Effect Of Elevated Temperature on the Bending Strength of Bamboo Scrimber

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Abstract. Thermal modification of bamboo at elevated temperatures is used as a modification method to improve its dimensional stability and biological resistance. The effect of different heat treatment temperatures on the bending strength of bamboo scrimber was investigated by treating bamboo strips at 140°C, 160°C, 180°C, and 200°C. Results showed that bamboo scrimber made from strips treated at 140°C had higher modulus of elasticity (MOE) and modulus of rupture (MOR) compared to those treated at higher temperatures. However, the bending strength of the scrimber decreased as the treatment temperature increased beyond 140°C.

Keywords: Modulus of Elasticity, Modulus of Rupture, Treatment, Temperature.

1 Introduction

Bamboo is a fast-growing grass that can reach heights of up to 25 meters in just six months. Each shoot emerges from the ground at its full diameter and does not increase in thickness as it matures; instead, it narrows towards the top and grows taller through cell division between the nodes. After around five to six years, the structural strength of the bamboo culm starts to weaken. Although bamboo's lignocellulosic nature makes it an attractive alternative to wood, its use in construction is limited due to issues such as dimensional instability with temperature changes, high moisture absorption, and low durability. To overcome these challenges, various modification techniques—including thermal (heat) treatments, chemical methods, and biological processes—are employed [1,2].

There has been an increasing focus lately on using natural plant fibers to reinforce polymer composites for engineering material applications. Bamboo, known for being sustainable, widely available, and biodegradable, is commonly employed in the production of bamboo-based composites like bamboo scrimber [4].

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Bamboo scrimber is manufactured by arranging bamboo bundles longitudinally in parallel orientation, impregnating them with a water-soluble phenol-formaldehyde (PF) resin, and subsequently compressing the assembly to attain the specified thickness and density. The fabrication process principally comprises an initial cold pressing stage followed by hot curing to achieve polymerization and consolidation. Relative to other bamboo-based composites, bamboo scrimber demonstrates a higher raw material utilization efficiency, accompanied by favorable surface texture, elevated hardness, and superior longitudinal mechanical strength [5].

Bamboo scrimber absorbs moisture at a slower rate due to its increased density and the extensive resin infusion it undergoes. The resin fills the pores within the bamboo structure, reducing the ability of water to penetrate and spread. As a result, this material shows a decreased tendency to take up moisture compared to untreated bamboo, which improves its dimensional stability and limits damage caused by moisture (15–20%). However, prolonged exposure to humid environments or direct contact with water can still cause moisture uptake and swelling. The scrimber retains the bamboo fibers oriented longitudinally, with the resin matrix binding these fiber bundles together. When swelling occurs, the expansion stresses can cause the resin bonds to break. Consequently, the swelling experienced by this compressed lignocellulosic material is not entirely reversible upon drying, resulting in permanent deformations. Therefore, it is essential to protect bamboo scrimber from moisture, either through application of water-repellent coatings or, preferably, by minimizing its exposure to prolonged humidity. Ensuring dimensional stability remains a significant challenge for bamboo scrimber, which restricts its broader use, particularly in outdoor applications [6]. The application of preservatives through chemical treatments is acknowledged as crucial for enhancing bamboo's suitability in furniture and construction. However, due to the unique chemical makeup of bamboo, this approach is not consistently effective since bamboo is often resistant to treatment[2]. Thermal treatment serves as an alternative approach for preserving and enhancing bamboo by inducing changes across various attributes. This method influences the physical, chemical, biological, and mechanical characteristics of bamboo. Additionally, heat treatment alters the coloration of bamboo, and it has been observed that the mechanical responses to thermal modification may differ according to bamboo species [7-13].

High-temperature thermal treatment is a common method used to modify bamboo, aiming to enhance its dimensional stability and biological durability. This process reduces the material's affinity for water and improves stability by breaking down hemicelluloses, which play a key role in moisture absorption [14]. Lignin undergoes notable structural changes when subjected to thermal treatment, resulting in significant alterations to its chemical composition and properties [15]. Thermal treatment leads to increased crystallinity in wood, which is attributed to transformations in various wood components that enhance the crystallization of cellulose during the heating process. This method also effectively evens out and deepens the color of the material. However, it tends to diminish the mechanical strength of the wood and reduces its surface wettability. Studies have shown that thermally treated bamboo exhibits improved dimensional stability compared to untreated bamboo. Nevertheless, the heat-induced structural modifications cause a significant decline in mechanical properties, as revealed by ultrasound analysis, with the most pronounced effects observed in impact resistance and static bending performance. Additionally, thermal treatment has been reported to enhance the resistance to thickness swelling and decay durability of reconstituted bamboo lumber, although these improvements come at the cost of reduced strength characteristics [8-10, 16-19].

This study focused on evaluating how subjecting bamboo to high-temperature treatment influences the bending characteristics of the resulting bamboo scrimber.

