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Developing cement bonded particleboard from *Bambusa balcooa* and *Bambusa vulgaris*

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Abstract: Laboratory size (500 mm × 500 mm) cement bonded particleboards (CBPBs) with a thickness of 12 mm and densities 1100 kg/m^3 and 1200 kg/m^3 were produced using coarse particles and fines of *Bambusa balcooa* and *B. vulgaris*, two locally grown bamboo species of Bangladesh. The effects of cold and hot water soaking of the bamboo materials prior to board production (2 days in cold water and 3 h in hot water) and coarse –fines ratio on board properties were examined. $CaCl_2$ was used as an additive to accelerate cement hydration. Bamboo particles needed prior soaking to develop acceptable quality boards. Hot water treated particles (50:50 mixture of coarse and fine and 100% coarse particles) from *B. balcooa* produced boards with MOR values comparable to standards at 1200 kg/m^3. The MOR values for boards from *B. vulgaris* were well below the minimum specified for the British standards. The average internal bond strengths of the boards met the standard values only at 1200 kg/m^3 with 100 per cent fines and 50:50 coarse-fines mixtures in case of *B. balcooa*, and only for 100 per cent fines in case of *B. vulgaris*. Hot water treatment reduced both the thickness swelling and water absorption, and the boards from both the species were superior to standards in terms of thickness swelling.

Keywords: *Bambusa balcooa*, *Bambusa vulgaris,* cement bonded particleboard, mechanical properties, dimensional stability.

INTRODUCTION

Cement-bonded particleboard (CBPB), a panel product from particles of wood or other lignocellulosic materials mixed with Portland cement, an inorganic binder, has the characteristics of poured concrete. It has already been recognized as a low cost environmentally-friendly green-building material for its exceptional durability and low maintenance. It is virtually incombustible, rot, fungus and termite proof, highly resistant to water and can be readily machined with normal tools. It has both interior and exterior applications.

Bamboo, a short rotation natural resource in Bangladesh, could be an alternative to

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wood for the development of cement bonded particleboard. In this study we tried to assess the suitability of *Bambusa balcooa* and *B. vulgaris* for the production of cement-bonded particleboard. The product, if suitable, could alleviate the housing problem of low to medium income group people, ensuring simultaneously, maximum utilization of forest resources.

MATERIALS AND METHODS

Raw material collection and processing

The two bamboo species used in this study were collected from Nazirhat, a village in Chittagong district, Bangladesh. The culm length of *B. balcooa* and *B. vulgaris* was 13.1 m and 12.8 m, respectively. The bamboo culm wall is thickest at the bottom and these are used to prepare strips for the production of bamboo laminated panel. The leftover culm portions (above 5.4 m and 3.6 m from the base) of *B. balcooa* and *B. vulgaris*, respectively, were used for the development of cement-bonded particleboard. At first the segments were flattened by local hand tool and then hammer milled to chips. Then the chips were screened to separate the coarse particles and the fines.

About 50 kg of the coarse particles and fines of each bamboo species were soaked in cold water for 2 days in separate tanks. After 24 hours the water was drained and fresh water was added. At the end of the second day, half of the coarse particles and the fines were taken out and dried to equilibrium moisture content. The remaining materials were further treated in hot water at 60°C for 3 hours. The coarse particles and fines were then dried as before. Both the untreated and treated particles (coarse and fines) were used individually and in mixture for making cement bonded particleboard.

Board making

Three replicate particleboards were made at 1100 kg/m^3 and 1200 kg/m^3 density levels from both cold and hot water treated coarse particles, fines, and a 50:50 mixture of coarse and fines. Ordinary Portland cement in the ratio of 30:70 (bamboo: cement) by weight was used as an inorganic binder maintaining 45 per cent moisture content. In order to counteract the effect of bamboo related inhibitory substances on cement hydration, 2 per cent $CaCl_2$ based on cement weight was added as an additive (Irle and Simpson, 1993; Rahim *et al.,* 1996). The selection of cement-bamboo ratio and additive percentage was based on earlier studies (Moslemi and Pfister, 1987; Biswas *et al.* (1997).

