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REVIEW ARTICLE

Bamboo: Technology Innovations Towards Value-Added Applications

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Abstract: Bamboo is remarkably varied and adaptable with a wide range of anatomical, structural and chemical properties. All of the bamboo plant, from rhizome and root to culm and leaves is utilized -there are nearly two thousand recorded uses. Bamboo has gained considerable importance recently as a structural material. Bamboo is used to replace not only wood, but also plastics, steel, cement, and other materials in structural and product applications thanks to advances in processing technology and product innovation combined with scientific and engineering expertise. The sector, particularly in rural areas, has enormous potential for providing income and jobs. The National Mission on Bamboo Applications, launched by the Government of India under the 10th Five-Year Plan, is a major programme aimed at boosting the use of bamboo in value-added goods. Cross-cutting, splitting, knot removal, sliver making, strip making, and round stick making are all examples of primary bamboo processing that can be done in rural cluster zones. There is a lot of waste generated after the primary processing of bamboo. This waste can be effectively turned into goods with added value, such as activated carbon, charcoal etc.

Gasification is being used to transform bamboo into a useable amount of energy. These gases can substitute diesel up to 70% of the time, hence meeting energy demands (Tripathi, 2008). The volatiles produced as a by-product of biomass gasification are a rich source of compounds. For rural energy demands, the conversion of bamboo waste into charcoal is also being investigated. Sandwich composite technology has been used to build build cost-effective Fibre Reinforced Plastics (FRP) doors and doorframes to replace wood. The low-cost technology has the potential to be used for commercial manufacturing, especially in rural areas.

This review paper discusses in detail about the properties and application of bamboo as a substitute for wood, primary and secondary processing of bamboo and preservation of bamboo. The paper also brings out technology overview of the products and associated business opportunities.

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Introduction

Bamboo is a grass that is the most varied group of plants in the grass family, with over 1200 species dispersed among seventy genera on every major continent except Europe (Anu Gupta and Ajit Kumar, 2008). It is a long-lasting, adaptable, and highly renewable substance that has been understood and used by individuals and communities for thousands of years. Bamboo has long been a component of many countries cultural, social, and economic heritage. Thousands of people rely on it for their livelihood, as well as for home and utilitarian purposes. In exchange, communities have cultivated and preserved bamboo, and they have enormous knowledge and skills linked to bamboo propagation, processing, and use. They are among the world's fastest growing plants. Bamboo can be harvested in 2-3 years, making it a truly renewable resource.

Bamboo gives back as much as it takes from the earth and the environment. Bamboo produces 30% of its volume in biomass, making it an important component in the balance of oxygen and carbon dioxide in the atmosphere. Its specialized root and rhizome structures work as binders, preventing soil erosion and revitalization. Bamboo works as a windbreaker, noise and climate barrier in plantations Household bamboo plantations and agro-forestry can help with food security, soil

conservation, watershed development, and waste-land restoration.

Bamboo has a variety of novel applications that have been developed via the use of science and technology. Through advancements in processing technologies, product innovation, and the use of scientific and engineering abilities, it can technologically and commercially substitute not just wood, but also polymers, steel, cement, and composite materials in structural and product applications (Ray & Mondal S, 2005). In a short period of time, the bamboo industry, particularly in East and Southeast Asia, has undergone technological and structural changes. China, in particular, has emerged as a market leader and innovator with a wide range of new products and procedures that have made a substantial impact to the country's economy.

Bamboo : The Indian Context

In the bamboo business, India is particularly equipped, with abundant raw material and a long history of traditional skill and application. The availability of bamboo resources in India is the second largest in the world, ranking only behind China (Cane and Bamboo Technology Centre's Technical Papers III, 2008), with a diversity and distribution of over 130 species dispersed across eighteen taxa. These can be found growing naturally eighteen taxa These can be found growing naturally at elevations ranging from sea level to over 3500 meters in a diverse range of environments. Bamboo may be found in about ten million hectares of forestland. In addition, a significant proportion is grown on homestead land, as well as in private plantations and groves. Over a hundred million tones of growing stock are predicted to be available.

