Sustainable Production of Engineered Timber Scrimber Composites For Flooring Applications

Ubaid Bin Shabeer[1], Er Shilpa chauhan[2]

[1]Student of M tech CTM Eng. , Dept. of civil engineering, Rayat Bahra university Mohali Punjab
[2]Assistant professor, deptartment of civil engineering, Rayat Bahra university Mohali Punjab

Abstract

In this study, bamboo scrimber composites (BSCs) were prepared using untreated (BSC-C) and saturated-steam heat-treated (BSC-T) oriented bamboo fiber mats and phenol formaldehyde resin via successive mechanical decomposition and molding recombination processes. The heat treatment of the oriented bamboo fiber mats significantly improved the dimensional stability of the resulting BSCs, but degraded their bending performance. In this study, bamboo scrimber composites (BSCs) were prepared using untreated (BSC-C) and saturated-steam heat-treated (BSC-T) oriented bamboo fiber mats and phenol formaldehyde resin via successive mechanical decomposition and molding recombination processes. The heat treatment of the oriented bamboo fiber mats significantly improved the dimensional stability of the resulting BSCs, but degraded their bending performance. Among them, the modulus of rupture and modulus of elasticity of BSC-C were 196.6 MPa and 18.5 GPa, which were 1.35 and 1.19 times higher than those of BSC-T, respectively. The bending strength indexed values of both BSC-C and BSC-T conformed to the structural bamboo scrimber standard LY/T 3194-2020. The dimensional stability of BSC-T was particularly suitable for use in outdoor flooring applications according to the bamboo scrimber flooring standard GB/T 30364-2013. Consequently, the developed BSCs are promising alternatives to conventional engineered bamboo products for various construction and flooring applications. The concepts of sustainable development and sustainability are deeply rooted in society owing to the risks and challenges related to water pollution, climate change, energy, and the environment. Furthermore, many countries have taken measures to restrict the use and export of wood to protect remaining forests, resulting in a mismatch between the supply and demand for wood products, thereby, hindering the development of the wood industry. With the introduction of forest protection policies, wood resources have become increasingly scarce worldwide. Therefore, the utilization of bamboo as a substitute for hardwood has attracted considerable attention.

Keywords: physical properties; mechanical properties; durability; microstructure; thermo stability

INTRODUCTON

Compared to wood, bamboo has the disadvantages of a small diameter, hollow structure with thin walls, sharp taper, uneven material distribution, anisotropic properties, and poor durability, which significantly limit its applications in engineering structures. To overcome these limitations, BSC materials have been developed as an innovative bamboo-fiber-based composite with uniform structure, excellent performance, and controllable specifications. First, the bamboo was truncated in the transverse direction to a length of 2600 mm and split longitudinally into two semicircular bamboo tubes. Then, the bamboo tubes were mechanically fluffed along the fiber direction into oriented bamboo fiber mats (OFBMs), which were naturally dried to a moisture content (MC) of about 6.97 wt%. BSC can be prepared using OBFMs and phenol formaldehyde (PF) resin via mechanical decomposition followed by molding recombination, which produces high-quality products and provides efficient material utilization. With the advantages of good dimensional stability, high mechanical strength, high weather resistance, and excellent biodegradability, BSCs have considerable potential for industrialization, especially in China and other regions where bamboo is grown. Bamboo scrimber has been initially explored for use as a structural building material. Besides, the new type of steel-reinforced bamboo scrimber beams embedded in bamboo composite materials can also be used for long-span and heavy-duty bamboo structural engineering. Indeed, the use of BSCs has gradually expanded from middle-end applications, such as indoor flooring, furniture, and decorative materials, to high-end value-added products, such as outdoor flooring, garden landscape construction, transportation facilities, weather-resistant structures, and high-strength engineering materials.

Although the industrialized production of BSCs has demonstrated significant advances, the performance and stability of BSCs need to be improved to realize their application in diverse fields. Many studies have found that the mechanical properties and water resistance of BSCs improve with increasing density and resin content. A BSC with a density of 1.30 g/cm^3 and a resin content of 16 wt% exhibited a bending strength or modulus of rupture (MOR), modulus of elasticity (MOE), and shear strength (SS) of 310.0 MPa, 29.7 GPa, and 28.2 MPa, respectively. These values proved that the BSC is appropriate for use in structural materials, such as poles and beams. However, when BSCs are used in an outdoor environment where they will experience increased exposure to the elements (viz. the rain, sun, and wind), the dimensional stability and durability are critical factors affecting their performance. Therefore, dimensional stabilization of BSCs can improve their commercial value and expand their application range.

Numerous methods have been proposed to prolong the lifespan and added value of bamboo products through dimensional stabilization. Traditionally, physical and chemical modification are the two main methods of dimensional stabilization for bamboo. Resin impregnation using polymers such as phenol formaldehyde (PF) resin or, furfuryl alcohol resin have been used to improve dimensional stability in bamboo products. Compared to physical modification through polymer impregnation, chemical modification provides stronger effects on water resistance and dimensional stability as it radically reduces the number of active hydroxyl groups in the bamboo. In terms of sustainability and environmental performance, heat treatment to improve the dimensional stability of bamboo provides excellent environmental performance because there is no need to use harmful chemicals in the process and the embodied energy in waste heat-treated bamboo can be directly recovered by burning it as fuel. In addition, high-temperature heat treatment technology can improve the corrosion resistance of wood.

