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Comparative Study on Physical and Mechanical Properties of Plywood Produced from Eucalyptus (*Eucalyptus camaldulensis* Dehn.) and Simul (*Bombax ceiba* L.) Veneers

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Abstract

Plywood becomes very important material for various structural purposes in Bangladesh and used as a substitute of solid wood. Therefore, the objective of this study was to determine and compare the physical and mechanical properties of plywood produced with veneers of eucalyptus and simul tree. The commercial urea formaldehyde resin was used for fabricating the panels. Physical properties i.e., density, moisture content, water absorption and thickness swelling; and mechanical properties i.e., modulus of elasticity (MOE) and modulus of rupture (MOR) of the panels were determined according to the procedure of ASTM standards. It was found that the density of eucalyptus and simul plywood was 879 and 536 kg/m^3 respectively. Further, it was also observed that MOE and MOR of eucalyptus plywood were almost 2 and 2.5 times higher respectively than those of simul plywood. These differences were attributed to the variation in properties of veneer wood species and the effect of veneer wood species on some physical and mechanical properties of plywood was found statistically different.

Key words: *Eucalyptus camaldulensis, Bombax ceiba,* plywood, physical properties, mechanical properties.

Introduction

Wood is one of the earth's most important renewable building materials which can be used for different purposes as the properties of wood are comparable to those of other structural materials. Hence, with the modernization throughout the world, the utilization of woody materials increases day by day for making furniture, paper, wood based composites etc. in Bangladesh and are resulting in large quantities of woody raw material consumption by the processing industries. But forest degradation and deforestation occurs as a result of increased demand for wood products results in shortage of wood[1,2]. In-addition, solid wood goes through the three crucial drawbacks such as material anisotropy and heterogeneity, insufficient dimensional stability in the course of changes in the moisture content and problems in creating large areas and forms[3]. Therefore, to meet this ever increasing demand and overcome the crucial drawbacks of using solid wood, it is essential to use appropriate production techniques for the best yield. Therefore, plywood has been developed as an alternative to solid wood because it can overcome the three crucial drawbacks of solid wood by their cross banded construction arrangement[4]. Besides adhesive, wood is the primary raw material for plywood manufacturing. Though, it can be produced from small sized logs but the logs should be straight and defect free to ensure the quality of the plywood. Moreover, plywood has clear-cut advantages over the solid because of its cross banded construction as reported by Baldwin[5]. Thus, production of plywood from eucalyptus is perhaps one such approach to ensure the proper utilization of eucalyptus wood.

Eucalyptus plantations are being raised over an area of 8 million ha in the world[6]. It grows in poor and dry soil and is fast growing in nature with a high level of resistance against diseases. After seven years, some species of eucalyptus can reach 35m in height[7]. In 1930, *Eucalyptus camaldulensis* was introduced in Bangladesh from Australia and used for plantation throughout the Bangladesh by the farmers[8]. It becomes very popular for fuel wood because of its fast growing nature. But the use of these valuable eucalyptus wood remains restricted in only as fuelwood because of the limited research on the utilization of wood[9]. However the usage of the eucalyptus wood is very limited in Bangladesh. But eucalyptus becomes a subject of interest as raw material for wood composite panels in many tropical and subtropical countries including Thailand, Chile, Brazil and Malaysia[7]. In this study, the physical and mechanical properties of plywood produced from Eucalyptus and Simul veneers were characterized and the results were compared with each other. These species were chosen because eucalyptus reaches the suitable diameter in a short time with a straight bole and the simul wood has been used mostly to produce rotary cut veneer for manufacturing plywood in Bangladesh.

Material and Methods

Panel manufacturing: Some physical and mechanical properties of plywood obtained from eucalyptus and simul veneers were compared. Eucalyptus and simul logs had an average age of 5 years and diameter of 25-30 cm were collected from Manikgonj district in Bangladesh. Eucalyptus logs were steamed at 60-70°C for 20 hours before rotary cutting. The thickness of the veneers was 2.6 mm for both the species. The veneers were dried to the moisture content of 4 to 6% by an automatic roller track veneer drier. Five (5) ply plywood was manufactured where urea formaldehyde (UF) resin was applied to the alternative layers (glue line method) for both types of veneers by a glue spreader with a rate of 300 g/m^2. Table 1 illustrated the ingredients of UF resin. It was then hot pressed for 15 minutes at a temperature of 115°C with 9 N/mm^2 pressure according to Rahman et al.[2]. The expected thickness of the panel was 1.2 cm. The panels were trimmed into 240 cm × 120 cm with a circular saw and sanded by a 80 grade sand paper by a belt sander.

