raw material from wood into other lignocellulosic materials could be a promising solution. Bamboo is one of Indonesia's potential non-timber forest products (NTFPs) but has not yet reached optimal attention in its development and utilization (Bholanath et al., 2017). On the other hand, bamboo can be used as raw material due to its good strength, hardness, machining, finishing properties, and wide distribution (Ami et al., 2017; Badan Pusat Statistik, 2020; Febrianto et al., 2017; Bholanath et al., 2017). Therefore, many studies on OSB production from bamboo have been carried out (Adrin et al., 2013; Fatrawana et al., 2019; Febrianto et al., 2009, Febrianto et al., 2015; Maulana et al., 2021a; Maulana et al., 2021b; Maulana et al., 2020; Maulana et al., 2017; Maulana et al., 2019; Maulana et al., 2021c).

Previous investigations showed that bamboo OSB (BOSB) had superior qualities to wood-based OSB (Febrianto et al., 2015; Adrin et al., 2013). However, the somewhat pricey MDI adhesive is still used in BOSB production. Higher concentrations of less expensive adhesives, including phenol-formaldehyde (PF), were needed (Adrin et al., 2013) due to bamboo has high levels of extractive content (Maulana et al., 2021a; Maulana et al., 2017; Nugroho et al., 2013; Santhoshkumar and Bhat, 2014; Fatrawana et al., 2019). Extractives disrupted the adhesion process during the manufacturing of BOSB, resulting in OSB of inferior grade. According to earlier investigations, extractive materials might be removed from bamboo strands by heating them (Fatrawana et al., 2019; Maulana et al., 2021b; Maulana, 2016; Maulana et al., 2017; Maulana et al., 2019; Maulana et al., 2020; Maulana et al., 2021a), improved dimensional stability and mechanical characteristics of BOSB (Mangurai et al., 2022). However, high energy consumption in the heat treatment process still needs to be considered. Therefore, another modification method is necessary to complete information on the feasibility of using tropical bamboo as raw material for OSB. Alkali treatment was a cheap and efficient way to change natural fibers, especially bamboo (Chen et al., 2018; Wang et al., 2018).

Alkali treatment changed the surface state, acting as surface activation and making it simpler to develop the necessary strand properties. After steaming bamboo strands, alkali treatment utilizing the sodium hydroxide washing technique was beneficial in enhancing the dimensional stability and mechanical qualities of BOSB (Maulana et al., 2021a; Fatrawana et al., 2019). However, simpler alkali treatments, such as direct immersion treatment, must be considered to facilitate large-scale development. The wettability of bamboo fibers was increased by alkali treatment by soaking in sodium hydroxide at room temperature, while non-cellulosic substances such as fatty acids, pectin, natural oils, wax, and other inorganic impurities were degraded (Doczekalska et al., 2014; Wang et al., 2018; Zhang et al., 2015). The alkali treatment dissolved simple sugar, hemicellulose, tannin, resin acid, dyes, and depolymerized cellulose (Wang et al., 2009; Doczekalska et al., 2014; Zhang et al., 2015). Alkali-immersed application caused void cells to expand and enhance the presence of functional hydroxyl groups (Doczekalska et al., 2014). Thus, the mechanical connection between the bamboo strand and the adhesive is strengthened by having enough surface area and load transmission. Moreover, alkali treatment increased the pH value of the strand (Maulana et al., 2021b). PF adhesive cured more properly at higher pH values or in base conditions (Anwar et al., 2012), resulting in a better adhesion process (Fatrawana et al., 2019). Therefore, alkali immersion of bamboo strands is expected to enhance the BOSB's dimensional stability. However, scientific reports on alkali-immersed bamboo strands as raw materials for oriented strand boards are still limited. Thus, this study aimed to analyze the physical and mechanical properties of BOSB prepared from alkali-immersed strands.

