Bamboo Composite material : Game - changer for developing economies

Mohanty B.N* , **Sujatha.D**** & **Uday .D.N*****
IPIRTI, P.B.No2273, Tumkur Road, Bangalore, India
Pin: 560 022.
E-mail: director@ipirti.gov.in

Abstract

Bamboo, a Gift of Mother Nature, is an excellent raw material that produces Light weight, long Performance, high end and Functionally Graded Material every year for several decades. It can survive and over the years has thrived in marginal/degraded /waste lands against droughts, floods and cyclones. Even in such adversities, bamboo bushes, maturing in about 5 years, can give annual yields of 3 to 6 tons of dry bamboo culms of mature timber. Bamboo has always been an integral part of human life in rural India viz. in housing, traditional and cottage industry sector. Scarcity of wood has pushed bamboo to the centre stage as viable alternate raw materials due to its inherent properties of fast growth, mechanical strength and ease of use.

Bamboo and bamboo products are emerging as substitute of wood and wood based products for construction, housing and domestic/ agriculture need. Bamboo Mat Boards (BMB), Bamboo Mat Corrugated Sheets (BMCS), Bamboo laminates (BL), Bamboo Mat high density panels, Bamboo Mat Moulded Skin Board (BMMSB), Bamboo Mat Ridge Cap (BMRCS) & preservative treated bamboo poles have thrown up many high end profitable components in Housing, Resort, School Buildings, Pantry, Prefab housing for temporary shelter etc,. In so happening, bamboo has the potential to work as a game-changer for back ward economies in countries of Asia, Africa and Latin America.

The search for an healthy environment has now necessitated the restrictions on felling of trees in forest and thus use of wood has been curtailed manifold. Bamboo would be the best choice alternative to all the non-renewable materials and will have a great market potential for the future. It has all the characteristics to break the stereo-type of poor man's timber and to stake its claim as "Green Gold".

Key words: Bamboo. Products, housing, potential

Full addresses of authors:

*1) *Dr. B.N.Mohanty, Director,*
Indian Plywood Industries Research & Training Institute (IPIRTI),
Post Bag No.2273, Tumkur Road, Bangalore 560 0022
Tel. No.91-80-30534002, Fax No.91-80-28396361, E-mail: director@ipirti.gov.in

*2) **Ms. Sujatha. D, Scientist 'E' – HOD (Adhesive Technology)*
Indian Plywood Industries Research & Training Institute (IPIRTI),
Post Bag No.2273, Tumkur Road, Bangalore 560 0022
Tel. No.91-80-30534005 , , Fax No.91-80-28396361, E-mail: dsujatha@ipirti.gov.in

*3)***Mr. Uday . D.N, Scientist 'E' – HOD (PDES Division)*
Indian Plywood Industries Research & Training Institute (IPIRTI),
Post Bag No.2273, Tumkur Road, Bangalore 560 0022
Tel. No.91-80-30534011 , Fax No.91-80-28396361, E-mail: udaynd@ipirti.gov.in

INTRODUCTION

India has the second largest resource of bamboo both in terms of diversity and distribution (about 13% of the forests or app. 10 million ha.). India accounts for around 120 of about 1250 species of bamboo found in the world. Of this only 30 species are commercially important. Apart from being available in natural forests bamboo is also raised as plantations, both pure and as under planting, and also in homesteads. Bamboo is also suitable for restoration of degraded forest and other wastelands as well as of abandoned shifting cultivated areas.

Bamboo is a tree like woody grass which offers an excellent ecological benefits such as neutralize acidic soil, produce highest quantity of biomass generate extensive rhizome networks and bind soil. Bamboo is found in a wide variety of soil and is one of the most gifted plants found in forests and also in the homestead. Bamboo is one of the most useful plants on the earth. There are about 1500 known uses of bamboo from cradle to coffin. It is being used in food, medicines, furniture, music, construction, agricultural appliances, industry, housing, fisheries, transport and thousands of other products.