Bamboo is abundant and diverse in the North East, accounting for over two-thirds of all growing stock. Bamboo can also be found in large quantities in the Himalayan foothills, the Western Ghats, and large swaths of central, peninsular, and northern India, as well as the Andaman and Nicobar Islands. Three species make up four fifths of the growing stock: *Dendrocalamus strictus* (53 percent), *Bambusa arundinacea* (15 percent), and *Melocanna bambuisodes* (15 percent). *Phylostacchus bambuisodes*, farmed by the Apa Tani tribe on the Ziro plateau in Arunachal Pradesh, is the only sympodial (clump-forming) bamboo in India.

Bamboo is currently in the process of being 're discovered' in India. Its qualities and potential becoming more widely recognized. People have a lot to do with bamboo. Bamboo is commonly used in many sections of the country. Communities have developed expertise in using the material in artistic yet utilitarian ways over millennia of use. People are also knowledge repositories, which can be

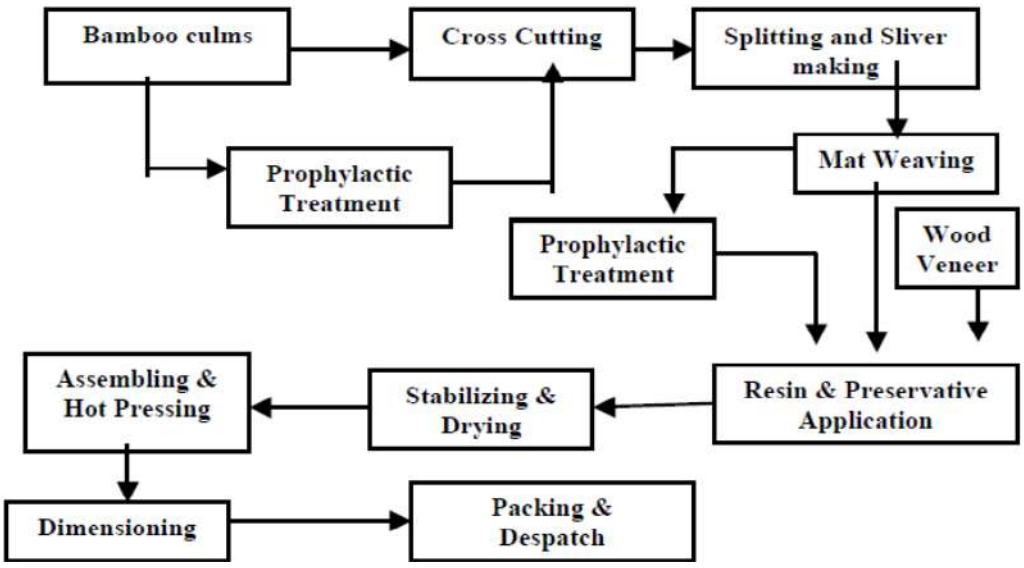

Fig. 1. A generalized process flow chart for Bamboo Mat Composites

[*Source: Mohanty B.N , Sujatha. D & Uday .D.N, Bamboo Composite Material: Game - Changer For Developing Economies,10th World Bamboo Congress, Korea 2015*]

immensely beneficial to the sector's development. The sector has enormous potential for producing revenue and employment, particularly in rural areas and among people that have historically been economically and socially disadvantaged.

Applications of Bamboo

Subsequently to the implementation of bamboo mission by Government of India, many applications has been identified.

I. Wood Substitutes and Composites

A. Bamboo and bamboo products are emerging as replacements for building, housing and domestic/agricultural requirements for wood and wood-based products. Bamboo Mat Boards (BMB), Bamboo Mat Corrugated Sheets (BMCS), Bamboo Laminates (BL), High Density Bamboo Mat Frames, Bamboo Mat Molded Skin Board (BMMSB), Bamboo Mat Ridge Cap (BMRCS) and preservative-treated bamboo poles have made several high-end components in Housing, Resort, School Buildings, Pantry, Prefab housing for temporary shelter etc. (Industrialization of the Bamboo Sector in India, a Report by India Development Foundation, 2007; Mohanty *et al*., 2015).

This category of products essentially comprises of boards and sticks of varying descriptions and uses, and which can further be used to manufacture finished products like wooden floors or blinds or goes into another industry as an input like incense sticks.