2 Materials and Methods

Bambusa bamboo species was used as the raw material. The bamboo processing involved several key steps including cross-cutting, splitting, removal of nodes, slat fabrication, and grooving. The main processing stages are as follows:

a) Cross cut: The bamboo culm is cut perpendicular to its fibers to the required length. After this step, the culm is ready for primary processing into splits and finer strips.

b) Outer nodes removal: After cross-cutting, the outer nodes on the bamboo culm are trimmed off to achieve a smooth surface.

c) Bamboo splitting: The bamboo culm is split radially into the desired widths using a circular splitter equipped with 4, 6, or 8 blades.

d) Removal of inner nodes: Following splitting, internal nodes and other protrusions remain on the bamboo pieces. These internal knots are trimmed off to produce smoother surfaces suitable for further processing.

e) Slat making: The split bamboo pieces, now free of knots and protrusions, are further processed into thin strips or slats, depending on the required thickness.

f) Grooving/ crushing: The bamboo slats are passed through a grooving machine, which longitudinally cuts interconnected grooves along the slats to facilitate resin impregnation and bonding.

Thermal Treatment: The crushed bamboo strips were treated in a vacuum oven at temperatures of 140°C, 160°C, 180°C, and 200°C for a duration of two hours. The samples were identified and labeled as indicated in Table 1.

Resin Application: Phenol formaldehyde (PF) resin was prepared by mixing equal parts of resin and water (1:1 ratio). Each bamboo strip was individually soaked in the resin solution for about five minutes to ensure complete impregnation.

Air Drying: After resin impregnation, the bamboo strips were placed vertically in a supported container to allow excess resin to drain over a period of 3 to 4 hours. Following this, the strips were sun-dried until achieving a moisture content of approximately 10–12%.

Assembly and Hot Pressing: The resin-coated, grooved bamboo strips were arranged in a unidirectional stack and subjected to hot pressing using a hydraulic press. The pressing operation was performed at a temperature of 145°C ± 15°C under a pressure of 20 kg/cm² for 15 minutes. This process produced panels measuring 1 foot by 1 foot with a thickness of 12 mm.

The pressed panels were then conditioned at ambient temperature (27 ± 2°C) and relative humidity (65 ± 5%) for 48 hours.

Testing: The resulting bamboo scrimber samples were evaluated for bending strength and density following the Indian Standard IS 1708 (1986), which specifies testing methods for small clear wood specimens. For each sample type, five specimens were tested, and the average values were recorded (N = 5).

3 Results and Discussions

Table1 Description and density of samples under different temperature

Sl. No.	Sample type	Description	Density (kg/m3)	St. Dev. (kg/m3)	Coeff. Var. (%)
1	T_C	Untreated (Control)	931	118.6	12.8
2	T_{140}	Heat treated at 140°C	1118	143.3	13.0
3	T_{160}	Heat treated at 160°C	1073	102.3	9.5
4	T_{180}	Heat treated at 180°C	989	153.8	15.5
5	T_{200}	Heat treated at 200°C	956	118.9	12.4

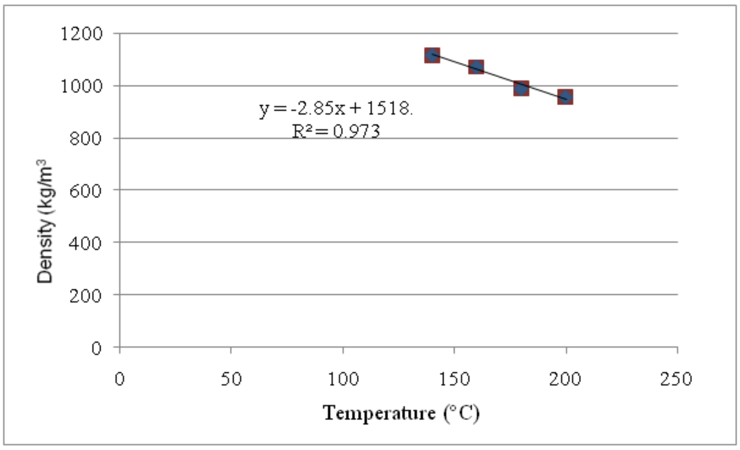

Fig. 1 Relation of density with treatment temperature

Table 2 Bending properties of composites

Sl. No.	Sample type	MOR (N/mm^2)	St. Dev. (N/mm^2)	Coeff. Var. (%)	MOE (N/mm^2)	St. Dev. (N/mm^2)	Coeff. Var. (%)
1	T_C	139.56	17.22	12.3	15501.2	1732.7	11.1
2	T_{140}	172.58	15.51	9.0	16389.3	936.4	5.7
3	T_{160}	167.13	22.50	13.4	15103.9	1774.4	11.7
4	T_{180}	136.49	9.04	6.6	14910.7	1558.7	10.4
5	T_{200}	86.73	8.50	9.9	10077.8	872.2	8.6