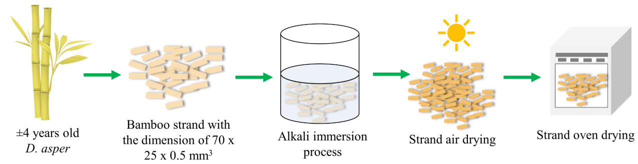


**Figure 1.** Preparation Steps of *D. asper* Strand

## 2. EXPERIMENTAL SECTION

### 2.1 Materials

Culms of *Dendrocalamus asper* ($\rho$ = 0.52 g cm$^{-3}$) ±4 years old were harvested from West Java, Indonesia's Sukabumi. The outer bamboo skin and node were then removed. A phenol-formaldehyde (PF) adhesive was provided from PT Pamolite Adhesive Industry (PAI), Indonesia, with a viscosity of 43.1% and a resin content of 2.25 poise. Wax with oil content, melting point, and color in saybolt of 0.43%wt, 52.8 C, +29, respectively, was obtained from Bratachem West Java, Indonesia's Bogor.

### 2.2 Methods

#### 2.2.1 Strand preparation

The *D. asper* strands were modified with alkali-treated by 1% sodium hydroxide solution immersion for 1, 2, and 3 hours at room temperature. Immersion was carried out with a ratio between strands and a 1% sodium hydroxide solution of 3:5 (w/v). The untreated strand without immersion (0 h) was also prepared as a control. The strands were then air-dried for seven days and then oven-dried at 60-80°C for ±72 h until the moisture content (MC) was less than 5%. In order to evaluate the slenderness ratio (SR) and aspect ratio (AR), 100 modified strands were randomly chosen. Figure 1 shows the diagram for strand preparation of the composites.

#### 2.2.2 BOSB preparation

The BOSBs (30 x 30 x 0.9 cm$^3$) were prepared according to Maulana et al. (2019) with a target density of 0.7 g cm$^{-3}$. Three layers of BOSB were bonded using PF adhesive with a concentration of 8%, with a 1% wax addition. The calculation of strand and PF adhesive using the following equation:

$$Mass of BOSB = 0.7x(30x30x0.9) = 567g \quad (1)$$

(The total ratio is 108 which consist of 100 strand and 8 adhesive)

$$Strand = (\frac{100}{108}x567) + (\frac{5}{100}x\frac{100}{108}x567) = 551.25g \quad (2)$$

$$Adhesive = \frac{(\frac{8}{108}x567)}{0.43} = 97.67g \quad (3)$$

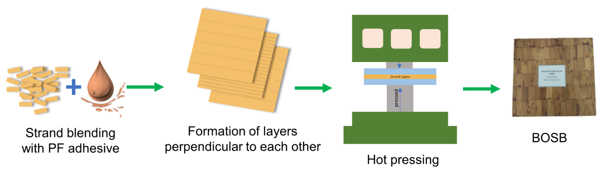


**Figure 2.** Manufacturing Steps of BOSB

The shelling ratio was set at 50:50. The boards were hot-pressed for nine minutes at a temperature of 135°C and a pressure of 2.45 MPa. Figure 2 shows the diagram for BOSB preparation.

#### 2.2.3 Evaluation of BOSB's physical and mechanical properties

The physical and mechanical properties of BOSB were evaluated in accordance with JIS A 5908:2003 Standard (JSA, 2003) after a 14-days conditioning period at 25°C room temperature. The MC, water absorption (WA), and thickness swelling (TS) were evaluated as part of the physical characteristics. In contrast, the modulus of elasticity (MOE) and the modulus of rupture (MOR), both parallel and perpendicular to the grain, and internal bond (IB) were the mechanical parameters that were assessed. Three samples were selected to test each parameter. The OSB commercial standard CSA 0437.0 (Grade O-1) (Structural Board Association, 2004) was used as a benchmark for comparison of the mechanical qualities and dimensional stability.

#### 2.2.4 Observations using a field emission scanning electron microscope (FE-SEM) and X-ray diffraction analysis

An X-ray diffractometer (Rigaku Miniflex) was used for measuring crystalline properties. Seagal's method and Scherrer's equation were used to analyzing bamboo strands' relative crystallinity and crystal width (Segal et al., 1959, Burton et al., 2009). The field emission scanning electron microscope (FE-SEM, Termo Scientific Quattro S, Brno, Netherlands, 5 kV) to investigate the surface morphology of the bamboo strands before and after alkali treatment.

