Physical-mechanical performance of bamboo scrimbers made from *Bambusa rigida*

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**Abstract:** Bamboo scrimbers (BCs) with excellent performances were made from *Bambusa rigida* (2 to 5 years old). It was found that BCs made from 3-year-old bamboo have the smallest thickness swelling (TS) and width swelling (WS). BCs prepared from 4-year-old bamboo has the maximum compressive strength (CS) and horizontal shear strength (HSS). The maximum modulus of rapture (MOR) and modulus of elastic (MOE) of BCs were observed in BCs made from bamboo with age of 5 years. Overall, the resin dosage of 11% was optimized to fabricate BCs with different maturing bamboo culms; 4-year-old bamboos were recommended to be used as the raw material for the production of BCs.

**1. Introduction**

Bamboo is the most important non-wood material. It has many advantages, such as sustainability, short maturity period (3-5 years), and high strength to weight ratio\(^[1]\). The bamboo used in industry is usually large-diameter bamboo, while the small-diameter bamboo receives less attention because it is difficult to be used. In recent years, a new mechanical process combined with phenolic resin (PF) has been developed to use small-diameter bamboo, i.e., bamboo scrimbers (BCs)\(^[2]\). This process not only greatly improves the utilization rate of bamboo, but also applies small-diameter bamboo to industry\(^[3,4]\). Resin, an interfacial phase, is directly related to the physical and mechanical properties of BCs\(^[5]\).

BCs made of bamboo will different ages may have different properties, because bamboo maturation process will produce different quality raw material. However, it is not clear whether there is any correlation between the physical and mechanical properties of the composite material made from different bamboo age. In order to ensure that the resulting BCs could meet the requirements of structural use, the following will be discussed in this paper: 1) determining the optimum resin dosage of bamboo BCs composites; 2) optimizing the bamboo age to obtain a best physical-mechanical performance of BCs.
2. Materials and methods

2.1 Materials
Sixty bamboo culms (Bambusa rigida), with age from 2 to 5 years old, were harvested from Sichuan province. A type of commercial phenol formaldehyde (PF) with solid content of 44.6%, acquired from Beijing Dynea Chemical Industry Co., Ltd (Beijing, China) was used as the resin for the composite fabrication.

2.2 Preparation of bamboo scrimbers (BCs)
1000mm long bamboo, with age from 2 to 5 years old, was sawed off and split in lengthways into semi-circular bamboo tube. After removing the internal nodes, the tubes were put into a fiber separator and crashed. The crashed bamboo tubes were soaked in PF resin to control the resin dosage from 7% to 15%. Then, they were dried in an oven until the moisture content was about 9%. A hot press was used to press the crashed bamboo tubes that are uniformly assembled in a mold, at 150 °C, holding for 10 min at pressure of 2.5 MPa. The density of resulting BCs was controlled at 1.0 g/cm-3. Finally, BCs with dimensions of 450 × 350 × 15 mm³ were obtained.

2.3 Determination of BCs physical-mechanical performance
The thickness swelling (TS/%) and width swelling (WS/%) of BCs were measured according to the bamboo flooring standard (GB/T 30364-2013) issued by the national standard of the People's Republic of China. The compressive strength (CS/MPa) and horizontal shear strength (HSS/MPa) of the BCs were measured according to ASTM D3501-2005 and ASTM D 2344-2013. The modulus of rupture (MOR/MPa) and the modulus of elasticity (MOE/GPA) of BCs were tested according to the Chinese national test material standard (GB/T 17657-1999). Twelve replicates were carried out for each test.

3. Results and discussions

3.1 Effect of resin dosage on the properties of BCs
As shown in Fig. 1a, with the increase of resin dosage, the overall TS and WS of BCs showed a decreasing trend, and the minimum TS was observed when the resin dosage was 13%. The minimum WS was obtained as the resin content was 11%. This may be due to the interaction between the polar hydroxyl group of phenolic resin and the hydrophilic fiber, which results in high water resistance[4]. Furthermore, under high pressure conditions, the cured PF resin may also block the water pathway, resulting in high water resistance.

CS and HSS increased first and then decreased with increasing resin content. As shown in Fig. 1b, when the RD increased from 7% to 11%, CS and HSS reached the maximum values of 100.0 MPa and 16.2 MPa, respectively. This may be because increasing the amount of resin helps fiber bundle to strengthen CS and HSS, while extra resin will only increase the bond thickness, which will reduce CS and HSS[5]. Another possible reason is the decrease in bundle weight due to the increase of resin dosage to keep a same composite density, which leads to the decrease in CS and HSS.

The MOR and MOE of BCs showed a fluctuating trend as indicated in Fig. 1c. As the resin dosage was 9%, both MOR and MOE were the minimum, while the maximums were observed at RD of 13%. In general, fiber bundles play a major role in the bending properties of composites, rather than resin dosage[5]. Comprehensively, the resin dosage of 11% was optimized to fabricate BCs with different maturing bamboo culms.
3.2 Effect of bamboo age on the physical-mechanical properties of BCs

As shown in Fig. 2a, the minimum TS and WS of 3-year-old bamboo were 10.9% and 1.9%, respectively. Therefore, the BCs prepared from 3-year-old bamboo had a good water resistance. The CS and HSS of BCs reflect its resistance to pressure and shear forces, respectively[6]. The CS and HSS of the four-year-old bamboo were the highest. It is worth to note that both of them decreased significantly at the fifth year (Fig. 2b). This results indicated that the 4-year-old bamboo was suitable for the preparation of high-performance BCs.

As for MOR and MOE, it was observed from the Fig. 2c that the MOR and MOE of 3-year-old bamboo were the minimum, which were 189.5 MPa and 23.0 GPa, respectively. After that, the MOR and MOE of BCS increased with the bamboo age, which was mainly attributed to the thickening of cell walls during bamboo maturation. According to the above results, it can be concluded that different maturity stages of bamboo do have an effect on the performance of BCs.
Fig. 2 Physical-mechanical properties of bamboo scrimbers with response to bamboo age

4. Conclusion

In order to prepare high-performance BCs, this paper was to optimize the PF resin dosage and bamboo age factors. The results indicated that the PF dosage of 11% was the most suitable to produce high-performance BCs. The maximum CS and HSS of BCs were found from 4-year-old bamboo, thus it was suggested that 4-year-old *Bambusa rigida* should be used in the manufacture of bamboo scrimbers.

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