At first $CaCl_2$ was mixed with water and then added to bamboo and cement mixture which was then mixed by hand until the bamboo particles were thoroughly coated with cement paste. Cement-coated mixer required for one board was then spread in a wooden forming box (500 mm × 500 mm) and placed on a plywood caul to form a mat. A steel sheet was placed between the plywood caul and the mat for preventing the boards from sticking during pressing. In this way, several mats were formed and stacked one on top of each other, separated by the plywood cauls. The mats were compressed to 12 mm thickness using 1.05 N/mm^2 pressure with the aid of a hydraulic press. The target thickness was achieved by placing wooden stoppers between cauls. After pressing, boards were kept under compression for 24 h. They were then unloaded from the press and conditioned for three weeks for final curing.

Property testing

The conditioned boards were cut into test specimens of sizes 300 mm × 75 mm × 12mm, 50 mm × 50 mm × 12mm and 100 mm × 100 mm × 12mm. Modulus of rupture (MOR) and internal bond strength (IB) of the specimens were assessed according to the British Standards BS 5669 (BS,1989). Thickness swelling and water absorption properties were also measured after the specimens had been immersed in water for various lengths of time (BS,1989; Biswas *et al*., 1997), At first the initial weight and thickness of the specimens were taken for determining thickness swelling and water absopption properties. Then the samples were immersed in cold water. At the end of 2 hours, 1, 2, 3, 15 and 30 day the test specimens were withdrawn from the water, wiped with a cloth, reweighed and remeasured the thickness. The percent thickness swelling as well as percent water absorption was determined.

RESULTS AND DISCUSSION

Initial attempts were made to make CBPBs from untreated bamboo particles and Portland cement, but all the boards were of very poor quality (Fig. 1). In an earlier study Biswas *et al.* (1997) also observed that untreated *Albizia falcataria* chips failed

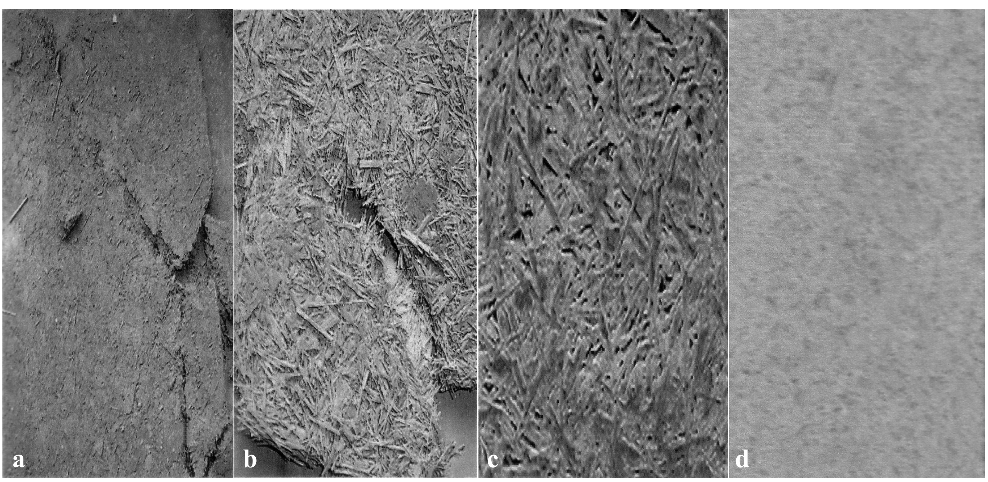

Figure 1. Surface appearance of cement bonded particleboards made from particles of *B. balcooa* (a) untreated fine; (b) untreated coarse; (c) treated coarse and (d) treated fines.

to produce quality boards and concluded that the cold water soluble components (2.97%) present in the wood were responsible for improper curing of cement. Rahim *et al.* (1987) concluded that the sugars present in biomass significantly affect cement curing even at very low concentrations (0.4%). The culm portions of the bamboo species used in this study contained 5.4 to 5.6 per cent cold water solubles and 6.5 to 6.6 per cent hot water solubles which probably acted as inhibitors and resulted in poor cement curing (Biswas, 2008).

