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Full Length Research Article

Durability to Natural Weathering of Methylene Diphenyl Diisocyanate-Bonded Bamboo Oriented Strand Board

Dini Lestari[1], Astri Aulia Suwanda[2], Rio Ardiansyah Murda[2], Muhammad Iqbal Maulana[3], Sarah Augustina[3], Aditya Rianjanu[4,5], Tarmizi Taher[5,6], Wahyu Hidayat[7], Sena Maulana[2,3,5,*], Muhammad Adly Rahandi Lubis[3,**]

[1] Forestry Study Program, Faculty of Agriculture, University of Mataram, Mataram, Indonesia
[2] Department of Forestry Engineering, Institut Teknologi Sumatera (ITERA), Lampung Selatan, Indonesia
[3] Research Center for Biomass and Bioproducts, National Research and Innovation Agency (BRIN), Cibinong, Indonesia
[4] Department of Material Engineering, Institut Teknologi Sumatera (ITERA), Lampung Selatan, Indonesia
[5] Center for Green and Sustainable Materials, Institut Teknologi Sumatera (ITERA), Lampung Selatan, Indonesia
[6] Department of Environmental Engineering, Institut Teknologi Sumatera (ITERA), Lampung Selatan, Indonesia
[7] Department of Forestry, Faculty of Agriculture, University of Lampung, Bandar Lampung, Indonesia
[*] Corresponding Author. E-mail address: sena001@brin.go.id
[**] Corresponding Author. E-mail address: muha142@brin.go.id

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ABSTRACT

This study aimed to examine the qualities of bamboo-oriented strand board (BOSB) made from *Dendrocalamus asper* bamboo strands, both with and without steam treatment. Furthermore, the effect of exposure length to natural weathering on the physical and mechanical characteristics of BOSB was examined. The steam treatment lasted one hour at 126°C and a pressure of 0.14 MPa. Methylene diphenyl diisocyanate (MDI) and paraffin were utilized as adhesives and additives, with concentrations of 5% and 1%, respectively, based on oven-dried weight. The BOSB was exposed to natural weathering in different exposure durations (0, 1, and 3 months) in Bukit Bogor Raya Pajajaran, West Java, Indonesia. Subsequently, the BOSB was tested for its physical and mechanical properties and retention value. The result showed that steam treatment improved the dimensional stability and mechanical properties of BOSB bonded with MDI adhesive more than untreated BOSB. However, steam treatment has a better protection level against natural degradation than untreated samples. These confirm that BOSB with steam treatment is a durable and sustainable construction material.

1. Introduction

Biocomposites are applied in numerous industries, such as packaging, healthcare, and construction, and it required to enhance their properties (Pokharel et al. 2022). Biocomposite materials such as particle board, plywood, and oriented strand board have already applicated to construction materials for renewable resources (Almeida et al. 2017; Febrianto et al. 2017; Ferreira et al. 2022; Misra et al. 2015). Concerning the continuously expanding global demand for these lignocellulose materials, alternative resources are needed to maintain the security of the raw materials supply (FAO 2021).

Considering its durable properties, oriented strand board (OSB) was introduced as a sustainable answer for construction materials. Bamboo is an abundant material and relatively easily adapts to existing processing technology, so it could be an alternative raw material for OSB production (Chaowana 2013). Notably, bamboo conversion to OSB is relatively easy due to its properties, and it involves simple processes such as cutting, splitting, and shaping (Febrianto et al. 2017). Several species of bamboo such as andong (*Gigantochloa verticillata*), ampel (*Bambusa vulgaris*), and betung (*Dendrocalamus asper*), have been investigated for their feasibility for developing BOSB. Among these, betung bamboo has evident to show satisfied physical, mechanical, and wettability properties, and it is compatible for BOSB production (Baiti et al. 2021b; Febrianto et al. 2012, 2015; Mangurai et al. 2022; Maulana et al. 2019; Murda et al. 2022a).

However, the large amount of extractive content in bamboo has a negative effect on bonding quality, which avoids the adhesive penetration process in bamboo-oriented strand board (BOSB) production (Fatrawana et al. 2019; Murda et al. 2018, 2022a). The extractive content prevents the adhesive from spreading and entering the cell wall, influencing the overall quality of BOSB. The use of high temperatures in the steam treatment process may reduce this case through enhanced physical and mechanical properties of BOSB (Fatrawana et al. 2019; Wang et al. 2020b; Zhang et al. 2017).

The type of adhesive and its content were basic factors that influenced the quality of biocomposite products that affect physical and mechanical properties (Febrianto et al. 2015; Hariz et al. 2021). In the previous studies, the manufacturing process of BOSB used the formaldehyde adhesive base (Mangurai et al. 2022; Maulana et al. 2019), which may cause harmful environmental formaldehyde emissions. To avoid this issue, this research uses a formaldehyde-free adhesive, especially methylene diphenyl diisocyanate (MDI), to produce BOSB. Hence, to truly comprehend BOSB's potential for construction purposes, it is crucial to investigate the role of steam treatment in BOSB that integrates MDI adhesives. More importantly, this investigation should address its resilience against natural weathering factors, a significant aspect of structural applications (Maulana et al. 2019).

