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Short Communication

Some Physical and Mechanical Properties of Bamboo Mat-Wood Veneer Plywood

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Abstract

This paper presents the manufacturing of bamboo mat-wood veneer plywood (BW_{ply}) for higher strength purposes using muli bamboo (Melocanna baccifera) mat and simul (Bombax ceiba) wood veneer and urea formaldehyde resin, and its basic physical and mechanical properties. To compare the properties of BW_{ply}, bamboo mat plywood (B_{ply}) and wood veneer plywood (W_{ply}) were produced. Physical properties i.e., density, moisture content, water absorption and thickness swelling; and mechanical properties i.e., modulus of elasticity (MOE), modulus of rupture (MOR), face and edge screw withdrawal and tensile strength (TS) perpendicular to surface of BW_{ply}, B_{ply} and W_{ply} were tested according to the procedure of ASTM standard D-1037. Water absorption of BW_{ply}, B_{ply} and W_{ply} were 30.83, 28.62 and 65.5%, respectively. Further, MOE of BW_{ply}, B_{ply} and W_{ply} were 5276, 6176 and 3879 N/mm^2, respectively. MOR was higher for BW_{ply} (39.5 N/mm^2) compared to the B_{ply} and W_{ply} panels. Though some properties of BW_{ply} were lower than that of the B_{ply}, the properties of BW_{ply} meet the minimum requirements of ASTM standard. Finally, the results indicate that BW_{ply} made from bamboo mat and wood veneer exhibits superior physical and strength properties compared to the commercial plywood made for structural purposes.

Keywords: Bamboo mat, simul veneer, plywood, physical properties, mechanical properties.

Introduction

Wood is a renewable building material but anisotropic in nature and heterogeneous in composition has certain disadvantages which can be largely overcome in the cross-banded construction of plywood[1]. The demand of plywood increased all over the world for house construction, furniture manufacturing and interior decoration (wall and ceiling paneling) due to their strength properties and workability. Moreover, there has been a steady increase in the number of plywood industries in Bangladesh. Therefore, it is manufactured in great quantities and as the primary raw material for plywood remains wood which results in large quantities of woody raw material consumption by the processing industries causing a threat to the natural forest as well as to the environmental sustainability. On one hand, deforestation and forest degradation, and on the other hand, increasing demand for wood-based panels has caused an important raw material issue in the sector for a long time in Bangladesh[2]. Therefore, wood-based industries must find appropriate production techniques for producing panels by using locally available raw materials in addition with wood. The manufacture of bamboo mat-wood veneer plywood from muli bamboo and simul wood is perhaps one such approach.

Bamboo is one of the oldest building materials for both structural and decorative purposes[3] and are fastest growing plant on earth in addition to being a renewable natural resource[4]. Compared with some commercial wood species, bamboo exhibits equal or better physical and mechanical properties, which offer good potential for processing it into composites (bamboo-based panels) as a wood substitute[5]. During the recent years, bamboo has been used for the production of mat boards, plywood, strand boards, sandwich board, bamboo particle boards, bamboo zephyr board[6], bamboo fiberboard and bamboo-based wafer board[4]. Although many studies have been conducted on bamboo plywood, an extensive literature search did not reveal any information about the manufacturing of bamboo mat-wood veneer plywood from muli bamboo and simul wood to evaluate its properties. Thus, in order to ensure the proper utilization of this valuable resource and to reduce the excess pressure on wood, this study was carried out to manufacture structural plywood from bamboo (muli) mat and wood veneer. Simul (*Bombax ceiba*) a hardwood species, which is commonly used for manufacturing of commercial plywood in Bangladesh. Bamboo mat, instead of bamboo strip, was used in the study to make the panel bigger size having higher strength. To compare the properties, bamboo mat plywood and simul veneer plywood were also made. Therefore, the objective of this study was to manufacture and characterize the physical and mechanical properties of bamboo mat-wood veneer plywood.

Material and Methods

Raw materials: Simul (*Bombax ceiba*) log used in this study had an age of 5 years and a diameter of 25-30 cm. Three years old, defect free, straight and mature muli bamboo (*Melocanna* *baccifera*) was used in this study. Length and diameter of the culms were 6-7 m and 8-9 cm respectively. Sharp knife was used to split the bamboo into 1.3 mm thin slivers. The outer and inner layer of slivers, which contain silica, wax and parenchyma, was removed to increase the bond ability of the slivers. These slivers were weaved into mats to form approximately 2.6 mm thick bamboo mats. About 2.6 mm simul veneer was produced by rotary chuck less roller type veneer lathe. The bamboo mats and simul veneers were clipped 250 cm × 130 cm in accordance with trimming allowance. Veneers were dried to a moisture content of 4.3% by automatic roller track veneer drier. The bamboo mats were dried in the kiln to a moisture content of 5.3%.