In the industrial production of BSCs for outdoor applications, it is often necessary to heat treat OBFMs to different degrees to improve their dimensional stability and durability. Heat treatment in both hot, dry air and saturated steam media effectively improve the dimensional stability of BSCs, but the MOR and SS are significantly reduced. For example, after high-temperature steam treatment, the MOR of a BSC was found to reduce by 45% because of the changes in the main chemical components of OBFM during the process. Furthermore, the heat-treatment media used to process Moso bamboo bundles influences the mechanical properties and water resistance of the final BSCs. Related research has shown that a BSC made from hot, dry bamboo bundles air-treated at 180 °C for 10 h exhibited water resistance suitable for use in outdoor landscaping, exterior decorations, and garden furniture. In contrast, BSCs made from bamboo bundles subjected to saturated steam-treatment at 0.35 MPa for 150 min exhibited superior mechanical properties, indicating that they were better suited to structural applications [19]. In addition, heat treatment improves the weathering resistance and biological durability of BSCs. For example, in the preparation of *Neosinocalamus affinis* BSC, it has been suggested that saturated steam treatment at 180°C for 2 h is necessary for enhanced durability and physicomechanical properties. However, the available literature on BSCs has primarily investigated the influence of the heat-treatment process parameters on service performance under laboratory conditions; less attention has been paid to the effect of realistic industrial processing parameterised.

Therefore, the study employed a simple and sustainable chemical-free industrial saturated steam treatment technique to modify OBFM, and then BSCs were fabricated from untreated and heat-treated OBFMs and PF resin. The chemical composition of the heat-treated OBFMs was examined by Fourier-transform infrared attenuated total reflection spectroscopy (FTIR-ATR) and X-ray photoelectron spectroscopy (XPS). Furthermore, the bending properties and water resistance of the BSCs were assessed to determine their relationships with the chemical modification on the OBFM. It is expected that the results of this study will contribute to the fundamental knowledge regarding the properties of heat-treated OBFMs and provide a reference for future structural and flooring applications of engineered BSCs.

Materials and methods

Bamboo bundles were purchased from bamboo-flooring factory in Kashmir Province India, . Phenol-formaldehyde (PF) resin was purchased from Guangdong RR Chemical Industry Co., Ltd. Other agents, including furfuryl alcohol, sodium borate, citric acid, and oxalic acid, were purchased from Sinopharm Chemical Reagent Co., Ltd.

Furfurylation of Bamboo Bundles

The furfurylation of bamboo bundles was slightly changed on the basis of the previous furfurylation of bamboo strips by Ubaid bhat. Bamboo bundles were impregnated with 30% and 50% FA solutions using soaking and vacuum–pressure–vacuum impregnation processes, respectively. In the soaking process, bamboo bundles were soaked in 50% FA solution for 24 h and 48 h under atmospheric pressure. The vacuum–pressure– vacuum impregnation process consisted of 10 min vacuum impregnation, followed by 1.2 MPa pressure impregnation for 10 min and then vacuum impregnation for 10 min. The impregnated bamboo bundles were left to sit for 4 days and then wrapped in aluminum foil for the curing stage. At this stage, the FA in the bamboo bundles was polymerized at 105 °C or 115 °C for 5 h. After polymerization, the modified bamboo bundles were further dried for 16 h at 80 °C and, subsequently, air-dried until the moisture content was below 10%. Specific sample information is shown in Table 1

Table 1. Abbreviation and processing-technology information of samples.

Abbreviation	Samples	Treatment of Bamboo Bundles	Impregnation Times	Curing Temperature
Bamboo	Bamboo bundles	untreated		
BSC-C	Bamboo-scrimber composites	untreated		
FA-BSC-I		furfurylated with 30% FA through V–P–V impregnation	10 min vacuum +10 min pressure +10 min vacuum	105 °C
FA-BSC-II				115 °C
FA-BSC-III		furfurylated with 50% FA through V–P–V impregnation		105 °C
FA-BSC-IV				115 °C
FA-BSC-V		furfurylated with 50% FA through soaking impregnation	24 h	105 °C
FA-BSC-VI			48 h	105 °C

Preparation of Bamboo-Scrimber Composites

Bamboo-scrimber composites were fabricated according to Yu et al. , with a slight modification. Before dipping, PF resin with 52% solid content was diluted with water to 17.5% solid content. Bamboo bundles were completely soaked in PF resin for 11 min, placed horizontally for 4 min, and then laid flat to dry until the moisture content was less than 10%. The PF-resin dosage of bamboo bundles was controlled to 14% of the oven-dried weight of the bamboo bundles. Bamboo bundles were laid in five parallel layers and hot-pressed.

Finally, bamboo-scrimber composites with dimensions of 450 mm _ 550 mm _ 18 mm were obtained.