This study aimed to study the impacts of steam treatment on betung BOSB bonded using MDI adhesives and investigate physical and mechanical properties after exposure to natural weathering. Focus on bamboo as a potential renewable material for BOSB production and a combination of steam treatment and MDI adhesive, this research displays comprehensive information about future sustainable construction materials. Finally, our objective is to investigate the feasibility and deficiency of bamboo in reduction on the demand-supply gap in the construction industry, mostly in natural weathering. Recommendations will be made based on these findings to enable further research and refinement of sustainable and durable construction materials.

2. Materials and Methods

2.1. Materials

The primary material in this experiment was betung bamboo (*D. asper*) stems aged about four years, which were removed from the inner and outer parts obtained from Cikereteg, Bogor Regency, West Java, Indonesia. The adhesive used was MDI type H3M adhesive, which has a 98% solids content of 5% concentration, and paraffin as an additive of 1% concentration, purchased from Polychemie Asia Pacific, Jakarta, Indonesia.

2.2. Strands Preparation

Strand was made manually using simple tools such as sharp knives and scissors. Strands were created with lengths of 5–7 cm, widths of 2–3 cm, and thicknesses of 0.1–0.5 cm (Febrianto et al. 2012). To measure strand quality, about 100 strands were randomly selected to determine the aspect ratio and slenderness ratio. The ratios were 3.21 ± 0.25 and 77.56 ± 12.37, respectively. After that, the strands were steamed in an autoclave at 126°C and 0.14 MPa pressure for 1 hour. The strands were then air-dried for 7 days before being dried in an oven at 60°C for 36 hours to reach a moisture content of 5%.

2.3. BOSB Manufacture

Fig. 1 shows the BOSB production process in constructing a three-layer model with dimensions 35 mm × 35 mm × 10 mm. The target density was 0.7 g/cm^{3}, and the structural composition was set at a 1:2:1 ratio for the face, core, and back layers (Hidayat et al. 2011). An MDI resin, which comprised around 5% of the weight of the oven-dried material, was utilized as the adhesive binder. The strands and adhesive were combined through a rotating drum and subjected to a pressure of about 25 kg/cm^{3} at a temperature of 160°C for seven minutes (Adrin et al. 2013). The hot-pressed machine used was made by the Indonesian Institute of Sciences (National Research and Innovation Agency/BRIN) Indonesia in 1999. The boards were left for two weeks in a controlled room at 25–30°C and a relative humidity of 60–65%.

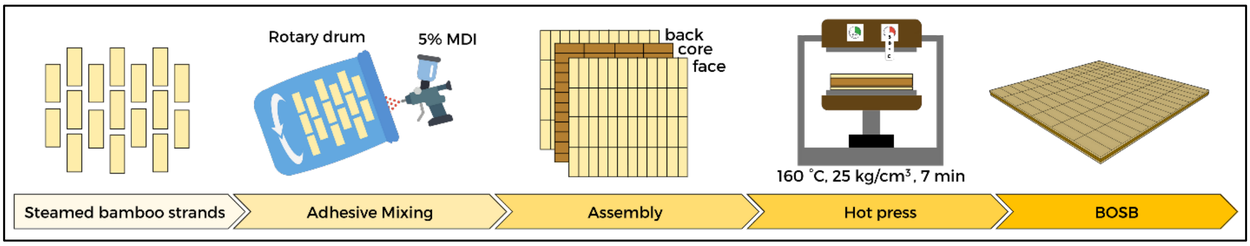

Fig. 1. BOSB production.

2.4. Physical and Mechanical Properties after Exposure to Natural Weathering Test

The configured BOSBs were then exposed to natural weathering, as applied in the actual installation. The BOSB samples were exposed outdoors for 0, 1, and 3 months in the Bogor Raya Pajajaran Hills area, West Java, Indonesia (6°36’39” S, 106°49’20.7” E). The BOSB samples were orientated to the north and south to ensure they would experience a comprehensive range of weather conditions, and a spacing distance of 20 cm was maintained between each sample to obtain optimal results (**Fig. 2**). This site has an average rainfall value: January (20.12 mm), February (18.10 mm), March (31.93 mm) (BMKG 2013). After the designated weathering period, the BOSBs were retrieved for evaluation. The physical and mechanical properties were then assessed by the JIS A 5908-2003 (JSA 2003) to maintain established scientific rigor.

2.4.1. Density and moisture content

In air-dried conditions, samples for BOSB density testing were weighed, and their volume was measured. The value of BOSB density is determined by Equation 1. The moisture content of BOSB was estimated using Equation 2 by assessing the weight of the samples and after undergoing oven-drying at a temperature of 103 ± 2°C for 24 hours.

$$D = \frac{W}{V} \quad (1)$$

$$MC = \frac{W_1 - W_0}{W_0} \times 100\% \quad (2)$$

where D is density (g/cm^3), W is weight in air-dried conditions (g), V is volume in air-dried conditions (cm^3), MC is moisture content (%), W_1 is initial weight (g), and W_0 is oven-dried weight of the sample (g).