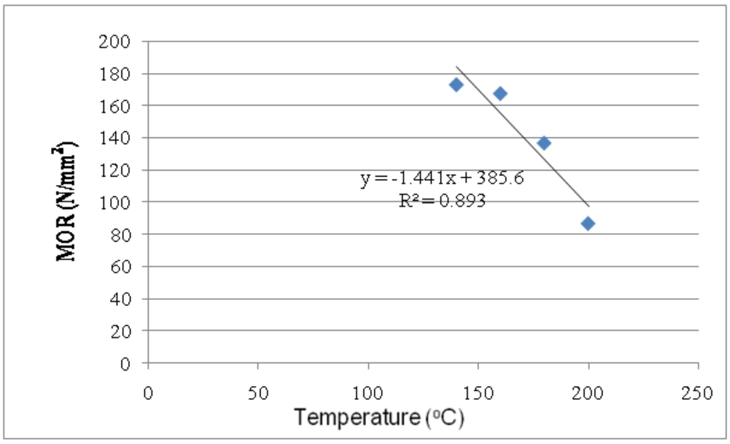

Fig. 2 Relation of MoR with treatment temperature

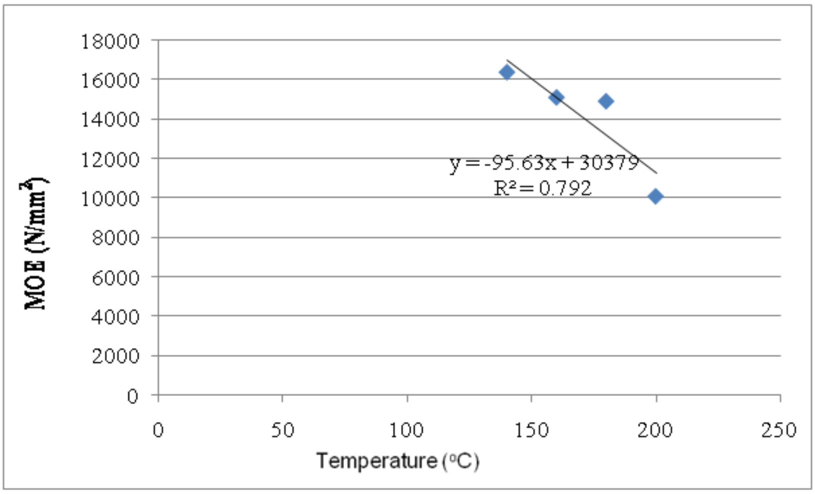

Fig. 3 Relation of MoE with treatment temperature

Table 1 shows the nomenclature and density of the samples. Table 2 shows the strength (bending) properties. The density of the scrimber was reduced with increase in treatment temperature as seen in Fig. 1. MOE & MOR of the untreated sample (control sample) are 139.56 N/mm^2 and 15501.17 N/mm2 which are increased to 172.58 N/mm^2 &16389 N/mm^2 for sample treated at 140°C. The density also increased by 20% compared to control sample. The thermal treatment at 140°C may be decomposing natural and artificial impurities, creating extra sites for resin absorption. Thus increasing the overall density. Removing impurities improves the surface's adhesive qualities by producing a rougher texture, which consequently increases the modulus of rupture (MoR). But, with the increase in temperature of treatment from 160°C to

200°C, the MOR & MOE goes on decreasing and there was a drastic decrease at 200°C as shown in Fig 2 and Fig. 3; this may be due to the degradation of cellulose and hemicellulose and also resin absorption capacity of fibers decreases at higher temperature; This may also lead to poor adhesion. Poor bonding and weakened fiber lead to reduction in MOE & MOR. The Young's modulus initially increases as cellulose crystallinity rises and wood moisture content decreases. However, as the heat treatment progresses further, degradation caused by the elevated temperature becomes more significant, resulting in a decline in the Young's modulus [8]. Energy (heat) input in bamboo (100-200°C) can cause change in the structure by depolymerisation, bond formation, fragmentation, rearrangement and crystallization [9]. The best results are obtained at thermal modification hot pressed scrimbers at temperature 140°C. Density also increases at 140°C and then it decreases with increases in treatment temperature.

4 Conclusions

Bamboo strips were thermally treated at 140°C, 160°C, 180°C, and 200°C to evaluate the effect of heat treatment on the bending strength of bamboo scrimber made from these treated strips. The scrimber produced from bamboo treated at 140°C demonstrated enhanced mechanical properties compared to the untreated control sample. Therefore, thermal treatment at 140°C is recommended for bamboo fibers when the goal is to improve the bending strength of bamboo scrimber. However, treatments conducted at temperatures above 140°C resulted in comparatively poorer performance, which is attributed to deterioration of surface bonding properties caused by the higher temperature exposure.

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