

# 15 Bamboo Based Composites: Material for Future

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## 1. Introduction

Bamboo, a woody grass, has always been known as an enduring, versatile and renewable resource. There are more than 125 species of bamboos in India spreading across 18 genera.

In India, bamboos grow in about 9.60 M 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 in terms of volume and 28 per cent in terms area are in the northern region. The total estimated stock of bamboo resource in the country is 130 Mt. The estimated annual harvest of bamboo in India is around 13.5 Mmt (mmt). Four-fifths of the growing stock of bamboo in India comprise three species: *Dendrocalamus strictus* (53%), *Bambusa bambos* (15%) and *Melocanna baccifera* (15%). Species suitable for commercial applications are *D. asper* (for shoots and timber), *D. hamiltonii* (for shoots), *D. stocksii* (for craft, structural and household applications) and *B. bambos*, *B. balcooa*, *B. tulda*, *B. nutans* and *D. strictus* (for wood substitutes). According to FAO (2006) the total area under bamboo in India in 1990 was 10,711,000 ha, which was increased to 11,361,000 ha in 2005. Of these, around 1,754,000 ha were under private ownership and the rest in the state owned forests.

In general, there are two types of bamboos (approximate 75 genera or 1,250 species in the world), divided according to their growth pattern. Tropical bamboos (approximate 45 genera or 750 species) usually grow in clumps which are called sympodial bamboos. The pattern of clumps can also vary. For example, bamboo culms within a clump can be closely spaced (*B. bambos*) or loosely spread out (*B. vulgaris*). On the other hand, places like China and Japan host non-clump-forming or runner bamboos (called monopodial bamboos) that send out long underground rhizomes. Individual shoots come out of these underground rhizomes. Sympodial bamboos grow

faster than monopodial bamboos and have a higher yield; they can fully rejuvenate within a few years of cutting.

In India, clump-forming bamboo (sympodial bamboos) constitutes over 67 per cent of the total growing stock. *M. baccifera*, a non clump-forming bamboo, accounts for 20 per cent 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 to be 5 Mmt in 2003-2004 (air dry) considering that, on average, 250 air-dried culms weigh one tonne and the price is around Rs. 1,600 (auction rate about US\$40). It has been estimated that 50 per cent of this production is used by the paper and pulp industries and the rest is consumed for rural construction, scaffolding, handicrafts, etc., India reportedly taps into only one-tenth of its bamboo potential and its share in the global market is only about 4 per cent (PIB, 2004).

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 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.

Extensive studies have been carried out in IPIRTI on the use of bamboo/bamboo composites, such as bamboo mat board (BMB), bamboo mat veneer composite (BMVC), bamboo mat corrugated sheet (BMCS), bamboo mat ridge cap (BMRC), bamboo mat moulded skin board (BMMSB), etc. which can lead to reduction in pressure on non-renewable building material, reduce pollution and lead to substantial energy conservation. In other words bamboo and bamboo composites emerge as potential structural and eco-friendly building material. The NMBA efforts to develop and commercialize the new range of products and applications have increased the value added utilization capacity of the bamboo sector (excluding pulp and paper, incense sticks and handicrafts) from 10,000 t per annum during 2004 to about 190,000 t per annum during 2006 (Pande and Pandey, 2008).

Bamboo is a tall, hollow, cylindrical grass containing nodes at uniform interval along its full length. The fibres remain aligned along their length whereas at nodes fibres grow across the length and form diaphragm within the hollow cylindrical part of the bamboo. Bamboo in its natural form has several uses especially mature bamboo which is very strong and durable. Split bamboo is very susceptible to fungus and termite attack unless given proper preservative treatment. To convert bamboo into

panel or wood - like products preliminary processing of bamboo is required which converts hollow, cylindrical bamboo into basic raw materials slivers/bamboo mat or strips to be used for further processing into useful products. Bamboo can also be split open, crushed and glued to panel products.

## 2. Bamboo Processing

Processing of bamboo into panel and structural products, housing components, other utility items, furniture from bamboo laminates, etc. involves two steps (a) primary processing of bamboo, e.g., bamboo to bamboo mat (Fig. 2.1.) and (b) industrial processing or processing into basic or useful component, e.g., bamboo mat board, bamboo laminates, etc. (Fig. 2.2.).



Fig. 2.1. Bamboo primary processing unit in the IPIRTI.



Fig. 2.2. Pilot plant in IPIRTI for manufacture of bamboo mat board (2.44 m × 1.22 m size).

## **2.1. Primary Processing**

The traditional method of bamboo processing practised by craftsmen in villages is purely a manual processing operation using only one tool called 'Dao' or knife. All processing activities like cross-cutting, splitting, slab, sliver, stick making, etc., are done with the help of this tool.

