November 8th – 11th 2016, Fuzhou Empark Exhibition Grand Hotel, Fuzhou, China

Paper #16

STRENGTH PROPERTIES AND ECONOMIC FEASIBILITY OF CEMENT BONDED PARTICLEBOARD MADE FROM BAMBOO AND WOOD

D. BISWAS, KHURSHID AKHTER, M. M. RAHMAN AND M. A. T. HOSSAIN

Bangladesh Forest Research institute, P O Box 273, Chittagong 4000, Bangladesh

ABSTRACT

Introduction of cement bonded particleboard (CBP) could alleviate the housing problem of densely populated country like Bangladesh. .In this study, physical and mechanical properties of CBP made from Ipil-Ipil (*Leucaena leucocephala*), Rubber tree (*Hevea brasiliensis*) and Borak bamboo (*Bambusa balcooa*) at a density level of 1100 kg/m^3 has been evaluated. The bonding of untreated wood particles with cement was very poor. After hot water treatment of the chips for 3 h, prior board formation, produced boards of acceptable quality. Calcium chloride was used as an additive to accelerate cement hydration. The tensile strength and thickness swelling property of the boards met the standard requirement but the bending strength was rather low. For improvement of bending strength, additional additives, which may improve the compatibility of wood and bamboo chips with cement, could be tried. The economic feasibility for establishing cement bonded particleboard manufacturing plant was assessed based on capital investment, wages and salaries for personnel engaged in different activities, required equipment, consumption of raw material, etc. The sensitivity analysis was done by changing economic situations. The scenarios showed that the investment for the plant would be profitable. It would give a guideline for the entrepreneurs in establishing CBP industries.

KEYWORDS:

Bambusa balcooa; *Hevea brasiliensis*; *Leucaena leucocephala*; Hydration of cement, Benefit-Cost ratio.

INTRODUCTION

Cement-bonded particleboard (CBP), a panel product made 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 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 (Ajayi 2006a; Olanike *et al*. 2008). Cement bonded particleboard is environment friendly as it does not emit harmful chemical substances during and after manufacture or while in service (Ajayi 2006b).

Bangladesh is a densely populated country regularly hit by natural disaster like flood, cyclone, etc. The most damages caused by these natural hazards are primarily to rural houses which are mainly made of bamboo, thatch and mud that makes them extensively vulnerable. Anything more durable than bamboo and thatch tends to be expensive and beyond the means of most of the rural people. However, the quality of the houses can be improved by using prefabricated building materials which are cheaper, durable and hazard free.

With this aim, Biswas *et al.* (1997) tried to make cement bonded particleboard with *Albizia falcataria* at a density level 1000 kg/m^3 and found that the boards were dimensionally stable but bending strength was low. They suggested that this property could be compensated by increasing the density level and by using longer and thinner flakes.

Later on in a BFRI (Bangladesh Forest Research Institute) Clients Technology Transfer Seminar, Biswas (2000) pointed out that feasibility and pilot commercial production are required to determine if the positive attributed of CBP identified in the test and research level can be achieved under large scale production.

As a part of that programme, a preliminary study was undertaken to evaluate the suitability of *Leucaena leucocephala, Hevea brasiliensis* and *Bambusa balcooa* for production of cement bonded particleboard and assess the economic feasibility of the panel for entrepreneurship development.

MATERIALS AND METHODS

Raw material collection and processing

Logs of Ipil-Ipil (*Leucaena leucocephala)* and rubber tree (*Hevea brasiliensis*) were peeled to 1.5 mm thick veneer. Before converting the veneer into particles all identifiable defects (eg knots) were removed. The veneers were then hammer milled to chips and seived through 20 mesh screen to remove dust and fines. Borak bamboos (*Bambusa balcooa*) culms were collected from Nazirhat, a village in Chittagong district, Bangladesh. At first the segments were flattened by local hand tool. These were hammer milled to chips and then screened.

At first the untreated chips were used individually for the development of cement bonded particleboard but failed to develop useful boards. Then the materials were treated in cold water for 24 h and in successive hot water at 60°C for 3 h. The treated chips were dried to 12-14% moisture content. The treatments were done to reduce the sugar content of the material that is detrimental to cement hydration.