The mechanistic explanation behind improper cement curing is that when sucrose is present in cement-water mixture, a half-salt of sucrose-calcium i.e. $R\text{-}O^{-}\text{-}Ca^{+}\text{-}OH$ is formed. This half-salt adsorbs at growth sites on $Ca(OH)_2$ resulting in inhibition of nucleation and growth. Another possible explanation could be the formation of insoluble metal-organic complexes that precipitates over the cement particles retarding the hydration.

The modulus of rupture (MOR), tensile strength (IB), percent thickness swelling (TS) and water absorption (WA) of CBPBs made from both cold and hot water treated coarse, fines and mixture of coarse and fine particles of *B. balcooa* and *B. vulgaris* at two density levels were measured. The data were statistically analyzed to assess any influence of density variation, particle size and water treatments on both mechanical and physical properties (thickness swelling and water absorption) of the panels. The F-values and levels of significance are given in Table 1.

Table 1. F-values and levels of significance of variables and interaction on the properties of cement bonded particleboard

Source of variation	DF	Modulus of rupture	Tensile strength	Thickness swelling after soaking of 30 day	Water absorption after soaking of 30 day
Species (S)	1	336.9**	43.91**	226.5**	3.5ns
Density (D)	1	336.8**	160.35**	282.5**	154.2**
Particle mixing composition (C)	2	109.9**	113.23**	356.2**	13.4**
Treatment (T)	1	285.2**	7.70**	247.0**	17.5**
S x D	1	123.0**	0.05ns	0.3ns	49.9**
S x C	2	5.8*	2.83ns	3.3*	0.2ns
S x T	1	0.1ns	4.43*	13.0**	2.4ns
D x C	2	3.1ns	14.43**	55.7**	0.5ns
D x T	1	26.3**	0.95ns	1.3ns	6.1*
C x T	2	0.5ns	0.93ns	20.1**	3.9ns
S x D x C	2	10.5**	3.70*	28.3**	0.3ns
S x D x T	1	19.76**	1.17ns	1.5ns	11.6**
S x T x C	2	2.48ns	1.74ns	22.0**	1.6ns
D x T x C	2	1.02ns	1.05ns	18.5**	0.4ns
S x D x C x T	2	4.65*	1.22ns	1.4ns	2.4ns
Error	48				
Total	71				

** = significant at 1% level of probability, * = significant at 5% level of probability, ns = not significant

Modulus of Rupture

The modulus of rupture (MOR) of CBPBs made from cold water extracted and hot water extracted particles at 1100 kg/m^3 and 1200 kg/m^3 board density levels were shown in Figs. 2a$_1$, 2a$_2$, 2b$_1$ and 2b$_2$. There was a gradual increase in MOR as the proportion of coarse particles was increased, and the trend remained the same for both cold and hot water extracted materials for both the species. The HWE panels showed better properties than CWE panels with only one exception with *B.balcooa* fines at 1200 kg/m^3 where it remained almost the same for both CWE and HWE materials. The gradual increase in strength with coarser particles supported the fact that particle geometry was an important factor for strength properties of CBPB. However, panels from none of the species met the BS standard values (10.00 N/mm^2 in BS) at 1100 kg/m^3. With an increase in density from 1100 to 1200 kg/m^3, the bending strengths for the panels made with hot water treated coarse particles from *B.balcooa* showed a value of 10.1 N/mm^2. These panels gave comparable values as mentioned in the British Standard for two grades of board, namely, T_1 (low to moderate level of performance in the presence of moisture) and T_2 (high level of performance in the presence of moisture) (BS 5669 part 4, 1989). The maximum MOR value for the corresponding panel from *B.vulgaris* was 7.31 N/mm^2, which was far below the set value for the standards. Significant effect on MOR at 1 per cent level of probability was also found due to species, particle size, particle treatment and density variation (Table 1).

$CaCl_2$ is a widely used additive for the manufacture of cement bonded particleboard, but in the present study, it was found that this additive was not good enough to neutralize the inhibitory effect of chemical components of *B. vulgaris* to the desired extent. However, Rahim *et al.* (1996) reported that the CBPBs made from *B. vulgaris* at a bamboo cement ratio of 1:2.75 with 2 per cent of either $Al_2(SO_4)_3$ or $Al_2(SO_4)_3$ and Na_2SiO_3 mixture produced boards meeting the requirements of Malaysian Standard (9.00 N/mm^2 in MS934) at 1250 kg/m^3. It is thus possible that the MOR values in the present studies would improve further with the inclusion of $Al_2(SO_4)_3$ and Na_2SiO_3 as an additive.