B. Several years of R&D at Indian Plywood Industries Research and Training Institute (IPIRTI), Bengaluru have resulted in the development of cost-effective and ecofriendly technology for the production of several products based on bamboo (Development of Improved and New Products from Bamboo Mats, 1983; Pandey; PIRTI, 2019). Final products can be graded as follows, based on the preliminary processed bamboo:

a. **Bamboo Mat Based Products** – the detailed list of the bamboo products includes the following:
   a) Bamboo Mat Board [BMB]
   b) Bamboo Mat Veneer Composites [BMVC]
   c) Bamboo Mat Corrugated Sheet [BMCS]
   d) Bamboo Mat High Density Panel
   e) Bamboo Mat Molded Skin Board (BMMSB)
   f) Bamboo Mat Ridge Cap (BMRCS)

A detailed product flow chart is shown in figure 1.

b. **Bamboo Strip Based Products** – the list includes the following:
   g) Bamboo Wood [Laminates]
   h) Bamboo Flooring Tiles
   i) High Density Transport Flooring

Figure 2 shows the production and conversion process of bamboo wood.

c. **Bamboo in Round/Split/Composite Form** – the product list includes
   j) Bamboo Based Housing System
   k) Bamboo Match Splint

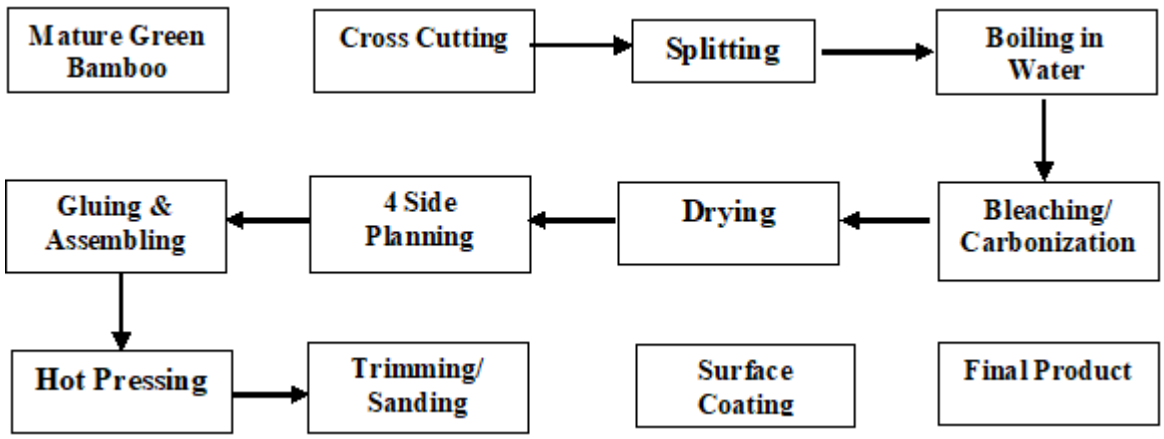

Fig 2. Flow chart for the manufacture of bamboo wood

[Source: Mohanty B.N , Sujatha. D & Uday .D.N, Bamboo Composite Material: Game - Changer For Developing Economies,10th World Bamboo Congress, Korea 2015**]**

a) Bamboo Mat Board (BMB)

The use of any new material depends on its suitability compared to the materials currently in use for different applications. In the adoption of any new content, the creation of suitable application technology plays a significant role. BMB is basically a composite layer consisting of many layers of woven mats with excellent inner bond strength and is resistant to rot, insects and termite attachment. They have physical and mechanical properties and are resistant to fire at the same degree as waterproof plywood. Their mechanical characteristics depend on the material used to make mats, such as bamboo slivers, the pattern of weaving and the adhesive used for bonding. The BMB strength properties of different thicknesses are given in Table 1. Unlike plywood with cross-grain layers, BMB has herringbone weaving pattern mats arranged in the same direction with respect to the weaving pattern. At an angle of 45 to the grain direction of the slivers, the stresses (tensile and compressive) applied along the length and width of the board would be. For this reason, the tensile strength of BMB will be lower than that of round bamboo along the length. For the same cause, BMB's tensile power, rupture modulus (MOR) and elasticity modulus (MOE) are lower compared to that of structural plywood. However, the strength of BMB in stress or bending at an angle of 45 to the length or width of the board has also been found to be greater than the equivalent strength along or around the length of the board.

b) Bamboo Mat Veneer Composite (BMVC)