The manual processing of bamboo is very labour intensive, tedious, and monotonous. It also leads to the production of poor quality slivers, sticks, etc., and generates more wastage of raw materials.

The machinery employed in bamboo preliminary processing for production of slivers and laminates are bamboo cross-cutting machine, bamboo splitting machine with knives, bamboo splitting machine with circular saws, bamboo width sizing, knot removing and planing machine, bamboo four side planing machine, one side planing machine, bamboo slab making machine, bamboo sliver making machine. These machines are presently made by a few Indian manufacturers.

### **2.1.1. Bamboo cross-cutting machine**

This machine is used for making a straight, smooth and square cut across the culms without development of any additional splits on the culms and leads to drastic reduction in raw material wastage. A tungsten carbide tipped (TCT) saw is used for cross-cutting bamboo culms and it needs periodic re-sharpening. There is a provision in the machine where the desired length of bamboo to be cross-cut can be preset. Safety guards are provided on the machine to take care of the safety aspects during operation.

### **2.1.2. Bamboo splitting machine with knives**

The main function of this machine is to carry out splitting of bamboo culms with knives to the desired width. The tool used for splitting is called knife ring. Knife rings are available with knives placed at different interspaces and the one that suits the diameter of bamboo culms and the intended width of split can be selected. The bamboo culms are pressed and moved fast against the knife ring with a pushing device moving on a sliding bed, which result in instantaneous and simultaneous splitting action. Safety guards are provided on the machine and should be in place to take care of safety in operation. However, adequate precautions are taken during operation of the machine to prevent accidents and injury.

### **2.1.3. Bamboo splitting machine with circular saws**

This machine is employed for splitting bamboo using circular saws to get parallel width. The advantage of this machine is that uniform width can be obtained for splits even if there is tapering in diameter of bamboo culms. Uniformity in split width is a very essential

requirement in the manufacture of bamboo laminates or floor tiles. In this machine, two parallel mounted TCT saws set to the desired split width, do the cutting action.

#### **2.1.4. Bamboo width sizing, knot removing and planing machine**

This machine is very effective in carrying out the planing operation as the work is done by two carbide cutters. There is also provision in the machine to do other functions such as width sizing and knot removal, with the help of sizing knife and knot removing knife, respectively.

#### **2.1.5. Bamboo four-side planing machine**

Planing of all four sides of bamboo strips is done by this machine with the help of four carbide cutters for the production of bamboo laminates. The width and thickness of the strips can be set in this machine and smooth surfaces and uniform size for all strips are thereby obtained.

#### **2.1.6. Bamboo one-side planing machine**

The planing of bamboo laminate after hot pressing operation is carried out in this machine. At one pass, one surface of the laminate is planed using a planing cutter to a smooth surface.

#### **2.1.7. Bamboo slab making machine**

This machine is utilized for the production of slabs as preparatory step to the manufacture of slivers for mat making. A horizontally mounted slicing knife (HCHR), whose position can be altered depending upon the thickness of slab, does the cutting action. The thickness of slab is normally set to 2.4 mm or in multiples of final sliver thickness.

#### **2.1.8. Bamboo sliver making machine**

The slivers used for weaving mats are produced in this machine. A horizontally mounted slicing knife, whose position is moved up or down depending upon the desired thickness of sliver, does the cutting action. The normal thickness of sliver is about 0.6 to 0.8 mm.

Bamboo mat based panel or bamboo laminates will find many uses, especially where plywood is being used at present. However, such products can be further processed into utility items or structural component by further processing. Such utility items may be a box from bamboo mat panel or furniture from bamboo laminates. The secondary products can be made in a cottage industry or a small sister unit adjoining to a bamboo processing units. An improved version of

carpenter shop can act as such units and can be situated where big bamboo mat panel or laminates are manufactured.

### **2.1.9. Bamboo treatment**

Harvested bamboo is susceptible to borer and fungal attacks. Various treatment practices have been developed, but there is great scope for applied research in this area. Processes of bamboo treatment at preprocessing stage either by boiling in water and chemical treatment have been well established. There is a need to develop facility for bamboo treatment and seasoning before sending it for industrial use so as to resist deterioration before use.

## **2.2. Industrial Processing (Products and Technologies Developed at IPIRTI)**

### **2.2.1. Bamboo mat board**

Use of any new material depends upon its suitability for various applications *vis-a-vis* the materials already in use. Development of appropriate application technology plays an important role in acceptance of any new material. BMB is essentially a layered composite (Fig. 2.2.1.1.) comprising several layers of woven mats having excellent internal bond strength, and are resistant to decay, insects and termite attack. They have physical and mechanical properties at par with waterproof plywood and are fire resistant. Their mechanical properties depend upon the material used for making mats, i.e., bamboo slivers, the weaving pattern and the adhesive used for bonding (IPIRTI, 1993).

