*J. Bamboo and Rattan,* Vol.8, Nos. 3&4, pp. 131-141 (2009)

# Development of bamboo laminates from *Bambusa balcooa* and *Bambusa vulgaris*, two native species of Bangladesh

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**Abstract**: A continuous decline in wood resources has triggered research interest in alternative raw material search for wood based industries in Bangladesh. Bamboo, a fast growing, renewable, economical and easily workable material, could be a very promising alternative to wood raw material. Two local bamboo species, *Bambusa balcooa* and *Bambusa vulgaris,* have been studied for their suitability for the manufacture of bamboo laminates. A culm portion up to 5.4 m and 3.6 m (from the base) were used to get rectangular strips for laminate production of *B. balcooa* and *B. vulgaris* respectively. Various preservative treatments like borax-boric acid, bleaching and carbonization were given to the strips for extending the service life of the laminates. Three-layered bamboo laminates of 12 mm thickness were made at two different grain orientations (parallel and cross) using the treated strips. Urea formaldehyde (UF) and polyvinyl acetate (PVA) were used as binder. The parallel laminates glued with both UF and PVA had higher mechanical properties like modulus of rupture and modulus of elasticity compared to cross laminates. However, parallel laminates glued with PVA were less dimensionally stable. Between the species, parallel laminates made from *B. vulgaris* performed better. Laminated bamboo falls under moderately high strength category. It could be used as structural panel, flat pack furniture component, floor tiles, wall panel, *etc.* However, further research on durability and creep behavior of the product in service condition is warranted.

*Keywords*: *Bambusa balcooa, Bambusa vulgaris,* bamboo laminates, polyvinyl acetate, urea-formaldehyde.

## INTRODUCTION

Human beings depend to a large extent on wood resources for their everyday living. The increasing needs of growing population and environmental awareness have put severe restrictions on the management of forest resources in Bangladesh. This has resulted in shortage of wood required in housing, transport and other sectors. People are becoming more dependent on plastic goods, ceramic fittings with aluminium, and

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steel made items to meet their needs. However, these non-wood alternatives have serious limitations on account of non-sustainability, high-energy requirements and non-bio-degradability. In this situation there is an urgent need for development of sustainable and environment friendly wood alternatives. Bamboo, a fast growing giant grass, occurring mostly in the tropics as well as in the subtropical and temperate regions, except Europe, is fast emerging as a highly potential natural and renewable material to fill the void. Apart from being available in natural forests, bamboo is also raised as plantations, both pure and in mixture, and also in homesteads. Bamboo is also suitable for restoration of degraded forest and other wastelands as well as of abandoned shifting cultivated areas.

Since 1980s, guided by dwindling wood supplies in the tropics, interest on bamboo as an alternative material has intensified resulting in its emergence as potentially the most important non-wood renewable fibre to replace wood in construction and other uses. Bamboo produces biomass faster than many fast growing timber and its physical and mechanical properties are superior to wood available from fast growing plantation species (Latif *et al.*, 1990; Lee *et al.*, 1994; Yuming and Jian, 1994). These characteristics have given rise to worldwide interest on theoretical and applied research for bamboo based products to replace wood in housing, furniture, packaging and transport sectors. Recently, the glue laminated technology has helped boosting the utilization of bamboo in advanced architectural purposes (Zheng *et al.,* 2003; Hunter, 2003) and for fabrication of furniture (Zhangfa and Quisheng, 2002). It has been assumed that bamboo product will become one of the leading commodities for foreign exchange earnings in the global forestry sector (Yan, 2004). The environmental and socioeconomic implications of bamboo based panel industries also favour their promotion on priority.

Bamboo grows naturally in the forests and is also cultivated in the villages of Bangladesh like other countries of the tropics (Banik, 2000), but development of composites like laminates and particleboard using bamboo is not commonly practised in the country. Some earlier studies have revealed that bamboo in panel form is best suited to substitute wood and, therefore, development of cost effective technologies to produce bamboo based panels is now identified as an extremely important area of research in Bangladesh. With this aim in view, the study has been undertaken to find out the suitability of *Bambusa balcooa* and *Bambusa vulgaris*, the two local bamboo species, for the development of bamboo laminates.