Horizontal Shear Strength

Mechanical-testing machine (AGS-X plus-50 kN, Shimadzu, Tokyo, Japan) was applied to test the horizontal shear strength of bamboo scrimber, according to the method in GB/T 30364-2013 [27]. For outdoor use. The specimens were subjected to a 28-h treatment, as described in Section 2.4.1, before mechanical testing.

The horizontal shear strength wascalculated using the following equation:

t=3F/4bh

where t is the HSS (MPa), and F, b, and h are the maximum failure load, width, and thickness of the specimen, respectively.

2.4.3. Bending Strength and Modulus of Bamboo-Scrimber Composites The MOR and MOE of the bamboo-scrimber-composite specimens were determined in a direction parallel to the face grains, according to GB/T 17657-2013 [28]. The specimens were tested using a three-point bending model with a bearing span of 280 mm and a loading speed of 8 mm/min. The MOR and MOE were calculated using Equations (4) and (5), respectively:

$$MOR = \frac{3P_{\max}L}{2bh^2}$$

$$MOE = \frac{P_\rho L^3}{4\delta bh^3}$$

where Pmax is the maximum failure load of the sample (N), L is 280 mm, b and h are the width and thickness of the samples (mm), respectively, Pr is the load increase (N) determined from the straight-line section of the load–deflection curve, and d is the midspan deflection (mm) of the sample under Pr. 2.5. Biological Durability 2.5.1. Anti-Mildew Property Mold resistance was evaluated following the method described in GB/T 18261- 2013. Aspergillus niger V. Tiegh, Penicillium citrinum Thom, Trichoderma viride Pers. ex Fr, and Botryodiplodia theobromae Pat were tested. Bamboo-scrimber samples were placed in culture dishes and incubated in an incubator at 22–25 _C and 85% RH for 4 weeks.

Finally, the samples' infected areas were recorded, and the infection values were judged, as shown in Table 3. The mold-prevention efficacy was calculated as follows:

$$E = (1 - \frac{D_1}{D_0}) \times 100\%$$

where E is the mold-prevention efficacy (%), and D0 and D1 are the infection values of the untreated and furfurylated BSCs, respectively, after infection.

Table 3. Reference for evaluation of infection value.

Infection Value	Sample Infected Area
0	No visible growth
1	Mold infection covered less than 1/4 of the surface of the sample
2	Mold infection covered between 1/4 and 1/2 of the surface of the sample
3	Mold infection covered between 1/2 and 3/4 of the surface of the sample
4	Mold infection covered more than 3/4 of the surface of the sample

Anti-Fungal-Decay Properties

Fungal-decay resistance was evaluated according to GB/T 13942.1-2009. The white-rot fungus Coriolus versicolor and the brown-rot fungus Gloeophyllum trabeum were tested. Masson's pine and poplar were selected as feed wood and control wood, respectively. Both measured 20 mm _ 20 mm _ 10 mm (T _ R _ L). All samples, including control wood, were weighed, and their dry weights were recorded before they were placed in a flask inoculated with decay fungi. After 8 weeks of infection with decay fungi at a temperature of 25 _ 2 _C and a humidity of 85 _ 5%, the dry weights of all samples were measured again, and the weight-loss rate of each sample was obtained according to the following equation:

$$\mathrm{WLR} = \frac{M_1 - M_2}{M_1} \times 100\%$$

where WLR is the mass-loss ratio (%), and M1 (g) and M2 (g) are the weights of the samples before and after infection, respectively.

Thermal Stability

The thermal stability of untreated and furfurylated BSCs was evaluated using thermal analyzer (NETZSCH STA 449F3, NETZSCH Gertebau GmbH, Selb, Germany) to determine TG and DTG values.

Characterization of Changes in Chemical Composition

Fourier-transform infrared spectroscopy (Nicolet-iS10, Thermo Scientific,Waltham, MA, USA) and XPS (Escalab 250Xi, Thermo Fisher Scientific, Waltham, MA, USA) were employed to analyze the functional groups and the O/C ratios, respectively, of the untreated bamboo bundles, untreated BSC, and furfurylated BSCs.

Results and Discussion

Physical Properties

The physical properties of the untreated BSC and the BSCs furfurylated by different processes were measured (Figure 1). In this study, the method of preparing the same density was not selected, but the same paving method and the same number of layers were selected to prepare the BSCs. As shown in Figure 1a, the density of the BSC-C was 1.121 g/cm3, which was lower than that of the furfurylated BSCs. The highest density of the BSC that was furfurylated with 50% FA and cured at 105 _C through V–P–V impregnation was 1.362 g/cm3. In general, the density of the BSC modified with 50% FA was higher than that of the BSC modified with 30% FA. Furthermore, the density of the BSC impregnated by the V–P–V process was higher than that of the BSC impregnated by the soaking process, even though the soaking time (24 h/48 h) was significantly longer than the pressure treatment time (10 min). The higher the concentration of the FA in the modified solution, the higher the weight-gain rate of the modified BSC. The efficiency of vacuum-pressure impregnation is higher than that of soaking treatment.