Bamboo is super strong and durable. It is not less than 27 per cent harder than oak, 13 per cent than maple and 50 per cent more stable than common wood. It is one of the fastest growing plants on the earth. Highest recorded growth of one species in Japan was which grew 47.6 inches in 24 hours.

Prediction for 21st century are that the demand for timber by the various wood based industries in Asia as a net importer of forest products and elsewhere will exceed the existing timber supply. With the objective of an anticipated shortage, the wood based panel industry are reflecting to use bamboo instead of wood wherein bamboo is found to be closer to medium density hardwood. Also bamboo pocess higher strength values than Juvenile hardwood obtained from fast growing species. From all aspects Bamboo is well suited to replace wood in several applications.

However, as a modern engineering material, when bamboo is used to replace steel and cement, it can fetch three to four fold higher returns in the market (Rs. 12000 to Rs.30000/yr/ha). The local value added processing of bamboo into structural elements and their use in rural areas would help rural economy with increased employment.

Bamboo Composites

It has now been realized that bamboo produces biomass faster and has superior physical and mechanical properties compared to wood available from many fast-growing wood species. Some earlier studies have revealed that bamboo in panel form is best suited to substitute wood in several applications. Development of effective technologies to produce bamboo-based panel material is now an important area of research not only in bamboo-growing countries but also in several other countries. The first recorded production of panels from bamboo was during the Second World War to make ply-bamboo by hot pressing woven bamboo sheets coated with casein glues (Tecli.Rep and Chengtu 1945). Almost at the same time research was initiated in India to develop synthetic resin bonded bamboo mat board (P.M.Ganapathy et al. 1999). More than 30 types of panel products, some of bamboo only and others of bamboo in combination with wood, other lingo-cellulosic materials and inorganic materials have been developed using bamboo either as woven mats or slabs/strips.

Development Of Bamboo Composites In India

In India, research efforts to make building boards from bamboo were initiated in the mid-1950s at the Forest Research Institute, Dehra Dun, and several processes were evolved till early

sixties (D.Narayanamurthi and B.S.Bist 1963) . However, industrial production of BMB in the country started in the mid-1980s following the development of technology for making BMB from the reed bamboos, *Ochlandra travancoric*a and *Ochlandra rheedi,* by IPIRTI under a project sponsored by the All India Handicrafts Board (IPIRTI 1983). To improve economic viability of the technology and enhance product acceptability, further research was conducted at IPIRTI under the project 'Bamboo Mat Board (India)' funded by the International Development Research Center (IDRC), Canada and a cost effective process was developed (IPIRTI 1993, S.S.Zoolagud and T.S.Rangaraju 1993, A.K.Bansal and S.S.Zoolagud 1999). BMB technology has been further modified for manufacturing Bamboo Mat Veneer Composite (BMVC) made from bamboo mats in combination with veneers from fast-growing plantation species for panels thicker than 6 mm. BMB are made from manually woven bamboo mats and hence production of BMB has immense employment generation potential particularly for rural and tribal women who can virtually 'weave money' at home. Thus, while BMB technology is environmentally sustainable it is also people friendly. The technology was assessed to be an exemplary demonstration of implementation of Agenda 21 by the International Selection Commission of EXPO-2000 was registered as a Project around the World at EXPO-2000 Hannover. Germany (Expo 2000). Seeing the potential of the BMB technology, the Building Material and Technology Promotion Council (BMTPC) of India funded IPIRTI a project for development of technology for manufacturing bamboo mat corrugated sheets (BMCS) as an eco-friendly roofing material. Under this project, a pilot scale facility with a one-day light hydraulic hot press fitted with specially designed matching platens has been established at the Institute. Full size (0.9 m x 1.8 m) sheets manufactured at the pilot press have been used for roofing in several demonstration structures. Bonded with phenolic resin these sheets are very durable and possess decay, insect and fire resistant properties. BMCS has very high strength-to weight ratio and has great potential to be used as roofing material in place of asbestos cement corrugated sheets which have already been banned in many countries on environmental and health considerations. Apart from roofing, BMCS has high potential in wall panels, packaging, transportation, etc. The Institute has already commercialized the BMCS technology in collaboration with BMTPC under a project funded by the Ministry of Environment and Forests, Government of India for up scaling the BMCS technology for commercialization. An Indian Patent has been applied jointly by IPIRTI and BMTPC (Application no. 653/MAS/2001 dated 8th August2001). IPIRTI has completed design development of low-cost bamboo shelter using split bamboo grid with cement plaster for walls, BMCS for roof with bamboo trusses, and BMB for panel door/window shutters in collaboration with TRADA Technology of UK, under a project funded by DFID. Under this project two demonstration structures have already been constructed at Bangalore (A.K.Bansal et al. 2001, IPIRTI 1/2001). High shear modulus of BMB and BMVC can be advantageous in designing earth quake resistance **.** The production of doors using imported skin board is about 12 lakh boards per year. Any user of doors with HB/MDF skin board can replace them with Bamboo Mat moulded skin Board (Uday D.N et al. 2008) overlaid with PVC membrane foil with wood texture, grain and colour.