Board making

Particleboards were made in three replications with treated materials at a density of 1100 kg/m^3. Ordinary portland cement was used as an inorganic binder at 45% mat water content. The wood/bamboo chips–cement ratio by weight was 30:70. In order to control setting process, 2% $CaCl_2$ based on cement weight was added. At first $CaCl_2$ was mixed with water and then added to chips and cement mixture which were then thoroughly mixed by hand until a uniform mixture was obtained. Mat was formed manually in a 500 mm × 500 mm wooden frame and cold pressed to a target thickness of 12 mm applying 1.05 N/mm^2 pressure. After 24 h, the panels were stripped off the caul plates and watered for 7 days. Then, for final cure, the panels were kept vertically for three weeks.

Board testing

Samples were prepared from three replicate boards and conditioned at 65 ± 5% relative humidity and 20 ± 2°C until a uniform moisture content of about 9 to 10% was attained. The modulus of rupture, tensile strength, thickness swelling and water absorption tests were performed according to BS 5669 part 1: 1989. Thickness swelling and water absorption were determined after prolonged soaking in water for 30 days.

Economic feasibility

The capital investments for establishing cement bonded particleboard plant were land, building and equipment. Raw materials included wood/ bamboo chips, portland cement, additive, sanding material, paint etc. The annual costs for each item were considered based on present market price. Annual wages and salaries of personnel were considered according to national pay scale'2015 of Bangladesh. Depreciation cost was determined by declining balance method. A number of capital budgeting techniques or investment criteria such as Net present value (NPV), Internal rate of return (IRR), Benefit-cost ratio (B/C ratio) and Pay – back period (PBp) were used for evaluating the financial feasibility of CBP panel. A sensitivity analysis was performed to assess the performance of the new venture under some alternative scenarios. Here, three changed circumstances like market prices of the finished products, purchase prices of the raw materials and labor wages rate were considered.

RESULTS AND DISCUSSION

Strength properties

The untreated particles of bamboo and wood were used individually for the development of cement bonded particleboard but the developed products were of very inferior quality. The products showed delamination when scratched with nails or any hard tool and, thus, could not be used for determination of strength properties and dimensional stability

Many researchers observed that when wood was used as an aggregate in cement–water mixture, the wood constituents like organic salts, cyclitons, galactons and pectin, simple sugars, sugar acids, and extractives (phenol and tannins) caused certain unfavourable reactions to the setting of the cement slurry (Ahn and Moslemi, 1980; Browning 1967). In the furnish, they acted as cement "poison" and inhibited the normal setting of cement (Biblis and Lo, 1968; Hachmi and Cambell, 1989, Simatupang *et al*., 1989; Weatherwax and Tarkow, 1964; Weatherwax and Tarkow, 1967; Zhenglian and Moslemi,1985). Biswas *et al.* (1997) studied the suitability of *Albizia falcataria* for making of cement bonded particleboard. They observed similar effect as the untreated chips of *Albizia falcataria* failed to produce quality boards. They assumed that the 2.97% cold water solubles present in *Albizia falcataria* were responsible for improper curing of cement. Scientists pointed out that high level of starch and sugar contents would influence the quality of cement bonded particleboard (Simatupang 1986; Simatupang *et al*., 1989). The sugars are sucrose, glucose and fructose that have significant effects on cement setting even at 0.4% concentration (Rahim *et al.,* 1987). In addition, Birchall and Thomas (1984) mentioned that among sugars, sucrose and raffinose retard cement setting more strongly.

After hot water treatment, the water soluble components leased out and, thus, greatly improved the wood/bamboo – cement bond resulting the production of reasonably good panels. The results of strength tests of the panels are given in Table 1. The values are compared with the British Standards Specification (BS 5669 part 4 1989). Thickness swelling and water absorption values of the boards are given in Table 2 and 3. The results showed that the tensile strength perpendicular to surface were 0.71, 0.86 and 0.61 N/mm^2 for boards made from *Leucaena leucocephala, Hevea brasiliensis* and *Bambusa balcooa* respectively. These were at per with the values mentioned in the British Standard both for the 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). Statistical analysis showed that the tensile strength of particleboards made from three species was found highly significant. Among them, tensile strength of *Hevea brasiliensis*,was found best followed by *Leucaena leucocephala,* and *Bambusa balcooa* .