2.4.2. Water absorption and thickness swelling

The water absorption of BOSB was calculated by assessing the weight of samples both before and after immersion in water for 24 hours. Thickness swelling was evaluated by measuring the thickness of samples both before and after immersion in water for 24 hours was also conducted. The values of water absorption and thickness swelling were calculated using Equation 3 and Equation 4, respectively.

$$WA = \frac{W_2 - W_1}{W_1} \times 100\% \quad (3)$$

$$TS = \frac{T_2 - T_1}{T_1} \times 100\% \quad (4)$$

where WA is water absorption (%), W_2 is weight after immersion (g), W_1 is weight before immersion (g), TS is thickness swelling (%), T_2 is thickness after immersion (mm), and T_1 is thickness before immersion (mm).

2.4.3. Modulus of elasticity and modulus of rupture

The modulus of elasticity (MOE) and modulus of rupture (MOR) values of BOSB were tested in both parallel and perpendicular directions to the grain, under dry and wet circumstances using a Universal Testing Machine (Instron-3369, Norwood, USA). For the wet test, BOSB samples were submerged in water 24 hours before testing. The tests were done using a one-point loading technique with a load speed of 10 mm/minute and a span length of 15 cm. The MOE and MOR values were calculated via Equation 5 and Equation 6.

$$MOE = \frac{\Delta P \times L^3}{4 \times \Delta y \times b \times h^3} \quad (5)$$

$$MOR = \frac{3 \times P \times L}{2 \times b \times h^3} \quad (6)$$

where MOE is the modulus of elasticity (MPa), P is the maximum load (N), ΔP is the difference between the maximum and minimum load (N), L is the length of the span (mm), Δy is variance in deflection between the top and bottom load (mm), b is sample width (mm), h is sample thickness (mm), and MOR is the modulus of rupture (MPa).

2.4.4. Internal bonding strength

The internal bonding (IB) strength of BOSB was performed by bonding the sample into two blocks of wood. The two blocks were pulled opposed to the sample's surface at a rate of 2 mm/minute, and suffered till achieved maximum load. The values of IB were determined by Equation 7.

$$IB = \frac{P}{2bl} \quad (7)$$

where *IB* is internal bonding (MPa), *b* is sample width (mm), and *l* is sample length (mm).

3. Results and Discussion

3.1. Physical Properties of BOSB

3.1.1. Density and moisture content

The density of the BOSB is the main factor affecting its strength. The BOSB density value was intentionally set at 0.7 g/cm^3 to avoid the influence of density on the resulting strength. The values of density and moisture content (MC) ranged from 0.67–0.70 g/cm^3 (**Fig. 3a**) and 11.25–13.35% (**Fig. 3b**), respectively**.** Based on statistical tests, steam treatment, and exposure duration did not significantly affect the density value but affected the MC value. This implies that steam treatment plays a key role in extending the resistance of BOSB to changes in temperature and humidity levels due to environmental factors. Steam treatment can reduce hemicellulose and extractive content. This leads to reduced hydroxyl groups in bamboo, resulting in lower MC values (Fatrawana et al. 2019). In addition, as the exposure time increases, the MC value will increase (Maulana et al. 2019). This phenomenon can be attributed to BOSB being composed of hygroscopic bamboo strands that have the ability to absorb moisture (Baiti et al. 2021a; b; Murda et al. 2022b; Sipahutar et al. 2021).

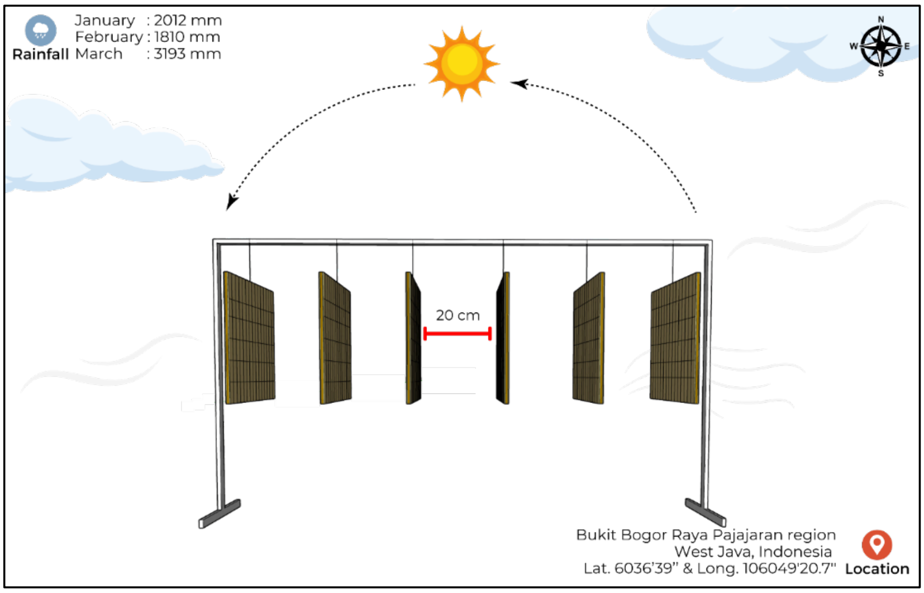

Fig. 2. Natural weathering scheme of BOSB.