Materials and Methods

Guided by dwindling wood supply in India and potential supply of bamboo as an alternate material, research had been strengthened in nineteen eighties to use bamboo as non-wood renewable fibre to substitute wood in several uses. It was observed that bamboo attains full growth in one year thus can be grown as a part of agro forestry. Also bamboo attains full maturity in two years when some of its physical mechanical properties are superior to wood available from most fast growing plantation species. This has evolved keen interest in bamboo to undertake theoretical and applied research on bamboo based products for use in housing, furniture, packaging, transport sectors and others.

Bamboo is a tall, hollow, cylindrical grass containing nodes at uniform interval along its full length. The fibres remain aligned along its length whereas at nodes fibre grows 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 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.

At IPIRTI, several years of R & D has resulted in development of cost effective, people and eco-friendly technology for manufacture of several bamboo based products (IPIRTI. 1983,1993,2000, 2001,2003,2004). Based on the preliminary processed bamboo, final products may be classified as follows:

A. Bamboo Mat Based Products

1. Bamboo Mat Board [BMB]
2. Bamboo Mat Veneer Composites [BMVC]
3. Bamboo Mat Corrugated Sheet [BMCS]
4. Bamboo Mat High Density Panel
5. Bamboo Mat Moulded Skin Board (BMMSB)
6. Bamboo Mat Ridge Cap (BMRCS)

B Bamboo Strip Based Products

1. Bamboo Wood [Laminates]
2. Bamboo Flooring Tiles
3. High Density Transport Flooring

C. Bamboo in round/split/composite form

1. Bamboo Based Housing System
2. Bamboo Match Splint

The process flow chart for A and B is given in Fig 1 and Fig 2.

Woven bamboo mats form the raw material for all mat based composites. Till date these mats are hand woven by artisans specially women. With growth of mat based industry, mat weaving machines have been developed

Fig 1. A generalized process flow chart for Bamboo Mat Composites is as follows:

