

ECO-FRIENDLY ROOFING SOLUTION FROM BAMBOO

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Abstract

Studies were carried out at IPIRTI (Indian Plywood Industries Research and Training Institute (IPIRTI)) to develop roofing system from ecofriendly material Bamboo under financial assistance from BMTPC (Building materials and technology Promotion council) and MoEF & CC. (Ministry of Environment, Forests and Climate Change) As corrugated sheets are more ideal for roofing application, attempts were made to develop Bamboo Mat Corrugated Sheet (BMCS). Studies were carried out on the profile of corrugated sheets and ultimately sinusoidal wave pattern profile having definite pitch to depth ratio was standardized. To cover the roof top and corners a compatible eco-friendly material was required, accordingly Bamboo mat ridge cap (BMRC) was designed and developed. Extensive experiments were carried out for the manufacture of BMCS and BMRC using woven bamboo mats and phenol formaldehyde resin. Sheets were subjected to rigorous test for evaluating bond integrity, performance tests like load bearing capacity, water permeability, resistance to boiling water, fire resistance and weather endurance. BMCS and BMRC were found to possess excellent load bearing capacity and meets the requirements as per IS 15476: 2004 (Indian Standard Bamboo Mat Corrugated Sheets — Specification)

BMCS roofing sheet has enhanced characteristics like toughness, resilience and ductility. Apart from this BMCS is environment friendly, energy efficient and possesses good fire resistance. The BMCS developed is first of its kind in the country and is adopted commercially by two units in India and one in Nepal. A patent application has been filed by IPIRTI for BMCS & BMRC.

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Key words: Bamboo, Corrugated sheets, Ridge cap, Roofing

Introduction:

Bamboo, a woody grass, has always been known as an enduring, versatile and renewable resource. There are more than 125 species of bamboo in India, spread across 18 genera. In India, bamboo grows in about 9.60 million ha of forestland. In addition, substantial bamboo resources are cultivated on homestead land, private plantations and in groves. Sixty six percent of the country's bamboo resources are in the northern regions in terms of volume and 28 percent in terms area. The total estimated stock of bamboo resource in the country is 130 million tons. The estimated annual harvest of bamboo in India is around 13.5 million metric tons (mmt). Four-fifths of the growing stock of bamboo in India comprises three species: *Dendrocalamus strictus* (53 percent), *Bambusa Bambos* (15 percent) and *Melocanna baccifera* (15 percent). Species suitable for commercial application are *D. asper* (for shoots and timber), *D. hamiltonii* (for shoots), *D. stocksii* (for craft, structural and house hold applications) and for wood substitutes *B. balcooa*, *B. tulda*, *B. nutans*, *B. bambos*, *D. strictus*. (Bansal 1999). According to FAO (2006), the "total area under bamboo in India was 10 711 000 hectares in 1990, which increased to 11 361 000 hectares in 2005. Of these, around 1 754 000 hectares was under private ownership and the rest in the forests, which are under state ownership".

In general, there are two types of bamboo in the world (approximate 75 genera or 1250 species), divided according to their growth pattern. Tropical bamboo (approximate 45 genera or 750 species) usually grows in clumps which are called sympodial bamboo. The pattern of clumps can also vary, for example, bamboo culms within a clump can be closely spaced (*Bambusa Bambos*) or loosely spread out (*Bambusa vulgaris*). On the other hand, colder climates like China, Japan host non-clump-forming or runner bamboos (called monopodial bamboos) that send out long underground rhizomes. Individual shoots come out of these underground shoots or rhizomes. Sympodial bamboo grows faster than monopodial bamboo and has a higher yield; they can fully rejuvenate within a few years of cutting. In India clump- forming bamboo (sympodial bamboo) constitutes over 67 percent of the total growing stock. *Melocanna baccifera*, a non clump- forming bamboo, accounts for 20 percent of the growing stock and is found in the northeastern states (ICFRE 2001). The annual bamboo harvest in India is reported to be 13.5 mmt; however, annual production worked out at 5 mmt (air dry) considering that, on average, 250 air-dried culms weigh one tone and the price per ton of air-dried bamboo is around 1600 Indian rupees (INR) (auction rate about US\$27). It has been estimated that 50 percent of this production is used by the paper and pulp industries and the rest is consumed for rural construction, scaffolding, handicraft, etc. India reportedly taps into only one- tenth of its bamboo potential, and its share in the global market is only about 4 percent (PIB 2004; Pandey 2008).