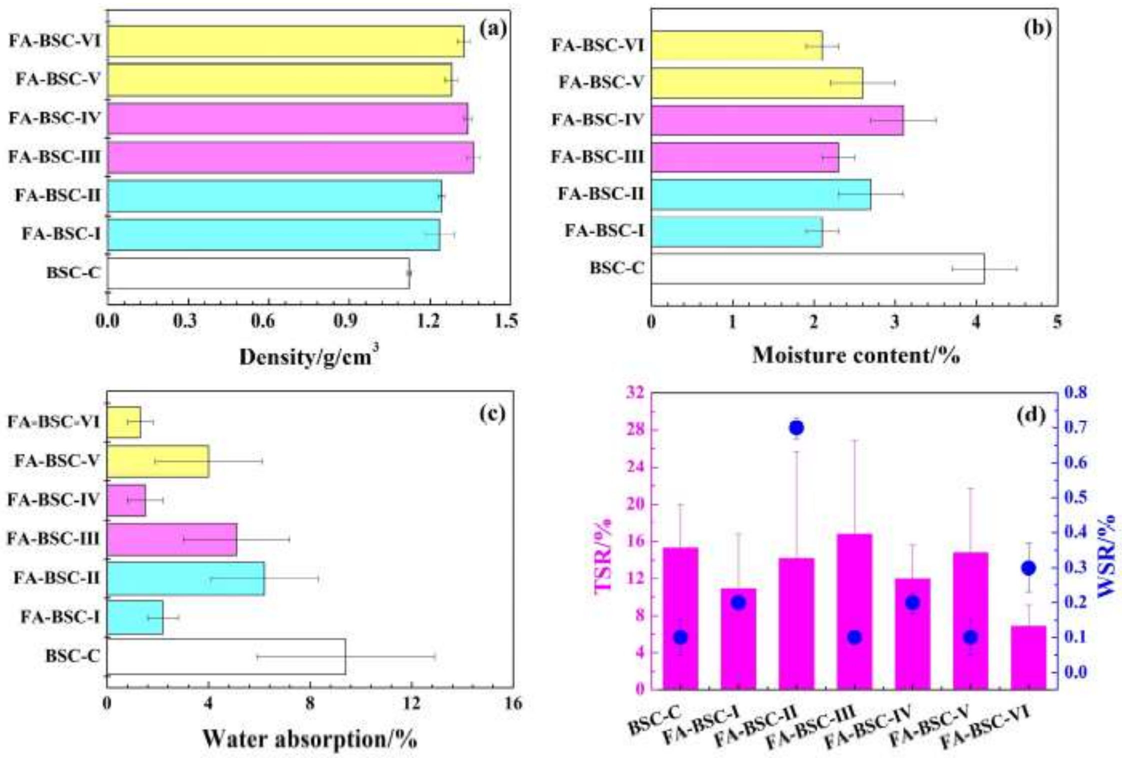

Figure 1. Physical properties of untreated BSC and furfurylated BSC. (**a**) Density; (**b**) moisture content; (**c**) water absorption; (**d**) thickness and width swelling rate.

Bamboo is a naturally porous material containing many hydroxyl groups that absorb moisture and water through hydrogen bonds. Previous studies found that furfurylation can significantly reduce the hygroscopicity of bamboo. Figure 1b shows that the average moisture content of the BSC-C was approximately 4%, while that of the fur furylated BSCs was only 2–3%. Similarly, the water absorption of the furfurylated BSCs was also significantly lower than that of the untreated BSC, as shown in Figure 1c. This was mainly because the BSC was a relatively high-density plate made by hot-pressing the bamboo bundles. After the furfurylation, the hydrophobic FA resin filled the bamboo-cell cavities and even the micro-pores of the cell wall, which further prevented the water molecules from reaching the hydrophilic polymers in the bamboo-cell walls. The dimensional stability of the BSC samples was characterized by TSR and WSR. The TSR and WSR of the untreated BSC were 15.3% and 0.1%, respectively; the corresponding values for most of the fur furylated BSCs decreased, except for the TSR of the FA-BSC-III (16.8%) and the WSR of the FA-BSC-II (0.7%), which were slightly higher. For the FA-BSC-III sample, which had the highest weight-gain rate, the TSR was higher. This result may have been due to the cracking of the inter-layer adhesive layer during the boiling (4 h), roasting (20 h), and boiling (4 h) processes of the fur furylated BSCs, leading to an increase in thickness expansion.3.2. Mechanical Properties The HSS of the BSCs for both outdoor and indoor use were measured (Figure 2a). The HSSs of the untreated BSC were 13.7 MPa and 19.0 MPa for outdoor and indoor use, respectively. In contrast, the HSS of the fur fur ylated BSCs for indoor use increased slightly compared with that of the untreated bamboo. In particular, the HSS of the FA-BSC-VI, that is, of the bamboo bundles soaked in 50% modified FA solution for 48 h, increased by 21% compared with that of the untreated BSC. For outdoor use, the HSSs of some of the fur furylated BSCs with higher weight-gain rates were lower than that of the untreated BSC. The FA-BSC-III samples had the lowest HSSs, approximately 10% lower than that of the untreated BSC. These results indicate that the bonding strength of the fur furylated BSCs was affected during the boiling (4 h), roasting (20 h), and boiling (4 h) processes.