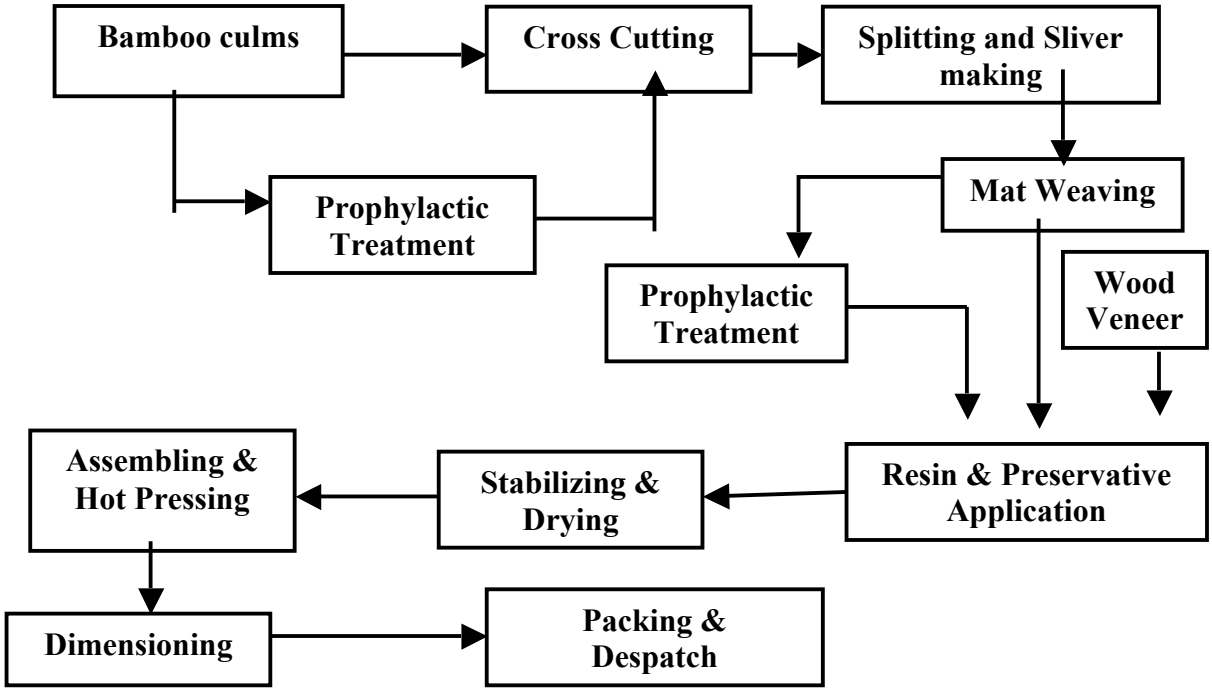
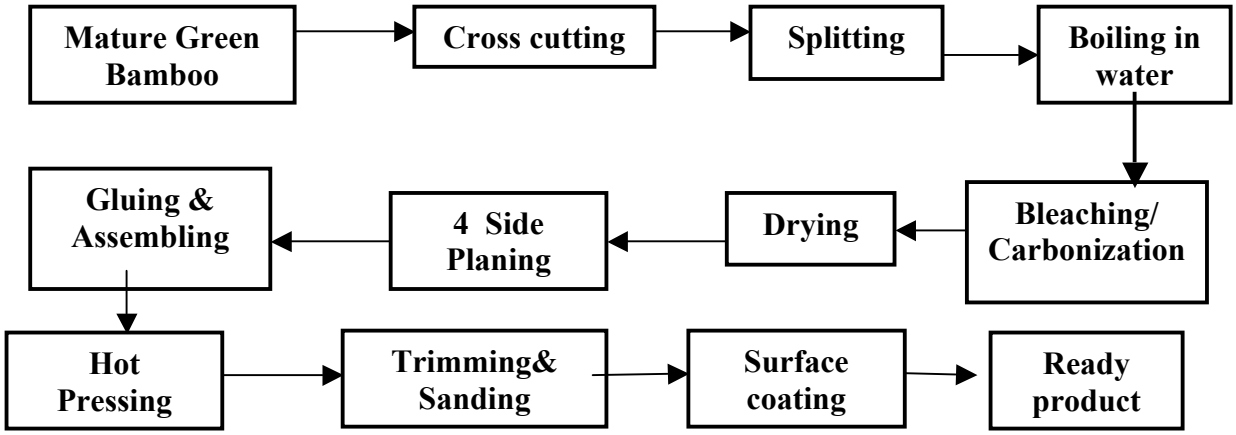


Fig 2. Flow Chart for the manufacture of Bamboo Wood



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 sheet, exterior grade bamboo crushed board, 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 is being used.

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 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.

Hot Press Conditions

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

Temperature

For PF resin based products usual pressing temperature used is 140 – 150^{0}C. MUF resin based products are pressed by employing a temperature of 115 – 125^{0}C in the hot press.