Regarding the board appearance, it was found that the coarse particles were not well coated with cement due to poor contact between the coarse particles and the cement paste. This resulted in panels with uneven surfaces and there appeared a hardened water- cement layer in the lower side of the board. The smoothness of the panels could, however, be increased with the inclusion of the fine particles.

Internal Bond or Tensile Strength

The variations of internal bond (IB) strength of CBPBs with particle type and treatments at two density levels were shown in Figs. 3a$_1$, 3a$_2$, 3b$_1$ and 3b$_2$. Boards produced from

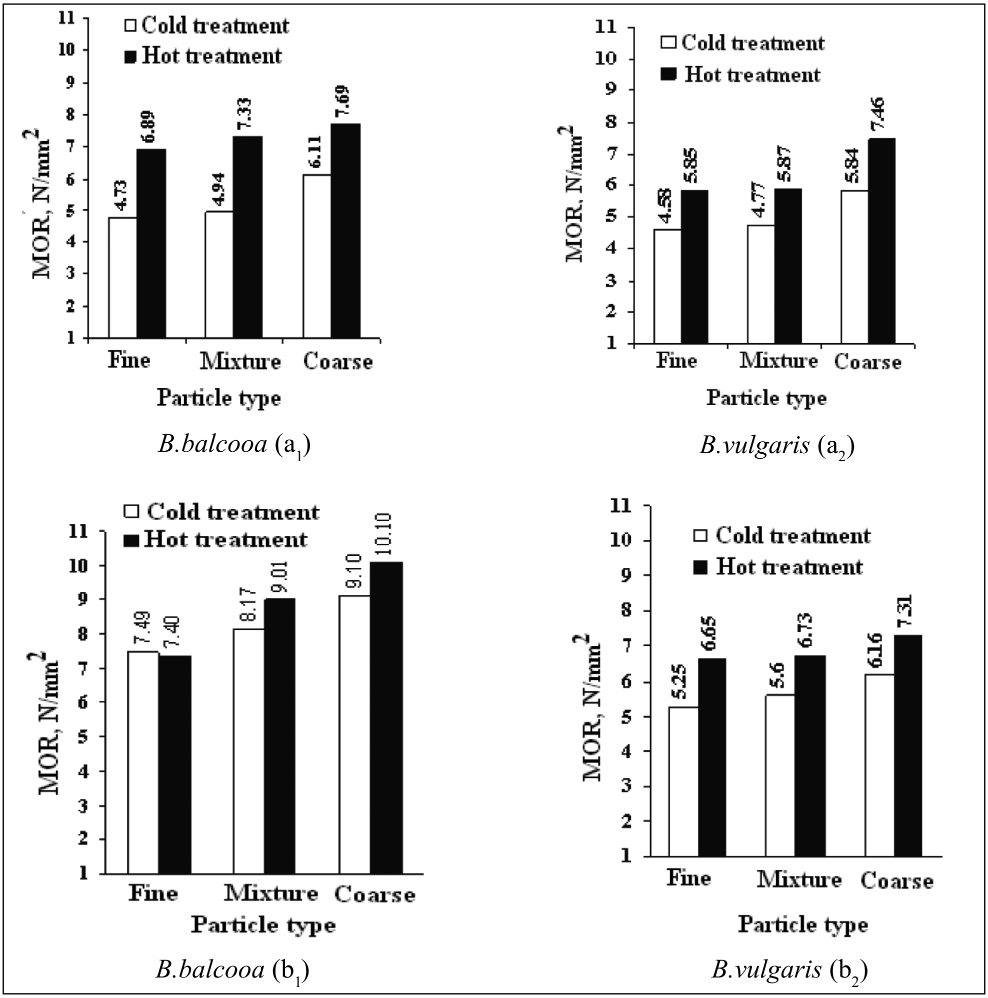

Figure 2. Effect of particle size and water treatments on modulus of rupture (MOR) of cement bonded particleboard made from *B .balcooa* and *B.vulgaris* at (a) board density 1100 kg/m^3 and (b) board density 1200 kg/m^3.

fines had higher tensile strength than boards made from coarse-fines mixture or coarse particle alone. Rahim *et al.* (1995) also observed that the tensile strength of CBPB manufactured from oil palm trunk fiber was higher for finer particles.