The average bending strength value for the species *Leucaena leucocephala, Hevea brasiliensis* and *Bambusa balcooa* were 8.34, 7.22 and 7.40 N/mm^2 respectively. This is approximately 15% to 30% lower than the recommended value. Biswas and Bose (2010) utilized upper portion of *Bambusa balcooa* culm (above 5 m from the base) for development of cement bonded particleboard and found similar results for the boards of 1100 kg/m^3. On the other hand Ajayi and Badejo (2005) obtained lower MOR values of about 5.15 N/mm^2 for boards made from *Leucaena leucocephala* at 1100 kg/m^3. This is probably due to variability in flake dimension and low use of $CaCl_2$. Badejo (1988) found that both flake dimension and board density are important factors that control the bending strength. He also reported that like resin bonded particleboard, longer and thinner flakes produce CBP of higher MOR. In a case study prepared for the FAO (Anon 1975), it is reported that the bending strength of the board at a density level 1000 kg/m^3 and a wood cement ratio of about 1:1.8 is approximately 25% lower than the recommended standard value. It may therefore inferred that the bending strength as observed in the study could be improved by increasing the density level up to 1200 kg/m^3 of the panel and by using longer and thinner flakes. In statistical analysis, it was found that cement bonded particle boards from the three individual species were found insignificant (Table 4).

Table 1- Strength properties of cement bonded particle board made from hot water treated chips

Property	*Leucaena leucocephala*	*Hevea brasiliensis*	*Bambusa balcooa*	Standard requirement	
				T_1	T_2
Static bending strength, N/mm^2	8.34 (7.63 – 9.80)	7.22 (6.53 -8.76)	7.40 (6.72-8.06)	10.0	10.0
Tensile strength, N/mm^2	0.71 (0.68-0.73)	0.86(0.78 – 0.90)	0.61 (0.55 – 0.63)	0.5	0.45

T_1 = CBP that has only low to moderate levels of performance in the presence of moisture
T_2 = CBP that has very high levels of performance in the presence of moisture

Thickness Swelling

Table 2 showed that thickness swelling increases initially with soaking time. After first hour of soaking, maximum increase in thickness took place. Then the rate of thickness increment decreased. The average thickness swelling ranged from 1.93 to 4.44% for *Leucaena leucocephala,* 0.95 to 3.29% for *Hevea brasiliensis* and 0.63 to 2.05% for *Bambusa balcooa.* Analysis of variance showed that the effect of species was visible in the case of thickness swelling after long term soaking. However, the thickness swelling values of *Hevea brasiliensis* and *Bambusa balcooa* met the minimum requirement of the standard for both T_1 and T_2 boards In case of *Leucaena leucocephala,* the boards were much better than T_1 board but slightly inferior to T_2 board in the same condition.

Table 2 - Thickness swelling of cement bonded particleboard after prolonged soaking in water

Water soaking time	Thickness swelling (%)				
	Leucaena leucocephala	*Hevea brasiliensis*	*Bambusa balcooa*	Standard requirement	
				T_1	T_2
1 h	1.93 (1.54-2.50)	0.95 (0.61-1.22)	0.63 (0.42-0.91)	3	1.5
2 h	2.51 (1.97 –2.95)	1.43 (1.00-1.69)	0.92 (0.80-1.09)		
24 h	2.87 (2.50 –3.37)	1.73 (1.4-2.06)	1.06(0.97 – 1.15)	12	1.8
3 days	2.94 (2.38 – 3.49)	1.78 (1.4- 2.0)	1.15(0.82 – 1.65)		
7 days	3.15 (2.69 – 3.78)	2.16 (1.53- 2.62)	1.25(0.99-1.48)		
14 days	3.59 (2.93 – 3.99)	2.17 (1.99- 2.37)	1.57(0.99-1.99)		
21 days	4.09 (3.95 – 4.32)	2.83 (2.02-3.26)	1.92(1.86-2.18)		
30 days	4.44 (4.01 – 5.24)	3.29(2.59-3.36)	2.05(1.75-2.38)		