However, these properties can be altered by changing the weaving pattern of bamboo slivers used in mat making used for making board in order to get required values for MOR, MOE, tensile strength, etc. Thus, it can be inferred that the strength and stiffness of BMB is related to the weaving pattern of the mats. However, modulus of rigidity (MOR) or shear modulus of BMB in the plane of the board is very high and is comparable to the required values for structural plywood as per Indian specifications IS: 10701. It is interesting to note that MOR of BMB far exceeds that of both structural plywood and wood. This is attributable to the herringbone weave pattern. Clearly, BMB has high in-plane rigidity and hence, high racking strength and is more flexible than equivalent plywood. This property of BMB can be advantageously used in many engineering applications. In fact, BMB has been found useful as sheathing material in structural and semi structural uses such as walling, partitions, roof sheeting, door skins, box furniture, built up hollow beams, gussets, and containers. Investigations have also been undertaken at the IPIRTI with regard to suitability of BMB for manufacture of secondary parts of aircraft and gliders as substitute for speciality plywood made from *Dysoxylum malabaricum* and *Palaquium ellipticum*.

BMB meet all the requirements prescribed in the relevant Indian specifications and have in fact much higher cross sectional shear strength compared to plywood.

### **2.2.2. Bamboo mat veneer composite**

In Bamboo mat veneer composite (BMVC), wood veneers are placed in between the layers of bamboo mats (Fig. 2.2.2.1.). The properties of BMVC depend upon the mechanical properties of wood veneers that are placed in between bamboo mat layers, in addition to the properties of the bamboo mats and the adhesives used in bonding.

Investigations have shown that strength of a panel made by plantation timber is substantially enhanced when made in combination with bamboo mats. MOE and MOR of BMVC are higher than equivalent plywood and this depends on the number of layers of veneers for a given thickness of BMVC. Due to the presence of woven bamboo mats, BMVC has different mechanical properties along and across the length of the board (BIS, 1999).

The properties are comparable to those of structural plywood. Hence, for all practical purposes BMVC can be used in a way similar plywood for structural applications. BMVC will be economical in higher thickness as compared to BMB.

### **2.2.3. Bamboo mat moulded products**

Considering the flexibility of bamboo mats due to '*Herringbone*' weave pattern, an idea was mooted to produce moulded products like trays, chair seats, etc. (Fig. 2.2.3.1.) in various forms like rectangular, round, as well in different sizes. A process was developed including the moulds to produce such products get them in finished form which can be subsequently finished with coating materials to enhance the appearance and acceptability by the consumers. The moulded products like trays, were found to be highly durable and leak proof which can be conveniently used for various applications like the ones based on metals, plastics, etc. The technology for the manufacture of bamboo mat tray has been transferred to two units, one in Pune and the other one in Bangalore (IPIRTI, 1983).

### **2.2.4. Bamboo mat corrugated sheets**

The idea of development of corrugated sheets was a result of development of bamboo mat moulded products like trays to enhance stiffness for the BMB developed through corrugation techniques (Fig. 2.2.4.1.). Roofing materials such as asbestos cement corrugated sheeting (ACCS), corrugated fibre reinforced plastics (CFRPs). Corrugated aluminium sheeting (CAS) and corrugated galvanized iron sheeting (CGIS), which have been established for 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. Scaling up of the pilot scale technology for its industrial adoption has been successfully carried out under a project funded by Ministry of Environment, Forests and Climate Change, Govt. of India. The comparative strength properties of BMCS with other existing roofing sheets are given in Table 2.2.4.1. Bureau of Indian Standards has brought out a standard on the specification of bamboo mat corrugated sheets for roofing [IS:15476-2004].

**Table 2.2.4.1. Strength properties of BMCS in comparison with other existing roofing sheets**

Particular	Thick-ness (mm)	Width (mm)	Max load (N)	Load bearing capacity (N/mm)	Weight of sheet (2.44m x 1.05 m) (kg)
BMCS [4 layers]	3.7	400	1,907	4.77	9.78
GI Sheet	0.6	400	1,937	4.84	10.43
Aluminium sheet	0.6	405	669	1.67	3.92
ACCS	6.0	330	1,800	5.45	21.5

A few demonstration structures have been put up in several parts of the country by utilizing BMCS developed and produced at IPIRTI's pilot plant. The process of BMCS has been standardized and the plant has been commissioned for commercial production of BMCS. Commercially available coating compositions have also been evolved to ensure the durability of BMCS. Some demonstration structures are under observation and is reported that the demand for such sheets are steadily increasing presumably based on the advantages over its counterparts.