3.1.2. Water absorption and thickness swelling

The BOSB's WA values, with and without steam treatment, ranged from 23.57–29.38% and 28.25–37.65%, respectively (**Fig. 4a**). Notably, the maximum WA was found in non-steam-treated BOSB following a three-month exposure period. At the same time, the minimum was observed in steam-treated BOSB during the same period. The TS value of BOSB ranged between 1.67–7.67% when treated with steam and 2.27–5.73% without treatment (**Fig. 4b**). The highest TS value was observed in the BOSB treated with steam before exposure to natural weather. At the same time, the lowest was noted in the BOSB with steam treatment following a one-month weathering period.

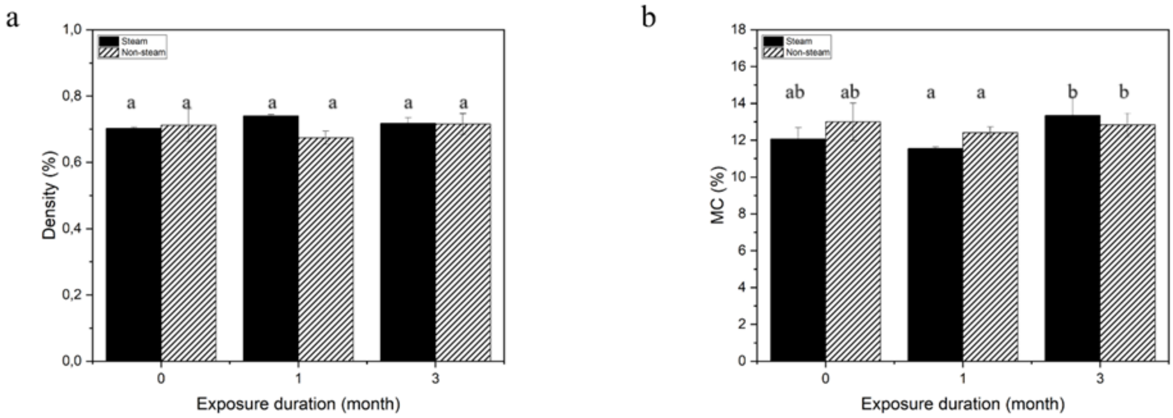

Fig. 3. (a) Density and (b) moisture content (MC) values of BOSB with and without steam treatment after natural weathering.

The data indicates that the use of steam treatment and duration of exposure significantly impact the dimensional stability, as evident from the values obtained for WA and TS. In conjunction with findings by Fatrawana et al. (2019), Febrianto et al. (2017), and Maulana et al. (2017), the reduction of extractive levels in treated BOSB resulted in its reduced water permeability and hence, lower WA and TS values compared to the untreated. The findings align with a previous study suggesting that steam treatment likely eliminated hemicellulose and extractable compounds, decreasing the number of hydroxyl groups in the bamboo strands and lowering MC values (Fatrawana et al. 2019; Maulana et al. 2016, 2017; Murda et al. 2018). Previous studies confirmed this phenomenon that the intensity of the OH functional group absorption peak in the FTIR spectra decreased due to steam treatment (Nishida et al. 2017; Wang et al. 2020a; b). Therefore, reducing extractable compounds improved adhesive penetration (Tian et al. 2021). Moreover, the choice of adhesive impacted the WA value. For example, the hydrophobic properties of MDI adhesive result in a board that absorbs less water, thus leading to reduced WA (Adrin et al. 2013; Aisyah et al. 2021).

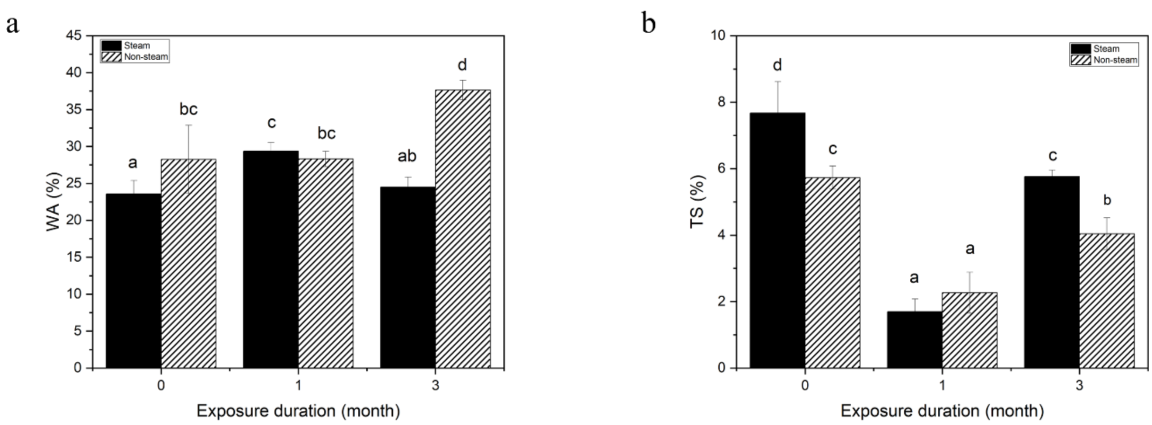

Fig. 4. (a) Water absorption (WA) and (b) thickness swelling (TS) values of BOSB with and without steam treatment after undergoing natural weathering.