The MOR and MOE of the BSCs are shown in Figure 2b. The average MOR and MOE values of the untreated BSC were 171.6 MPa and 17.1 GPa, respectively. The furfurylation had little effect on the MOE of the bamboo scrimber but had an obvious effect on its MOR.The MOR of the furfurylated BSCs in the different impregnation processes differed. The MOR of the furfurylated BSCs prepared from the bamboo bundles treated with V–P–V impregnation was higher than that of the untreated BSC. The MOR of the BSCs prepared by using the soaking treatment was slightly lower than that of the untreated BSC. This effect could be explained by the filling of the FA resin in bamboo cell cavities and the bulking of the FA resin in the bamboo-cell wall. Proper filling and bulking could improve the mechanical strength of the material, but excessive bulking would reduce the mechanical strength of the material. In our previous research, we found that the MOR of bamboo furfurylated with 15% FA was significantly higher than that of untreated bamboo, while that of bamboo furfurylated with 50% FA was lower than that of untreated bamboo. In addition, in this study, the properties of the modified and untreated BSCs with the same paving mode were compared, instead of the properties of materials with the same density. The density of the modified BSCs was significantly higher than that of the untreated BSC, which was also a reason for the increase in the mechanical strength compared with the untreated BSC.

Durability

The mold-resistance-test results of the untreated and furfurylated bamboo scrimbers The mold-prevention efficacy of the BSC-C was zero for the four types of mold fungi selected, which illustrated that it was highly susceptible to mold. In contrast, the mold resistance of the furfurylated BSCs significantly improved. The mold-prevention efficacy of thefurfurylated BSCs was more than 75% against A. niger and T. viride. The prevention efficacy of the FA-BSC-III, FA-BSC-V, and FA-BSC-VI against P. citrinum also improved to some extent. The mold resistance of the furfurylated BSCs with 50% FA was slightly better than that of the furfurylated BSCs with 30% FA. Furfurylation is not sufficient to improve resistance to B. theobromae, one of the major fungi causing the discoloration of wood and bamboo, and this requires further investigation in follow-up studies.

Bamboo scrimber is believed to possess excellent decay resistance, especially against basidiomycetes. Trametes versicolor (white rot) and Serpula lacrymans (brown rot) were used to test the decay resistance of bamboo scrimber, and the results showed that bamboo scrimber can be classified as highly resistant to both fungi.

Microstructure

Bamboo mainly consists of vascular bundles (fiber cells and vessel cells) surrounded by basic tissues (parenchyma cells). The SEM analysis revealed that almost all the cells were compressed and deformed to varying degrees. The deformation of the parenchyma cells and vessel cells was particularly obvious., the parenchyma cells of the untreated BSCs were empty and compressed from their original round shape to an oval shape, and some even closed. Although the deformation of the fiber cells was relatively small, some cells also showed cell-wall collapse or interlayer tearing. This was consistent with previous studies. Rao et al. and Li et al. reported that the thin-walled vessel cells and parenchyma cells of bamboo were compressed or even closed, and that the thick-walled fiber cells remained essentially unchanged. Compared with the untreated BSC, the parenchyma cells of the furfurylated BSCs were filled with large quantities of FA resin, and the parenchyma cells were compressed and deformed more significantly, as. This indicates that the dispersed bamboo bundles, which were the bamboo-based units used to prepare the BSCs, were easily permeated by the furfuryl alcohol. In addition, furfurylation may cause thin-walled cells, such as parenchyma cells, to become compressed more easily. Moreover, some of the fiber cells were also filled, but they remained almost intact, This indicates that a certain amount of FA-resin filling plays a particular role in supporting thick-walled cells, such as fiber cells. It was further observed that the furfurylation reduced the porosity and increased the density of the BSCs, which may have been the reason for the enhanced mechanical properties and durability and decreased water absorption of the BSCs.

