Effect of Preservative Treatment on Physical and Mechanical Properties of Bamboo (*Gigantochloa scortechinii*) Strips

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Using a vacuum pressure cylinder, *Gigantochloa scortechinii* was treated with boron and copper chrome boron (CCB) preservative at different concentrations of 2% and 3%. The treatability of untreated and treated bamboo, as well as its physical and mechanical properties, were investigated. Both preservatives showed a high level of penetration into the bamboo strips. Weight percent gain (WPG) and extent of retention of CCB-treated bamboo strips were higher than those of the boron-treated samples. Swelling and shrinkage were proportionately reduced with treatment, with a significant difference between radial and tangential dimensions. When compared to untreated bamboo, treated bamboo showed a greater reduction in radial swelling but a lower reduction in shrinkage. The mechanical properties of untreated and treated samples differed in modulus of elasticity (MOE) and compression. Untreated samples had the highest MOE of 26,100 $N.mm^{-2}$, while boron and CCB had MOE values of 22,800 and 22,900 $N.mm^{-2}$, respectively. Copper chrome boron samples had the highest compression value of 86.3 $N.mm^{-2}$, while the boron and untreated samples had values of 84.0 and 78.3 $N.mm^{-2}$, respectively.

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INTRODUCTION

Bamboo is one of the non-timber forest products that is abundant in the forest. Bamboo grows naturally in a variety of climates and is most commonly found in logging areas, riverbanks, and hillsides. It has been reported that there are 70 bamboo species in Malaysia, divided into 10 genera. Based on the utilisation of the industries, a total of 13 species have been classified as commercial species (Azmy and Baharuddin 2015; Abdullah Siam *et al.* 2019). *Gigantochloa scortechinii* has been identified as the most commonly used bamboo species due to its availability and strength properties (Zakikhani *et al.* 2017; Abdullah Siam *et al.* 2019), making it well-publicized in research.

Bamboo is one of the potential alternative raw materials to be used for a variety of applications, particularly as a structural material, due to its strong characteristics and durability (Sharma *et al.* 2015). Bamboo is frequently converted into strips or thin flat laminae to produce laminated products due to its hollow cylindrical features (Zaidon *et al.* 2016; Bakar *et al.* 2019). To ensure the long-term viability of the applications, bamboo must be preserved to protect it from harmful organisms and to extend its lifespan (Rabbi *et al.* 2015). Despite the availability of numerous preservatives, waterborne preservatives are frequently used in treatment due to their advantages and effectiveness (Smith 2020). Boron and copper chrome boron (CCB) are the most commonly used (Abdul Karim *et al.* 2020). Furthermore, these preservatives have been widely used by the bamboo industries in Asia and other bamboo regions for a variety of product applications, including structural purposes (Liese and Tang 2015; Kaminski *et al.* 2016; Jivkov *et al.* 2021).

The use of these preservatives, however, is still subject to the environmental conditions. Boron is an effective preservative in treated bamboo, but its use is limited to dry and interior applications because it can be leached out if exposed to rain (Liese and Tang 2015). In contrast, copper chrome boron is better suited for exterior applications due to its better fixation and thus weather resistance (Shanu *et al.* 2015; Gauss *et al.* 2020).

Similarly, the use of a suitable preservative for the environmental conditions must be evaluated by examining the impact on the strength properties. Several studies have found that boron-based preservative treatment improves physical properties by increasing density and dimensional stability (Gecer *et al.* 2015; Baraúna *et al.* 2021; Aristri *et al.* 2021). In terms of strength, boron-based preservatives have been reported to affect it to some extent (Kartal *et al.* 2008; De Souza Almeida *et al.* 2019). In contrast, some studies show that the strength increased proportionately with the treatment (Perçin *et al.* 2015; Daud *et al.* 2018).

The use of appropriate preservatives with promising strength values, particularly for structural purposes, has been highly desired. There have been very few studies on the treatment ability of boron and CCB on *G. scortechinii* bamboo strips, particularly for these purposes. The previous study by Gauss *et al.* (2019) focused on the quality assessment of boron-based treated moso bamboo poles and discovered that mechanical properties were not affected by treatment.

As a result, this current study investigated the physical and mechanical properties of *G. scortechinii* bamboo strips treated with boron and CCB at the manufacturer's recommended concentrations. The performance of the bamboo was evaluated in terms of changes in moisture content, density, dimensional stability, and strength properties.

EXPERIMENTAL

Materials

Sample preparation

Twenty matured *Gigantochloa scortechinii* culms were cut at approximately 1 m above ground level in Hulu Langat, Selangor, Malaysia, and only 2.4 m length was taken. The culms were dried for 14 days before being processed into bamboo strips with a splitter machine (Chin Yung, Changhua, Taiwan) and thicknesser planner (SCM, Rimini, Italy) to the required size of 2400 x 20 x 5 mm^3. The bamboo strips were then divided into two groups: control and treatment.