The decline in timber availability and the emergence of new technologies and product options have spurred interest in bamboo –based composites and wood substitutes. Many bamboo-based composites products provide promising linkages between the organized and unorganized sectors, for instance, resin-bonded boards (organized) made from hand woven mats (unorganized). This highlights the potential for employment, especially in areas that are relatively disadvantaged. The highest priority- because of the employment intensity and the linkages between industrial scale units and the cottage sector- needs to be accorded to mat-based composites (Uday et al.2008). Roofing is an essential component of any house and in India several roof cladding materials are in use such as burnt clay/mangalore tiles, thatch, corrugated sheet of galvanized iron, aluminum and asbestos cement. Burnt clay thatch is preferred for semi-permanent structures whereas Asbestos Cement Corrugated Sheets (ACCS) and Corrugated Galvanized Iron Sheets (CGIS) are the major roofing materials. ACCS are being replaced with other alternative materials in many countries as asbestos has been proved to be a hazardous material. Corrugated Aluminum Sheet (CAS), CGIS which have been established for more than several decades, are being subjected to scientific scrutiny on several counts, including their impact on workers health and environment, the energy requirement for their manufacture, and sustainable supply of raw materials.

Of late priority is being given, and rightly so to 'green' building materials, based on renewable resources. Considering the necessity to provide an alternate roofing material to ACCS, IPIRTI took up the work of developing an eco-friendly roofing material. BMCS & BMRC were successfully

developed using bamboo mats. BMCS has several other potential uses like walling, container/packaging, sandwich construction, prefabricated houses, flooring and structural components like Stress skin panels. A patent application has been filed by IPIRTI for BMCS & BMRC.

Materials and Methods

Meloconna baccifera, *Ochlandra travancorica* and *Bambusa bambos* species were used for the manufacture of BMCS and BMRC. Phenol formaldehyde resin of 1: 1.6 (wt ratio) manufactured using phenol (98% purity), formalin (37%) and sodium hydroxide as catalyst.

Manufacturing of Bamboo mats

Hand woven mats from slivers were made from mature green bamboos. The bamboos were cut to size and after cross cutting in to required lengths and splitting. Epidermal layer was removed/peeled off. 0.6mm ($\pm 15\%$) thick slivers were made either mechanically or manually. Slivers were woven into mats in herring-bone pattern. Prophylactic treatment against fungal/borer infestation was given to woven bamboo mat.

Manufacture of BMCS and BMRC

The hand woven mats were coated with PF resin incorporated with suitable preservative chemical using a resin applicator. Resin coated mats were stabilized by stacking for about 2 hours. Stabilized mats were dried to about 8% moisture content. These bamboo mats were assembled in 4 layers and hot pressed in specially designed press with corrugated platens having definite pitch to depth ratio (Figure 1). Process flow followed for the manufacturing of BMCS and BMRC (Figure 2). Process parameters have been worked out with regards to resin/adhesive formulation and resin application, stabilization of resin coated/treated mats, drying schedules of resin coated/treated mats. Hot press temperature and specific pressure to be employed, and time of hot pressing have been worked out. Industrial production trials at Meghalaya using multi day light hot press have also been studied for the up gradation of the technology after the successful trials at pilot scale.

BMCS and BMRC manufactured at IPIRTI and Industrial units were subjected for evaluation as per the requirements of IS:15476-2004. Resistance to decay and insects were tested as per IS: 13958-1994. Thermal Conductivity test were carried out as per IS 3346-1980.