#### 2.2.5 Data analysis

Simple CRD with a single factor, an alkali-immersed treatment with four levels, was used for this study's experimental setup. The data were examined using analysis of variance. Additionally, DMRT was used to analyze any substantial variation in the factor's level.

## 3. RESULT AND DISCUSSION

#### 3.0.1 Strand Geometry

The suitability of bamboo strands as OSB raw materials was assessed using the SR and AR values. Figure 3 shows that the strand distribution and SR and AR values are 118.95 and 3.225, respectively. According to Maloney (1993), strands

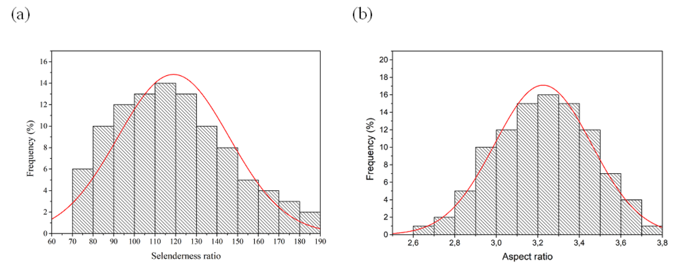


**Figure 3.** Distribution of the Bamboo Strands' Aspect Ratio (b) and Slenderness Ratio (a) (n=100)

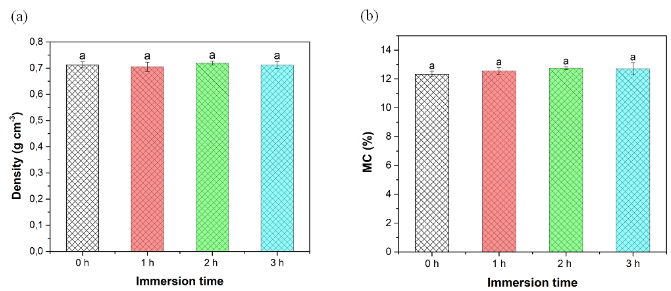


**Figure 4.** The Density (a) and MC (b) of the BOSBs at Various Times of Strand Alkaline Immersion. There was a Significant Difference Between Different Letters

with high AR and SR provided better contact and improved the mechanical properties of biocomposite products, including BOSB. A value of AR of at least two was needed to produce good mechanical properties of BOSB (Maloney, 1993). Previous research showed that BOSB glued with MDI adhesive and manufactured by *D. asper* strand with SR values of 76.6 and 73.8 had good mechanical and physical properties (Febrianto et al., 2009). Our previous studies showed that BOSB bonded with PF adhesive exhibited good physical and mechanical properties when AR values were greater than three and SR greater than 100 (Mangurai et al., 2022; Maulana, 2016; Maulana et al., 2017; Maulana et al., 2019; Maulana et al., 2021c).

### 3.1 Physical properties of BOSB

The target density was specified as 0.7 g $cm^{-3}$ to maintain the effect of density on the board. After conditioning, the values of density and MC of the BOSBs were 0.71-0.72 g $cm^{-3}$ and 12.34-12.70%, respectively (Figure 4). according to statistical analysis, the density and MC of BOSB were unaffected by the alkali immersion time.

According to Figure 5, the BOSBs' WA and TS values after 24 hours of immersion in water were 37.65–42.08% and 7.23–12.77%, respectively. The dimensional stability of composite materials like BOSB is directly correlated with the values of WA and TS. As the BOSBs were immersed for a longer period in 1% NaOH, their WA and TS were reduced. Statistical analysis showed that alkali immersion time significantly

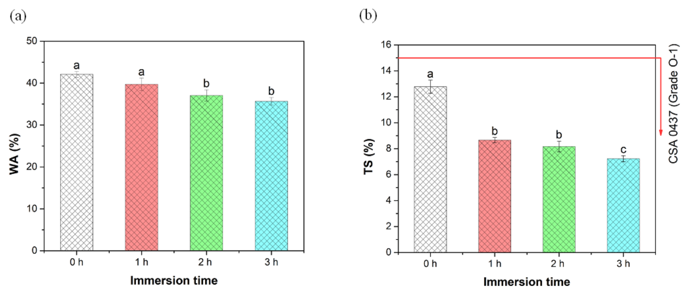


**Figure 5.** The WA (a) and TS (b) of the BOSBs at Various Times of Strand Alkaline Immersion. There was a Significant Difference Between Different Letters