Wood veneers are placed in between the layers of bamboo mats in BMVC. The properties of BMVC depend, in addition to the properties of the bamboo mats and the adhesives used in bonding, on the mechanical properties (Table 2) of the wood veneers that are mounted between the bamboo mat layers. Research has shown that the power of a plantation timber panel is significantly enhanced when made in combination with bamboo mats. BMVC's MOE and MOR are higher than comparable plywood and this depends on the amount of veneer layers for a given BMVC thickness. BMVC has various mechanical properties along and around the length of the board due to the existence of woven bamboo mats.

c) Bamboo Mat Corrugated Sheets (BMCS)

The corrugated sheets are used to manufacture products moulded by bamboo mat such as trays to increase BMB rigidity, roofing materials such as asbestos cement corrugated sheeting (ACCS), corrugated fiber reinforced plastics (CFRPs), corrugated aluminum sheeting (CAS), corrugated galvanized iron sheeting (CGIS) etc. The pilot scale technology has succeeded in scaling up its industrial acceptance under a project funded by Ministry of Environment and Forests, Govt. of India. The form and area of various corrugated roofing materials, namely BMCS, ACCS, CGIS and CAS, under the load-deflection curves, clearly illustrate the comparative advantage of BMCS over other corrugated materials.

Table 1. 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 waving is rectangular
Source: *Mohanty B.N , Sujatha. D & Uday .D.N, Bamboo Composite Material: Game - Changer For Developing Economies, 10th World Bamboo Congress, Korea 2015*]

Table 2. Physical and mechanical properties of BMVC

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

Source: *Mohanty B.N , Sujatha. D & Uday .D.N, Bamboo Composite Material: Game - Changer For Developing Economies, 10th World Bamboo Congress, Korea 2015*]

A requirement for the specification of Bamboo Mat Corrugated Sheets for roofing was also provided by the Bureau of Indian Standards.

d) Bamboo Mat Moulded Products (BMMP)

Due to the "Herring-Bone" weave pattern, Bamboo could be formed into items such as trays in various shapes such as rectangular, round as well as in different sizes, given the versatility of bamboo mats. In order to improve the appearance and acceptability of customers, these items are then finished with coating materials. The moulded items have been found to be very robust and leak-proof, which can be used for various applications.

e) Bamboo Mat Moulded Skin Boards [BMMSB]

Hard boards for making Hollow core flush doors are currently being imported for high density or medium density. Bamboo Mat Molded skin board is an alternative material for making hollow core doors and is superior in quality to skin board imported into the world. The new creation thus assists in the replacement of imports. The production of doors using imported skin boards is approximately 12 lakh boards per year. They can be replaced by Bamboo Mat moulded skin board overlaid with PVC membrane foil with wood texture, grain and colour by any user HB/ MDF skin door boards.

f) Bamboo Mat Ridge Cap

Recently, a technology for the development of bamboo mat ridge caps has been developed at IPIRTI in cooperation with BMTPC. The primary raw material for the production of the ridge cap is the bamboo mat. The item is dimensionally stable, fire resistant, non-permeable, boiling water proof, anti-termite and weather resistant, and compatible with bamboo mat corrugated sheet, both environmentally and human-friendly**.** Existing bamboo mat corrugated sheet production units can transform one of the daylights into a hydraulic hot press with a specially built die size of 2.4 m x 0.43 m for the normal production of bamboo mat ridge caps.

B. Bamboo Strip Board

During assembly, bamboo strips are arranged in one and the same direction, and then bi-directionally pressed. Until pressing, the strips are bleached or carbonized. The items are multi-layered, of great size. The laminated bamboo board has a fine-grained finish. They can be used as laminated veneer wood or high-grade wood for furniture making and interior decoration. This is a new style of flooring for bamboo-wood with bamboo exterior

Table 3. Strength properties of bamboo laminates

Sl. No.	Property	Vertical Laminates		Horizontal Laminates	
		UF	MUF	PF	MUF
1	Density Kgs/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	4999	4006	4683	3235
	Edge	2333	3659	3216	5375

Source: *Mohanty B.N , Sujatha. D & Uday .D.N, Bamboo Composite Material: Game - Changer For Developing Economies, 10th World Bamboo Congress, Korea 2015*]

appearance and wood characteristics. It consists of thin pieces of bamboo as front and rear surface layers, 8 ~ 15 mm thick wood boards as internal layers. IPIRTI has grown both horizontal and vertical bamboo laminates. In Table 3.0 the strength characteristics of horizontal and vertical laminates are given.