## MATERIALS AND METHOD

### Strip preparation

*B. balcooa* and *B. vulgaris* culms were collected from Nazirhat, a village in Chittagong district, Bangladesh. 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. At first, the selected culms were cross cut into 0.6 m long pieces and submersed under water. After 3 weeks of submersion the pieces were air-dried to lower the moisture content around 20 per cent. Then each of the dried pieces was splitted manually into 6 fragments. These were then converted into uniform rectangular strips.

### Strip preservation

The strips contain nutrients that provide excellent nourishment for insects and fungi. So, for ensuring extended service life of the laminates, the following three treatments were given to the strips.

#### *Borax-boric acid treatment*

A 5 per cent 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 easier and uniform distribution

#### *Bleaching*

In this process, hydrogen peroxide solution was used as bleaching agent. In addition 2.54 per cent boraxñboric 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 per cent hydrogen peroxide (v/v) was added gently. The strips were bleached for 2 h maintaining a temperature of 80∞C. In this operation the colour differences between various strips were minimized.

#### *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.

### Panel making and testing

The moisture content of the strips became high after each treatment. The treated strips were dried in open air until they attained equilibrium moisture content (EMC). The dried strips were glued with two types of organic binders such as urea formaldehyde (UF) and polyvinyl acetate (PVA). The UF resin in powder form was imported from Iran under the brand name Samino 800. At first the powder glue was mixed with water and extended with 15 per cent flour. Then 2 per cent liquor ammonia was added. Finally, the prepared glue was catalyzed with ammonium chloride. The PVA was collected from local market under the brand name New diamond gum CC-66 manufactured by Synthetic Adhesives Ltd., Chittagong. It is sold in the market as a ready to use glue and did not require the addition of an extender or a hardener.

Three layered parallel and cross laminates of 12 mm thick were constructed separately with the treated strips. In the case of parallel laminates, the core layer was placed parallel to those of the outer layers (face and back) and for cross laminates, the core layer was placed perpendicular to those of outer layers. For each variable, three replicate boards were produced. The assemblies were pressed at room temperature for 24 h maintaining pressure of 1 $N/mm^2$. Test samples were prepared and then conditioned to attain uniform moisture content of about 9 to 10 per cent before testing. The modulus of rupture (MOR), modulus of elasticity (MOE), hardness, thickness, swelling and water absorption were measured in accordance with ASTM standards ASTM D3043 (2000); ASTM D1037 (1999).

## RESULTS AND DISCUSSION

### Strip Colour

The colour of *B. vulgaris* strips was yellowish brown and that of *B. balcooa* was reddish brown. The preservative treatments changed the colour of the strips. Boraxñ boric acid treated strips of *B. vulgaris* were slightly reddish brown with bright appearance and the clear bamboo grain were seen. Under the same treatment, *B. balcooa* strips were 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 colour of *B. vulgaris* strips turned into yellowish white. Visually, *B. vulgaris* strips were brighter compared to *B. balcooa* strips which revealed that colour change due to bleaching was species dependent. Carbonization produced dark brownish strips having coffee flavour.

### Panel properties

Bamboo laminates were made from treated strips of *B. balcooa* and *B. vulgaris* using PVA and UF as binder. Various properties like density, MOR, MOE, hardness, per cent thickness swelling and water absorption characteristics of the laminates were evaluated to assess the suitability of the products for their end-uses.

### Density

The results for the laminates made from *B. balcooa and B. vulgaris* are given in Table 1. The density values of the cross laminates from both the species were higher than the parallel laminates for all the treated strips. Similar results were reported by Zheng *et al.* (2003). PVA used laminates were denser than UF glued products because of the higher viscosity of the former binder. The viscosity values ranged from 2000 to 3000 cp at 21∞C (Kim and Kim, 2005) for PVA whereas, it was in the range of 200 to 300 cp for UF. Moreover, UF glue was applied by glue spreader, whereas PVA was