A 2% solution of boron (Celcure Chemical, Selangor, Malaysia) and 3% of CCB (Celcure Chemical, Selangor, Malaysia) were prepared. Boron was prepared by diluting 5 kg of boron in 250 litres of water to make a 2% solution concentration while CCB was prepared by diluting 75 litres of CCB in 250 litres of water to make a 3% solution concentration. The bamboo strips were then treated using the vacuum chamber method as follows:

- Initial vacuum: > 85 kPa for 30 min (to suck the air out of the bamboo)
- Applying pressure: > 1300 kPa for 60 min after the preservative solution was introduced into the treatment cylinder
- Final vacuum: > 85 kPa for 20 min (to remove the access preservative from the bamboo)

Treatability Evaluation of Bamboo

Retention and penetration

A total of 10 specimens for each treatment with the size of 300 mm x 20 mm x 5 mm were used in this test. All the specimens' weights and dimensions were weighed and measured before treatment. After treatment, the excess solution was drained off and conditioned at 20 °C ± 3 °C and 65% relative humidity until constant weight was achieved.

The weight percent gain (WPG) and net dry salt retention (NDSR) were calculated using Eq. 1 and Eq. 2, respectively,

$$\text{WPG (\%)} = [(W_t - W_u)/W_u] \text{ x } 100 \qquad (1)$$

where W_t is the weight (g) of the treated specimen and W is the weight (g) of oven-dried of bamboo strips, and

$$\text{NDSR (kg/m}^3) = [(W_t - W_u)/\text{V}] \text{ x treating solution concentration} \qquad (2)$$

where W_t is the weight (g) of the treated specimen, W_u is the weight (g) of the initial specimen, and V is the volume (m^3) of the treated specimen.

After specimens were dried, two replicates of each treatment were cut to 20 mm x 20 mm pieces to assess the penetration level using chemical reagents. The chemical reagents used were Azurol S (Celcure Chemical, Selangor, Malaysia) for copper detection in CCB preservative and Curcumin (Celcure Chemical, Selangor, Malaysia) for boron detection. Boron was tested using a curcumin solution composed of turmeric powder and ethyl alcohol (10% wt/vol alcohol). Meanwhile, the penetration of copper was analysed using the solution of Chrome Azurol S and sodium acetate mixed in water. The presence of boron was indicated by the red colour, while the blue colour indicates the presence of copper. The penetration pattern referred to MS 833 (1984) in Table 1.

Table 1. Visual Classification of Preservative Penetration

Penetration	Grading	Condition
Nil	1	No penetration
Slight	2	Less than 25% of the cross-sectional area penetrated
Moderate	3	25% to 50% of cross-sectional area penetrated
Heavy	4	50% to 75% of cross-sectional area penetrated
Complete	5	75% to 100% of cross-sectional area penetrated

Fourier transform infrared (FTIR) analysis

From the same specimens, three specimens from each treatment were ground into 40- to 60-mesh particles using IKA Grinder (Wilmington, USA) and run for FTIR testing for chemical content analysis. The FTIR measurements were conducted using a Perkin Elmer FTIR instrument (Llantrisant, UK) (1 cm^{-1} resolution, 32 scans, KBr method) in a laboratory of the Fibre and Biocomposite Centre (FIDEC) located in Banting, Selangor, Malaysia.

Physical Properties Evaluation

The procedures used for the determination of moisture content and density were conducted following the Indian Standard of Method of Tests for split bamboo (IS 8242 (1976)) as described by Anwar Uyup *et al.* (2005). Of these, 10 specimens of each treatment were used in the determination of moisture content and density. The equation for moisture content (MC) and density were calculated according to Eqs. 3 and 4, respectively,

$$\text{MC (\%)} = [(W' - W)/W] \times 100 \qquad (3)$$

where W' is the initial weight of bamboo strips (g) and W is the weight of oven-dried bamboo strips (g), and

$$\text{Density (kg/m}^3\text{)} = W/V \qquad (4)$$

where W is the weight after oven drying (g) and V is the volume of the sample (mm^3).