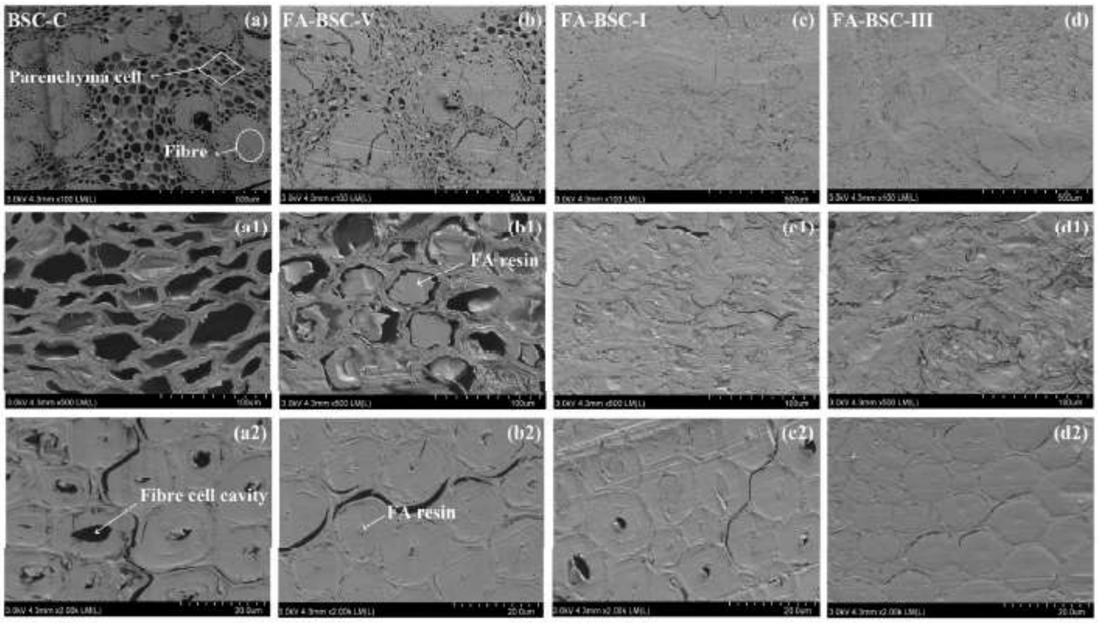

Figure 3. SEM images of untreated and furfurylated BSC cross-sections: (**a,a1,a2**) from BSC-C; (**b,b1,b2**) from FA-BSC-V; (**c,c1,c2**) from FA-BSC-I; (**d,d1,d2**) from FA-BSC-III. (**a1,b1,c1,d1**) Parenchyma cells. (**a2,b2,c2,d2**) Fiber cells.

Analysis of Thermal-Degradation Behavior

Figure 7 shows the results of the thermogravimetric analysis of the untreated and furfurylated BSCs. The thermogravimetric profiles mainly consisted of three stages. The first stage was between 30 and 160 _C; it featured minor weight loss, which was mainly associated with the removal of free water and bound water. The second stage refers to the decomposition of the hemicellulose and unstable cellulose. The weight loss mainly occurred in this stage, in the temperature range of 160–340 _C, with a corresponding weight loss of 38.32% in the BSC-C and a weight-loss range of 28.50 to 35.94% in the furfurylated BSCs.

The last stage consisted of a slowdown in the thermal decomposition between 340 and 800 _C. The remaining residue at 800 _C for the BSC-C was 39.6%, and for the furfurylated BSCs, it ranged from 38.1 to 42.2%. Similar results were reported for the furfurylated bamboo samples. Liu et al. (2022)

reported that the weight residue of furfurylated bamboo was 18%, while the weight residue of their control was 13%. These results indicated that the furfurylation increased the weight residue and improved the thermal stability of the BSCs to a certain extent by filling the materials with FA resin. Additionally, the maximum DTG cure was attained at approximately 320 _C for the untreated BSCs and 335 _C for the furfurylated BSCs, which further indicated that the furfurylation increased the thermal stability of the BSCs. For the BSCs furfurylated by different processes, the peak temperatures of the DTG curves were almost equal, but the maximum weight-loss rate and residual mass were slightly different. When the temperature was 335 _C, the weight-loss rates of the furfurylated BSCs were ranked as follows, from high to low: FA-BSC-I > FA-BSC-II > FA-BSC-III = FA-BSC-IV > FA-BSC-V > FA-BSC-VI. This was attributed to the incorporation of the FA polymer into the bamboo structure.