Bamboo strip boards made of bamboo strips are highly resistant, strong and rigid. It is distinguished by deformation resistance, abrasion resistance and weathering. Its bending strength characteristics are superior to wood panels and therefore the potential for application is very high, particularly as platform boards, vehicle platforms, transport floorings, etc. Properties of strength as given in Table 4.

g) **Bamboo Wood (Laminates)**

For bamboo-based products, one of the most promising areas of application is as a wood substitute. These include laminate, flooring, panels, particleboard, corrugated roofing, false ceiling, insulation material, chipboard, wafer board, woven mat-board, bamboo ply-substitutes and veneer, boards of different descriptions and uses. In certain ways, bamboo is stronger than wood and compares favorably with even teak and other hardwoods on essential criteria. In many applications, bamboo laminates can replace the use of timber, mainly in construction.

Sector-Wise Applications of Bamboo Boards/ Laminates:

- Building & Construction, Interior design: sheds, scaffolding, ladders, roofing, poles and composite bamboo laminates for flooring tiles, panels & partitions, doors & windows, reconstituted wood, etc.
- Marine & Industrial Applications: vessels, pads for printing, thermal & acoustic insulation.
- Transportation: Bridges, rafts, walk-ways, truck body, partitions.
- Consumer applications: Kitchen tools & diner-ware, furniture, decorative artifacts etc.

A**dvantages of Bamboo Based Boards/Laminates** :

- Bamboo board strength, hardness and intensity are better than common wood board.
- Can withstand unique high vapor pressure processes.
- Longer-lasting, long life and strong recyclability can withstand heavy duty use.
- Waterproof
- Unable to rust and with a strong luster.
- Twice as stable, 25 percent more difficult than red oak and 23 percent more difficult than rock maple.
- Bamboo has no "rays" like those that are found in wood. Rays are locations where food is transported and processed, often

Table 5. Physical and mechanical properties for bamboo composite laminates

Sl. No.	Physical Properties	Bamboo Composites with Resin Content		Teak
		5.5%	9.3%	
1	Moisture	8.60	6.60	9.7
2	Density g/cm^3	0.99	0.62	0.596
3	% water absorption, 24 hrs soaking	16.27	46.50	15.7
4	% volumetric shrinkage, AD to OD	4.36	4.61	5.05
5	% swelling in water after 24 hrs. soaking			
	Breadth	0.89	1.47	0.88
	Thickness	3.62	3.12	1.09
	Volumetric	4.51	4.59	1.97
	Mechanical Properties			
6	Modulus of rupture, kg/cm^2	1169	1062	959.0
7	Tensile strength parallel to grain, kg/cm^2	1048.8	698.6	-
8	Compressive strength parallel to grain, kg/ cm^2	1057.4	675.5	632.0
9	R A Impact, Kg-cm	343.2	186.0	68.0
10	Shear strength, Kg/cm^2	201.9	127.9	102.0
11	Modulus of elasticity 1000 x kg/cm^2	247.0	155.0	119.6
12	Screw holding strength (kg)	348.5	361.4	326.0

but they weaken the content. This makes bamboo stronger than wood in shear strength in particular.

- In structural efficiency, bamboo is better than wood .

The physical & mechanical properties for bamboo composite laminates made from Indian species are given in Table 5.

h) **Bamboo Flooring**

Bamboo flooring is a premium product that has a large global consumer market. It advantages over floors include its smoothness, brightness, stability, high resistance, insulation qualities and - exibility. Bamboo flooring maintains its soft natural lustre and natural gloss like bamboo fibre. China is the largest exporter of bamboo flooring. The export of bamboo flooring from China to the world was valued at USD 333 million in 2012, about 91% of the world exports of bamboo flooring (INBAR 2014a). The largest importer is the EU, with an import value of USD 47 million in 2012, accounting for 44% of the world import of bamboo flooring (ibid). As per the survey conducted by the National Mission on Bamboo Application (NMBA), the real estate market in India was growing at the rate of 10% in year 2003-2004. Thus the potential for the bamboo flooring market is expected to be around 2.03 million square feet in India alone, which is equivalent to a value of INR 405 million (Brunner 2010).

