World Academy of Science, Engineering and Technology
International Journal of Chemical and Molecular Engineering
Vol:11, No:3, 2017

Gluability of *Bambusa balcooa* and *Bambusa vulgaris* for Development of Laminated Panels

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Abstract**—**The development of value added composite products from bamboo with the application of gluing technology can play a vital role in economic development and also in forest resource conservation of any country. In this study, the gluability of *Bambusa balcooa* and *Bambusa vulgaris*, two locally grown bamboo species of Bangladesh was assessed. As the culm wall thickness of bamboos decreases from bottom to top, a culm portion of up to 5.4 m and 3.6 m were used from the base of *B. balcooa* and *B. vulgaris*, respectively, to get rectangular strips of uniform thickness. The color of the *B. vulgaris* strips was yellowish brown and that of *B. balcooa* was reddish brown. The strips were treated in borax-boric, bleaching and carbonization for extending the service life of the laminates. The preservative treatments changed the color of the strips. Borax–boric acid treated strips were reddish brown. When bleached with hydrogen peroxide, the color of the strips turned into whitish yellow. Carbonization produced dark brownish strips having coffee flavor. Chemical constituents for untreated and treated strips were determined. *B. vulgaris* was more acidic than *B. balcooa*. Then the treated strips were used to develop three-layered bamboo laminated panel. Urea formaldehyde (UF) and polyvinyl acetate (PVA) were used as binder. The shear strength and abrasive resistance of the panel were evaluated. It was found that the shear strength of the UF-panel was higher than the PVA-panel for all treatments. Between the species, gluability of *B. vulgaris* was better and in some cases better than hardwood species. The abrasive resistance of *B. balcooa* is slightly higher than *B. vulgaris;* however, the latter was preferred as it showed well gluability. The panels could be used as structural panel, floor tiles, flat pack furniture component, and wall panel etc. However, further research on durability and creep behavior of the product in service condition is warranted.

Keywords**—***Bambusa balcooa, Bambusa vulgaris,* polyvinyl acetate, urea formaldehyde.

I. Introduction

THE survival of human beings and their living standard depend to a large extent on wood. With the continuous increase in human population there is a gradual rise in the demand for more wood resources. As a result, forest resources are becoming scarce every day.

People have tried various items like plastic goods, ceramic fittings with aluminum, and steel made items to substitute wood in many of its uses. These materials have lots of limitations; they are non-renewable, need intensive energy in their production and cause enormous environmental pollution during processing and on degradation. These factors have created added interest in searching for alternatives that are natural and renewable, and could effectively replace wood without posing any threat to our environment. Scientists believe that bamboo is such a resource that can replace wood.

Bamboo, is a fast growing and high yielding renewable resource [1], and exhibits equal or better strength characteristics compared to wood available from fast growing plantation species [2]-[4]. In Bangladesh, bamboo grows also abundantly both in forests and villages of Bangladesh. So far, about nine genera and more than 33 species of bamboo have been found in Bangladesh, out of which, seven are occurring naturally in the forest areas. In the plains of Bangladesh, 26 cultivated species of bamboo are available [5].

Bamboo is widely used in the housing sector and also in the cottage industries, especially for making handicrafts in round or split form, all over the world. In the modern world, glue laminated technology has helped in diversification of the application of bamboo composites in the area of architectural design and also fabrication of furniture.

China is far more advanced in the development of bamboo-based composites than other bamboo producing countries. There are about 100 factories that manufacture bamboo mat plywood, 25 produce bamboo strip plywood, 20 manufacture bamboo curtain plywood, and 20 factories are producing bamboo particleboard. [6]. Bamboo product is exported to Japan, the USA, Hong Kong and Taiwan.

It is evident that like other countries, bamboo composites have bright prospects in Bangladesh but the research on gluing characteristics of bamboo panel product has not done yet. With this aim, the glue bonding characteristics of *Bambusa balcooa* and *Bambusa vulgaris*, two thick-walled bamboos of Bangladesh, was evaluated.