**Table 1.** Mechanical properties of bamboo laminates made from treated strips

| Species | Glue used | Treatments | Properties | | | | |
|---|---|---|---|---|---|---|---|
| | | | Grain orientation | Density (kg/m$^3$) | Modulus of rupture (N/mm$^2$) | Modulus of elasticity ×100 (N/mm$^2$) | Hardness (N) |
| | | | | Mean | Mean | Mean | Mean |
| *B. balcooa* | PVA | Borax-boric acid | Cross | 734 | 94 | 104 | 5752 |
| | | | Parallel | 733 | 119 | 101 | 5646 |
| | | Bleaching | Cross | 730 | 92 | 121 | 5338 |
| | | | Parallel | 716 | 98 | 121 | 5197 |
| | | Carbonization | Cross | 693 | 70 | 96 | 5034 |
| | | | Parallel | 674 | 93 | 99 | 3521 |
| | UF | Borax-boric acid | Cross | 719 | 79 | 110 | 6100 |
| | | | Parallel | 682 | 117 | 119 | 6042 |
| | | Bleaching | Cross | 681 | 91 | 145 | 6100 |
| | | | Parallel | 677 | 114 | 158 | 5566 |
| | | Carbonization | Cross | 681 | 72 | 113 | 5465 |
| | | | Parallel | 657 | 109 | 117 | 4330 |
| *B. vulgaris* | PVA | Borax-boric acid | Cross | 719 | 131 | 107 | 7026 |
| | | | Parallel | 709 | 167 | 108 | 6161 |
| | | Bleaching | Cross | 705 | 110 | 122 | 6446 |
| | | | Parallel | 697 | 139 | 130 | 5983 |
| | | Carbonization | Cross | 680 | 90 | 87 | 5078 |
| | | | Parallel | 669 | 125 | 115 | 3462 |
| | UF | Borax-boric acid | Cross | 711 | 138 | 118 | 7536 |
| | | | Parallel | 701 | 164 | 119 | 6613 |
| | | Bleaching | Cross | 683 | 121 | 143 | 7026 |
| | | | Parallel | 678 | 133 | 145 | 6613 |
| | | Carbonization | Cross | 680 | 88 | 103 | 5328 |
| | | | Parallel | 661 | 122 | 109 | 4382 |
| [1]Laminated bamboo lumber | | | | | | | |
| *Phyllostachys pubescens* | | | - | 620 - 660 | 71.3 | 80.2 | |
| [2]Bamboo wood (vertical laminate*)* | | | | | | | |
| *B. bamboos* | | | - | 715 | 75.0 | 109.7 | |
| [3]Bamboo floors | | | - | - | 90.0 | - | |
| [4]Teak (*Tectona grandis*) | | | - | 604 | 100.8 | 131 | |

Note: MOR ñ Modulus of rupture; MOE ñ Modulus of elasticity
[1]Lee *et al*., 1998; [2]Anon, 2005; [3]Quisheng *et al*., 2003; [4]Sattar *et al.,* 1999

spread with a spade as uniform glue spreading was not possible in case of PVA. Among the treatments, laminates made of carbonized strips showed the lowest density for both the species. This was due to the removal of highest amount of water soluble hemicelluloses along with other wood components during carbonization compared to other treatments (Biswas, 2008).

## Modulus of rupture

The effect of treatments such as borax-boric acid, bleaching and carbonization on

MOR of laminates made with PVA and UF are given in Table 1. Parallel laminates exhibited higher MOR values for both PVA and UF than cross laminates. The possible explanation was that in these 3-ply panels, the upper ply of both cross and parallel laminates was in compression and the lower ply was in tension. The compressive and tensile stresses were theoretically nil in the middle ply. When load was applied on the middle of the span, the sample started to deflect from the horizontal direction causing a shortening of the fiber on the upper ply, and an elongation of those on the lower ply. As the load increased, compression failure developed on the upper ply and the middle ply moved towards the lower one. At the same time, there was stress development on the interphase of the glue line and the bamboo substrate that caused failure. As the failure depends on the visco-elastic behaviour of the glue line and the fiber orientation, failure occurred earlier in the case of cross laminates.