Evaluation of plywood properties: Before going to sample preparation, the panels were conditioned in a conditioning chamber at a temperature of 23°C and a relative humidity of 65±2% for 48 hours. Samples were prepared according to the ASTM D 1037-93 standard for physical and mechanical properties testing[10]. 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.

Table-1
Formulation of UF adhesive mixture

Ingredients of Adhesive	Quantity (%)
Liquid UF resin (solid content 58%)	82
Wheat flour	17.5
NH_4Cl	0.5

Physical properties: The density and moisture content of plywood was measured based on the ovendry weight, which was obtained after drying the samples at 103±2°C until constant weight is reached. The weight of the samples of each board was measured by an electrical balance. The dimensions of each test sample were measured using a digital slide caliper, and thus volume of the samples was calculated by multiplying the length, width and thickness of the samples.

Density (D) was determined from the mass and volume of each sample by the following equation:

$$D = \frac{m}{v}$$

Where m is the mass v is the Volume of the plywood sample.
Moisture content (mc) was calculated by the following equation:

$$mc(\%) = \frac{m_{\text{int}} - m_{od}}{m_{od}} \times 100$$

Where m_{int} initial mass (g) and m_{od} is the oven-dry mass of the plywood sample (g).

In this study the 24 h water soak test determines the water absorption behavior of the panels and the effects of the absorbed water on panel thickness. The water absorption and thickness swelling was measured by the difference in weight and thickness of the samples respectively, before and after 24 hrs immersion in water. The water absorption (A) and thickness swelling (G) of the samples were calculated as percentages and are measured by using electrical balance and digital slide calliper respectively.

The water absorption was calculated by the following equation:

$$A(\%) = \frac{m_2 - m_1}{m_1} \times 100$$

Where m_2 is the weight of the sample after immersion in water and m_1 is the weight of the sample before immersion in water.

The thickness swelling was calculated using the following equation:

$$G(\%) = \frac{A_2 - A_1}{A_1} \times 100$$

Where A_1 is the thickness before the test and A_2 is the thickness (mm) after the test.

Mechanical properties: MOE and MOR were measured following the three point bending test by using universal testing machine IMAL-IB600 according to the ASTM D 1037-93 standard[10]. Plywoods were cut into rectangular sections for determining MOE and MOR. The dimension of each plywood sample was 240 mm × 50 mm × 12 mm. MOE and MOR were calculated using the following equations:

$$MOE = \frac{P^{/} L^3}{4 \Delta^{/} bd^3}$$

$$MOR = \frac{3\, PL}{2\, bd^2}$$

In both equations, b is the width of sample (mm); d is the thickness (depth) of sample (mm); P' is the load at proportional limit (N); Δ′ is the center deflection at proportional limit load (mm); MOE is the modulus of elasticity (N/mm^2); MOR is the modulus of rupture (N/mm^2); L is the length of span (mm); P is the static bending maximum load (N).

Statistical Analysis: For the different plywood properties, general statistical description including average and standard deviation were determined. The significance of different treatments was determined by using unpaired t-test ($\alpha \leq 0.05$) and the data analysis was carried out by using the SPSS software package.