II. Materials and Methods

B. balcooa and *B. vulgaris* culms were collected from Nazirhat, a village in Chittagong District, Bangladesh. Generally the culm length of *B. balcooa* was 13.1 m, which was slightly higher than the *B. vulgaris* (12.8 m) and the culm wall thickness of bamboos decreases from bottom to top. So, the culm portion of up to 5.4 m and 3.6 m from the base of *B. balcooa* and *B. vulgaris* were used. These were converted into rectangular strips of uniform thickness**.** At first, the selected culms were cross cut into 0.6 m long pieces and submersed under water. After three weeks of submersion, the pieces were air-dried to lower the moisture content to around 20%. Then

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each of the dried pieces was split manually into six fragments, which were then converted into uniform rectangular strips.

Bamboo contains nutrients that provide excellent nourishment for insects and fungi. Three types of preservative treatment likely, borax-boric acid treatment, bleaching and carbonization, were given to the strips for ensuring the extended service life of the product.

Borax-Boric Acid Treatment: A 5% borax-boric acid solution (w/v) was prepared in warm water maintaining borax to boric ratio of 3:2. The strips were first boiled for 2 h in water prior soaking, and then dipped in the hot borax-boric acid solution for 1 h for easy and uniform distribution of preservatives.

Bleaching: In this process, hydrogen peroxide solution was used as bleaching agent. In addition, 2.54% borax–boric acid solution (w/v) in the ratio 1.54: 1 was added. At first, the strips were put into the warm water of 50°C. Then the required amount of borax-boric acid was added to the warm water. When the temperature attained 70 °C, 2.5% hydrogen peroxide (v/v) was added gently. The strips were bleached for 2 h maintaining a temperature of 80 °C.

Carbonization: Carbonization of the strips was carried out in autoclaves at 130 °C for 3 h. The treated strips were taken out and kept for further processing.

The moisture content of the strips became high after each treatment. The treated strips were dried in open air until it attained equilibrium moisture content (EMC). The dried strips were glued with two types of organic binders such as UF and PVA. Three layered parallel laminates of 12 mm thick were constructed with the treated strips. The assemblies were pressed at room temperature for 24 h maintaining a pressure of 1 N/mm^2. Test samples were prepared and then conditioned to attain uniform moisture content of about 9% to 10% before testing. The glue block shear test, and abrasive resistance were measured in accordance with ASTM standards [7], [8].

III. Results and Discussion

A. Surface Characteristics of Bamboo Strip

B. balcooa strips were reddish brown in color and there were frequent darker streak along the grain (Fig. 1 (a)). This was probably the result of a staining fungi attack, as the species required longer time for seasoning due to its thick culm wall. A lump of silica particles were observed on the upper surfaces. The surface of the strip was rough with some raised grain near the node. Strip preparation was a bit difficult for *B. balcooa*. The processing difficulties were probably related to the anatomical characteristics.

Strips of *B. vulgaris* were yellowish brown in color. The surface of the strip was smooth and no raising of the grain was seen, but found somewhat lustrous (Fig. 1 (b)). Strip preparation was relatively easy with *B. vulgaris*.

B. balcooa and *B. vulgaris* strips were subjected to various treatments like borax-boric acid treatment, H_2O_2 bleaching and carbonization at 130ºC prior to the making of bamboo laminates. It was observed that the color of the strips changed from its original color and it was different for various treatments. Borax – boric acid treated strips of *B. vulgaris* were slightly reddish brown with bright appearance (Fig. 1 (c)) and the clear bamboo grain was seen. Under the same treatment, the color of *B. balcooa* was pale reddish brown. Black streak in line was observed on the surface due to the attack of staining fungi. When bleached with H_2O_2, the color of the *B. vulgaris* strips turned to whitish yellow (Fig. 1 (d)). Visually *B. vulgaris* strips were brighter compared to *B. balcooa* strips, which revealed that color change due to bleaching was species dependent. Zaidon et al. [9] also observed more whitish color of *B. vulgaris* compared to *G. scortechinii* and *D. asper*, the two Malaysian bamboos. Carbonization produced dark brownish strips having coffee flavor (Fig. 1 (e)). Xie and Zhao [10] studied the technology of pigmentation of bamboo strips by carbonization and dyeing treatment. They concluded that the surface character of carbonized bamboo strips was related to carbonizing temperature, time, and surface quality of untreated strips and the age of the bamboo. Generally for high carbonizing temperature and time, the chromatism was greater. The aged bamboo developed deeper color after carbonization.