For cross orientation, the strength reduction for *B. balcooa* was 21 per cent for borax-boric acid treatment, 6 per cent for bleaching and 25 per cent for carbonization in the case of PVA glue. For UF glue, the reduction became 32 per cent for borax-boric acid treatment, 20 per cent for bleaching and 34 per cent for carbonization. In the case of *B. vulgaris,* the decrease was 22 per cent for borax-boric acid treatment, 21 per cent for bleaching and 28 per cent for carbonization for PVA glue. The reduction was 16 per cent for borax-boric acid treatment, 9 per cent for bleaching and 28 per cent for carbonization for UF laminates. It seemed that the decrease of strength was very high for carbonized strips. High temperature during carbonization delignified the fibers to some extent which in turn lowered stiffness of the bamboo resulting lowest MOR. Zheng *et al*. (2003) also found similar results for Yunnaicus and Pubescens bamboo. Analysis of variance (ANOVA) showed the effect of the variables like species, grain orientation and treatment, were highly significant. However, the interaction of all the variables was not significant (Table 3). Alipon *et al*. (2001) concluded that bamboo laminates made from *Bambusa blumeana* and *Dendrocalamus asper* fell under class 2 (moderately high strength) according to FPRDIís (Forest Products Research and Development Institute) strength classification due to its high bending strength. In this study the parallel laminates made from borax-boric acid treated strips of *B. balcooa* and *B. vulgaris* performed better compared to *B. blumeana* and *D. asper*. These materials could find use in places where medium to moderately high strength is required.

### Modulus of elasticity

The modulus of elasticity (MOE) of the laminates made from treated strips of *B. balcooa* and *B. vulgaris* with PVA and UF glues are given in Table 1. Similar trends, as seen in the case of MOR, were observed for MOE due to grain orientation. However, the difference was not that noticeable. Zheng *et al.* (2003) also observed such effects. Analysis of variance showed insignificant effect of interaction for four variables such as species, glue, grain orientation and treatments. It was seen that like MOR, elasticity of laminates made from carbonized strips was the lowest compared to other two treatments for both the species.

### Hardness

Mean hardness values of *B. balcooa* and *B. vulgaris* laminates made with PVA and UF in both parallel and cross grain arrangement are given in Table 1. Unlike MOR and MOE, the laminates made with cross grain orientation were harder than parallel grain orientation in all the cases. The probable reason was that during hardness test the hemispherical end of a steel rod (11.28 mm in diameter imbed into a panel to a depth of 5.64 mm) needed to penetrate through the middle ply of bamboo. In the case of parallel grain orientation, less force was required for crossing the upper ply and to penetrate the middle ply as the bamboo had low resistance to splitting along the grain and could split easily. For panels with cross grain orientation, more force was needed for penetration as the grain orientation of the middle layer was perpendicular to both top and bottom layers. For *B. balcooa* incremental percentage was 2 per cent for borax-boric acid treatment, 3 per cent for bleaching and 43 per cent for carbonization in the case of PVA glue. The incremental percentages became 1 per cent for borax-boric acid treatment, 10 per cent for bleaching and 26 per cent for carbonization for UF glue. In the case of *B. vulgaris,* the values were 14 per cent for borax-boric acid treatment, 8 per cent for bleaching and 47 per cent for carbonization for PVA glue. For UF laminates, these were 14 per cent for borax-boric acid treatment, 6 per cent for bleaching and 22 per cent for carbonization (Table 1). It showed that the anatomical character of species along with treatments had significant influence on this property. Lee and Liu (2003) evaluated the hardness and the hardness reduction of laminated bamboo lumber (LBL) and found higher hardness value for both natural and carbonized bamboo flooring than red oak flooring. Simultaneously, they pointed out that carbonization did not affect the hardness value. However, they did not mention the treatment schedule (temperature and time). The results differed from the present investigation. However, no significant effect was seen for equal interaction of four variables.