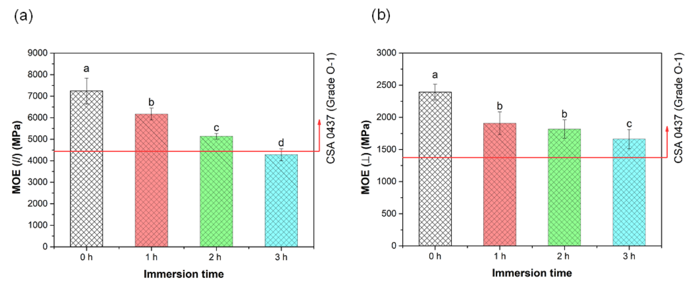


**Figure 6.** The MOE of the BOSBs at Various Times of Strand Alkaline Immersion. There was a Significant Difference Between Different Letters. Parallel (//) and Perpendicular (⊥) to the Grain Directions

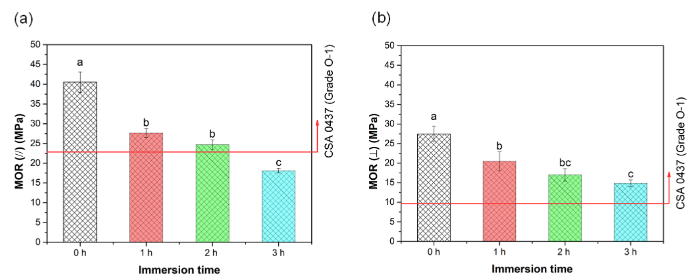


**Figure 7.** The MOR of the BOSBs at Various Times of Strand Alkaline Immersion. There was a Significant Difference Between Different Letters. Paralel (//) and Perpendicular (⊥) to the Grain Directions

affected WA and TS BOSB. Moreover, the DMRT confirmed that, compared to other BOSB, the BOSB with a 3 h alkali immersion duration had the lowest WA and TS. The OSB commercial specifications CSA 0437 (Grade O-1) for BOSBs in this study, which required a TS value of under 15%, were all met by every BOSB in this investigation (Association et al., 2004).

The BOSBs in this study revealed remarkable dimensional stability and conformed with the OSB market criteria for those parameters. We believe dimensional stability increases due to more adhesive entering the strand cavity. According to previous research, extractives interfere with the gluing process resulting in poor-quality boards (Maloney, 1993). Sodium hydroxide degraded extractive substances, hemicellulose, pectin, wax, and phenolic acid (Benyahia et al., 2014). This phenomenon was also supported by previous research that alkali-immersed removed non-cellulosic materials and enhanced wettability (Doczekalska et al., 2014; Wang et al., 2018; Zhang et al., 2015). Murda et al. (2022) reported that 1% sodium hydroxide immersion treatment for 1 – 3 hours significantly decreased the level of betung bamboo extractives. Our previous research showed that the decrease in extractive substances significantly affects the increase in adhesion quality (Fatrawana et al., 2019; Maulana et al., 2017; Maulana et al., 2019). Removing interference from the gluing process increased the ease with which the adhesive penetrated the strand. Therefore, better-gluing quality occurred, and the accessibility of the BOSB to absorb water was reduced. Previous research supported this statement, stating that bonding improvement should enhance dimensional stability (Maraghi et al., 2018).

### 3.2 Mechanical properties of BOSB

The BOSBs' MOE parallel and perpendicular orientations to the grain ranged from 4283 to 7241 MPa and 1662 to 2392 MPa, respectively (Figure 6). According to statistical analysis, the alkali immersion period significantly affected the MOE value in both parallel and perpendicular orientations to the grain. All the MOEs of BOSB in perpendicular directions met OSB commercial standards CSA 0437 (Grade O-1) requirement. Only BOSBs made from 3-hour alkali-immersed strands had not met the standard requirements parallel to the grain orientations.