### **2.2.5. Bamboo mat ridge cap**

Recently, a technology has been developed at IPIRTI in collaboration with BMTPC for the production of bamboo mat ridge cap. (Fig. 2.2.5.1.). The main raw material for the production of ridge cap is mat from bamboo. The product is both environment- and people-friendly. The product is dimensionally stable, fire resistant, non permeable, boiling water proof, anti-termite and weather resistant, and compatible with bamboo mat corrugated sheet. The existing units producing bamboo mat corrugated sheets can convert one of the daylight in hydraulic hot press with specially designed die of size 2.4 m x 0.43 m for regular production of bamboo mat ridge caps. Technology is available for commercialization.

### **2.2.6. Bamboo mat overlaid particle board**

Processes have been developed for overlaying wood/rice husk particle boards with bamboo mats (Fig. 2.2.6.1.). The overlaying is found to improve physical and mechanical properties of the boards as well as the appearance. The bamboo mat overlaid particle boards may be suitable even for semi structural applications. The results obtained from bamboo mat overlaid wood particle board in comparison with the data on wood particle boards indicated that water absorption and swelling properties of bamboo mat overlaid wood particle board improved considerably enhancing the durability of such panels even under adverse climatic conditions.

Mechanical strength properties of wood particle board increased considerably due to bamboo mat overlaying, e.g., MOR over 150 per cent, MOE over 65 per cent and screw holding power by around 50 per cent suggesting the utilization of BMWPB for enlarged end use applications. Water absorption and swelling properties of BMRHP are improved over 100 per cent indicating the durability of such panels even under adverse climatic conditions. Mechanical strength properties of RHPB increased considerably due to bamboo mat overlaying, e.g., MOR: over 115 per cent; MOE: over 60 per cent: Screw holding power by 60 per cent suggesting the utilization of BMRHB for enlarged end use applications.

### **2.2.7. Bamboo wood**

Development of appropriate technologies for the manufacture of both horizontal and vertical laminates using synthetic resin like UF, MUF and PF resins have been developed (Fig. 2.2.7.1.). Design and development of machinery for exerting side pressure for making laminates has also been made. Preliminary tests carried out on these laminates shows that it is superior to plantation timbers. End use application such as furniture, other household component and flooring have been developed and put to use (IPIRTI, 2003).

### **2.2.8. Bamboo mat moulded skin board**

IPIRTI has developed a process for the manufacture of Bamboo mat moulded skin board (BMMSB) (Fig. 2.2.8.1.). Having high strength and stiffness, there is reduction in timber consumption like battens, face veneers, etc. The cost of the door is 15 per cent less than that of HDF doors with additional strength properties like high impact resistance leading to import substitution, high density, moulded fibre board used as doors (Uday *et al.*, 2008).

### **2.2.9. High density shuttering grade BMB**

High density shuttering grade bamboo mat boards developed in IPIRTI will be an alternate to compreg manufactured at present. It has high physical mechanical properties and can be used wherever compreg is used (Fig. 2.2.9.1.).

### 2.2.10. Flexi-ply with bamboo mat as core

IPIRTI has developed a technology for flexi-ply with the inner layer of veneer being replaced by bamboo mat (Fig. 2.2.10.1.). This reduces the possibility of breakage when rolled. Plywood of 3 mm and higher thickness have the tendency to break when rolled, i.e., due to the non flexibility of the product. The flexi-ply developed in combination with bamboo mat has flexibility even with 8 mm thick panels. The flexi-ply so developed has great potential for applications in cabins of hemispherical shapes and arch panels.

### 2.2.11. Application of bamboo based products in housing

Development of best construction techniques for house using bamboo and its composites and plantation wood were carried out in the IPIRTI. Houses built in the institute campus with industrial products from bamboo for various purposes are displayed in Fig. 2.2.11.1. It is meant to promote the techniques for the awareness and the information of regulatory bodies/housing associations (Jagadeesh *et al.*, 1998).



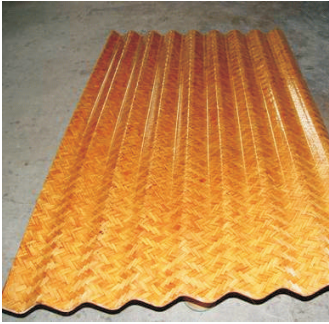
Fig. 2.2.1.1. Bamboo mat board.



Fig. 2.2.2.1. Bamboo mat veneer composite.



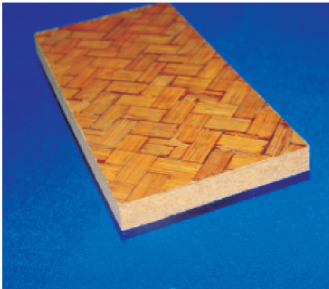
Fig. 2.2.3.1. Bamboo mat moulded products.