T_1 = CBP that has only low to moderate levels of performance in the presence of moisture
T_2 = CBP that has very high levels of performance in the presence of moisture

Water Absorption

The average values of water absorption after prolonged soaking in water for 30 days ranged from 16.7 to 29.9% for *Leucaena leucocephala,* 15.0 to 31.9% for *Hevea brasiliensis* and 17.1 to 28.4% for *Bambusa balcooa.*

These values supported the findings of Prestemon (1976) for 25 mm thick CBP boards made from sawdust of oak and elm following 24 h soaking time. This indicated that the results ascertained in this study (after prolonged soaking for 1 month) were highly satisfactory. Some parts of Bangladesh are low lying and submersed under water for a long time. Cement bonded particleboard could be a useful product in such environmental situation.

Table 3 - Water absorption of cement bonded particleboard after prolonged soaking in water

Water soaking time	*Leucaena leucocephala*	*Hevea brasiliensis*	*Bambusa balcooa*
1 h	16.7 (14.1 – 18.8)	15.0 (12.4 – 16.8)	17.1 (14.9 – 18.6)
2 h	17.7 (16.1 – 18.8)	15.4 (12.8 – 17.7)	19.5 (18.6 – 20.5)
24 h	23.1 (20.8 – 25.0)	22.7 (20.1 - 24.2)	20.0 (19.8 – 20.5)
3 days	25.3 (22.9 – 27.7)	26.0 (18.2 – 30.6)	24.1 (21.2 – 25.7)
7 days	26.4 (23.3 – 27.7)	28.7 (26.2 – 32.1)	24.4 (23.1 – 26.0)
14 days	28.1 (23.7 – 32.2)	29.2 (26.7 – 32.2)	26.4 (23.3 – 28.7)
21 days	29.7 (26.4 – 32.2)	31.2 (29.6 – 33.0)	27.3 (25.4 – 28.4)
30 day	29.9 (27.2 – 30.8)	31.9 (30.8 – 33.5)	28.4 (28.0 -28.7)

Table 4 - Influence of species on mechanical properties and dimensional stability of cement bonded particle board

Source	DF	Mechanical properties		Dimensional stability	
		Static bending	Tensile strength	Thickness swelling after soaking of 30 day	Water absorption after soaking of 30 day
Species	2	2.88^{ns}	64.13^{**}	49.97^{**}	12.37^{**}
Error	12	-	-	-	-
Total	14				

ns : not significant
** Significant at 1% level of probability

Economic feasibility of the cement bonded particleboard (CBP)

The production and fabrication of cement bonded particleboard is not practiced in Bangladesh, as there is no mill exists in Bangladesh. Production of CBP from local wood and bamboo species are found technically suitable. In the following paragraph, the economic feasibility of the product was described.

The cost calculations of cement bonded particleboard (CBP) were performed based on the following facts.

1.	Location (Site for medium scale industry	Sitakund Industrial Area, Chittagong District.
2	Land area	6,000 m^2
3	Purchasing year	December, 2015
4	Building size (semi pacca)	4,000 m^2
5	Board dimensions	2.5 m × 1.22 m × thickness based on consumers requirement
6	Effective work time per day	7 h
7	Annual production capacity	97,500 m^2 × variable thickness
8	Daily production capacity	325 m^2 × thickness based on consumers requirement
9	Working days in a year	300 days

In addition, one day per week would be used for general maintenance and cleaning of the plant in order to keep the equipment in optimal operational condition. Besides, production would be stopped two weeks every year for complete overhauling of the plant. The capital investment for the establishment of CBP industry is 358.11 thousand USD (Table 6).

The required equipments were Storage tank (4 m × 3 m), Clipper machine, Chipper machine, Screening machine, Chemical mixture machine, Dust collector, Water treatment tanks (3 m × 1 m × 1 m), Wet chips storage bin, Hot water vats, Cold press, Circular saw, Drying chamber with dehumidifier, Side trimming saw, Weighing balance, Fork lift truck for board transport, Trolly Caul plate, Small tools/accessories, Computer with accessories.