Figure 7 shows the MOR for BOSBs parallel and perpendicular to the grain orientations were 18-41 MPa and 15-27 MPa, respectively. All BOSBs had MORs perpendicular to the grain that surpassed the CSA 0437 (Grade O-1) criteria for OSB commercial standards, which requires a minimal level of 9.41 MPa. Unfortunately, only the BOSBs with 3-hour alkali immersion in 1% sodium hydroxide solution had failed the requirement, which requires a MOR of at least 22.95 MPa, in MOR parallel to the grain. Statistical analyses showed that alkali immersion time affected the MOR parallel and perpendicular to the grain orientations.

The IB values for the BOSBs varied from 0.32 to 0.36 MPa (Figure 8). The IB values of BOSBs produced from strands immersed in alkali fulfilled the Grade O-1 of OSB Commercial Standard CSA 0437, which requires a minimum of 0.34 MPa. According to statistical analysis, the IB of BOSB was significantly affected by the alkali immersion period. Additionally, the DMRT revealed that, compared to other BOSB, the BOSB without alkali immersion had the lowest IB.

The study showed that alkali immersion improved the adhesion quality. Although there was no significant difference in IB among BOSB prepared from alkali-immersed strands,

 

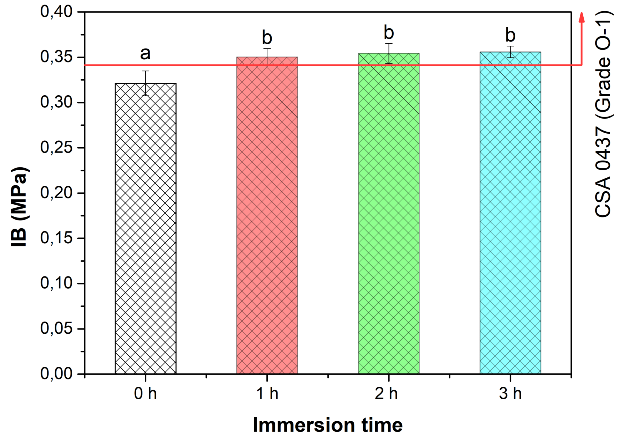


**Figure 8.** The IB of the BOSBs at Various Times of Strand Alkaline Immersion. There was a Significant Difference Between Different Letters

alkali immersion time in the range of 1-3 hours tended to improve the IB value of BOSB. According to Ebissa et al. (2022) and Wang et al. (2018), alkali immersion provided an effective contact area for superior bonding due to changing morphology and chemical composition. This phenomenon was supported by previous research that the wettability of woody materials enhanced after alkali immersion (Doczekalska et al., 2014; Wang et al., 2018; Zhang et al., 2015). The extractive degradation due to alkali immersion may be responsible for increased IB value (Maloney, 1993).

The alkali immersion treatment on the strand in 1% sodium hydroxide solution for 1-3 hours positively affects the dimensional stability and IB of BOSB. However, the higher alkali immersion time decreased the bending strength properties of BOSB. A similar phenomenon has been found in manufacturing BOSB from steamed and alkali-treated strands (Maulana et al., 2021c). The damage of bamboo fibers and lignin degradation during the alkali immersion process may be responsible for decreasing the bending strength of BOSB.

The SEM results on bamboo strands before and after modification are presented in Figure 9. The untreated bamboo strand had a relatively smooth surface and no damage. In contrast, the alkali-immersed strand had a damaged surface and was relatively brittle. According to (Wang et al., 2018), excessive alkali immersion time damaged the strength of a single cellulosic bamboo fiber due to lignocellulosic degradation and ruptured the fiber surface. Therefore, there was decreasing bending strength after alkali immersion at 1-3 hours. Thus, the fiber textures were refined and brittle (Ismail et al., 2021). Damaged fiber due to alkali treatment caused weak load transfer, resulting in low bending strength (Manalo et al., 2015). According to several earlier research, fiber fracture caused by alkali immersion reduced the mechanical properties (Ebissa et al., 2022; Ismail et al., 2021; Mahjoub et al., 2014; Manalo et al., 2015; Wang et al., 2018)