**Fig. 2.2.4.1. Bamboo mat corrugated sheets.**



**Fig. 2.2.5.1. Bamboo mat ridge cap.**



**Fig. 2.2.6.1. Bamboo mat overlaid particle board.**



**Fig. 2.2.7.1. Bamboo wood.**



**Fig. 2.2.8.1. Bamboo mat moulded skin board.**



**Fig. 2.2.9.1. High density shuttering grade BMB.**



**Fig. 2.2.10.1. Flexi-ply with bamboo mat as core.**



**Demonstration house**



**Two bedroom guest house**



**Double storeyed house**



**Prefab house**

**Fig. 2.2.11.1. Houses built in IPIRTI campus with bamboo products.**

### **3. The Industrial Processing Parameters**

The industrial processing parameters including type of adhesives, application of the resin and pressing conditions are dealt with here. Woven bamboo mats form the raw material base for all mat based composites. Till date, these mats are hand woven by artisans specially women in rural tribal areas. The generalized flow charts for processing bamboo mat composites and bamboo wood are displayed in Fig. 3.1. and Fig. 3.2.

#### **3.1. Adhesives**

Depending on the end use of the products, two types of thermoset resins are being used phenol formaldehyde and melamine urea formaldehyde. For bamboo mat board, corrugated sheets, etc., phenol formaldehyde resin are being used. For products like floor board, moulded products like tray, MUF resin has been used whereas for the high density products like chair sheet, compreg manufacture, phenolic resins are being used.

#### **3.2. Resin Application**

Bamboo strips can be resin coated with brush or roller coater. But for bamboo mat such coating is not suitable. Specially designed resin applicator is being used, so that resin

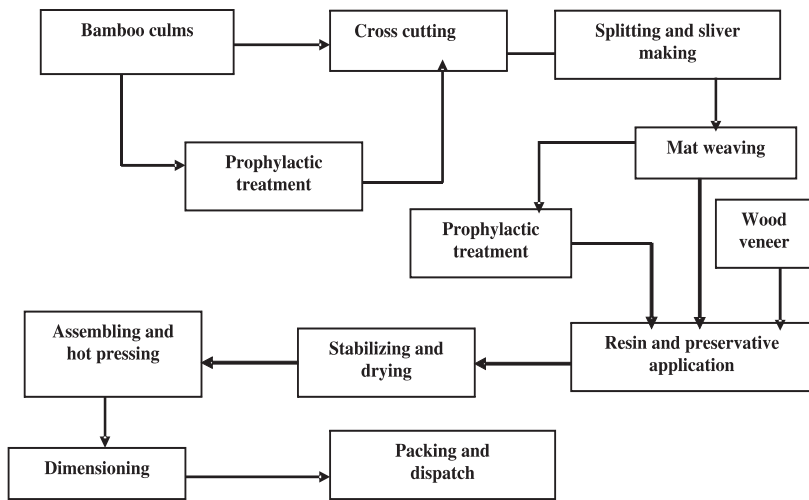


Fig. 3.1. Process flow chart for bamboo mat composites.

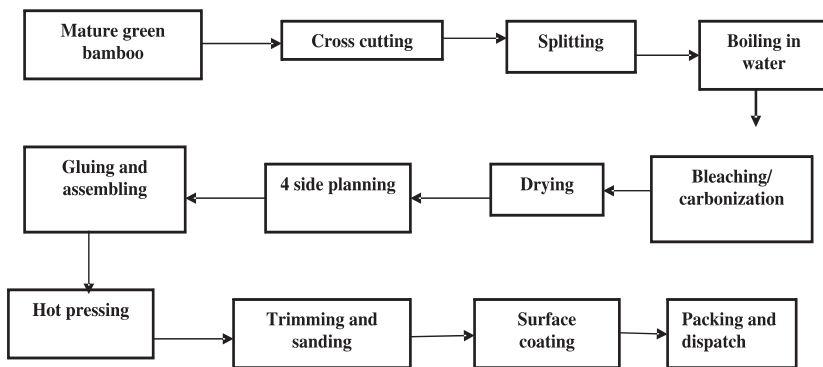


Fig. 3.2. Process flow chart for the manufacture of bamboo wood.

can penetrate into intersliver spaces. Moisture plays a vital role in the curing of resin on bamboo surfaces. Conditioning of the glued mat/strips to bring glued surface to desired moisture content and equilibrium distribution of the same is necessary before hot pressing.

### 3.3. Hot Press Conditions

Pressing conditions varies from product to product and also the resin system used for coating the surfaces.

### 3.4. Temperature

For PF resin based products usual pressing temperature used is 140°-150° C. MUF resin based products are pressed by employing a temperature of 115°-125° C in the hot press.

### 3.5. Pressure

Pressure applied varies widely depending on the ultimate density of the products. Density of bamboo at 12 per cent moisture content, ranges from 0.65 to 0.70. For products to be obtained with density 0.7-0.75, pressure of 14-16 kg cm<sup>-2</sup> was enough. Where high density products of density 1.2-1.4 were to be obtained hot press pressure of 80-120 kg cm<sup>-2</sup> was used. Where strip based products like laminates, simultaneous side pressures, vertical and horizontal pressure has to be applied for which a specially designed hot press has been designed for the purpose and put to use.