### Thickness swelling and water absorption

The thickness swelling and water absorption values of *B. balcooa* and *B. vulgaris* panels made with PVA and UF after 2 h and 24 h of water immersion are given in Table 2. It was found that percentage swelling increased with the increase of soaking time for all the treatments and the binders. Analysis of variance showed, the effect of every single variable was visible in the case of thickness swelling. After 24 h of soaking time, the interaction of all the variables on thickness swelling property became significant only at 5 per cent level of probability. Considering grain orientation, the cross laminated panel showed slight increase in thickness swelling. Zheng *et al.* (2003) also observed that the thickness swelling of cross panels was higher than parallel

**Table 2.** Dimensional stability of bamboo laminates made from treated strips

| Species | Glue used | Treatments | Grain orientation | Dimensional stability | | | |
|---|---|---|---|---|---|---|---|
| | | | | Thickness swelling (%) | | Water absorption (%) | |
| | | | | 2 h | 24 h | 2 h | 24 h |
| | | | | Mean | Mean | Mean | Mean |
| *B. balcooa* | PVA | Borax-boric acid | Cross | 1.7 | 3.6 | 10.2 | 27.0 |
| | | | Parallel | 1.2 | 3.2 | 9.6 | 23.7 |
| | | Bleaching | Cross | 2.5 | 7.1 | 12.9 | 39.0 |
| | | | Parallel | 2.1 | 6.9 | 12.6 | 39.1 |
| | | Carbonization | Cross | 6.0 | 9.9 | 24.5 | 45.0 |
| | | | Parallel | 5.1 | 8.7 | 23.9 | 44.3 |
| | UF | Borax-boric acid | Cross | 1.6 | 3.7 | 11.2 | 26.9 |
| | | | Parallel | 1.2 | 3.0 | 11.1 | 25.3 |
| | | Bleaching | Cross | 2.7 | 6.3 | 14.7 | 33.3 |
| | | | Parallel | 2.2 | 7.3 | 12.5 | 32.9 |
| | | Carbonization | Cross | 5.9 | 7.5 | 23.8 | 36.8 |
| | | | Parallel | 4.9 | 6.0 | 17.7 | 33.9 |
| *B. vulgaris* | PVA | Borax-boric acid | Cross | 1.6 | 4.9 | 11.4 | 23.2 |
| | | | Parallel | 1.4 | 3.6 | 10.1 | 22.4 |
| | | Bleaching | Cross | 1.7 | 5.0 | 12.8 | 25.7 |
| | | | Parallel | 1.4 | 4.8 | 11.0 | 24.4 |
| | | Carbonization | Cross | 4.5 | 7.1 | 19.4 | 41.1 |
| | | | Parallel | 3.9 | 6.7 | 19.9 | 40.9 |
| | UF | Borax-boric acid | Cross | 1.4 | 3.5 | 11.7 | 22.8 |
| | | | Parallel | 1.3 | 3.4 | 10.9 | 21.2 |
| | | Bleaching | Cross | 2.5 | 5.3 | 14.3 | 26.7 |
| | | | Parallel | 2.0 | 4.3 | 11.6 | 27.0 |
| | | Carbonization | Cross | 4.9 | 7.8 | 22.9 | 37.3 |
| | | | Parallel | 4.7 | 7.4 | 19.3 | 37.0 |

Note: TS ñ Thickness swelling; WA ñ Water absorption

panels for Yunnanicus and Whangee bamboos. However, the magnitude of the value was lower than the present study as they used water proof glue in making panel. Carbonized panels did swell in greater extent for both the species (Table 2). In the present study, strips were carbonized above 130∞C which in turn increased accessibility of water resulting in highest thickness swelling. Secondly, during this treatment owing to high temperature, more water solubles were leached out which ultimately lowered the laminates density (Table 1), and thereby increased the thickness swelling due to higher porosity. Lee *et al.* (1994) conducted an experiment to observe technical feasibility of moso bamboo as a raw material for the manufacture of laminated bamboo. Their observations agreed well with the thickness swelling values for borax-boric acid and bleached panel of *B. balcooa* and *B. vulgaris*.

The amount of water absorbed by the laminate made from the treated strips in two different grain orientations with UF and PVA glue are given in Table 2. Results showed that water absorption values of the laminates made from *B. balcooa* and *B. vulgaris* increased with the increase of immersion time. Statistical analysis showed that effect of species variation, pattern of grain orientation, water repellent property of adhesives and also preservative treatments were highly significant (Table 3). Laminates made from parallel grain orientation absorbed less water. The reason was that in cross grain orientation, the middle ply was arranged at right angles to the top and bottom plies and more openings were available for moisture uptake.