(a) (b) (c) (d) (e)

Fig. 1 Strips of different color (a) untreated *B. balcooa*, (b) untreated *B. vulgaris*, (c) borax-boric treated *B. vulgaris* (d) bleached *B. vulgaris* and (e) carbonized *B. vulgaris*

B. pH and Buffering Capacity

The pH and buffering capacity values of untreated and treated strips of *B. balcooa* and *B. vulgaris* are given in Table I. From the results, it was seen that before treatment *B. balcooa* (pH 5.37) was less acidic than *B. vulgaris* (pH 4.40). John and Niazi [11] determined the pH and buffering capacity for water extract of the heartwood and sapwood of 10 hardwoods and nine softwoods. The pH value ranged from 4.00 to 5.86 for hardwood and 4.02 to 5.82 for softwood. This means that the pH values of bamboos under study resembled wood pH values. Ahmed [12] measured the acidity of *Dendrocalamus strictus* (Calcutta bamboo) along the culm collected from four different locations. The pH range was 5.13–5.44, which resembles the pH value of *B. balcooa*.

Upon treatment, the pH value of the strips was changed abruptly for both the species. Among the treatments, carbonization made the strips more acidic (Table I). In the case of wood, the organic compounds formed during water hydrolysis were believed to play a role in the changes of the chemical properties of wood [13]. Like wood, during carbonization, the high temperature catalyzed the hydrolysis and probably formed formic and acetic acids that resulted in acidic pH of the carbonized bamboo strips.

TABLE I
pH AND BUFFERING CAPACITY OF TREATED AND UNTREATED STRIPS OF *B. BALCOOA* AND *B. VULGARIS*

Treatment	pH	Acid buffering capacity(mmol l^{-1})	Alkaline buffering capacity (mmol l^{-1})	[1]Relative acid buffering capacity	[2]Absolute acid buffering capacity(mmol l^{-1})	[3]Total buffering capacity(mmol l^{-1})
			Species: *B. balcooa*			
Untreated strips	5.37	0.193	0.422	0.457	-0.229	0.615
			Treated strips			
Borax-boric acid treatment	6.85	0.305	0.603	0.506	-0.298	0.908
Bleaching	6.23	0.449	0.421	1.067	0.028	0.870
Carbonization	4.06	0.346	0.185	1.874	0.161	0.531
			Species: *B. vulgaris*			
Untreated portion	4.40	0.212	0.212	1.00	0.00	0.424
Borax-boric acid treatment	6.86	0.359	0.494	0.727	-0.135	0.853
Bleaching	6.27	0.503	0.458	1.098	0.045	0.961
Carbonization	4.08	0.209	0.158	1.323	0.051	0.367

[1]Relative acid buffering capacity = acid buffering capacity / alkaline buffering capacity
[2]Absolute acid buffering capacity = acid buffering capacity - alkaline buffering capacity
[3]Total buffering capacity = acid buffering capacity + alkaline buffering capacity

In case of bleaching, hydrogen peroxide (H_2O_2) could act both as a lignin preserving and lignin removing chemical. It dissociates in aqueous solutions to form a hydroperoxide anion that reacts with lignin and other chromophores by nucleophilic addition to lignin functional groups. The resulting reactions alter the chromophore without an extensive degradation and dissolution of lignin [14], [15]. According to the researchers, peroxide bleaching is performed at 50ºC – 60ºC at an initial pH value of about 11, which drops toward the end to about pH 9. Below pH 9, hydrogen peroxide is negligibly dissociated and, therefore, has little bleaching effect. The brightness of the material improves between pH 9 to 11. But as UF glue sets in the acidic region, so it is better to keep the substrate/adhered in the acidic region. In the present study, the pH values of 6.23 for *B. balcooa* and 6.27 for *B. vulgaris* were probably due to the inclusion of borax:boric (1:1.5) with 2.5% H_2O_2 solution.