### 3.6. Time

For different types of bamboo based products, hot press had been worked out through experimentation to find out that farthest glue line from the surface was being cured during hot pressing and consequently during stabilizing period.

### 3.7. Finishing of Products

Bamboo mats are thoroughly coated with resin before hot pressing which gets cured at the surface of mats. Further finishing is not required for many products. Some of the high density moulded products are overlaid with phenolic and melamine resin based film for which also further finishing of the surface is not required.

However, most of the strip based products where bamboo forms the surface requires sanding and further coating to impart aesthetic appearance. For the present work, melamine resin or polyurethane based resin were applied for surface coating. In case bamboo based products are overlaid with wood veneer, usual wood finish was applied as in the case of plywood or particle board.

### 3.8. Testing of Panels

Test specimens from bamboo mat based and strip based products were conditioned to moisture content around 10 per cent. Tests were statistically designed for a probability of 68.3 per cent [one sigma level] and an experimental precision of 3 per cent. Minimum number of test specimens required for testing was determined from the co-efficient of variation already established for similar material. A recheck was also carried out to confirm the validity of these co-efficient of variation. Results for BMB, BMCS, BMVC, BL, BPB and BMMSB are given in Tables 3.8.1., 3.8.2., 3.8.3., 3.8.4.,

**Table 3.8.1. Physical and mechanical properties of BMB of different thicknesses**

Property	Thickness (mm)				
	3	6	6*	8	9
Thickness of the panels (mm)	3	6	6*	8	9
Density (kg m <sup>-3</sup> )	766	711	935	790	892
I.B. strength (N mm <sup>-2</sup> )					
Dry	2.18	2.42	0.82	1.97	2.2
Wet	1.98	2.14	0.61	1.73	1.8
Surface strength (N mm <sup>-2</sup> )					
Dry	11.42	11.23	4.9	9.47	13.10
Wet	11.42	10.47	3.47	9.10	10.5
Tensile strength (N mm <sup>-2</sup> )	22.69	26.59	89.17	29.54	31.4
Compressive strength (N mm <sup>-2</sup> )	16.77	30.35	50.60	35.30	57.5
MOR (N mm <sup>-2</sup> )	50.74	56.31	102.57	59.35	68.8
MOE (N mm <sup>-2</sup> )	3,678	3,220	12,033	3,114	3,930
MORI (N mm <sup>-2</sup> )	5,881	6,050	3,527	6,066	5,750

\*Pattern of weaving is rectangular.

I.B.= Internal bond; MOR= Modulus of rupture; MOE= Modulus of elasticity; MORI= Modulus of rigidity.

**Table 3.8.2. Physical mechanical properties of BMVC**

Property	Structural plywood	BMVC (67%)
Thickness (mm)	-	21
Density (kgs m <sup>-3</sup> )	750	602
I.B. strength (N mm <sup>-2</sup> )		
Dry	-	2.30
Wet	-	1.65
Surface strength (N mm <sup>-2</sup> )		
Dry	-	8.00
Wet	-	6.80
Tensile strength (N mm <sup>-2</sup> )		
	54	36.40
⊥	34	35.80
Compressive strength (N mm <sup>-2</sup> )		
	34	43.90
⊥	29	40.20
MOR (N mm <sup>-2</sup> )		
	49	68.50
⊥	29	55.40
MOE (N mm <sup>-2</sup> )		
	7,355	7,820
⊥	3,923	3,210
MORI (N mm <sup>-2</sup> )	588	3,316

3.8.5., 3.8.6. and 3.8.7., respectively. Comparative results as per Indian Standard (wherever available) are also given.

Based on the research carried out at this IPIRTI, it has been established that various bamboo mat and strip based products developed are comparable to wood

**Table 3.8.3. Strength properties of bamboo laminates**

Property	Vertical laminate			Horizontal laminate (MUF)
	UF	MUF	PF	
Density (kg m <sup>-3</sup> )	728	745	796	782
MOR (N mm <sup>-2</sup> )	122.5	149.1	145.2	164.4
MOE (N mm <sup>-2</sup> )	12028	16570	16800	17300
Compressive strength (N mm <sup>-2</sup> )	61.7	84.7	96.0	87.9
Block shear strength (N mm <sup>-2</sup> )	11.89	12.8	12.7	9.65
Screw withdrawal strength (N)				
Face	4,999	4,006	4,683	3,235
Edge	2,333	3,659	3,216	5,375