Before exposure, the BOSB had a higher TS than a BOSB exposed for 1 month. This is thought to have occurred because initially, the BOSB was in a dry condition, and the TS test caused permanent swelling of the cell wall. Unrecoverable stresses are released when the thickness of the board increases, leading to a permanent thickness swelling (PTS) that persists even after the board has been dried once again (Del Menezzi et al. 2008; Korai et al. 2014). Therefore, BOSB exposed for one month may experience limited TS due to previous TS. However, with a more extended exposure period (3 months), it is thought that changes in the structure and chemical components occur, which causes an increase in the BOSB response to humidity. The extended exposure period can cause damage to the adhesive bond and crack in the wood surface, facilitating water diffusion (Del Menezzi et al. 2008; Huang et al. 2012).

3.2. Mechanical Properties of BOSB

3.2.1. Modulus of elasticity and modulus of rupture

The modulus of elasticity (MOE) signifies the capacity of a material - in this context, BOSB - to withstand external forces that may result in shape alterations. **Fig. 5** and **Fig. 6** represent the MOE values for BOSB after exposure to natural weathering. Under dry conditions, MOE parallel and perpendicular to the grain observed a range of 614.68 to 10054.79 MPa (**Fig. 5a**) and 1429.09 to 3191.69 MPa (**Fig. 5b**), respectively. Parallelly, the MOE recorded a range between 823.53 and 7311.66 MPa under wet conditions (**Fig. 6a**). Conversely, the MOE ranged from 584.15 to 3191.69 MPa when measured in the perpendicular direction (**Fig. 6b**). Statistical analysis indicated that steam treatment amplified the MOE parallel to the grain under dry conditions.

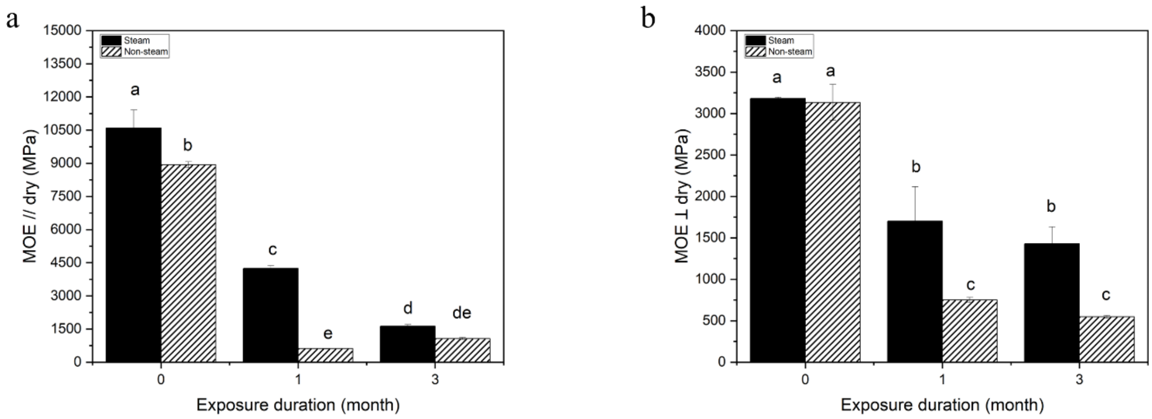

Fig. 5. The modulus of elasticity (MOE) in the (a) parallel (//) and (b) perpendicular (⊥) to the grain of BOSB in dry conditions after undergoing natural weathering.

The variability of BOSB's modulus of rupture (MOR) before it breaks, as presented in **Fig. 7** and **Fig. 8**, was studied over different exposure durations. Under dry circumstances, MOR parallel to the grain was between 7.34 and 59.23 MPa (**Fig. 7a**). In comparison, MOR perpendicular to the grain ranged from 9.65 to 42.82 MPa (**Fig. 7b**). When encompassing dry and wet conditions, the MOR parallel and perpendicular to the grain direction, depicted a range of 11.35–42.55 MPa (**Fig. 8a**) and 7.66–31.84 MPa (**Fig. 8b**), respectively. An analysis of variance indicated that these MOR values were significantly influenced by earlier steam treatment and discrepancies in exposure duration under dry and wet conditions.