Pressure

Pressure applied varies widely depending on the ultimate density of the products. Density of bamboo at 12% moisture content, ranges from 0.65 – 0.70. For products to be obtained with density 0.7 – 0.75 gms/cc, pressure of 14-16 kgs/cm^2 was enough, for high density products of density 1.2 – 1.4gms/cc hot press pressure of 80 – 120 kg/cm^2 was used. While 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.

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.

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.

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 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.

Table I gives the strength properties of BMB of various thicknesses studied at the Institute under the project 'Wood Substitute (India)' [15] sponsored by IDRC, Canada. Unlike plywood that has cross-grain layers, BMB has mats with herringbone weaving pattern arranged in the same direction with respect to weave pattern. Stresses (tensile and compressive) applied along the length and width of the board will be at an angle of 45 to the grain direction of the slivers. For this reason, the strength of BMB in tension will be lower than the strength of round bamboo along the length. It is for the same reason that tensile strength, modulus of rupture (MOR) and modulus of elasticity (MOE) of BMB is lower compared to that of structural plywood. However, it has been observed that strength of BMB in tension or bending at an angle of 45 to the length or the width of the board is also higher than the corresponding strength along or across the board length.

Table I
Physical and mechanical properties of BMB of different thickness

Sl.No.	**Property**					
1	Thickness of the panels	3mm	6mm	6mm*	8mm	9mm
2	Density, kg/m^3	766	711	935	790	892
3	I.B. Strength N/mm^2					
	Dry	2.18	2.42	0.82	1.97	2.2
	Wet	1.98	2.14	0. 61	1.73	1.8
4	Surface Strength N/mm^2					
	Dry	11.42	11.23	4.9	9.47	13.10
	Wet	11.42	10.47	3.47	9.10	10.5
5	Tensile strength N/mm^2	22.69	26.59	89.17	29.54	31.4
6	Compressive strength N/mm^2	16.77	30.35	50.60	35.30	57.5
7	Mod. of Rupture N/mm^2	50.74	56.31	102.57	59.35	68.8
8	Mod. of Elasticity, N/mm^2	3678	3220	12033	3114	3930
9	Mod. of Rigidity, N/mm^2	5881	6050	3527	6066	5750

** Pattern of weaving is rectangular*

Bamboo mat veneer composite

In BMVC, wood veneers are placed in between the layers of bamboo mats. The properties of BMVC depend upon the mechanical properties **(Table II)** 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

Table II
Physical Mechanical Properties of BMVC

Sl. No.	Property	Structural plywood	BMVC (67%)
1.	**Thickness**		**21mm**
2.	**Density kgs/m^3**	750	602
3.	I.B., N/mm^2 Dry Wet	 -	 2.30 1.65
4.	SS N/mm^2 Dry Wet	-	 8.00 6.80
5.	Tensile strength N/mm^2 || ⊥	 54 34	 36.40 35.80
6.	Compr. Strength, N/mm^2 || ⊥	 34 29	 43.90 40.20
7.	MOR N/mm^2 || ⊥	 49 29	 68.50 55.40
8.	MOE N/mm^2 || ⊥	 7355 3923	 7820 3210
9.	Mod. of Rigidity, N/mm^2	588	3316

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

Bamboo Mat Moulded Products

Considering the flexibility of bamboo mats due to "Herring-Bone" weave pattern, an idea was mooted to produce moulded products like trays 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.