Results and Discussion

Density: Density is the characteristic property of plywood that explains the plywood strength. It was found that, the average density of eucalyptus and simul plywood was 879 and 536 kg/m^3 respectively (table 2). From statistical analysis (table 2) it was found that the density of eucalyptus and simul plywood is significantly different. This variation is mainly attributed to the raw material's density that affects the plywood density as the manufacturing condition was same for both types of plywood. Based on the oven dry volume, the specific gravity value for eucalyptus is 0.68 as reported by Kabir *et al.*[9] while the value of simul is 0.34[11]. Tenorio *et al.*[12] 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. Moreover, according to ASTM standards[13] and Franz *et al.*[14], the density of standard plywood is 430 kg/m^3 to 794 kg/m^3. Therefore, the plywood made from eucalyptus follows the standard. It was also observed that the mean density of eucalyptus plywood was substantially higher than that of bamboo mat-wood veneer plywood (694 Kg/m^3)[2], southern pine plywood (514.24 kg/m^3), douglas-fir plywood (512.64 kg/m^3)[15], *Gmelina arborea* plywood (516 kg/m^3)[12] and spruce plywood (475.99 kg/m^3)[4] but lower than that of bamboo mat plywood (939.96 Kg/m^3) and garjan-bamboo plywood (938.89 Kg/m^3)[16].

Moisture content: Dimensional stability of lignocellulosic materials is closely related to moisture content. After curing it was found that, the moisture content was 7.4 and 15.5% respectively for eucalyptus and simul plywood and it was also observed that the moisture content of two types of plywood is statistically different (table 2) . This may be due to the variation in density of plywood i.e., higher density of plywood restricts moisture uptake because higher board density results in a lower number of pores in the plywood. According to ASTM standard[13] and Franz *et al.*[14], the moisture content of standard plywood is 7.30 % to 12.70 %. Therefore, the plywood made from eucalyptus follows the standard. The moisture content of eucalyptus plywood (7.4%) was substantially lower than that of bamboo mat-wood veneer plywood (11.7%)[2], bamboo mat plywood (10.73%) and garjan-bamboo plywood (10.51%)[16], Gmelina arborea plywood (12.35%)[12] but it was higher than Spruce plywood (6.47%)[17].

Water absorption: When water absorption of eucalyptus and simul plywood was compared, it was observed that the mean value of water absorption followed the same trend of moisture content. Table 2 showed the mean water absorption of two types of 12 mm thick plywood after 24 hours immersion in water. The mean water absorption of eucalyptus plywood (36.9%) was significantly lower than that of simul plywood (65.4%) suggesting that the eucalyptus panels are less susceptible to water absorption than the simul panels. According to the result of t-test, the differences between water absorption of panels made of eucalyptus and simul veneers were found to be significant when t-value is -8.82 (table 2). This variation in water absorption is mainly attributed to the difference in holocellulose (cellulose and hemicelluloses) content of the studied veneer species. Due to the presence of free –OH group in the molecular structure, cellulose and hemicelluloses are responsible for water absorption as reported by Wardrop[18]. The Holocellulose content of eucalyptus wood is 55.6% as reported by Dutt and Tyagi[19] where as simul wood contains 75%. Thus, the lower holocellulose content of eucalyptus wood compared to simul wood might restrict the absorption of water in eucalyptus panels. The water absorption of eucalyptus plywood (36.9%) were lower than that of bamboo mat plywood (37.03%)[16] but it was higher than bamboo mat-wood veneer plywood (30.83%)[2], garjan-bamboo plywood (34.24%)[16].

Thickness swelling: It was found that the trend of thickness swelling was similar to the trend of water absorption of eucalyptus and simul plywood (table 2). Thickness swelling is independent of panel size and thickness of veneer as stated by Kelly[20]. When the thickness swelling values were compared, the mean value of eucalyptus plywood (1.5%) was evidently lower than that of simul plywood (2.9%) (table 2). From the statistical analysis, it was also observed in this study that, higher density and lower water absorption of eucalyptus plywood lead to a decrease in thickness swelling (table 2), than those of eucalyptus panels. Again this variation in thickness swelling is mainly due to the difference in holocellulose content of eucalyptus and simul wood. Dutt and Tyagi[19] found 55.6% holocellulose for eucalyptus wood, while simul wood consists of 75% holocellulose. It was also observed in this study that, higher density and lower water absorption of eucalyptus plywood lead to a decrease in thickness swelling. Therefore, the thickness swelling varies with the types of panels i.e., with veneer species though they are produced by maintaining the same manufacturing conditions. Further, thickness swelling of eucalyptus plywood (1.5%) was substantially lower than that of bamboo mat-wood veneer plywood (2.5%)[2], bamboo mat plywood (5.73%) and garjan-bamboo plywood (5.46%)[16].