Table 5 - Personnel (administrative and operational) engaged in different activities

Administrative / Managerial				
Sl. No.	**Position**		**No**	**Activity/ Function**
1	Manager		1	Planning, marketing and production
*2	Engineer		1	Mechanical
3	Accountant		1	General accounts
4	Office attendant		1	
5	Driver		2	Operation of vehicle/truck
Operational/ technical				
6	Unit head		2	Maintenance (1) and product supervision (1)
7	Technician		2	Mechanical (1) and Electrical (1)
Workers				
8	Unit-1 (Material processing)	Unskilled	1	Raw material storage
10		Unskilled	2	Chips making
11		Unskilled	2	Air drying
12		Unskilled	2	Screening
13		Unskilled	3	Chips treatment
14		Unskilled	2	Drying
15	Unit – 2 (Board making and final processing)	Skilled	2	Chips and other material weighing
16		Unskilled	3	Blending
17		Skilled	6	Mat forming
18		Skilled	6	Cold pressing
19		Unskilled	3	Opening press
20		Unskilled	2	Curing/watering
21		Skilled	4	Panel sizing
22		Skilled	2	Quality control
23		Unskilled	2	Storage
24		Skilled	2	Finishing
25		Unskilled	2	Cleaning
26		Skilled	2	Saw doctoring

* Engineer would assist in procuring and assembling local equipment in the 1st year

Table 6 - Capital investment for establishing a cement bonded particleboard plant (in thousand USD)

Sl. No.	**Items**	**Value**
1	Land	30.64
2	Building cost with power and water facilities	89.37
3	Equipment and vehicle	238.10
	Total capital investment	358.11

Board production

It was assumed that 5-year time would be required for the plant machinery for achieving a stable production of 100 % capacity (Table 7). Annual output level would reach its maximum (100%) in the 5th year and it will be at its maximum up to the year 30. The break – up was shown below:

Table 7 - Annual production of cement bonded particleboard

Year	Amount of product (m^2)	Remark
Year 1	Nil	No production (construction, purchase and installations of machineries and equipments)
Year 2	24,375	25% of the full production capacity
Year 3	48,750	50% of the full production capacity
Year 4	73,125	75% of the full production capacity
Year 5	97,500	100% production from 5th year onwards up to 30th year
Total production would be 2,681,250 m^2 in the 30th year		

PRODUCTION COSTS

Total production costs included the cost for i) raw materials, ii) energy, iii) maintenance, iv) personnel, and v) post production activities.

Table 8 - Production cost of cement bonded particleboard (in USD)

Sl.No.	Items	Annual cost
*1.	Raw materials	221,953.62
**2.	Personnel (Managerial staff and workers)	114,443.04
3.	Energy cost	3,064.07
4.	Maintenance cost	358,11.00
5.	Post production activities (marketing, publicity)	2,553.39
Production costs excluding depreciation		377,825.12
***6	Depreciation costs of capital investment	5,370.83
Total production cost per year		383,195.95
Production cost per square meter		3.93

*Raw materials include wood/ bamboo chips, portland cement, additive, sanding material, paint. The annual cost for each item is considered based on present market price.
** Annual wages and salaries of personnel are considered according to present pay scale.
* **Depreciation cost was determined by declining balance method

A number of capital budgeting techniques or investment criteria were used in evaluating the financial feasibility of CBP panel. These were Net present value (NPV), Internal rate of return (IRR), Benefit-cost ratio (B/C ratio) and Pay – back period (PBp)

Financial analysis and or sensitivity analysis of bamboo cement bonded particleboard were performed considering the following situations:

If average local market price = R_0 = 4.53 USD per square meter

If average local market price decreased by 3% = R_1 = 4.39 USD per square meter

If average local market price increased by 3% = R_2 = 4.67 USD per square meter

Initial labour cost = C_0

If the labour wages increased, C_1 = 10%

If raw materials costs increased, C_2 = 10%

If both labour wages and raw materials cost increased, C_3 = 10% each

The manufacturing cost for 12 mm thick cement bonded particleboard was 3.93 USD per square meter (Table 8). This is a newly developed product for Bangladesh and it is not available in the market. It was seen that the NPV, IRR and B/C ratio for the investment proposal (R_0C_0 without changing the prices of components in cost calculation) were 422.6 thousand USD, 82%, 1.13, respectively and within one year the initial cash investment would be recovered (Table 9). The positive values for all capital budgeting criteria indicated that the owner could invest for the establishment of cement bonded particleboard plant.