**Table 3.8.4. Properties of bamboo strip board**

Property	Value obtained
Density (kg m <sup>-3</sup> )	921.00
Moisture content (%)	3.9
MOR (N mm <sup>-2</sup> )	
Along	118.56
Across	59.47
MOE (N mm <sup>-2</sup> )	
Along	12,383
Across	3,556
Block shear strength (N mm <sup>-2</sup> )	5.67

**Table 3.8.5. Properties of bamboo mat corrugated sheets**

Property	Result obtained	Requirement as per IS 15476:2004
Density (g cm <sup>-3</sup> )	0.75 – 0.8	0.75
Load bearing capacity		
Dry (N/mm)	5.7	4
Wet (N/mm)	4.9	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
Water absorption (%)	11.9 - 13.5	Max: 15
Cyclic test	No delamination even after 3 cycles	No delamination
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
Resistance to fire		
a) Flame penetration (min)	18.4	10
b) Rate of burning (min)	40.3	20
c) Surface spread of flame (mm <sup>2</sup> )	3,168	Max: 4,500

**Table 3.8.6. Strength properties of bamboo mat compregs and shuttering grade panels made from bamboo/plantation timbers in combination.**

Test	Result obtained	Prescribed value as per IS 3513	Prescribed value as per IS 4990	
			Along	Across
Specific gravity	1.10	0.95 to 1.25	-	-
Moisture content (%)	8.01	6 to 12	5 to 5	
Tensile strength (Mpa)	57.18	59	32.5	22.5
Static bending strength (Mpa)	107.60	59	50	30
Modulus of elasticity (Mpa)	5,701	-	7,500	4,000
Compressive strength (Parallel to laminae) (Mpa)	68.50	75	-	-
Compressive strength (Perp to laminae), (Mpa)	181.20	130	-	-
Impact strength (Perp. to laminae) (kgm cm <sup>-2</sup> )	0.55	0.2	-	-
Impact strength (Parallel to laminae) (kgm cm <sup>-2</sup> )	0.60	0.5	-	-
Hardness (Rockwell 'H' scale)	96.67	60	-	-

based panel products and solid wood and, thus, can replace wood and wood products in many end uses.

Studies on the suitability of bamboo mat board show that they can be used for non-load bearing applications similar to plywood in housing, furniture, packaging, storage and transportation. Utilization of bamboo mat board for load bearing structural applications similar to structural plywood, concrete shuttering plywood, etc. were not found suitable due to lower strength and stiffness ratio. However, introduction of wood veneer in the panel has increased these properties considerably except modulus of rigidity depending on the number of veneers and their position in the assembly. Though modulus of rigidity of composite panels has come down considerably as compared to the values obtained for bamboo mat boards, the composite panels have still much higher modulus of rigidity (four to nine times) than the values prescribed for structural plywood and, thus, bamboo mat veneer composites can be used for structural purposes.

Another important product variant from bamboo mat is bamboo mat corrugated sheet (BMCS). These are light but strong and possess high resilience. Being manufactured from bamboo, these are environment and people friendly and are expected to revolutionize house construction activity, particularly in disaster prone areas as prefab houses. BMCS withstand 72 hours of boiling in water and no percolation of water being observed after storing water for over 24 hours when tested for water permeability. Fire retardant property of BMCS is satisfactory.

Table 3.8.7. Strength properties of bamboo mat moulded skin board door in performance tests as per IS 4020

Test	Prescribed value as per IS 15380	Result		
		Door 1	Door 2	Door 3
Size L x B x T (mm)	-	1884.5 x 906 x 32.75	1882 x 909.6 x 32.36	1880 x 908.3 x 32.30
Squareness	Deviation not more than 1mm per 500mm length	0.5 mm	0.6 mm	0.8 mm
General flatness	Warping, cupping and twist not more than 6 mm	Warping = 1 mm Cupping = 0.75 mm Twisting = 0.75 mm	Warping = 0.65 mm Cupping = 0.90 mm Twisting = 3.4 mm	Warping = 0.75 mm Cupping = 0.15 mm Twisting = 2.25 mm
End immersion test	No delamination	No delamination	No delamination	No delamination
Glue adhesion test	No delamination	No delamination	No delamination	No delamination
Impact indentation	No cracking, tearing or delamination, depth of indentation not more than 0.2 mm	Conforms, depth of indentation is 0.18mm	Conforms, depth of indentation is 0.13mm	Conforms, depth of indentation is 0.1mm
Slamming test	No visible damage after 50 drops	No damage	No damage	No damage
Flexure (deflection in mm):				
15 min after loading 50 kg	Deflection at max load not more than 1/30 <sup>th</sup> of length and 1/15 <sup>th</sup> of width, whichever is less	35.20	26.77	29.77
3 min after load removal	Residual deflection not more than 1/10 <sup>th</sup> of maximum deflection.	1.43	0.87	1.36
Shock resistance: Soft and light body impact	No visible damage	No damage	No damage	No damage