Table-2
Physical properties Eucalyptus and Shimul Plywood

Physical Properties	Eucalyptus Plywood	Simul Plywood	t-value	Significant
Density (Kg/m^3)	879 (10.2)	536 (21.3)	45.794	*
Moisture content (%)	7.4 (1.6)	15.5 (1.4)	-11.771	*
Water absorption (%)	36.9 (3.82)	65.4 (9.4)	- 8.81897	*
Thickness swelling (%)	1.5 (0.6)	2.9 (0.7)	1.603	*

Numbers in parentheses are standard deviations from the sample mean. * indicates significantly different values within the same row.

Modulus of Elasticity (MOE): MOE of eucalyptus and simul plywood was 7879 and 3870 N/mm^2, respectively (table 3). The

MOE of eucalyptus and simul plywood were statistically different according to the unpaired t-test applied to compare the effect of wood species on the MOE of two types of 12mm thick plywood. Moreover, higher plywood strength results from the higher plywood density as seen in table 2 and 3, because there is a close correlation exists between density and mechanical properties. Thus, the results also indicated that the eucalyptus plywood posses almost 2 times higher MOE (7879 N/mm^2) than those of simul plywood (3870 N/mm^2). According to ASTM[13], MOE of the standard plywood ranges from 6,890 to 13,100 N/mm^2. The APA[21] requirements for MOE of the standard plywood is little higher than that of ASTM. The MOE of simul panels were below than the standards but the MOE of eucalyptus panels meet the requirements of both standards. Eucalyptus plywood in this study also showed higher MOE than those of previous researches on plywood includes bamboo mat-wood veneer plywood (5276 N/mm^2)[2], spruce (5176 N/mm^2)[4] and douglus-fir (890 N/mm^2)[22] but it showed lower MOE than bamboo mat plywood (8110.02 N/mm^2) and garjan-bamboo plywood (8041.09 N/mm^2)[16].

Table-3
Mechanical properties of Eucalyptus and Shimul Plywood

Mechanical Properties	Eucalyptus Plywood	Simul Plywood	t-value	Significant
MOE (N/mm^2)	7879 (1588)	3870 (288)	7.85	*
MOR (N/mm^2)	68.6 (9.6)	26.91 (1.61)	13.675	*

Numbers in parentheses are standard deviations from the sample mean. * indicates significantly different values within the same row.

Modulus of Rupture (MOR): The trend of MOR was similar to the trend of MOE for eucalyptus and simul plywood (table 3). It was observed that the MOR of eucalyptus plywood was 2.5 times higher than those of simil plywood. The mean value of eucalyptus and simul plywood was 68.6 and 26.91 N/mm^2 respectively and these values are significantly different (Table 3). According to ASTM[13] and APA[21], MOR of the standard plywood should ranges from 20.7 to 48.3 N/mm^2 and 21.4 to 49.8 N/mm^2, respectively. Therefore, MOR of simul plywood was within the ranges of MOR but the MOR of eucalyptus plywood was above the range. The MOR of eucalyptus plywood was higher than that of bamboo mat-wood veneer plywood (39.5 N/mm^2)[2], garjan-bamboo plywood (67.16 N/mm^2)[16], spruce plywood (37.3 N/mm^2)[4] and douglus fir (16 N/mm^2)[22] but MOR was lower than that of bamboo mat plywood (89.62 N/mm^2)[16].

Conclusion

In this study, 5-ply plywood panels were produced from eucalyptus and simul veneers by using UF resin as binder and properties of the panels were tested to compare the physical and mechanical properties. The results indicate that the manufacturing of eucalyptus plywood is feasible in terms of studied physical and mechanical properties. The properties of eucalyptus plywood meet the minimum requirements of ASTM and APA standards. The specific conclusions of this study are as follows - the plywood produced from eucalyptus and simul veneers showed difference in physical properties i.e., density, moisture content, water absorption and thickness swelling. Eucalyptus plywood showed superior physical properties compared to simul plywood. It was also found that the studied mechanical properties i.e., MOE and MOR were higher for eucalyptus plywood compared to the simul plywood. Finally, the obtained variation in physical and mechanical properties of eucalyptus and simul plywood were due to the difference in inherent characteristics of veneer wood species (eucalyptus and simul wood).

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