In case of buffering capacity, it was found that there were variations in the buffering capacities among treatments. Johns and Niazi [11] also observed similar trends. Hachmi and Moslemi [16] measured the pH and buffering capacity of wood and pointed out different wood may have the same pH, but possess different acid and base buffering capacities. The effects of pH and buffering capacity as well as the catalyst content of less desirable wood materials on the gel time of UF resin was investigated by Xang et al. [17]. They did not find any relationship between pH value and acid or alkaline buffering capacity; rather they observed strong co-relation to absolute acid buffering capacity and relative acid buffering capacity. From Table I, it was found that the pH values of the treated materials for both the species decreased with the increase of absolute and relative acid buffering capacities. It was due to the increased absolute acidity mass in the solution. These were in agreement with the findings of Xang et al. [17].

C. Glue Block Shear Test

The mean shear load of the parallel laminates made from treated strips of *B. balcooa* and *B. vulgaris* bonded with PVA and UF are shown in Fig. 2. From the figure, it is seen that the shear strength of a parallel panel glued with UF was higher than PVA for all the treatments. The highest value was found for bleached strips, 7.3 N/mm^2 followed by carbonization, 6.6 N/mm^2. Among the treatments, the low value was observed for borax-boric acid treated strips. The probable reason was that borax–boric acid treated strips of *B. balcooa* were less acidic and their alkaline buffering capacity was higher. The acid available in the process was not enough to create an acidic environment for the setting of the glue.

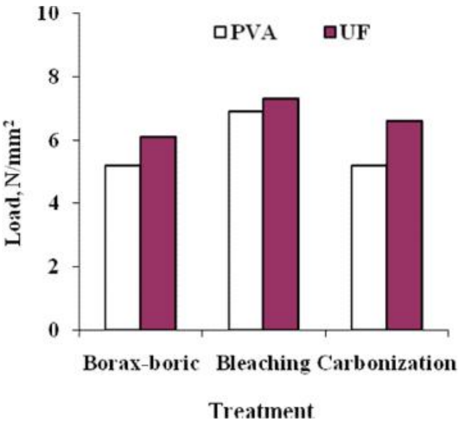
A study done by Blanchet et al. [18] on the bond performance of four adhesives PVA, UF, MUF (melamine urea formaldehyde) and PUR (polyurethane) for engineered wood parquet flooring showed that among the adhesives, PVA had the lowest performance with poor moisture resistivity. The value correlated well with the present study. For *B. vulgaris*, a similar trend of shear strength and glue failure percentage for the panel was noted between PVA and UF glue (Fig. 2 (b)). However, shear strength value for UF glue was more or less similar in three treatments. For all the treatment, *B. vulgaris* performed well compared to *B. balcooa*.

In the present study, bleaching did not affect the shear strength very much due to the addition of a lower percentage of H_2O_2 (2.5%) compared to other studies where the bleaches amount were 12.5% [9] and 6%, w/v [19], respectively. They pointed out that bleaching reduces the strength properties of bamboo to some extent.