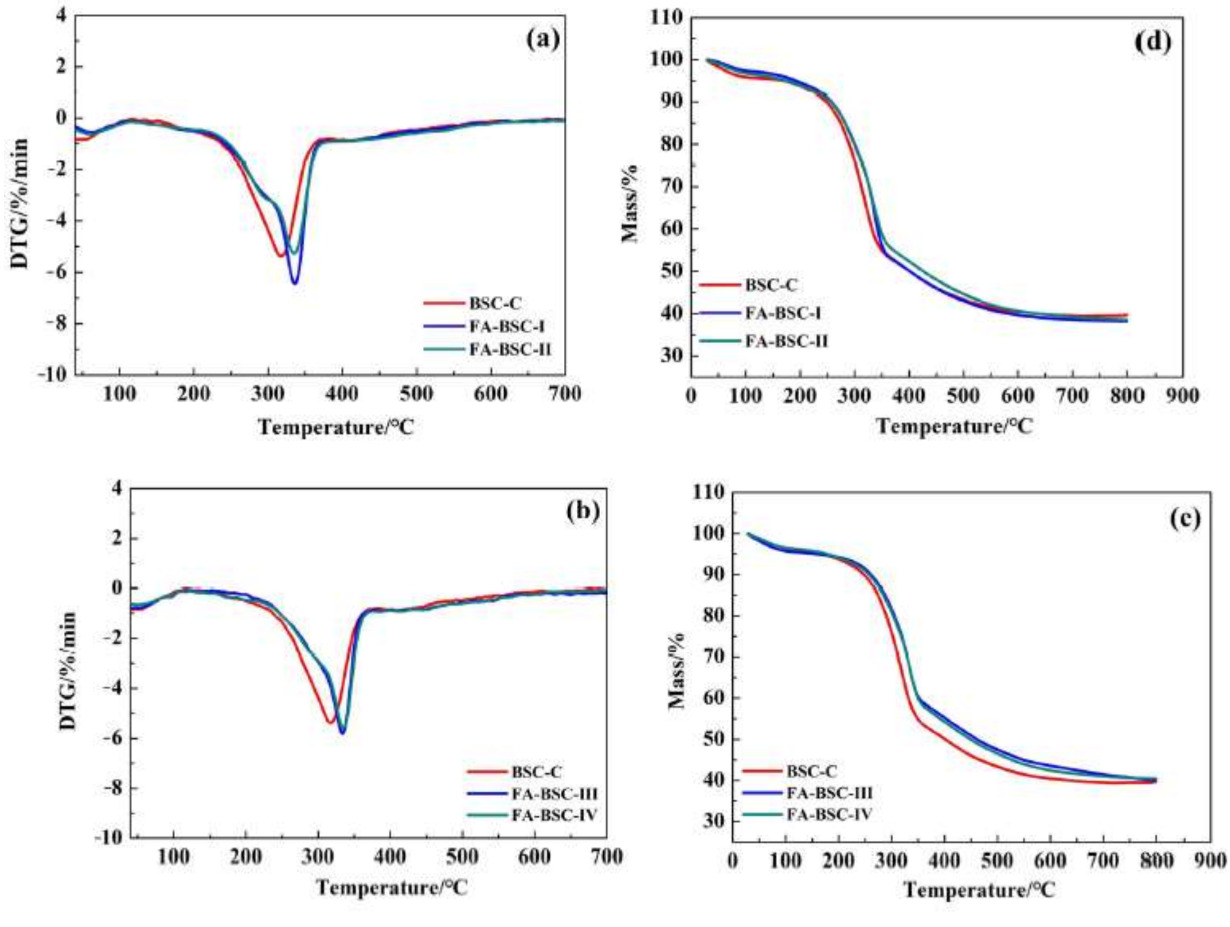

Figure 7. Thermogravimetric analysis of untreated BSCs and furfurylated BSCs. (a,d) from BSC-C, FA-BSC-I and FA-BSC-II; (b,e) from BSC-C, FA-BSC-III and FA-BSC-IV;

CONCLUSIONS

This study evaluated the physical–mechanical properties and durability of furfurylated BSCs with different impregnation processes, different FA concentrations, and different curing temperatures. The furfurylated BSCs had a higher density, lower moisture content and water-absorption rate, and better dimensional stability than the untreated BSCs. The improvements in these properties were directly related to the changes in the microstructure. As observed using SEM, the FA resin effectively filled in the bamboo-cell cavities and vessels, and the modified bamboo-parenchyma cells were compressed more tightly and evenly. In terms of the mechanical properties, the furfurylation had a slight negative effect on the mechanical strength of the BSCs, and the MOR and HSS of the furfurylated BSCs increased to a certain extent under most of the treatment conditions, although the FTIR and XPS spectroscopy showed that the cellulose and hemicellulose underwent acid hydrolysis to a certain extent after the furfurylation. This may have been related to the relatively high density of the furfurylated BSCs. In addition, the furfurylation significantly improved the mold and decay resistance of the BSCs, especially the decay resistance, which was raised from decay resistance (class II) to strong decay resistance (class I). The present study highlights the potential of furfurylation as a modification method to enhance BSC products. Based on the results of this study, a combination of the V–P–V impregnation process, a concentration of FA of 50%, and a curing temperature of 115 _C was proposed as the set of starting processing parameters for the furfurylation of bamboo-scrimber composites. Further research should focus on improving the ability of furfurylated BSCs to prevent staining fungi. Additionally, the influence of FA resin on the bonding strength of PF adhesives should be further clarified.

REFRENCES

1. Jiang, Z.H. Bamboo and Rattan in the World; China Forestry Publishing House: Beijing, China, 2007.
2. Sharma, B.; Gatoo, A.; Bock, M.; Ramage, M.H. Engineered bamboo for structural applications. Constr. Build. Mater. **2015**, 81, 66–73. [CrossRef]
3. Yu,W. Development of bamboo-fiber based composites. China Wood Ind. **2011**, 25, 6–8.
4. Shukla, S.R.; Kelkar, B.U.; Yadav, S.M.; Bijila, A. Studies on laminated and scrimber composites produced from thermally modified D. strictus bamboo bonded with melamine-based adhesive. Ind. Crops Prod. **2022**, 188, 115649. [CrossRef]
5. Yu, Y. Manufacturing Technology and Mechanism of High Performance Bamboo-Based Fiber Composites. Doctoral Thesis, Chinese Academy of Forestry, Beijing, China, 2014.
6. Wang, J.; Cao, P.; Guo, X.; Xue, H.; Jia, G.; Wang, B. Effect of process parameters on cutting forces and surface roughness during peripheral up milling of bamboo scrimber. BioResources **2015**, 10, 8414–8425. [CrossRef]
7. Yu, Y.; Zhu, R.;Wu, B.; Hu, Y.; Yu,W. Fabrication, material properties, and application of bamboo scrimber. Wood Sci. Technol. **2015**, 49, 83–98. [CrossRef]
8. Kumar, A.; Vlach, T.; Laiblova, L.; Hrouda, M.; Kasal, B.; Tywoniak, J.; Hajek, P. Engineered bamboo scrimber: Influence of density on the mechanical and water absorption properties. Constr. Build. Mater. **2016**, 127, 815–827. [CrossRef]
9. He, S.; Xu, J.; Wu, Z.; Yu, H.; Chen, Y.; Song, J. Effect of bamboo bundle knitting on enhancing properties of bamboo scrimber. Eur. J. Wood Wood Prod. **2018**, 76, 1071–1078. [CrossRef]
10. Rao, F.; Zhu, X.; Zhang, Y.; Ji, Y.; Lei, W.; Li, N.; Zhang, Z.; Chen, Y.; Yu, W. Water resistance and mechanical properties of bamboo scrimber composite made from different units of Bambusa chungii as a function of resin content. Constr. Build. Mater. **2022**, 335, 127250. [CrossRef]
11. Sun, F.L.; Mao, S.F.; Wen, G.F. Anti-mold effects of bamboo timber treated with different solutions. J. Zhejiang For. Coll. **2006**, 23, 135–139.
12. Sun, F.L.; Bao, B.F.; Ma, L.F.; Chen, A.L.; Duan, X.F. Mould-resistance of bamboo treated with the compound of chitosan-copper
1. complex and organic fungicides. J. Wood Sci. **2012**, 58, 51–56. [CrossRef]