It is widely accepted that the production and marketing of the products are very sensitive to the various economic situations. The investment becomes profitable under favorable economic conditions, but it was quite difficult to predict the future state of economic situations. Thus, a sensitivity analysis was performed to assess the performance of the new venture under some alternative scenarios. Here, three changed circumstances like market prices of the finished products, purchase prices of the raw materials and labor wages rate were considered. It is regarded the higher the value in investment criterion, the better would be the investment choice.

So, a sensitivity analysis was done to measure the risk of the investment in different possible situations. In the present study it was thought that three factors like market price of the finished product, purchase price of raw material and labour wages rate would contribute the most toward the success of the project. The financial analysis for the production of cement bonded particleboard at two discount rates (10% and 12%) was given in Table 9. It was found that all the possible combinations were supportive to the investment proposal except the combination of R_1 with C_3 where long time would be required to recover the initial cash investment for cement bonded particleboard production. So, it is seen that management would have the flexibility to alter their decisions under changed economic conditions.

The manufacture and utilization of the product as housing component is in practice around the world. Peoples of Soviet Union, Japan, Germany, Switzerland, Italy, Malaysia, Philippines, France, Turkey, Thailand use this panel as low cost housing element. The product is virtually incombustible, water proof, and fungus and termite resistant. In Bangladesh, this technology is unknown to people. However, the country has its own cement production. In addition, wood and bamboo resources are available in the country. So, easy availability of raw material and with excellent properties this product could find local market as there will always be a greater needs for housing material.

Table 9 - Financial analysis of cement bonded particleboard at two different discount rate

Situations	**Criterion**							
	NPV		IRR		B/C ratio		PBp	
	10%	12%	10%	12%	10%	12%	10%	12%
R_0C_0	422.6	343.4	82	82	1.13	1.13	0.8	1.0
R_0C_1	325.6	261.7	62	62	1.10	1.10	1.1	1.4
R_0C_2	243.8	194.1	52	42	1.07	1.07	1.5	1.9
R_0C_3	145.5	111.1	34	34	1.04	1.04	2.5	3.2
R_1C_1	218.3	172.4	45	45	1.07	1.06	1.6	2.1
R_1C_2	135.3	103.4	34	34	1.04	1.04	2.6	3.5
R_1C_3	38.3	21.7	16	16	1.01	1.00	9.4	16.5
R_2C_1	531.1	432.8	99	99	1.17	1.16	0.7	0.8
R_2C_2	351.1	283.4	70	70	1.10	1.10	1.0	1.3
R_2C_3	252.8	200.4	51	51	1.07	1.07	1.4	1.8

CONCLUSION

This study indicated the suitability of *Leucaena leucocephala, Hevea brasiliensis and Bambusa balcooa* for making cement bonded particleboard. Based on the results, the following conclusions were drawn.

1. Inferior quality cement bonded particleboards were produced from untreated chips of *Leucaena leucocephala, Hevea brasiliensis and Bambusa balcooa.*

2. The hot water treatment of chips prior board making improved the board properties. The tensile strength and thickness swelling property of the boards met the standard requirement but the bending strength was rather low.

3. In the present study only $CaCl_2$ was used. Additional additives, which may improve the compatibility of wood and bamboo chips with cement could be tried.

4. The economic feasibility assessment based on the capital budgeting techniques such as NPV, IRR, B/C ratio, and PB period shows that establishment of factories for producing cement bonded particleboard would be a profitable investment.

REFERENCES

Ahn, W.Y., and Moslemi, A. A. 1980. SEM examination of wood – portland cement bonds. Wood Science and Technology 13 (2): 77 – 82.