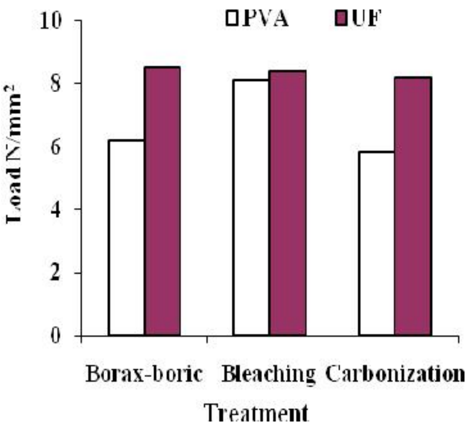
D. Abrasive Resistance

The test was done to measure the wear resistance of the surface only. The abrasiveness (wear resistance) was measured for only panels made with UF glue, as the UF glue performed well for both the species. The results showed that the percent thickness loss of the panels after 500 revolutions for *B. balcooa* was lower than that of *B. vulgaris* for all the three treatments i.e., borax-boric acid, bleaching and carbonization (Fig. 3), and the surface view of the wood and bamboo laminate samples after testing are shown in Fig. 4.

Generally, the species of high specific gravity had the more wear resistance compared to the species of low specific gravity [20]. *B. balcooa* is denser than *B. vulgaris* [21], [22]. Probably due to this, the former showed better result than the latter. Anatomical properties like pore size and their distribution, as well as the fiber structure, also influence the wear resistance of the materials [20].



(a)



(b)

Fig. 2 Effect of treatments on shear of (a) *B. balcooa* and (b) *B. vulgaris* panels glued with PVA and UF

Among the treatments, carbonized sample showed highest wear resistance for both the species (1.20% in *B. balcooa* and 1.45% in *B. vulgaris)*. The percent thickness loss of the two bamboo species was much lower than that of teak (*Tectona grandis*, 2.16 %). This indicated that *B. balcooa and B. vulgaris* were more resistant to abrasion. In an observation, Mohmod et al. [20] also found that the two bamboo species, *B. vulgaris* and *G. scortechinii*, were more resistant to abrasion compared to kempas (*Koompassia malaccensis*), rubber wood (*Hevea brasiliensis*), the two timber species commonly used for flooring in Malaysia.

It was important to note that the presence of nodes reduced compression, tension and modulus of rupture [3]. But in the case of the wear resistance test, the nodal portion was found to be more resistant than the internodal portion [20]. It was assumed that the presence of a node in the panel fabrication would not deteriorate the quality of the products in service.

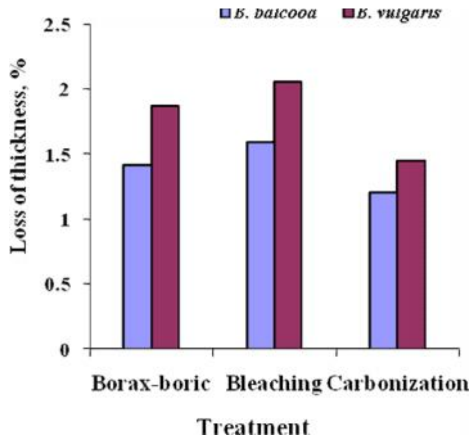


Fig. 3 Effect of treatments on abrasive resistance of panels made from *B. balcooa* and *B. vulgaris* with UF

IV. Conclusion

This study indicated the gluability of *Bambusa vulgaris* and *Bambusa balcooa* for making bamboo laminated panel. Based on the results, the following conclusions were drawn.

The shear strength of the UF-panel is superior to the PVA-panel for all treatments. The gluability of *B. vulgaris* is superior to that of *B. balcooa*. Thus, *B. vulgaris* is preferred for the development of bamboo composites. The laminated panels could be used for fabricating flat pack furniture, floor tiles, wall panel etc. However, further research on fastener holding capacity, durability and creep behavior of the products in service is warranted.

(a) (b)

Fig. 4 Surface view of samples after abrasive resistance (wear) test (a) Teak (*Tectona grandis*) and (b) Glue laminated bamboo panel

Acknowledgment

We would like to thank officers and staffs of Veneer and Composite Wood Products Division, Bangladesh Forest Research Institute for helping me in bamboo collection, board making and sample preparation. We are also highly indebted to the Bangladesh Forest Research Institute authority for providing logistic support for this research.

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