13. Möller, R.; Mild, G. Protection of Moso bamboo (Phyllostachys pubescens) materials against fungal decay and discolouration by treatment with wood preservatives. Eur. J. Wood Wood Prod. **2019**, 77, 139–145. [CrossRef]
14. Zhang, J.; Yuan, S.; Fan, H.; Li, Q.; Wang, H. Effect of different antimildew and antiseptic agents on reconstructed bamboo timber. J. Zhejiang For. Sci. Technol **2016**, 36, 8–12. (In Chinese)
15. Wu, Z.; Huang, D.; Wei, W.; Wang, W.; Wang, X.; Wei, Q.; Niu, M.; Lin, M.; Rao, J.; Xie, Y. Mesoporous aluminosilicate improves mildew resistance of bamboo scrimber with Cu-B-P anti-mildew agents. J. Clean. Prod. **2019**, 209, 273–282. [CrossRef]
16. Fu, B.; Li, X.; Yuan, G.; Chen,W.; Pan, Y. Preparation and flame retardant and smoke suppression properties of bamboo-wood
2. hybrid scrimber filled with calcium and magnesium nanoparticles. J. Nanomater. **2014**, 2014, 3. [CrossRef]
17. Shangguan, W.; Gong, Y.; Zhao, R.; Ren, H. Effects of heat treatment on the properties of bamboo scrimber. J. Wood Sci. **2016**, 62, 383–391. [CrossRef]
18. He,W.; Song, J.;Wang, T.; Li, J.; Xie, L.; Yang, Y.;Wu, B.; Zhang, Q. Effect of heat oil treatment on bamboo scrimber properties. China For. Sci. Technol. **2017**, 2, 15–19. (In Chinese)
19. Yang, K.; Li, X.; Wu, Y.; Zheng, X. A simple, effective and inhibitor-free thermal treatment for enhancing mold-proof property of bamboo scrimber. Eur. J. Wood Wood Prod. **2021**, 79, 1049–1055. [CrossRef]
20. Lande, S.;Westin, M.; Schneider, M. Properties of furfurylated wood. Scand. J. For. Res. **2004**, 19, 22–30. [CrossRef]
21. Esteves, B.; Nunes, L.; Pereira, H. Properties of furfurylated wood (Pinus pinaster). Eur. J. Wood Wood Prod. **2011**, 69, 521–525. [CrossRef]
22. Kong, L.; Guan, H.; Wang, X. In situ polymerization of furfuryl alcohol with ammonium dihydrogen phosphate in poplar wood for improved dimensional stability and flame retardancy. ACS Sustain. Chem. Eng. **2018**, 6, 3349–3357. [CrossRef]
23. Yang, T.; Wang, J.; Xu, J.; Ma, E.; Cao, J. Hygroscopicity and dimensional stability of Populus euramericana Cv. modified by furfurylation combined with low hemicellulose pretreatment. J. Mater. Sci. **2019**, 54, 13445–13456. [CrossRef]
24. Li, W.; Liu, M.; Wang, H.; Zhai, H.; Yu, Y. Preparing highly durable bamboo materials via bulk furfurylation. Constr. Build. Mater. **2020**, 262, 120726. [CrossRef]
25. Hadi, Y.S.; Mulyosari, D.; Herliyana, E.N.; Pari, G.; Arsyad, W.; Abdillah, I.B.; Gérardin, P. Furfurylation of wood from fastgrowing tropical species to enhance their resistance to subterranean termite. Eur. J. Wood Wood Prod. **2021**, 79, 1007–1015.
3. [CrossRef]
26. Liu, M.; Li, W.; Wang, H.; Zhang, X.; Yu, Y. Dimensionally stable and highly durable bamboo material prepared through a simple surface furfurylation. Constr. Build. Mater. **2021**, 276, 122156. [CrossRef]
27. GB/T 30364-2013; Bamboo Scrimber Flooring. Standardization Administration of China: Beijing, China, 2013.