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. Roofing materials such as asbestos cement corrugated sheeting (ACCS), corrugated fiber reinforced plastics (CFRPs). Corrugated aluminium sheeting (CAS), corrugated galvanized iron sheeting (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. Scaling up of the pilot scale technology for its industrial adoption has been

successfully carried out under a project funded by Ministry of Environment and Forests, Govt. of India. The shape and area under the load-deflection curves (Fig.3) of various corrugated roofing materials, namely BMCS, ACCS, CGIS and CAS, clearly bring out the comparative advantage of BMCS over other corrugated materials. The comparative strength properties of BMCS with other existing roofing sheets are given in **Table III.** Bureau of Indian Standards is bringing out a standard on the specification of Bamboo Mat Corrugated Sheets for roofing**.**

Fig.3
Load Deflection curves for corrugated sheets

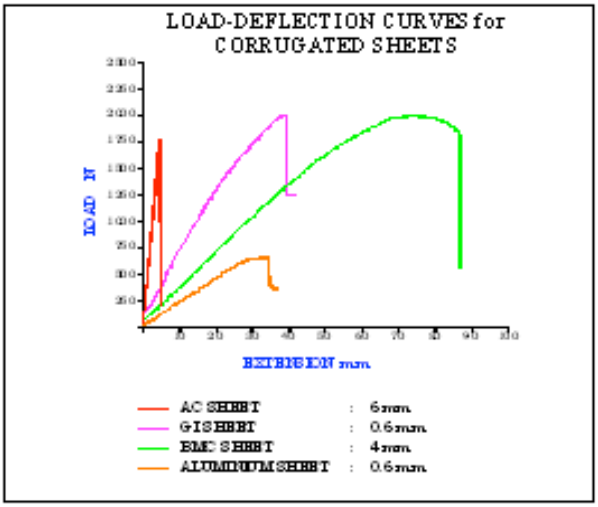


Table III
STRENGTH PROPERTIES OF BMCS IN COMPARISON WITH OTHER EXISTING ROOFING SHEETS

	Thickness, mm	Width in mm	Max Load, N	Load bearing capacity in N/mm	Weight of sheet(2.44m x 1.05m) in kgs
BMCS(4LAYERS)	3.7	400	1907	4.77	9.78
GI SHEET	0.6	400	1937	4.84	10.43
ALUMINIUM SHEET	0.6	405	669	1.67	3.92
ACCS	6	330	1800	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 Institute 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 their counterparts.

Bamboo Wood

Bamboo strips are arranged in one and the same direction during assembling, and then pressed bidirectionally. The strips are bleached or carbonized before pressing. The products are

multi- layered, of great dimension. The surface of laminated bamboo board is fine-grained. They can be used for furniture making and inner decoration like laminated veneer wood or high-grade wood.

This is a new type of bamboo-wood flooring with outward appearance of bamboo and properties of wood. It is composed of thin bamboo pieces as front and rear surface layers, wood boards 8 ~ 15 mm in thickness as inner layers. IPIRTI has developed bamboo laminates of both horizontal and vertical type. The strength properties of hortizontal and vertical laminates is given in Table IV.

Table IV

Strength properties of bamboo laminates

Sl No.	Property	Vertical Laminates			Horizontal laminates
		UF	MUF	PF	**MUF**
1	Density, Kg/m^3	728	745	796	782
2	MOR, N/mm^2	122.5	149.1	145.2	164.4
3	MOE, N/mm^2	12028	16570	16800	17300
4	Compressive strength N/mm^2	61.7	84.7	96.0	87.9
5	Block shear strength, N/mm^2	11.89	12.8	12.7	9.6
6	Screw withdrawal strength,N Face Edge	 4999 2333	 4006 3659	 4683 3216	 3235 5375

Bamboo Strip Board

Laboratory scale technology has been developed to make Bamboo strip boards from bamboo strips. The developmental work was limited to laboratory scale of size 45cm x 45cm. The panel developed poses high strength, stiffness and rigidity. It is characterized by resistance to deformation, abrasion and weathering. Its bending strength properties are superior to wood panel and therefore application potential, particularly as platform boards, vehicle platforms, transport floorings etc. is very high. Strength properties given in Table V.