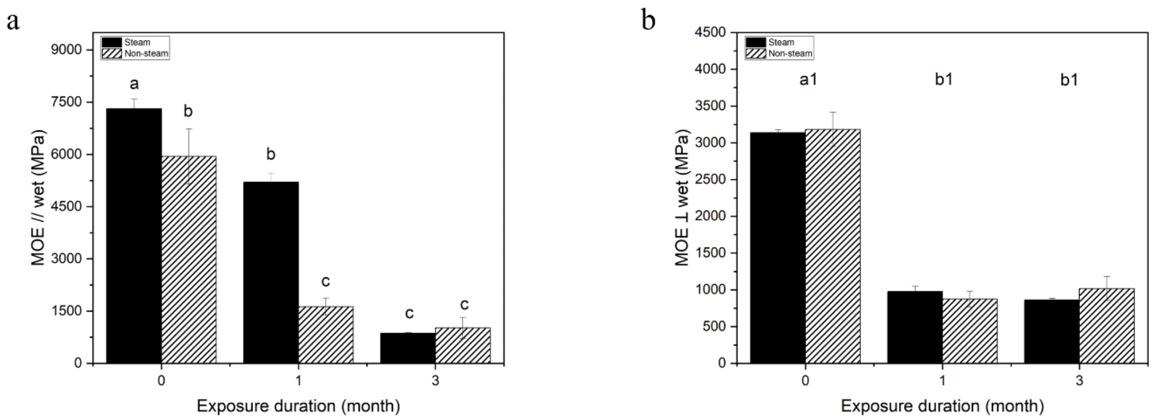

Fig. 6. The modulus of elasticity (MOE) in the (a) parallel (//) and (b) perpendicular (⊥) to the grain of BOSB in wet conditions after undergoing natural weathering.

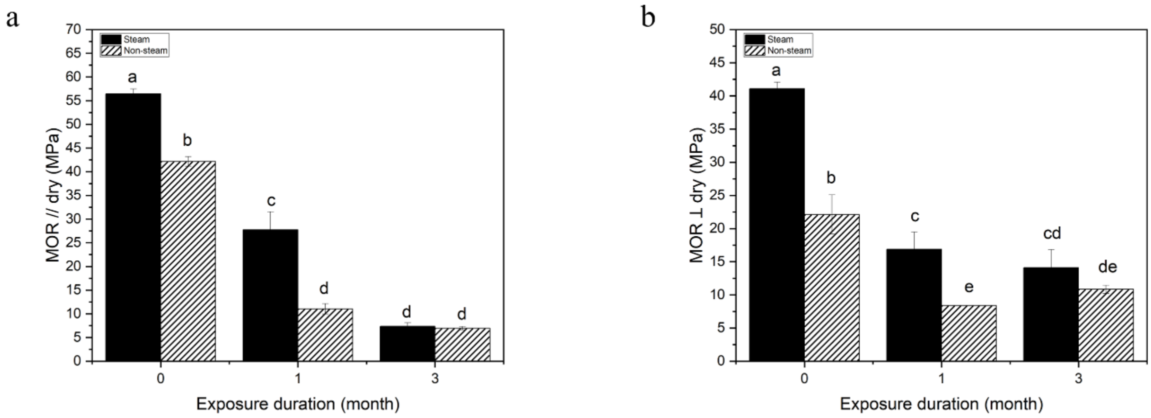

Fig. 7. The modulus of rupture (MOR) in the (a) parallel (//) and (b) perpendicular (⊥) to the grain of BOSB in dry conditions after undergoing natural weathering.

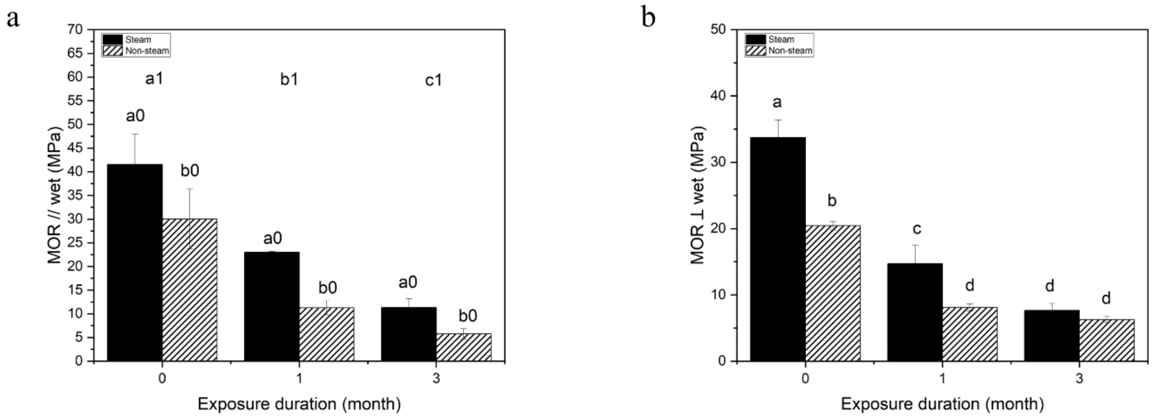

Fig. 8. The modulus of rupture (MOR) in the (a) parallel (//) and (b) perpendicular (⊥) to the grain of BOSB in wet conditions after undergoing natural weathering.