For the determination of radial and tangential shrinkage and swelling, 20 specimens were used and conducted according to ISO 13061-13 (2017) and ISO 13061-15 (2017), respectively. The equation for the linear shrinkage and linear swelling of the samples were determined and calculated by Eq. 5 to Eq. 10,

a) Linear shrinkage

$$\text{Radial shrinkage (\%)} = [(l_{r1} - l_{r2})/l_{r1}] \times 100 \qquad (5)$$

$$\text{Tangential shrinkage (\%)} = [(l_{t1} - l_{t2})/l_{t1}] \times 100 \qquad (6)$$

$$\text{Total volumetric shrinkage (\%)} = [[(l_{r1} \times 1_{t1}) - (l_{r2} \times l_{t2})]/ (l_{r1} \times l_{t1})] \times 100 \qquad (7)$$

where l_{r1} and l_{t1} are the dimensions (mm) of the green or fully saturated test piece measured in the radial and tangential directions, respectively, while l_{r2} and l_{t2} are the dimensions (mm) of the test piece at oven-dry condition measured in the radial and tangential directions, respectively. The linear swelling was calculated according to Eqs. 8 to 10,

b) Linear swelling

$$\text{Radial shrinkage (\%)} = [(l_{r2} - l_{r1})/l_{r1}] \times 100 \qquad (8)$$

$$\text{Tangential shrinkage (\%)} = [(l_{t2} - l_{t1})/l_{t1}] \times 100 \qquad (9)$$

$$\text{Total volumetric shrinkage (\%)} = [[(l_{r2} \times 1_{t2}) - (l_{r1} \times l_{t1})]/ (l_{r1} \times l_{t1})] \times 100 \qquad (10)$$

where l_{r2} and l_{t2} are the dimensions (mm) of the fully saturated test piece measured in the radial and tangential directions, respectively, while l_{r1} and l_{t1} are the dimensions (mm) of the test piece at oven-dry condition, measured in the radial and tangential directions, respectively.

Mechanical Properties Evaluation

Static bending

For the static bending test, 30 specimens of each treatment were prepared and tested according to the procedure described by Anwar Uyup *et al.* (2009) in reference to IS 8242 (1976). The modulus of rupture (MOR) and the modulus of elasticity (MOE) were calculated using Eqs. 11 and 12 as follows,

$$\text{MOR (N/mm}^2\text{)} = 3P'l/2bh^2 \tag{11}$$

$$\text{MOE (N/mm}^2\text{)} = Pl^2/4bh^3d \tag{12}$$

where P is the load (N) at the proportional limit, b is the width (mm) of the specimen, h is the depth (mm) of specimen, l is the span length (mm), P' is the maximum load (N), and d is the deflection (mm) at proportional limit.

Compressive strength

To determine compressive strength, 30 samples from each treatment were tested in accordance with the procedure described by Anwar Uyup *et al.* (2009) in reference to IS 8242 (1976) using a 10 kN Shimadzu universal testing machine (Shimadzu, Kyoto, Japan). The determination of compressive strength was calculated using the equation as follows:

$$\text{Compressive strength (N/mm}^2\text{)} = P/bh \tag{13}$$

where P is the maximum crushing load, b is width of the specimen, and h is the thickness of the sample.

Statistical analysis

Analysis of variance (ANOVA) at 95% confidence level ($p \leq 0.05$) was used to analyse the data by using statistical analysis software (SAS) (9.4, SAS Institute, Cary, NC). All mechanical properties were adjusted to 12% MC according to BS EN 408 (2010). Tukey's honest significant difference (HSD) test was employed to analyse the significant level for the mean value of each treatment.

RESULTS AND DISCUSSION

Treatability of Bamboo Strips

Retention and penetration

Both retention and penetration are important criteria for determining the efficacy of a preservative treatment. Retention is typically expressed as the weight of chemicals absorbed in the wood, whereas penetration is used to detect the presence of preservatives in the substance (Gauss *et al.* 2020). In contrast, weight gain was indicated as a chemical load in the substance (Baysal *et al.* 2006).

Table 2 displays the WPG of boron- and CCB-treated bamboo. The WPG and NDSR of boron-treated bamboo strips were 18.4% and 2.63%, respectively. In terms of CCB, a significantly higher WPG and NDSR of 23.12% and 4.92%, respectively, were recorded.

Table 2. Weight Percent Gain of Treated Bamboo Strips

Treatment	WPG (%)	Net Dry Salt Retention (kg.m^{-3})
Boron	18.43a (7.83)	2.63a (0.81)
CCB	23.12b (7.03)	4.92b (1.36)
Note: Values in parenthesis are standard deviations and means with the same letter are not significantly different ($p < 0.05$)		

Several studies on the retention of boron and CCB in other bamboo species have been conducted. Baysal *et al.* (2016) found that the average retention of boron and CCB in *Phyllostachys bambusoides* was 4.63 to 4.88 kg.m^{-3}, whereas Wahab *et al.* (2005) discovered that the average retention in *Gigantochloa scortechinii* bamboo was 4.41 to 6.30 kg.m^{-3}. Furthermore, Gauss *et al.* (2019) discovered that the extent of retention for *Dendrocalamus asper* was 11.82 to 17.41 kg.m^{-3} using 5% and 8% boron concentrations. The retention values in Table 4 were in accordance with the retention value for waterborne preservatives stipulated by the America Wood Preservative Association (AWPA), with a value limit of 2.8 kg.m^{-3} for boron and 4 kg.m^{-3} for CCB for interior dry and exterior usage, respectively (Smith 2020).