Table V

Properties Of Bamboo Strip Board

Sl No.	Property	Values obtained
1.	Density, kg/m^3	921.00
2.	Moisture content, %	3.9
3.	Modulus of rupture, N/mm^2 Along Across	 118.56 59.47
4.	Modulus of elasticity,N/mm^2 Along Across	 12383 3556
5.	Block shear strength, N/mm^2	5.67

Bamboo Mat Compregs

Technology for the manufacture of compregs have been developed using bamboo mats and veneers from plantation species or in combination of both which meets the relevant specification .Since there is no specification for bamboo mat based compregs the strength properties were tested as per the specification existing for wood veneer compregs. The strength properties are given in Table VI

Compregs made using all the 3 different combinations has a natural lustrous finish that can be restored by merely sanding and buffing when cut or scratched. It can be readily cut or turned using metal working tools operated at slower than normal speeds. It is quite resistant to decay and attack by termites and marine borers

Utiliation of bamboo mats and plantations species reduces the dependence on imported timber for the manufacture of compregs and also the final cost of the product would be minimized.

Table VI
Strength Properties Of Bamboo Mat Compregs And Shuttering Grade Panels Made From Bamboo/Plantation Timbers In Combination

SL no	Test	IS 3513 Prescribed values	Compregs with Bamboo mats	Bamboo mats and veneers in combination
1	Specific Gravity	0.95 to 1.25	1.2	1.2
2	Moisture content %	6 to 12	4.9	7.2
3	Tensile strength Mpa	59	71	63.5
4	Static bending strength, Mpa	59	105.3	107.7
5	Modulus of elasticity, Mpa		6646	9005
6	Compressive strength (Parallel to laminae), Mpa	75	65.1	75.8

Bamboo Mat Moulded Skin Boards [BMMSB]

At present high density or medium density hard boards are being imported for making Hollow core flush doors. Bamboo Mat Moulded skin board is an alternative material and superior in quality to skin board imported in to the country for making Hollow core doors. The present development thereby helps in import substitution. The production of doors using imported skin board is about 12 lakh boards per year. Any user of doors with HB/MDF skin board can replace them with Bamboo Mat moulded skin Board overlaid with PVC membrane foil with wood texture, grain and colour. A cost effective Technology for making door skin using bamboo mat has been developed at IPIRTI.

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% [one sigma level] and an experimental precision of 3%. 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, , BMVC, BMCS, BL, strip board and compregs from bamboo are given in Tables I, II, III, IV, V and VI respectively. Comparative results as per Indian Standard [wherever available] are also given.

To have impact of technologies developed, a number of production units should be established in order to derive benefits. The innovative products through value addition are also expected to generate huge employment opportunities for rural poor and in particular women involved in mat weaving activity.

RESULTS AND DISCUSSIONS

Based on the research carried out at this Institute, it has been established that various bamboo mat based and strip based products developed are comparable to wood based panel products and solid wood and thus can replace wood and wood products in many end uses.

Research studies on the suitability of bamboo mat board shows that they can be used for non-load bearing applications similar to plywood in areas like housing, furniture, packaging, storage and transportation. In the past utilization of bamboo mat board were not found suitable for load bearing structural applications due to lower strength and stiffness ratio. However, introduction of wood veneer in the panel has increased these properties and the values meets the requirement 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]. Theses 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 and 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.

BMCS has low thermal conductivity compared to other roofing materials [0.1928 kcal/m^0C for BMCS and 0.3422 k cal/m^0C for ACCS]. The sheets have been found to be resistant to decay, termite/insect. BMCS has very high use potential in several end use applications, major use being in roofing as an alternative to asbestos cement roofing sheet, GI aluminium and plastic roofing sheets.

Bamboo mat based moulded products as well as high density products are other variant of products from bamboo.

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

High density bamboo mat board [density upto 1.4gms/cc] 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 2-3 years old bamboo.

Parallel bamboo strip based products – Bamboo laminates and Cross laminates are ideal replacement of solid wood. Physical-mechanical properties of bamboo parallel laminates are comparable to teak wood and can be used where solid wood is being used. 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. 3 to 5 ply cross laminates made in the same fashion of plywood can be of different density and thickness. When densified upto 0.8 to 0.9gms/cc, board can be used for truck flooring. Medium density floor board having density of 0.7 - 0.75gms/cc 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 has many significance.