Based on the findings, MOE and MOR values decreased as the exposure period increased. This is attributed to the increased absorption and release of water vapor in BOSB during exposure and may intensify swelling and shrinkage, break adhesion bonds, and degrade mechanical properties (Maulana et al. 2019). Water uptake in BOSB is due to hydroxyl groups in the bamboo strand, affecting mechanical properties (Fatrawana et al. 2019). The potential factor contributing to water uptake is the existence of a polar group inside the strands (Dungani et al. 2020). These polar groups promote higher water uptake in the BOSB, creating voids at the matrix interphase. As a result, this can adversely affect the mechanical properties. However, BOSB treated with steam treatment before application had better MOE and MOR values than BOSB without steam treatment. High temperature in steam treatment causes the break-up of certain components in the cell wall, such as hemicellulose and cellulose with a low degree of polymerization (Fatrawana et al. 2019), which can result in looseness and pores in the cell wall, so that MDI adhesive can simply spread and penetrated on the substrate, resulting in a fairly strong glue nail (Tian et al. 2021). This treatment also slightly changes the degree of crystallinity of bamboo strands and has a beneficial effect on the spreading process of individual strands when BOSB is fabricated (Fatrawana et al. 2019). Finally, treatment by steam process decreased extractive content in BOSB strands, enhancing the overall bonding quality between strands. Enhancing MOE and MOR value in biocomposite products such as BOSB was necessary for future industrial applications.

This research also investigated the MOE and MOR retention values of BOSB after exposure to different conditions and pretreatment. These data provide insight into the durability and strength of BOSB under environmental conditions and the impact of previous pretreatment methods. **Table 1** illustrates the retention ratio value of MOE under different settings in both dry and wet conditions after exposure to natural weathering. The data showed that the retention ratio value of MOE decreased with increased exposure duration of BOSB without steam treatment. This implies prolonged exposure makes BOSB without steam treatment more susceptible to structural degradation. Instead, when the steam treatment was applied, the retention ratio value of MOE was higher than the untreated sample. In addition, MOE in parallel and perpendicular to the grain decline trend with increased exposure duration; however, the decline is mitigated by applied steam treatment as it offers added protection against structural degradation caused by weathering.

Table 1. Retention ratio values of modulus of elasticity (MOE) in parallel and perpendicular to the grain of BOSB

Pretreatment		Retention ratio MOE %					
		Parallel			Perpendicular		
		0-month	1-month	3-month	0-month	1-month	3-month
Dry	Steam	100 ± 0.00	42.25 ± 5.33	16.25 ± 1.74	100 ± 0.00	52.97 ± 14.18	44.32 ± 5.34
	Non-Steam	100 ± 0.00	6.81 ± 022	11.86 ± 0.33	100 ± 0.00	24.02 ± 2.66	19.42 ± 0.95
Wet	Steam	100 ± 0.00	71.25 ± 6.35	11.82 ± 0.76	100 ± 0.00	31.11 ± 1.79	27.52 ± 0.33
	Non-Steam	100 ± 0.00	27.88 ± 7.90	17.62 ± 7.44	100 ± 0.00	27.68 ± 5.46	32.27 ± 7.52

Table 2 illustrates the retention ratio value of MOR when subject to natural weather in dry and wet conditions. There was a decline in the retention ratio of MOR in both parallel and perpendicular to the grain over time with increasing exposure duration, regardless of whether it was treated with steam. However, this reduction is more pronounced in cases where no steam pretreatment was applied, particularly at the one-month and three-month intervals. In contrast, for the wet pretreatment group, utilizing steam treatment has a beneficial impact on preserving the structural integrity of BOSB, especially in the parallel direction. The results demonstrate that prolonged weather exposure can lead to degradation of BOSBs. Nevertheless, applying steam treatment has been proven effective in maintaining their strength even under severe environmental conditions.

The MOE and MOR retention ratio values after natural weathering have been used to evaluate the vulnerability of composite materials to structural degradation caused by environmental factors. Maulana et al. (2019) and Yildiz et al. (2011) reported that the MOE and MOR retention ratios decrease over time, revealing that different weather conditions affect different types of lignocellulosic materials. Jirouš-Rajković and Miklečić (2021) also reported that steam treatment can be an effective treatment for improving resistance to weather exposure in lignocellulosic materials. The advantage of steam treatment in protecting structural materials can be attributed to changes in the chemical and structure of the materials that reduce the level of degradation during prolonged exposure to diverse climatic conditions (Huang et al. 2012).

Table 2. Retention ratio values of modulus of rupture (MOR) in parallel and perpendicular to the grain of BOSB

Pretreatment		Retention ratio of MOR %					
		Parallel			Perpendicular		
		0-month	1-month	3-month	0-month	1-month	3-month
Dry	Steam	100 ± 0.00	46.64 ± 11.28	12.23 ± 2.61	100 ± 0.00	41.19 ± 7.29	34.40 ± 7.44
	Non-Steam	100 ± 0.00	26.63 ± 3.33	21.55 ± 6.27	100 ± 0.00	38.28 ± 5.12	17.62 ± 7.44
Wet	Steam	100 ± 0.00	56.62 ± 12.23	27.47 ± 1.29	100 ± 0.00	44.00 ± 11.84	22.88 ± 4.84
	Non-Steam	100 ± 0.00	38.20 ± 10.64	19.05 ± 0.88	100 ± 0.00	35.93 ± 6.55	27.80 ± 5.21

It should be emphasized that this study was conducted with a short exposure period of 0, 1, and 3 months. Research with more prolonged exposure will provide more precise information on the changes in mechanical properties that occur in BOSB. The result of this study will provide an explanation for the industry on the importance of applying the proper treatment in improving the durability and strength of BOSB in various environmental conditions. However, it is essential to conduct further research with more prolonged exposure durations for more comprehensive information on the long-term properties of BOSB.