Ajayi. B. and Badejo, S. O. O. 2005. Effect of board density on bending strength and internal bond of cement bonded flakeboards. Journal of Tropical Forest Science. 17(2):228-234

Alayi B. 2006a. Properties of maize stalk based cement bonded composites. Forest Product Journal. 56(6):51-55

Alayi B. 2006b. Inorganic bonded strand board manufactured from Yam (Dioscorea rotundata) strand. In: 10th Inorganic Bonded Fibre Composite Conference.November 15th – 18th. 2006. Sao Paul, Brazil. Pp.111-119.

Anonymous 1975. Cement bonded Particleboard Plant: Integrated with Low Cost Housing Production Unit: Case Study. FAO Portfolio of Small-scale Forest Industries for developing Countries, FAO. Rome. 58pp.

Badejo, S. O. O. 1988. Effect of flake geometry on properties of cement bonded particleboard from mixed tropical hardwoods. Wood Science and Tecnology. 22: 357-370.

Biblis, E. L. and Lo, C. F. 1968. Effect on setting of southern pine cement mixtures. Forest Products Journal 18 (8): 28-34.

Birchall, J.D. and.Thomas, N. L. 1984. The mechanism of retardation of setting of OPC by sugars. *British ceramic Proc.,* Sep.35.: 305 -315.

Biswas, D. and Bose, S. K. 2010. Developing cement bonded particleboard from *Bambusa balcooa* and *Bambusa vularis* . Journal of Bamboo and Rattan. 9 (3&4): 139-150.

Biswas, D., 2000. Cement bonded particleboard. In.Bose, S.K. and Roshetko, J. M. edit. Proceedings of BFRI Clients Technology Transfer Seminer.Bangladesh Forest Research Institute, Chittagong. 27-29.

Biswas, D., Sheikh, M. W., Hasnin, S. M. and Ali, M. 1997. Suitability of *Albizia falcataria* wood for cement bonded particleboard. Bangladesh Journal of Forest Science 26 (1): 62 – 67.

Browning, B.L. 1967. *Methods of Wood Chemistry,* Vol.1. Institute of Paper Chemistry, Appleton, Wisconsin.

BS 5669 part 1. 1989. Methods of sampling, conditioning and tests. British Standards Institution. London;

BS 5669 part 4. 1989. Specification for cement bonded particleboard. British Standards Institution. London.

Hachmi, M. H. and Campbell, A. G. 1989. Wood cement chemical relationships. In: Moslemi edit Fiber and particleboard bonded with inorganic binders. Forest Product Research Society. USA . 1. p. 43-47.

Olanike O. Aladenola, Ayodele E. Ajayi, Ayorinde A. Olufayo, Babatunde Ajayi. 2008. Assessment of Gmelina arborea sawdust – cement bonded rainwater storage tank. Environmentalist 28:123 – 127

Prestemon, D.R. 1976. Preliminary evaluation of a wood-cement composite. Forest Product Journal 26(2): 43-45.

Rahim, S.; Razak, M. A. and Zakaria, M. A. 1987. Chemical components in oil palm trunk influencing wood-cement board manufacture. Proceedings of the Regional Symposium on waste utilization in Asia and the Pacific, ENSEARCH. 23-30 pp.

Simatupang, M. H. 1986. Degradation reactions of glucose, cellobiose and wood under the influence of Portland cement paste. Holzforschung. 40: 3, 149 – 155. Seen in Abstr.

Simatupang, M.H.; Lange, H.; Kasim, A and Seddig N. 1989. Influence of wood species on the setting of cement and gypsum. In Fiber and Particleboards bonded with inorganic binder. Moslemi edit. Forest Product Research Society.USA.3 Pp.33-42

Weatherwax R. C, and Tarkow H. 1964. Effect of wood on setting of portland cement. Forest Products Journal. 14 (12): 567-570.

Weatherwax, R. C. and Tarkow, H. 1967. Effect of wood on setting of portland cement: Decayed wood as an inhibitor. Forest Products Journal, 17 (7): 30-32.

Zhengtian, L.; Moslemi, A.A. 1985. Influence of Chemical additives on the hydration characteristics of western larch wood-cement-water mixtures. Forest Products Journal. 35 (7).