Panel Manufacturing: Both bamboo mats and simul veneers were used to make three types of 5-ply plywood - bamboo mat plywood (B_{ply}), bamboo mat-wood veneer plywood (BW_{ply}) and wood veneer plywood (W_{ply}). For manufacturing of BW_{ply}, 3 bamboo mats and 2 veneers were assembled into 5-ply plywood alternatively consisting of bamboo mats as face, core and back and wood veneers. The glue line method was followed to spray urea formaldehyde resin by a glue spreader at a rate of 300 g/m^2. Subsequently the mats and veneers were assembled and hot pressed for 15 minutes at a temperature of 115°C with 9 N/mm^2 pressure. Then Bply and Wply plywood were manufactured from 5 bamboo mat and 5 wood veneer respectively by maintaining the same manufacturing conditions. The thickness for three different types of plywood was 12 mm. The plywood was trimmed to 244 cm × 122 cm with a circular saw and sanded by 80 grade sand paper with a belt sander.

Laboratory test: Before preparation of test samples, the panels were conditioned in a room at room temperature for 48 hours. According to the procedure of ASTM standard D-1037[7], all specimens were carefully prepared and tested to evaluate the physical and mechanical properties of each type of panels. Mechanical properties were measured by using universal testing machine IMAL-IB600 according to the ASTM standard. During sample testing, temperature and relative humidity of the room were maintained to 23±2°C and 65±2%, respectively. Six specimens were used for each type of panel for evaluation of each physical and mechanical property.

Statistical Analysis: A general statistical description (average and standard deviation) was determined for the different plywood properties. Data analysis was performed by using the SAS system software package. The significance of different treatments was determined by variance analysis (ANOVA) and LSD (least significant difference) test ($\alpha \leq 0.05$).

Results and Discussion

Physical properties: The averages, standard deviation and statistical analysis of the physical properties of 12 mm thick three types of plywood manufactured from *M. baccifera* and *B.ceiba* are summarized in table 1. ANOVA and LSD (table 1) showed statistical differences in the physical properties; though moisture content, water absorption and thickness swelling of BW_{ply} and B_{ply} was not statistically different. However the manufacturing conditions of the panels were same, the main responsible factor for the differences in physical properties of plywood might be the different raw material i.e., physical properties of the raw materials. The results also comply with the results of Abdul *et al.*[8]. Tenorio *et al.*[9] reported that there would be significant differences in the physical properties of the plywood fabricated from the different raw materials by maintaining the same manufacturing conditions due to the variation in physical properties of raw materials.

Table - 1
The mean value, standard deviation and statistical analysis of physical properties of three types of plywood

Physical Properties	B_{ply}	BW_{ply}	W_{ply}
Density (Kg/m^3)	766^A (35.1)	694^B (22.2)	536^C (21.4)
Moisture content (%)	11.5^B (0.6)	11.7^B (0.8)	15.6^A (1.4)
Water absorption (%)	28.62^B (3.4)	30.83^B (2.8)	65.5^A (9.5)
Thickness swelling (%)	2.3^B (0.64)	2.5^B (0.46)	3.4^A (0.38)

Means with the same letter within the same row are not significantly different. Numbers in parentheses are standard deviations from the sample mean.

The characteristic property of plywood strength is density. The mean density of BW_{ply}, B_{ply} and W_{ply} was 694, 766 and 536 kg/m^3 respectively (table 1). According to ASTM standard[10] and Franz *et al.*[11], the range of density of standard plywood is 430 to 794 kg/m^3. Hence, the density of BW_{ply} was at the top of the standard range though it was lower than that the density of B_{ply}. By using the same compression of the veneer during hot pressing and glue, density of plywood varied. This might be due to the raw materials density, which affects the plywood density. Based on the oven dry volume, the specific gravity value of bamboo is 0.75[12], while the value of simul is 0.34. It was also observed that the density of BW_{ply} is substantially higher than that of southern pine plywood (514 kg/m^3), douglas-fir plywood (512.64 kg/m^3)[13] and spruce plywood (476 kg/m^3)[14].

Water absorption and thickness swelling properties of lignocellulosic materials are directly related to moisture content. It was found that the moisture content of BW_{ply} and B_{ply} plywood was 11.7 and 11.5%, respectively whereas the moisture content of W_{ply} was 15.6% (table 1). According to ASTM standard[10] and Franz *et al.*[11], the range moisture content of standard plywood is 7.3 to 12.7%. Therefore, the moisture content of BW_{ply} and B_{ply} followed the standard. The mean value of water absorption and thickness swelling are summarized in table 1. Water absorption and thickness swelling in BW_{ply} panel was slightly higher than the B_{ply} but significantly lower than the W_{ply} (table 1), suggesting that the BW_{ply} panel is less susceptible to water absorption as well as to thickness swelling than W_{ply} panels. Moreover it was also observed that higher water absorption results in higher thickness swelling in all the panels. The proportion of holocellulose and alpha cellulose tends to lessen but the lignin content remains unchanged or increases slightly in bamboo culms having age more than one year[15]. Due to the presence of free –OH group in the molecular structure, cellulose and hemicelluloses are responsible for water absorption as reported by Wardrop[16]. In-addition Skaar[17] found that hygroscopicity of hemicellulose is higher than the cellulose and lignin. Hemicellulose content of *M. baccifera* is 17.3%[18], whereas hardwood contains 25-35%. Thus, lower cellulose and/or hemicellulose content of 3 years old mature bamboo compared to hardwood might restrict the absorption of water as well as thickness swelling in BW_{ply} and B_{ply} panels.