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

One of the great achievement for this Institute 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.

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, 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 air and water pollution. A new direction to use of bamboo for large scale, eco friendly engineering use for rural & agricultural structures which in turn will increase the demand for bamboo, its cultivation in wasteland & income for the farmer and rural artisans can be achieved.

Considering the vast social and environmental implications and employment potential, a policy thrust at national level is necessary for development of bamboo resources in general and promotion of bamboo composites in particular. As a first step, Government has already given a favorable push by exempting bamboo composites from excise duty. Eco-labeling of the products will also help promote exports.

Alternatively almost all products which can be made from wood can also be made from bamboo. Growing and use of this wonder grass helps in fixing atmospheric carbon while tapping solar energy and requires less energy while processing into useful products. These products are biodegradable and thus do not pollute nature. Bamboo in all forms are environment friendly. It is a renewable raw material base at short cycle for many of useful products for housing in the future.

REFERENCES

1. A.K.Bansal and S.S.Zoolagud 1999. .Bamboo based composites- background paper for All India Seminar on Bamboo Development, organized by UNIDO and GOI at New Delhi , INBAR Journal Vol 1. 15pp.
2. A.K.Bansal. H.N.Jagadeesh and H.Guruvareddy 2001. Bamboo based housing system, seminar document of the National Seminar Waves of the Furture – Civil Engineering in the 21st Century organized by the Association of Consulting Civil Engineers (India) at Bangalore.pp 25-28 .
3. Bamboo based housing system, seminar document of the National Seminar Waves of the Furture – Civil Engineering in the 21st Century organized by the Association of Consulting Civil Engineers (India) at Bangalore. Pp 25-28 (A.K.Bansal. H.N.Jagadeesh and H.Guruvareddy 2001).
4. EXPO 2000. Bamboo Mat Board – India, in Projects Around the World of Expo 2000, International projects , Vol 2 published by, Hannovr, GmbH. pp. 738-739.
5. IPIRTI 1983. Development of improved and new products from bamboo mats, Technical report of the project sponsored by the All India Handicrafts Board pp100.
6. IPIRTI 1993. Bamboo Mat Board (India) 3-p-89-0228, Final Technical Report. pp 188.
7. IPIRTI 2000. Wood Substitutes (India) CF, 93-8309, Final Technical Report . 105pp.
8. IPIRTI 2001. Status of Bamboo Housing Technology developed at IPIRTI, IPIRTI Miscellaneous Report, 1/2001. 13pp.
9. IPIRTI 2003. Investigation Analysis for the Development of Technology Package for
10. Bamboo Boards (Bamboo Laminates) Final Technical report .
11. IPIRTI (2004) : Field Demonstration and Development of Bamboo based composite panels for housing in North Eastern region – Final Technical report
12. Narayanamurthi D and Bist B.S 1963. Building Boards from bamboo. Indian Forest Records New Series, Composite wood. 1 (2),48 .
13. P.M.Ganapathy.Z. Huan-Ming, S.S.Zoolagud, D.Turcke and Z.B.Espiloy 1999. Bamboo panel boards: a state of the art review, INBAR Technical Report No. 12(ISBN 81 -86247-28-9.) 115 pp.
14. S.S.Zoolagud and T.S.Rangaraju 1991. An improved and economical process for manufacture of Bamboo Mat Board in : proceedings : IV International bamboo Workshop, Changmai, Thailand, pp.1-4 .
15. S.S.Zoolagud and T.S.Rangaraju 1993. Bamboo Mat board manufacture in : Proceedings of National Workshop on Bamboo Mat Board, IPIRTI, Bangalore, India pp. 1-10 .
16. Teclin. Rep. Bur. Aeronaut. Res. And Chengtu, 1945. Forestry Abstracts No. 26. pp. 52.
17. Uday D N ., Mathews K.C., Sujatha.D., Mamatha.B.S. and Anand.N 2008. Development of Bamboo Mat Moulded Skin Board for hollow core doors, IPIRTI research report No108