The visual penetration assessment revealed that the preservative penetrated well into the treated bamboo strips (Fig. 1). The presence of test chemicals was determined by a change in the colour of the sample. Total penetration was determined by a blue colour for the presence of copper and a red colour for the presence of boron (Fig. 2). According to previous reports, the colour change during preservative penetration was caused by chemical treatment and atmospheric conditions (Bons and Dhawan 2013). The microscope images of the boron- and CCB-treated sample subjected to the test are shown in Fig. 2. Through the penetration test, one can see that the whole cross-section was fully absorbed with the preservative and turned into red (for boron treated sample) and blue (for CCB treated sample). According to MS 833 (1984), the samples were classified under grade 5 as completely penetrated with preservative.

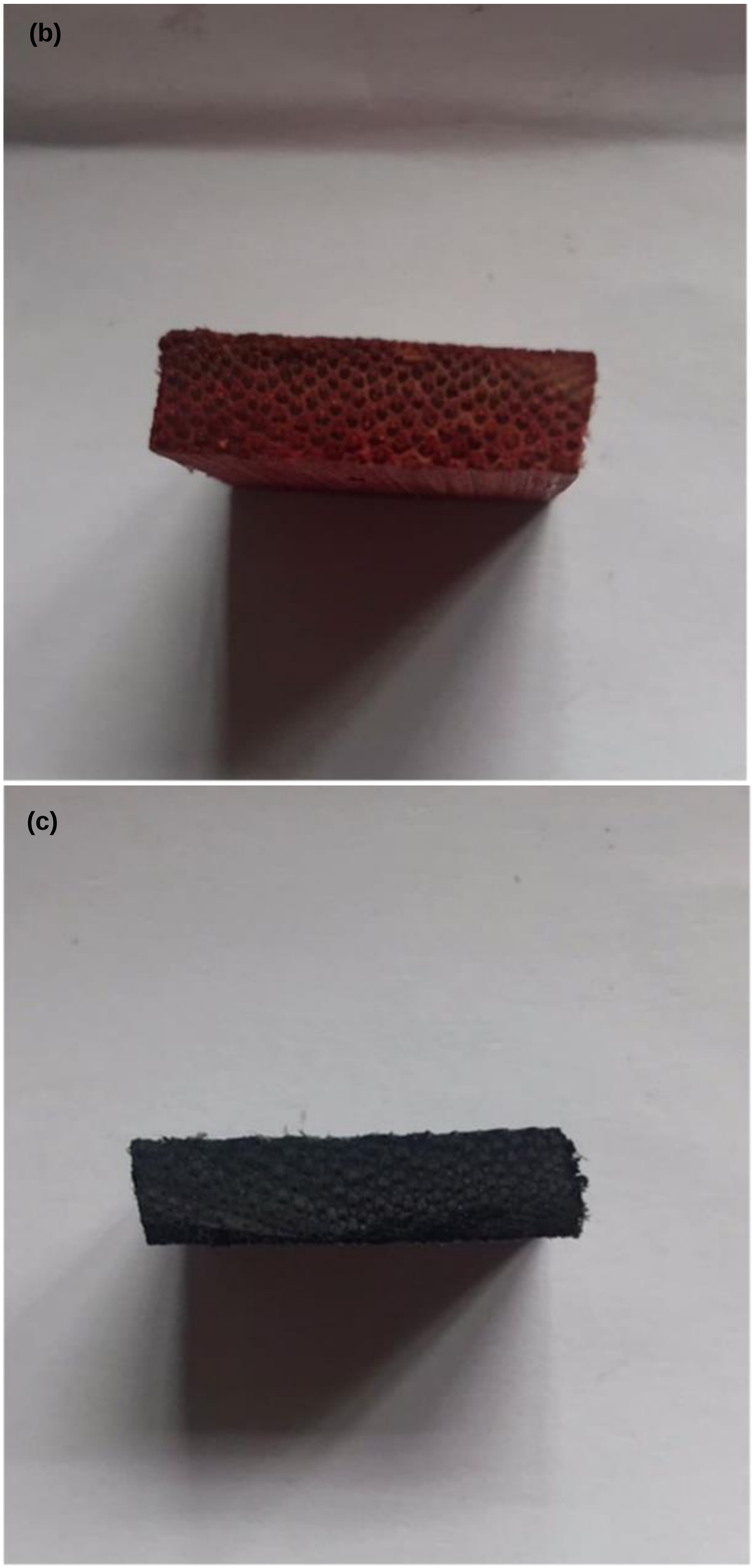
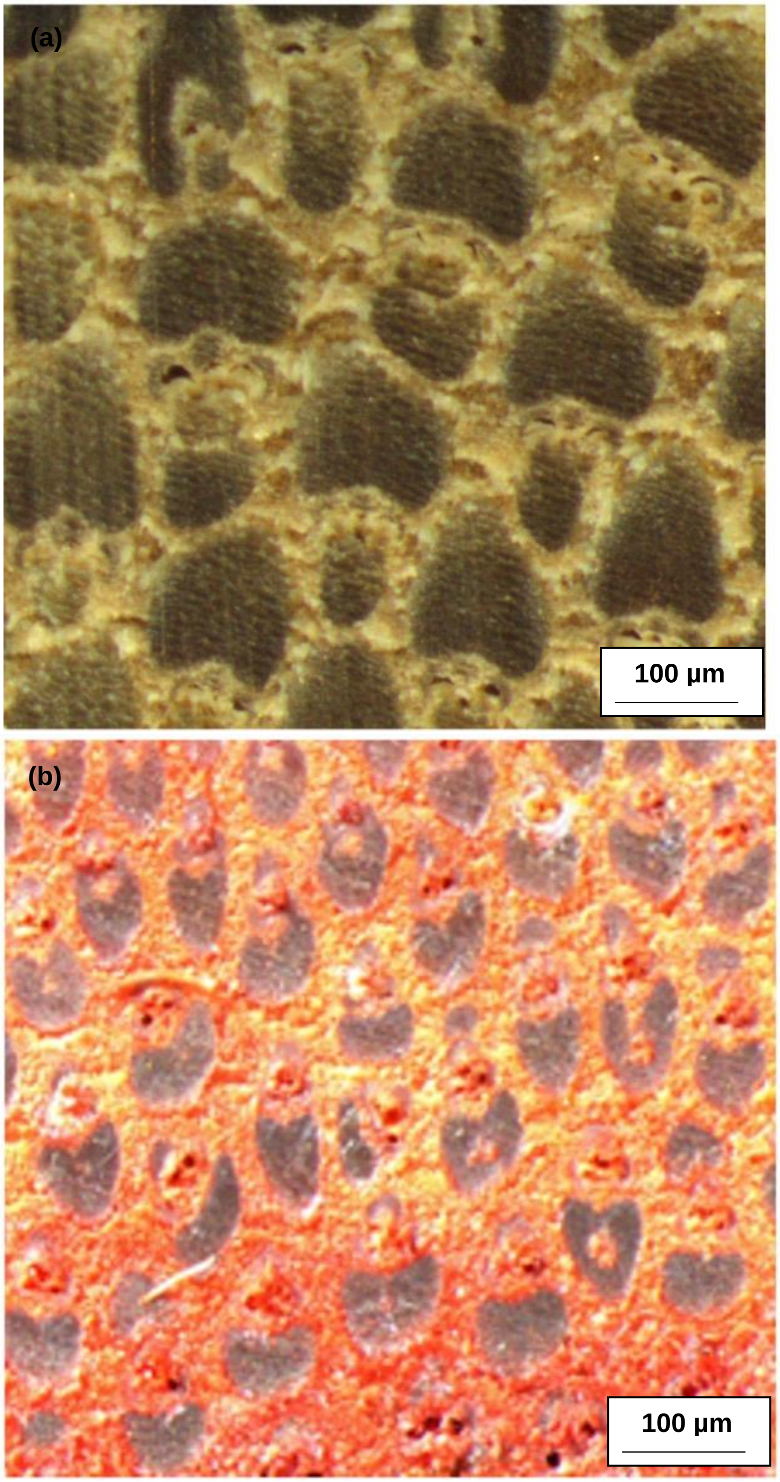