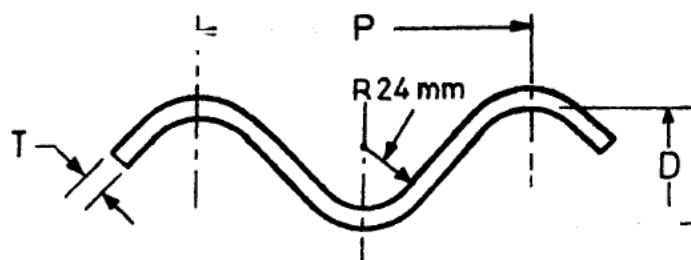


Figure.1

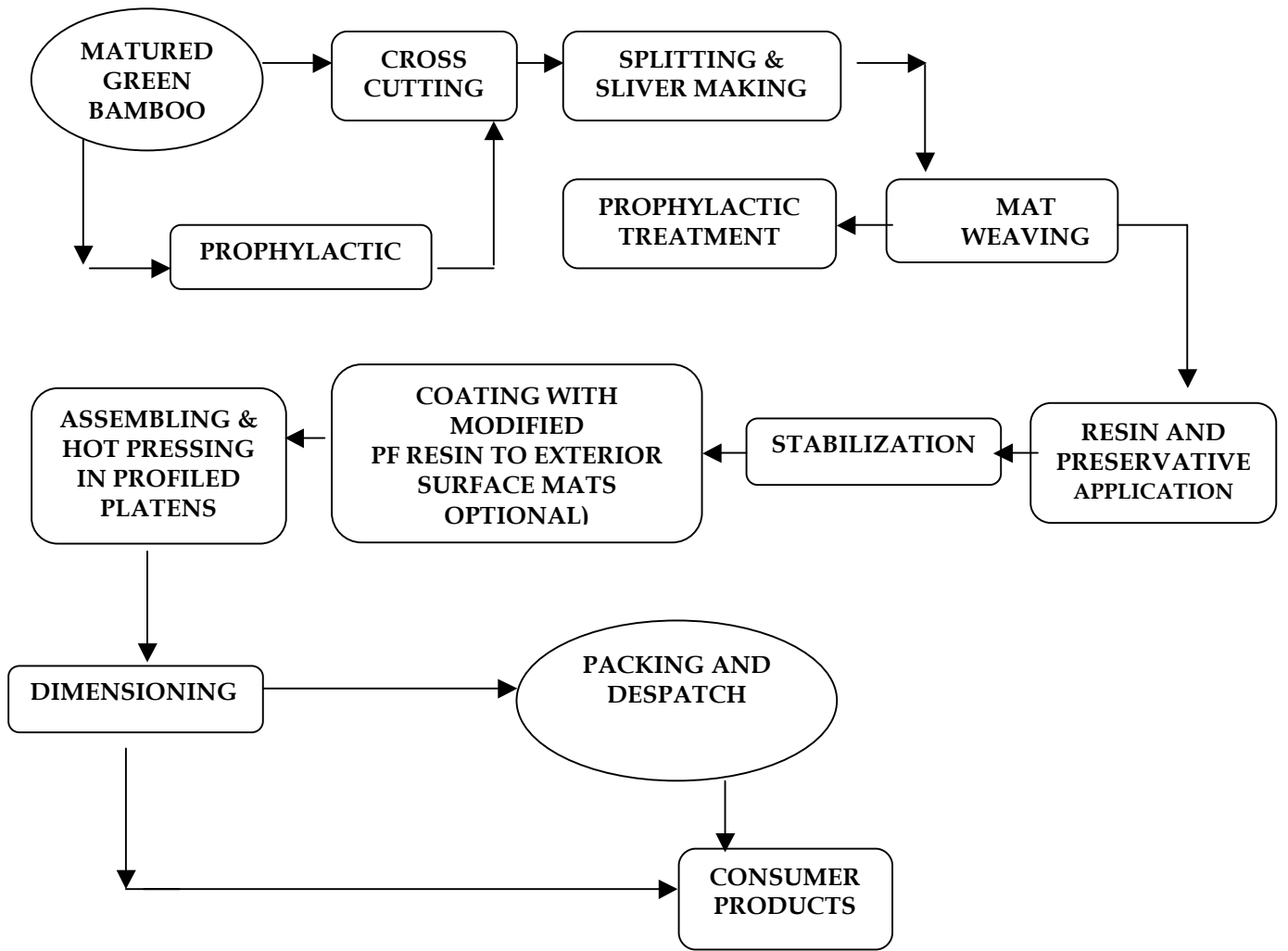


Figure 2

Testing of BMCS and BMRC

- A. **Bond Quality:** 30cm x 15cm pieces of BMCS were subjected to knife/peel tests in both dry and wet after subjecting to cyclic boil-dry tests 3 cycles comprising of 3 hours immersed in boiling water and dried to 12% moisture content.
- B. **Resistance to Decay and Insects:** BMCS and BMRC samples were subjected to graveyard test (buried in active termite mounds) and borer resistant tests (exposing the test specimens with infected borer samples).
- C. **Water Permeability test :**Standard size BMCS were mounted on a platform over which suitable metal frame to suit the corrugated profile were placed on BMCS and junction sealed with a putty, filled it with water to a height of 75mm above the crown level and observed for water leakage/seepage. Each cycle comprising of water filling up for 24 hours followed by removal of water and air-drying for 48 hours under sun.
- D. **Load Bearing Capacity test:** Load bearing capacity of BMCS and BMRC was studied in comparison with some of the existing roofing materials like ACCS, CGI Sheets and Aluminum Corrugated Sheets. The comparative result is as shown in table -1
- E. **Thermal Conductivity:** Thermal conductivity of BMCS was determined by measuring the thermal conductivity of flat BMB made by employing the process parameters for making BMCS.
- F. **Thermal comforts:** Inside temperature of the room covered with Asbestos roofing sheets were compared with that of BMCS covered roof.
- G. **Accelerated ageing tests:** In order to assess the durability and correlate with conventional exposure tests; 10cm x 15cm specimens were immersed in boiling water for 3 hours followed by immersion in cold water to cool to ambient temperature and finally drying at 60-65°C for a period of 20 hours. This constitutes one cycle. Repeated these cycles for 3 times and finally examined for visual delamination of sheets, forceful separation of mats or slivers using knife. Sheets were exposed to high relative (90±2%) humidity coupled with high temperature of 40°C and high temperature 50°C and very low relative humidity of 15-20% in the presence of U.V Light.