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Soft and heavy body impact	No visible damage	No damage	No damage	No damage
Buckling (deflection in mm):	No deterioration	No deterioration	No deterioration	No deterioration
After 5 min of 40 kg loading	Initial deflection not more than 50 mm	36.70	19.40	24.59
15 min after load removal	Residual deformation after 15 min. of load removal not greater than 5 mm	2.47	2.36	2.5
Misuse	No permanent deformation of the fixing or any other part of door	Conforms	Conforms	Conforms
Edge loading (deflection in mm):	Deflection at max load not more than 5 mm.	3.97	3.03	3.11
After 15 min of 100 kg loading	After load removal Residual deflection not more than 0.5 mm	0.49	0.32	0.47
3 min after load removal	Not less than 1000	2,494	2,715	2,622
Screw withdrawal strength (N)	Recovery - at least 90% of the change in dimension	95%	93.5%	96.5%
Varying humidity test				

BMCS has low thermal conductivity compared to other roofing materials [0.1928 kcal/m<sup>0</sup>C for BMCS and 0.3422 kcal/m<sup>0</sup>C for ACCS]. The sheets have been found to be resistant to decay and termites. BMCS has very high potential in several end use applications, major use being in roofing as an alternative to asbestos cement, GI aluminium and plastic roofing sheets. Bamboo mat based moulded as well as high density products are other variant of products from bamboos.

Moulded trays and chair sheet can replace those made from wood, metal and plastic. With proper surface protection and/or densification such products assume enhanced service life and become resistant to bio-degradation and resistant to flame.

High density bamboo mat board (density upto 1.4) is an excellent replacement of compreg made from wood veneer. The product meets all physical and mechanical properties required for wood veneer based compreg. Whereas, wood veneer based compreg requires prime quality timber, bamboo mat based compreg can be made from two to three years-old bamboo.

Parallel bamboo strip based products, bamboo laminates and cross laminates are ideal replacement of solid wood. Physical and mechanical properties of bamboo parallel laminates are comparable to teak wood and can be used in place of solid wood. Both vertical and horizontal laminates have been developed and properties standardized for use in furniture, boxes, walling, flooring, door, etc.

Cross laminates have been designed for flooring three to five ply cross laminates made in the same fashion as plywood can be of different density and thickness. When densified upto 0.8 to 0.9, the board can be used for truck flooring. Medium density floor board having density of 0.7 - 0.75 can be used for house floor. Being cross laminated, these are dimensionally stable. Floor boards are also resistant to water, termite, mould and fire. Thus, these are superior to conventional floor board made of wood, particle board and MDF.

At IPIRTI, door skin has been developed from bamboo mat. It is an ideal substitute for moulded door skin made of HDF which is being imported. The bamboo door skin has elegant look and very strong to act as door skin.

Production of moulded door skin from bamboo mats would have the following significance :

- (i) It would substitute wood and wood panel used at present in door manufacture.
- (ii) It would substitute import of similar material (masonite skin board).
- (iii) It would generate rural employment and economy, in the process of weaving of bamboo mats.
- (iv) It would help in conservation of forest by substituting wood.

One of the great achievements of IPIRTI in utilizing bamboo is the development of cost effective housing system using bamboo in round/split form and its composite in combination with other traditional building material bricks and cement. Salient feature of these houses in relation to bamboo are:

1. Use of round bamboo columns and trussed rafter and main load bearing element.
2. Use of split bamboo grids/chicken mesh and plastered with cement mortar to act as shear wall for transmitting wind loads and enhance structural stability of the building.
3. Use of BMB gussets in combination with mild steel bolts for load bearing joints in roofing structure.
4. Use of bamboo mat corrugated sheets as a roofing material.

All bamboo components are given appropriate eco-friendly preservative chemical treatment depending on the degree of hazard the particular component has to encounter in use.

#### **4. Conclusion**

As a consequence of industrialization, change in concept on environment and increasing standard of living, types of products required by people have changed considerably. In the past, wood used to constitute basic raw material for making many of our personal and domestic need. Concept on protection of environment has necessitated to stop felling trees in tropical forest and, thus, use of wood has been curtailed manifold. Several wood alternatives from non-wood material such as plastic, metals, and minerals have come into existence. These non-wood alternatives are from non-renewable sources, with their limited availability, require high energy for production to make consumer goods leading to more air and water pollution.

Alternatively, almost all products which can be made from wood can also be made from bamboo. The growth and use of this wonder grass help in fixing atmospheric carbon while tapping solar energy. They need less energy while processing into beneficial products. These products are biodegradable and, therefore, do not pollute the nature. Bamboo in all forms is environment friendly, and it is a renewable raw material base obtainable at short cycle for making many useful industrial products for human consumption for the future.

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