Fig. 1. Analysis of penetration with Curcumin and Azurol S: (a) control sample, (b) boron-treated sample, and (c) CCB-treated sample


(a)
100 µm
(b)
100 µm

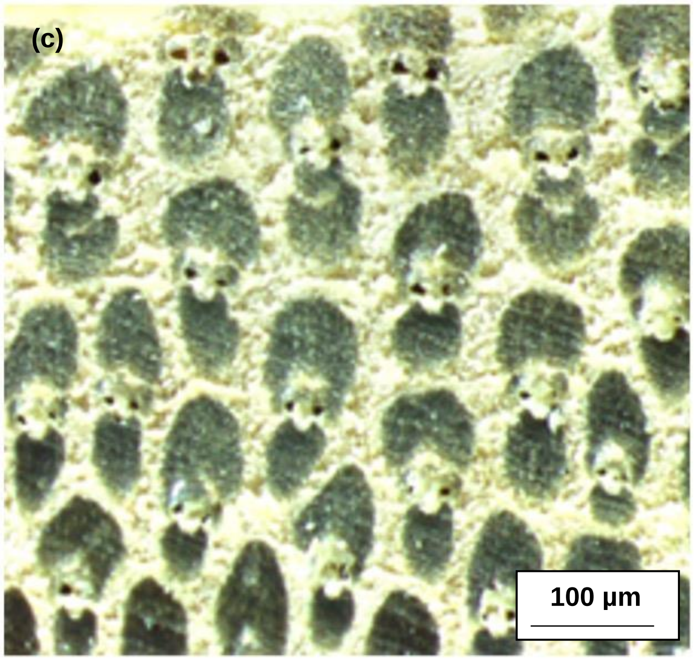


Fig. 2. Microscope image: (a) control sample, (b) boron-treated sample, and (c) CCB-treated sample

FTIR Analysis

The changes in chemical function groups of the bamboo strips before and after treatment with boron and CCB are displayed in Fig. 3.

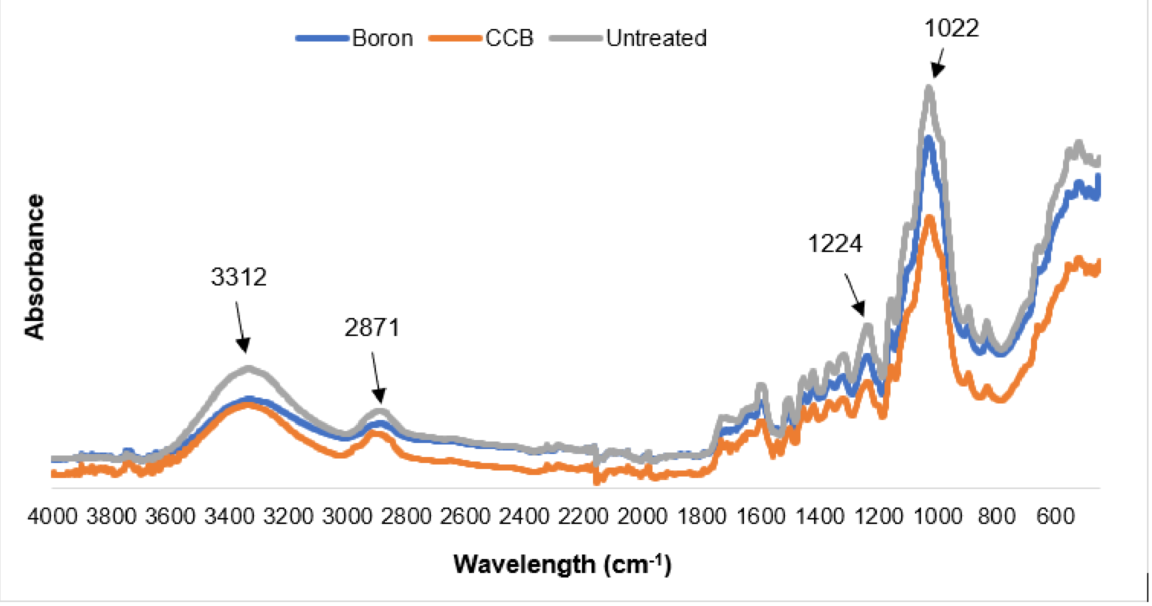


Fig. 3. FTIR spectra of untreated, boron-, and CCB-treated bamboo

The functional regions at 3312 and 2871 cm^{-1} respectively corresponded to the hydroxyl groups (-OH) and C-H stretching of cellulose. Both boron- and CCB-treated bamboo exhibited lower intensity at these peaks compared to that of untreated bamboo. The observation indicated that the boron- and CCB-treated bamboo has less tendency to absorb water. This is demonstrated by the reduced swelling of treated bamboo in the following section. Similar observations were also found near the peaks of 1224 and 1022 cm^{-1}, which corresponded to the guaiacyl ring breathing with CO-stretching (lignin and hemicelluloses) and primary alcohol (Gauss *et al.* 2021). The reduction in the intensity of C–O stretching vibration near 1224 cm^{-1} could be attributed to the modification of lignin by chromium (Yalinkilic *et al.* 1999).

Physical Properties

Table 3 shows the effect of preservative treatment on MC, density, swelling, and shrinkage for untreated and treated bamboo strips. Untreated bamboo showed the highest mean value in most of the physical properties compared to that of treated bamboo. For MC, both the untreated and CCB-treated bamboo had the same value of 9.9%, while boron-treated bamboo had slightly lower MC of 9.8%.