3.2.1. Internal bonding strength

The internal bonding (IB) strength of the BOSB ranged from 0.07–0.53 MPa (**Fig. 9**). The findings showed that BOSB subject to steam treatment before exposure had higher IB strength than those untreated BOSB. On the other hand, after 3 months under weather conditions, BOSB showed lower values. The results indicate a decrease in IB strength with increased exposure duration. Statistical analysis using analysis of variance (α = 0.05) revealed no significant interaction effect between steam treatment and exposure period on the IB strength; however, it should be noted that steam treatment generally yielded favorable outcomes concerning enhancing the IB strength of BOSB.

Previous studies have demonstrated that phenol formaldehyde (PF) can effectively serve as an adhesive for steam-treated bamboo strands to produce OSB (Adrin et al. 2013; Aisyah et al. 2021; Maulana et al. 2016, 2017, 2019). Similarly, MDI adhesive has also displayed a favorable performance of IB strength (Aisyah et al. 2021; Febrianto et al. 2015; Hariz et al. 2021; Iswanto et al. 2010). The results from experimental trials indicate that steam treatment enhances both the adhesion quality of strands and the effectiveness of MDI adhesive. Steam treatment transforms the free sugar in lignocellulosic materials, converting it into furan intermediates, ultimately contributing to formulating a furan resin (Rowell et al. 2002). This transition reduces hygroscopicity and equilibrium MC, improving mechanical properties in composite structures. Furthermore, this process facilitates the removal of extractive and hemicellulose content, thereby significantly enhancing IB strength. From the previous research, steam treatment at betung bamboo strand can reduce extractive levels in water soluble, hot water soluble, 1% NaOH soluble, and ethanol benzene soluble range from 5.63% to 4.62%, 7.64% to 6.45%, 19.43% to 18.51%, 9.09 to 8.89% respectively (Maulana et al. 2017). The amount of hemicellulose dropped from 30.72% to 28.18% (Fatrawana et al. 2019). Degradation of specific cell wall components, including hemicellulose and low-polymerization cellulose, can result in the loosening and formation of pores in the cell wall. This facilitates improved adhesive penetration, wetting, and diffusion into the wood, thereby simplifying the process of glue nail formation (Tian et al. 2021).

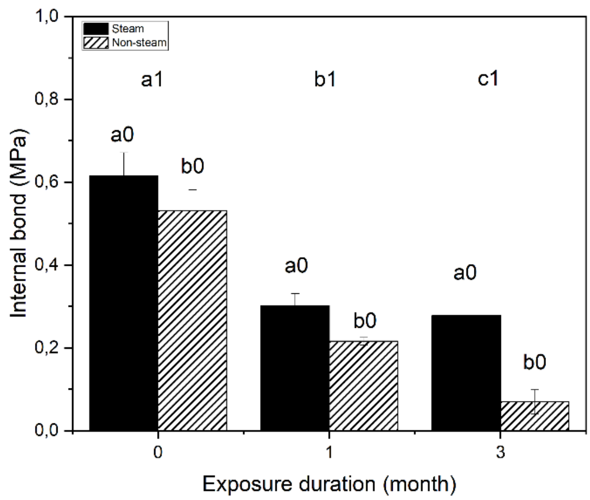

Fig. 9. The internal bonding (IB) strength of BOSB in wet conditions after undergoing natural weathering.

Maloney (1993) stated that extractives in the wood can hinder adhesive penetration, leading to poor bonding quality. Past studies have shown that steam treatment effectively reduces extractive levels in bamboo strands (Fatrawana et al. 2019; Maulana et al. 2017, 2019). Additionally, Korai et al. (2012) found that exposed BOSB panels are vulnerable to surface weathering caused by rainwater infiltration. The weathering of wood can cause long and large cracks in the longitudinal and tangential wood surfaces, which facilitate the diffusion of water (Huang et al. 2012). An increase in the intensity of swelling and shrinkage has the potential to break the adhesive bonds on the board, thereby reducing the IB strength. However, it was observed that BOSB panels with prior steam treatment demonstrate improved resistance against natural weathering compared to untreated BOSB panels, as evidenced by their higher IB strength.

4. Conclusions

Based on the findings, applying steam treatment in the production of BOSB with MDI adhesive is strongly recommended as it leads to improved properties in both the physical and mechanical aspects of BOSB. The steam treatment increased the durability of BOSB against natural weathering. However, the more prolonged exposure to natural weathering reduced the physical and mechanical properties due to the crack of the BOSB structure and the breaking of the adhesive bond. For future research, the implementation of a pilot scale could be considered to explore the scalability and feasibility of steam treatment in large-scale BOSB production.

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