Mechanical Properties: Average, standard deviation and statistical analysis of mechanical properties for 12 mm thick BW_{ply}, B_{ply} and W_{ply} plywood are presented in Table 2. From ANOVA and LSD it was observed that the mechanical properties are statistically different with exceptions in MOR of BW_{ply} and B_{ply} (table 2). Moreover according to ASTM standard[10], MOR of the standard plywood ranges from 20.7 to 48.3 N/ mm^2. Therefore, MOR of all the panels was within the ranges of standard and holds the upper position. Higher plywood strength results from the higher plywood density as seen in table 1 and 2, because there is a close correlation exists between density and mechanical properties. The results showed that the BW_{ply} have higher MOE value than the W_{ply} but lower than the B_{ply} using the same resin as an adhesive.

Table - 2
The mean value, standard deviation and statistical analysis of mechanical properties of three types of plywood

Mechanical Properties	B_{ply}	BW_{ply}	W_{ply}
MOE (N/mm^2)	6176^A (738)	5276^B (480)	3879^C (237)
MOR (N/mm^2)	38.58^A (4.9)	39.5^A (4.7)	32.28^B (2.3)
TS perpendicular to face (N/mm^2)	0.68^B (0.02)	0.8^A (0.1)	0.6^C (0.04)
Face screw withdrawal (N)	1512.98^A (57.84)	1412.81^B (18.82)	1355.2^C (38.87)
Edge screw withdrawal (N)	731.12^C (26.95)	773.32^B (14.46)	845.46^A (15.1)

Means with the same letter within the same row are not significantly different. Numbers in parentheses are standard deviations from the sample mean.

The MOE and MOR of the BW_{ply} plywood were higher than that of the plywood made from spruce (5176 N/mm^2 and 37.3 N/mm^2)[14] and douglas-fir (890 N/mm^2 and 16 N/mm^2)[19]. Higher mechanical strength of bamboo might be the cause of this higher MOE in bamboo based plywood and bamboo possesses higher mechanical strength probably due to the larger fiber length and thick cell wall of bamboo fibers which affects the mechanical properties of the products[20]. Lakkad and Patel[21] reported that bamboos composed of cellulose fibers embedded in a matrix of lignin and these fibers are oriented along the length of bamboo which ensures maximum strength and rigidity.

The mean tensile strength perpendicular to surface of BW_{ply}, B_{ply} and W_{ply} panels were 0.8, 0.68 and 0.6 N/mm^2 respectively (table 2). The result indicates that BW_{ply} showed surprisingly superior tensile strength when compared to the B_{ply} and W_{ply}. This variation is due to the higher mechanical interlocking by urea formaldehyde resin between the bamboo mat and wood veneer. It is observed that the tensile strength of the BW_{ply} was substantially higher than that of the *Gmelina arborea* plywood (0.66 N/mm^2)[9].

The mean face and edge screw withdrawal force of BW_{ply}, B_{ply} and W_{ply} plywood were presented in table 2. The higher mean value of face and edge screw withdrawal were found for B_{ply} and W_{ply} respectively. It is observed the mean face screw withdrawal force of BW_{ply} plywood was lower than that of southern pine plywood (1987 N) but higher than douglas-fir plywood (1173 N)[13]. The face screw withdrawal force of plywood increased with the increase of the panel density and this result supports by the result of Khalil *et al.*[22]. Depending on the type of tree from which the materials were produced, the moisture content, the orientations of grains and sections, the duration of extraction, the method of screwing, the dimensions and the surface smoothness the withdrawal strength of screw varies[23]. Khalil *et al.*[22] stated that withdrawal strength of screw also influenced by the glue type and layer thickness of the plywood.

Conclusion

This study investigated the potentiality of using bamboo mat and simul wood veneer in the manufacture of 5-ply BW_{ply} plywood and its basic physical and mechanical properties. On the basis of the physical and mechanical properties, it appears that manufacturing of BW_{ply} plywood is technically feasible for various structural purposes. The specific conclusions of the study are as follows: i. Due to the alternative assembling of bamboo mat and wood veneer in BW_{ply} plywood improved MOR and tensile strength was found, when compared with both B_{ply} and W_{ply} plywood. ii. Differences in the physical and mechanical properties among the plywoods are due to the raw material characteristics. Therefore, the properties of plywood are species dependent. iii. Compared to the commercial plywood, BW_{ply} showed higher physical and mechanical properties except the edge screw withdrawal.

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