There was an increase in IB values when particles were extracted with hot water compared to cold water extractions. But boards from neither species at 1100 kg/m^3 density were good enough to meet the requirements of the British Standard (IB of 0.5 N/mm^2). The tensile strength values improved with an increase in the board density. The boards from *B. balcooa* fines and coarse-fines mixtures had tensile strength values more than 0.5 N/mm^2, the standard value. In case of *B. vulgaris* it was only the fines that were able to produce boards with suitable IB strengths (0.58-0.62 N/mm^2). The

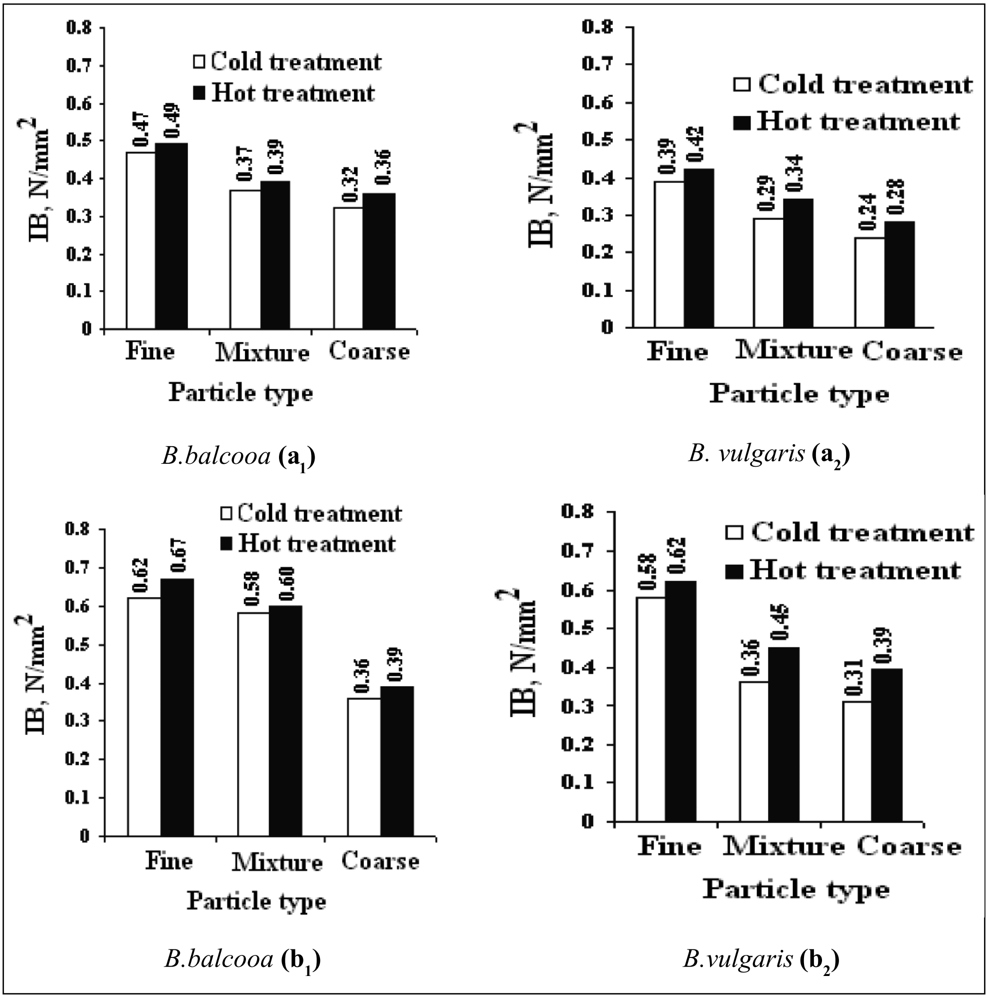

Figure 3. Effect of particle size and water treatments on tensile strength (IB) of cement bonded particleboard made from *B. balcooa* and *B. vulgaris* at (a) board density 1100 kg/m^3 and (b) board density 1200 kg/m^3

higher IB strengths of 1200 kg/m^3 boards were probably due to higher bamboo-cement materials per unit volume.