Table 3. Physical Properties of Untreated and Treated *Gigantochloa scortechinii* Strips

Specimen	Mean Value							
			Swelling			Shrinkage		
	MC (%)	Density (kg.m^{-3})	Radial (%)	Tangential (%)	Volumetric (%)	Radial (%)	Tangential (%)	Volumetric (%)
Untreated	9.9^a (0.1)	778.74^a (21.06)	9.581^b (3.5)	19.995^a (6.2)	16.852^a (5.5)	11.181^a (3.5)	5.380^a (1.7)	15.937^a (4.1)
Boron	9.8^a (0.1)	730.03^b (22.26)	7.694^{ab} (2.0)	19.323^a (6.2)	14.535^a (3.2)	9.836^a (2.9)	6.399^{ab} (1.1)	15.764^a (3.1)
CCB	9.9^a (0.2)	758.97^a (46.11)	6.839^a (2.4)	19.561^a (5.1)	13.700^a (3.9)	9.121^a (2.4)	7.190^b (1.4)	15.646^a (2.8)

Note: Values in parenthesis are standard deviations and means with the same letter are not significantly different ($p < 0.05$)

After boron and CCB treatments, the density of the bamboo strips decreased. The effect was more pronounced in boron-treated bamboo, which exhibited a reduced density of 6.3% when compared to untreated bamboo. Meanwhile, the density of CCB-treated bamboo fell approximately 2.5%. The decreasing value was most likely caused by the impregnation method employed in this study. Vacuum and pressure processes were used in this method to ensure the optimal filled solution in the treated material (Lahtela *et al.* 2013), causing the structure and chemical components of the bamboo to change (Tang *et al.* 2019). Gecer *et al.* (2015) discovered the same results, with decreasing density was observed in the impregnation treatment method. The same pattern was observed in other studies, including those reported by Shanu *et al.* (2015) in CCB-treated *Albizia richardiana* and by Kadir and Jantan (2016) in rubberwood (*Hevea brasiliensis*) treated with 2% boron.

After treatment, radial and tangential swelling of the bamboo strips decreased, particularly radial swelling for CCB-treated bamboo strips, which decreased remarkably compared to untreated bamboo strips. Overall, treated bamboo had less total volumetric swelling than untreated bamboo. Similarly, in terms of shrinkage, the treated bamboo exhibited a similar reduction trend in radial and volumetric shrinkage but differed in tangential shrinkage. The CCB-treated bamboo strips had the lowest radial shrinkage, followed by boron-treated and untreated bamboo strips. The total volumetric shrinkage followed a similar pattern. In contrast, tangential shrinkage increased after treatment. A similar pattern was observed by Baraúna *et al.* (2021), who discovered that boron-treated eucalyptus had a higher value in tangential shrinkage, which could be caused by the increase of density.

These findings suggest that the preservative treatments had an effect on the physical properties of bamboo strips. In comparison to boron, samples treated with CCB resulted in a greater reduction in both swelling and shrinkage, as shown in Table 3. The reported reduction in swelling and shrinkage was caused by chemical modification of the lignocellulosic materials, according to Gauss *et al.* (2021). The findings were also consistent with many other studies that used various other preservative treatments (Anwar Uyup *et al.* 2009; Meng *et al.* 2016; Huang *et al.* 2019). Changes in several chemical components were responsible for changes in some physical properties of bamboo, such as density, swelling, volume shrinkage, and equilibrium moisture content, according to these studies.

Evaluation of Mechanical Properties

Table 4 shows the mechanical properties of treated and untreated bamboo strips. Untreated, boron-, and CCB-treated bamboo strips had MORs of 183.0 N.mm^{-2}, 180.0 N.mm^{-2}, and 185.3 N.mm^{-2}, respectively. Boron-treated samples had a slight decrease in MOR when compared to untreated bamboo strips, whereas CCB-treated samples had a slight increase in MOR. The MOE decreased in both boron- and CCB-treated bamboo strips when compared to untreated bamboo strips. In contrast, compression strength of the bamboo strips increased after treatment, with increases of 4.86% and 8.96% for boron- and CCB-treated bamboo strips, respectively.

Table 4. Mechanical Properties of Untreated and Treated *G. scortechinii* Bamboo Strips

Sample	**Strength Adjusted at 12% MC**		
	MOR (N.mm^{-2})	**MOE (N.mm^{-2})**	**Compression (N.mm^{-2})**
Untreated	183.03^{a} (16.8)	25645.54^{a} (2633.0)	74.31^{a} (7.0)
Boron	180.03^{a} (30.3)	22223.23^{b} (2475.8)	77.92^{ab} (7.7)
CCB	185.34^{a} (27.8)	22417.10^{b} (2614.8)	80.97^{b} (7.3)

Note: Values in parenthesis are standard deviations and means with the same letter are not significantly different ($p < 0.05$)

The decreased strength properties after treatment were most likely caused by the increased rate of hydrolysis in the bamboo. The chemical structure and the fixation process with woods during impregnation were linked to strength reduction, according to Fidan and Adanur (2019). The acidic component of boron hydrolyzed wood sugars, which caused an interaction with cell wall components. The oxidation of cell wall components occurred during the fixation process, resulting in changes in the mechanical properties. Other researchers (Gecer *et al.* 2015; Perçin *et al.* 2015; Handana *et al.* 2020) discovered this reduction scenario in boron-impregnated wood and borax-treated bamboo, respectively.