Results and Discussions

BMCS and BMRC manufactured using Phenol formaldehyde resin was tested and evaluated as per the IS: 15476-2004. Test results indicate that load bearing capacity of BMCS is comparable with those of ACCS & CGI Sheets. It has been found that BMCS was much superior to Aluminum Corrugated Sheets (Table 1). Moreover, BMCS were found to be highly resilient compared to GI Sheets & Aluminum Sheets. Whereas ACCS were found to be highly brittle requiring special care during transportation as well as use as roofing sheets.

Thermal Conductivity of Bamboo Mat Board (BMB) and ACCS were compared with a view to correlate with BMCS and ACCS. Thermal Conductivity was found to be 0.1928 kcal/mh⁰c and of ACCS 0.3422 kcal/mh⁰c (Table 2). This was considerably lower compared to ACCS and GI sheets. Thus BMCS roofed houses will provide better thermal comforts compared to houses having ACCS or GI sheet roofs. It was noticed that there was 5°C less temperature in BMCS covered room, indicating that BMCS was more comfortable for the occupants of the room compared to that of Asbestos covered room.

The result of properties of BMCS shows that the manufactured sheets meets the requirements as per IS 15476:2004 (Table 3).The values of load bearing capacity in both dry & wet was found to be much

higher than the requirement. Impermeability tests did not show any sign of water droplets. Water absorption test after 24 hr. of dipping the samples in water indicated a decrease in absorption of water. Flame penetration and rate of burning test were observed to be much higher than the requirement as all the layers were coated with the resin. Bond quality test shows that the sheets were found to be intact without any sign of delamination or weakness even after cyclic boil-dry tests indicating good bonding. The sheets were found to be resistant to termites and to borer infestation as the sheets subjected to high humidity were found to be resistant to mold/fungus. There was no leakage/seepage of water even after three cycles of water permeability tests.

Table-1: Properties of corrugated sheets

	Thickness mm	Width mm	Max. Load N	Load bearing capacity N/mm	Weight of sheet (1.8 m x 0.9 m) Kg
BMCS (4 – LAYERS)	3.7	400	1907	4.77	6.18
G. I. SHEET	0.6	400	1937	4.84	6.6
ALUMINIUM SHEET	0.6	405	669	1.67	2.48
ACCS	6	330	1800	5.45	13.6

Table-2: Thermal properties of BMCS compared with other materials

Material	Thermal conductivity kcal/mh⁰c
BMCS	0.1928
ACCS	0.3422

Table-3: Properties of Bamboo Mat Corrugated Sheets as per IS 15476:2004

Sl. No.	Properties	Result Obtained	Requirement as per IS 15476:2004
1	Density g/cm ³	0.75 – 0.8	0.75
2	Load bearing capacity (dry), N/mm	5.7	4
	Wet, N/mm	4.9	3
3	Impermeability	The lower surface shall not show any formation of drops of water except for traces of moisture	The lower surface shall not show any formation of drops of water except for traces of moisture
4	Water Absorption, (after 24 hrs)%	11.9 - 13.5	max: 15
5	Cyclic test	No delamination even after 3 cycles	No delamination
6	Resistance to falling weight	Test piece does not break or show any crack or tear	Test piece shall not break or show any crack or tear
7	Resistance to fire		
	a) Flame penetration, minutes	18.4	Min: 10
	b) Rate of burning, minutes	40.3	Min: 20
	c) Surface spread of flame, mm ²	3168	Max: 4500

BMCS manufactured at the pilot plant facilities were tested in-house as well as and in an independent laboratory to confirm the load bearing capacity and bond integrity (Table 4 & 5). It can be seen from results that the values obtained in the independent laboratory agrees with the in-house testing indicating that the BMCS manufactured at pilot plant were excellent with respect to load bearing capacity & internal bond strength and hence can be used as an constructional material. The test results of the BMCS manufactured during trial production using multi daylight hydraulic hot press installed in one of the unit at Byrnihat, Meghalaya are comparable with that of BMCS made in the pilot plant (Table 6). This indicates that the process parameters followed for the manufacture of BMCS are technically feasible.