**Table 3.** Effect of species, glue, orientation and treatments, and their interactions on mechanical properties and dimensional stability of bamboo laminates

| Source of variation | DF | Mechanical properties | | | Dimensional stability after 24 h of water soaking | |
|---|---|---|---|---|---|---|
| | | MOR | MOE | Hardness | TS | WA |
| Species (S) | 1 | 1780.8** | 0.02ns | 158.9** | 45.3** | 265.2** |
| Glue (G) | 1 | 0.11ns | 381.0** | 116.8** | 18.2** | 96.3** |
| Orientation (O) | 1 | 1133.5** | 55.7** | 196.4** | 20.8** | 12.1** |
| Treatments (T) | 2 | 436.8** | 570.1** | 481.0** | 433.3** | 961.8** |
| S x G | 1 | 0.05ns | 28.9** | 0.1** | 12.51** | 43.3** |
| S x O | 1 | 15.4** | 3.3ns | 5.4* | 0.04ns | 1.7ns |
| G x O | 1 | 0.3ns | 0.11ns | 2.9ns | 0.6ns | 0.04ns |
| S x T | 2 | 132.8** | 6.8** | 43.1** | 31.7** | 91.0** |
| G x T | 2 | 19.7** | 29.0** | 1.8ns | 0.2ns | 45.4** |
| O x T | 2 | 36.9** | 9.8** | 37.1** | 0.2ns | 1.7ns |
| S x G x O | 1 | 43.4** | 31.5** | 2.7ns | 0.19ns | 0.5ns |
| S x G x T | 2 | 27.2** | 6.2** | 0.14ns | 17.3** | 24.7** |
| S x O x T | 2 | 0.1ns | 8.7** | 6.9** | 0.6ns | 1.0ns |
| G x O x T | 2 | 2.6ns | 11.0** | 3.2* | 1.96ns | 1.0ns |
| S x G x T x O | 2 | 5.6* | 1.4ns | 1.0ns | 3.4* | 1.4ns |
| Error | 48 | | | | | |
| Total | 71 | | | | | |

Note: MOR - Modulus of rupture; MOE ñ Modulus of elasticity; TS ñ Thickness swelling; WA ñ Water absorption
** = significant at 1% level of probability, * = significant at 5% level of probability,
ns = not significant

PVA laminates had higher water absorption values compared to panels made from UF glue as PVA is a thermoplastic adhesives and its water resistance property is poor compared to UF. Laminated bamboo lumber made from *Phyllostachys pubescens* with resorcinol based adhesives showed 32 per cent of water absorption after 24 h of water soaking Lee *et al.* (1998). The value agreed well with the water absorption values of laminates made from borax-boric acid treated strips. Among the treatments, carbonized strips of *B. balcooa* and *B. vulgaris* when glued with PVA or UF absorbed more water compared to borax-boric acid and bleached strips. The maximum value was observed for cross laminates of treated *B. balcooa* strips. Considering thickness swelling and water absorption values, boraxñboric acid treated panel was more dimensionally stable compared to other two treatments.

## CONCLUSIONS

This study indicated the suitability of *B. balcooa* and *B. vulgaris* for making laminated panel. Based on the results the following conclusions were drawn.

- Parallel laminates of both *B. balcooa* and *B. vulgaris* have better MOR, MOE, and dimensional stability compared to cross laminates. The product properties are similar to or even better than teak (*Tectona grandis*), with respect to mechanical strength.

- Carbonization treatment lowered the strength and dimensional stability irrespective of species and binder.

- Borax-boric acid treated strips of both *B. balcooa* and *B. vulgaris a*re suitable for the development of parallel laminates with UF. Between the species, *B. vulgaris* is preferred, as it showed better strength properties. These laminates could be used as structural panel where moderately high strength is required, for flat pack furniture, floor tiles, wall panel among others. However, further research on fastener holding capacity, durability and creep behaviour of the products in service is warranted.

## ACKNOWLEDGEMENTS

We would like to thank Mr. Dipak Bhattacharjee, Ex-Research officer, for his technical advice while using the machines of Seasoning and Timber Physics Division. We are highly indebted to the Bangladesh Forest Research Institute authority for providing logistic support for this research.

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