Moslemi and Pfister (1987) explained contribution of wood in strength development concluding that the presence of aggregate in concrete induces stress concentrations at the aggregate-cement interface. As percentage of wood particle increases, these regions of stress concentration around adjacent particles become more diffuse, resulting in an increased resistance to the stress applied. For example, concrete strength increases because of a decrease in the average stress concentration caused by inclusion of smaller aggregate particles. Larger quantities of aggregate distribute internal stresses over a larger specific surface per unit volume, to reduce the areas of high stress concentration where critical failure is more likely to occur. In this case, addition of increased amount of wood, helped complete matrix formation by decreasing internal stress and thereby improved the panel strength. Analysis of variance (ANOVA) showed significant influence of individual variables on this property at 1 per cent level of probability where the combined effect of the variables was not significant (Table 1).

Thickness swelling

The influence of treatment, particle size and soaking time on the thickness swelling of the CBPBs made from *B. balcooa* and *B. vulgaris* were presented in Figs. $4a_1$, $4a_2$, $4b_1$ and $4b_2$. It was observed that hot water of particles improved swelling properties. The thickness swelling of HWE panels is lower than the CWE panels for both density

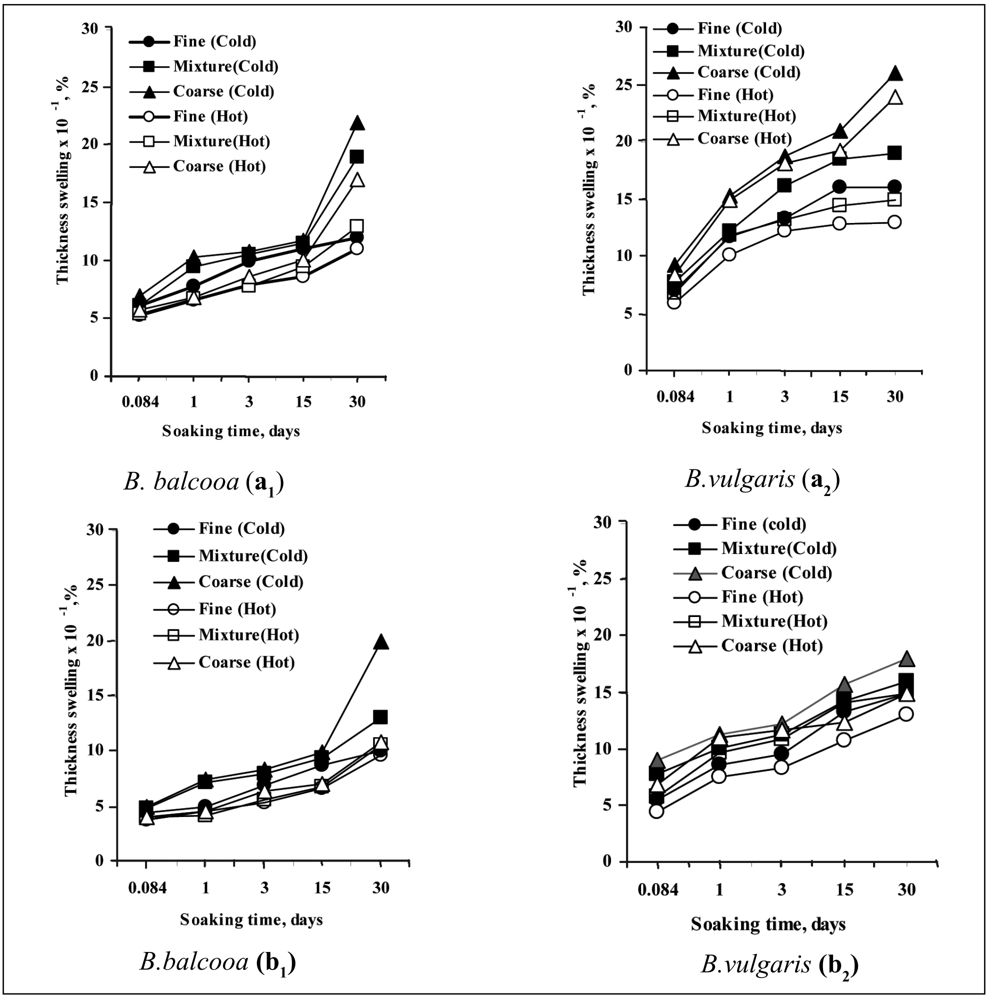

Figure 4. Effect of water treatments, particle size and soaking time on thickness swelling of cement bonded particleboard made from *B. balcooa* and *B. vulgaris* at (a) density 1100 kg/m^3 and (b) density 1200 kg/m^3.

levels. The reduction in thickness swelling may be due to the removal of hydrophilic components during hot water treatments.

The thickness swelling of CBPB did increase with the inclusion of coarse particle for both the species. This was probably due to the fact that the panels produced using coarse particles might have more space to allow substantial thickness swelling or expansion after being completely soaked in water than the fine particles under the same conditions.