In contrast, higher compression strength could be due to the formation of salt crystals within the bamboo microstructure, which may result in carrying the forces during loading (Gauss *et al.* 2019). Several studies with boron-based treatments have yielded similar compressive strength results. Icimoto *et al.* (2013) discovered higher compression to the grain of CCB-treated Paricá wood. Meanwhile, Shanu *et al.* (2015) investigated the strength properties of *Albizia richardiana* and discovered that boron-based treatment increased compressive strength approximately 9.11% when compared to untreated wood. Kurhekar (2014) obtained a similar result with bamboo samples. *Pseudoxytenanthera ritcheyi* bamboo treated with boric acid borax and CCB marked the highest compressive strength after being exposed and stored in environmental condition.

Overall, CCB-treated bamboo strips performed slightly better in terms of physical and mechanical properties than boron-treated bamboo strips. This difference could be due to the different properties of boron and CCB. Boron is a non-fixing preservative that will leach out when exposed to outdoor elements, such as rain, whereas fixing preservatives will not (Schröder 2021). Furthermore, higher WPG and NDSR in CCB-treated bamboo strips, as shown in Table 2, could contribute to such findings.

Leaching Issue of Boron- and CCB-treated Bamboo

Although boron is a more effective preservative than zinc or copper, its low fixation in wood is always an issue (Llyod *et al.* 2021). The same problem exists for CCB, which has higher leaching than CCA (Lima *et al.* 2021). A study by Tomak *et al.* (2022) reported that bamboo (*Phyllostachys bambusoides* Sieb. et. Zucc.) culms treated with CCB showed a different leaching rate of boron (B), chromium (Cr), and copper (Cu) during the field exposure test. Boron, a highly water-soluble compound, leached out completely after a 6-year field exposure. On the other hand, 55% chromium was leached from bamboos below groundline, while 47 to 70% copper was leached from all parts of bamboos below groundline. The study found that the CCB treatment improved biological resistance compared to untreated samples. However, due to the high amount of chemicals leached out of the samples, CCB-treated bamboo did not completely prevent degradation by soft-rot and brown-rot fungi attack. Furthermore, the laboratory leaching process reduced the mechanical strength of the leached samples (Yildiz and Kerimoğlu 2020).

As a result, reducing borate leaching from treated wood and bamboo is critical. Improving boron-based systems' fixation in wood is the key to expanding their use in wood preservation. A review by Obanda *et al.* (2008) has compiled 15 strategies for reducing boron leaching. Those strategies include: 1) surface treatments; 2) envelope treatment; 3) wood bulking resins and water repellants; 4) organo boron compounds; 5) precipitation of organo soluble salts within wood; 6) combination of biocides and nonbiocidal chemicals; 7) metallo-borates; 8) ammoniacal and amine metallo-borates; 9) stabilized boroesters; 10) protein borates; 11) tannin auto condensation; 12) *in situ* polymerization; 13) vaporization of organic boron compounds and boric acid; 14) boron-silicates; and 15) physical modification of wood. Tannin-boron-based formulations have been shown to be effective against white rot fungi, with less than 2% mass loss against the fungi in leached samples (Thevenon *et al.* 2009). Tannin was discovered to be capable of chemically fixing boron, which improved its leaching behaviour (Tondi *et al.* 2012a). 20% tannin in tannin-boron formulation has improved the resistance of treated wood against brown rot fungi (*Coniophora puteana*) and termites (*Reticulitermes santonensis*) even after leaching (Tondi *et al.* 2012b). A sophisticated treatment system is not considered a viable option in order to keep the cost of wood preservatives low. Boron-based preservatives are still commercially important, and future research will focus on developing a good strategy to solve its fixation problem in wood and bamboo.

CONCLUSIONS

Based on the findings, the following conclusions can be drawn:

1. Preservative treatment had a significant impact on the physical and mechanical properties of *Gigantochloa scortechinii* strips. Boron and CCB both penetrated the bamboo strips well and had different effects on their performance.
2. Based on the findings of this study, preservative had a significant effect on the dimensional stability of bamboo strips, indicating that bamboo has a superior ability in environmental applications.
3. Both boron and CCB preservatives had a significant effect on mechanical properties due to changes in the chemical structures inside the bamboo cell.
4. However, when compared to boron, CCB preservatives led to greater MOR and compression strength of the treated bamboo. This can be interpreted as a positive influence on the use of bamboo, particularly in structural applications.

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