Table-4: Loading Bearing Capacity

Average width 430 mm
 Thickness of the sheet 3.5 mm
 Span 1000 mm

Sample No.	Load bearing Cap N/mm of width	
	Independent Lab.	In-House
A ₁	5.2	4.04
B ₁	5.31	4.22
C ₁	5.26	4.06
D ₁	5.43	4.55

Table-5: Internal Bond Strength

Thickness of the Sheet 3.5 mm

Sample No.	Internal Bond Strength N/mm ²	
	Independent lab.	In-House
A ₁	2.35	1.86
B ₁	1.88	1.63
C ₁	2.12	1.78
D ₁	1.92	1.70

Table-6: Test Results of BMCS made during Production Trials

Sl. No.	Load bearing cap. N/mm ²	Internal Bond Strength N/mm ²
1.	4.56	0.98
2.	5.07	1.07
3.	4.41	1.08
4.	4.75	0.90
5.	4.73	0.95
6.	4.66	1.02

BMCS and BMRC technology has already been transferred to many industries to make the same on commercial scale (Figure 3 , 4). Indian railways have started using it for platform roofs extensively (Figure 5, 6).



Figure 3.



Figure 4

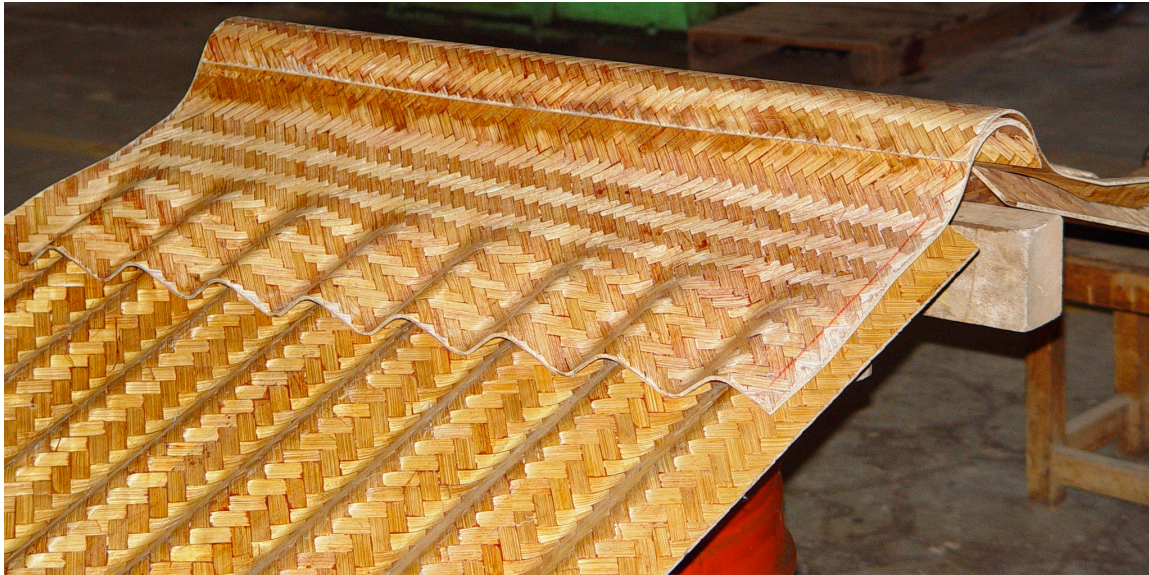


Figure 3 & 4



Figure 5



Figure 6

Conclusion

Studies carried out under the project clearly indicate that bamboo mats can be efficiently and effectively used for the manufacture of BMCS and BMRC. The platen profile was decided keeping in view the pattern of existing corrugated roofing material and the characteristics of the bamboo mats. The physical & mechanical properties of BMCS made in the pilot plant as well during production trials were found to be excellent especially with regard to load bearing capacity, water permeability and internal bond strength. Properties of BMCS meets requirement as per IS 15476:2004 (Indian Standard Bamboo Mat Corrugated Sheets — Specification). Production of BMCS and BMRC is technically feasible but the economic feasibility depends on the availability of bamboo mats and its cost per unit area. BMCS and BMRC will be an ideal ecofriendly material for roofing.

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Figure 1: Pitch and Depth of BMCS

Figure 2: Bamboo Mat Corrugated Sheets - Process Flow Chart

Figure 3: Bamboo mat Corrugated Sheets (BMCS)

Figure 4: Bamboo Mat Ridge Cap (BMRC)

Figure 5: Indian Railways, Haridwar PP Shelters

Figure 6: Indian Railways, Rewari Heritage