The percent thickness swelling of the panels increased with the increase of soaking time. The CBPBs made from *B. balcooa* had lower percentage of swelling compared to *B. vulgaris* at any particle combinations and density levels. In comparison to the standard, the panels were much superior to both T_1 and T_2 boards. The percent swelling was 3.0 and 12 for T_1 after 1h and 24 h of soaking, respectively. The corresponding values for T_2 were 1.5 and 1.8 per cent.

Fan *et al.* (1999) explained that the swelling of hydrated cement is due to the fact that prolonged moisture adsorption induced tensile stresses in inter-solid bond, disrupting some of the weak links and causing further adsorption. In the present study, the panels from both cold and hot water treated fines did swell less compared to those from coarse particle. This was probably due to the fact that fine particles were coated with cement slurry more uniformly than the coarse one which to some extent restrained swelling during water soaking. However, all the panels had remarkably smaller thickness swelling than those of the standard (12 for T_1 and 1.8 for T_2 after 24h of soaking) (BS 5669 part 4, 1989). ANOVA showed the species, particle size, treatment type and board density variation had positive influence on thickness swelling of the board. However, interaction of all the variables was insignificant.

The urea formaldehyde-bonded particleboard made from *B.vulgaris* showed high thickness swelling (about 28 %) after 24 hours of soaking (Hasnin *et al.*, 1997). Given the same soaking period, the particleboard bonded with Portland cement was found to swell only in the range of 0.90 per cent and with no tendency to delaminate after 30 days of soaking. This implied that CBPB made from bamboo would be more water resistant and dimensionally stable against humidity.

Water absorption

The water absorption results of the CWE and HWE boards after prolonged soaking are graphically represented in Figs. $5a_1$, $5a_2$, $5b_1$ and $5b_2$. It was observed that *B. balcooa* showed lower water absorption compared to *B. vulgaris* at all levels of composition mixtures and board densities. The water absorption values increased with the increase of soaking time, but there was a decrease in absorption with the increase of board density.