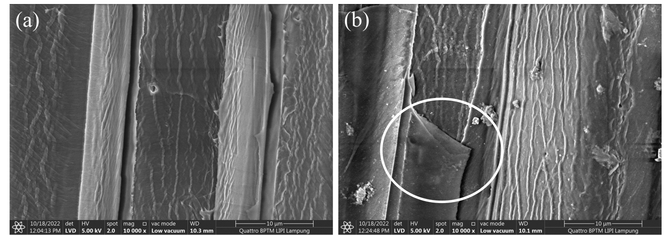


**Figure 9.** Scanning Electron Micrographs of the Surface in Untreated Bamboo Strand (a) and Alkali-immersed Bamboo Strand (b)

The crystallinity value and crystallite width of betung bamboo ranged between 61 – 73% and 0.03 – 0.20 nm, respectively (Table 1). Treatment using an alkaline solution reduced cellulose's crystallinity and formed Na-cellulose as an intermediate structure. Previous research showed that the rinsing process using alkali and drying steps changed the structure of Na-cellulose I to cellulose II, resulting in a decrease in crystallite size (Keshk, 2015). Alkaline immersion treatment at various concentrations and immersion times was also reported to cause a reduction in the crystallinity index of pine wood fibers (Raia et al., 2021). Fatrawana et al. (2019) also reported that steam treatment and rinsing of 1% sodium hydroxide decreased the crystallinity value of bamboo betung. The decrease in crystallinity value (see Figure 10) that occurred in bamboo betung due to the 1% NaOH immersion treatment for 1-3 hours correlated with the degradation of the bending strength of BOSB (see Figure 6 and Figure 7). The bending strength was reduced due to the decreased crystallinity of the strand (Maulana et al., 2021a). Soaking treatment with sodium hydroxide reduced cellulose crystallinity, making the strands more brittle (Ismail et al., 2021). This phenomenon legitimates the decrease in the mechanical properties of BOSB.

The study showed that alkali immersion increased the dimensional stability and IB of BOSBs. However, alkali immersion weakened the bending strength. Thus, the BOSB manufactured with a 3-hour alkali-immersed strand failed to meet the OSB commercial criteria CSA 0437. (Grade O-1). Therefore, alkali immersion treatment of *D. asper* strands for producing BOSB for 1-2 hours was still possible.

## 4. CONCLUSION

The bamboo-oriented strand board (BOSB) with different alkali-immersion time have been successfully manufactured and further analyzed. Increasing the alkali immersion duration in a sodium hydroxide solution improved the BOSBs' dimensional stability and internal bond (IB) (1 to 3 hours). Except for BOSBs produced from strands with alkali immersion treatment using 1% sodium hydroxide solution for three hours, all BOSBs produced met the commercial requirements for their physical and mechanical properties. Alkali immersion treat-

 

**Table 1.** The Crystallinity and Crystallite Width of Betung Bamboo Under Various Alkali Immersion Times

| Samples | Relative crystallinity (%) | Crystallite width (nm) |
|---|---|---|
| 1% NaOH 0 h | 73.04 | 0.20 |
| 1% NaOH 1 h | 64.21 | 0.04 |
| 1% NaOH 2 h | 62.73 | 0.03 |
| 1% NaOH 3 h | 61.84 | 0.03 |

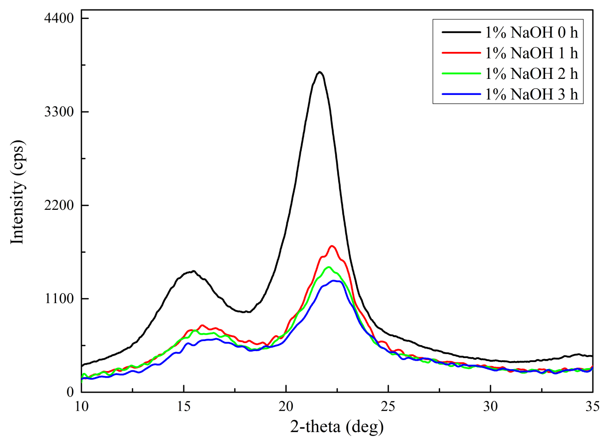


**Figure 10.** X-ray Pattern of the Betung Bamboo Under Various Alkali Immersion Times

ment of *D. asper* strands for producing BOSB for 1-2 hours was still acceptable.

## 5. ACKNOWLEDGMENT

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