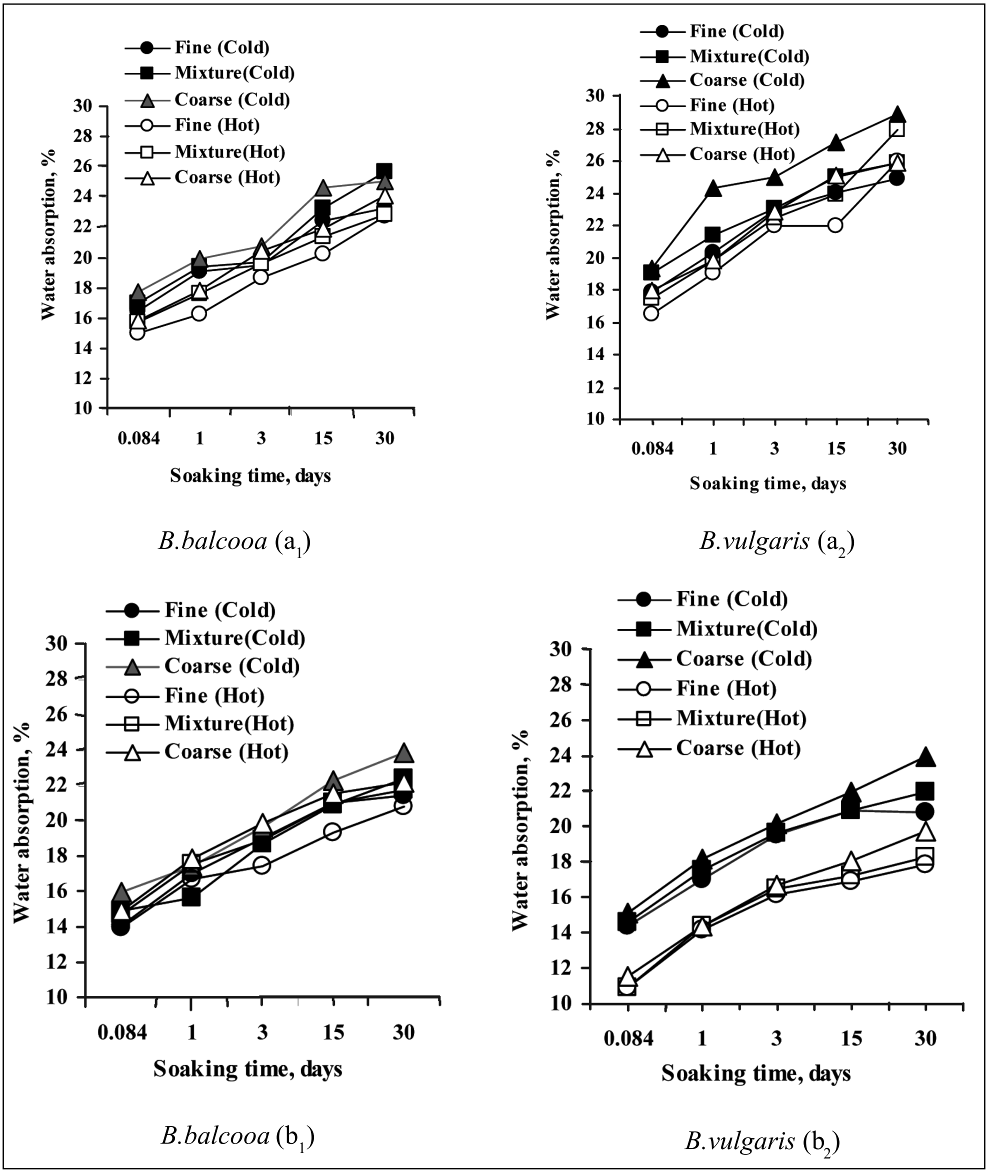

Figure 5. Effect of water treatments, particle size and soaking time on water absorption of cement bonded particleboard made from *B. balcooa* and *B.vulgaris* at (a) density 1100 kg/m^3 and (b) density 1200 kg/m^3.

Alpar *et al.* (2003) showed that there exists a direct relationship between capillary diameter and water penetration. For large capillary diameters, the speed of water penetration was found to be high. In high density boards the capillary diameter decreased due to high compaction. As a result the magnitude of water absorption in 1200 kg/m^3 density boards was lower compared to 1100 kg/m^3 density boards.

CONCLUSION

This study indicated the suitability of *B. balcooa* and *B. vulgaris* for making cement-bonded particleboard. Based on the results, the following conclusions were drawn.

1. Hot water treatment is superior to cold water treatment in improving the strength properties of CBPBs made from *B. balcooa* and *B. vulgaris*. The boards made from it are dimensionally stable but inferior in strength properties. Thus cement bonded particleboard from *B. vulgaris* compared to *B. balcooa* appears less suitable where strength is a prime need.

2. Panel density has significant influence on board properties. Higher density boards made from *B. balcooa* are stronger and dimensionally more stable.

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