C. **Bamboo in Round/Split/Composite Form**

For the development of compregs and shutter grade frames, imported timber is currently used. Indian Railways alone are rising several folds of the compregation requirement as the emphasis is now on the use of high-strength materials in coach construction. The factories are currently dependent on imported timber for the raw materials and the product to be produced is also very costly. For structural applications with reduced loss and greater recovery of the material during processing, the flattened bamboo board would be an alternative to the current BMB and BMVC.

Lumber will find a role for structural purposes as a replacement for high-quality timber. They can also be replaced by bamboo lumber if laminated veneer lumber is used.

i) **Bamboo Sticks for Blinds and Incense Industry**

India is not new to the art of making screens and blinds from bamboo. People have woven elegant

bamboo screens for decades, which have offered anonymity, sun protection and added aesthetic appeal to the living spaces. The wood used in the incense stick can be replaced by bamboo sticks generating units, and that industry is estimated to be worth US$400 million in the North Eastern Region of India.

j) **Bamboo Furniture**

Conventional bamboo furniture utilizes normal round or part bamboo. Another kind of 'pack-level,' 'knockdown' furniture utilizes stick covered bamboo boards. Dissimilar to the conventional plan, the new plan conquers a considerable lot of the issues of customary bamboo furniture, for example, high work and transportation costs, low efficiency, flimsiness, differing quality and helplessness to creepy crawlies and growths. Simultaneously, it holds the unmistakable physical, mechanical, synthetic, ecological and stylish elements of bamboo. Product of overlaid bamboo furniture is developing quickly. Be that as it may, exchange measurements at present don't catch the worth, inferable from the shortfall of a unique code for bamboo furniture. It is generally named wooden furnishings.

The global export value of bamboo and rattan furniture products was USD 290.4 million in 2012, which accounted for 15% of the world export of bamboo and rattan products. Of this, Asia is the main exporting area of bamboo and rattan furniture products. In 2012, Asia exported a significant amount of bamboo and rattan furniture products, accounting for 72% of the world export market, valued at USD 210.3 million (INBAR 2014a). The bamboo furniture group includes traditional items made of round or split bamboo (Photo 3.2) as well as newer 'pack-flat, knock-down' furniture that maintains bamboo's physical, environmental and aesthetic qualities while addressing variable quality, low productivity and high labor and transport cost deficiencies.

k) **Industrial Products**

Customarily the modern utilization of bamboo has been in the paper and mash industry. The tensile stiffness is fairly lower than softwood paper. The strain strength is between that of hardwood and softwood papers. Bamboo charcoal is utilized as a substitute for charcoal from trees or mineral coal. It can be used as a fuel, absorbent and are good conductors. The calorific value of bamboo charcoal arrives at close to half of that of oil. Bamboo incense sticks weight and the absorption capacity of activated bamboo charcoal is six times that of charcoal from trees of a similar weight (Gangopadhyay et.al. 2006).

Also, Bamboo's modern products fundamentally include the transformation into fuel or power by gasification. Bamboo can be processed into bamboo charcoal, oil and gas by pyrolysis. Bamboo-based gases could be utilized as an alternative to petrol . Bamboo charcoal is an ideal material used in barbeque and cooking fuel. The bamboo charcoal is utilized as a waste and moisture absorbent, disinfectant, medication, farm chemicals and absorber. Industrial utilization incorporates the utilization of bamboo waste for gasification and consequently creating power.

l) **Bamboo for Paper and Pulp**

Bamboo is used in paper and pulp in many bamboo producing countries, such as China, the North-Eastern Region and India. Bamboo paper has almost the same consistency as wood-based paper. Its luminosity and optical properties remain stable, while those of wood-based paper can deteriorate over time (World bamboo resources A Thematic Study Prepared in The Framework of the Global Forest Resources Assessment 2005 and Jamatia S,2012. The morphological characteristics of bamboo fibres are identical to those of paper with a high tear index. Compared with softwood paper, the tensile stiffness is much lower. Between that of hardwood and softwood papers, the strain strength is. Refining the pulp will increase the quality of paper.

m) **Bamboo Charcoal for Fuel**

Bamboo charcoal is generally utilized as a substitute for wood charcoal or mineral coal. It can be used as a fuel, absorbent and conductor. Activated bamboo charcoal can be utilized for cleaning the climate, retaining overabundance dampness and manufacturing medicines. Bamboo charcoal is brilliant for cooking and grilling. Initiated charcoal is utilized as purifier, sanitizer, medication, in the pharmaceutical industry and in industrial processes for absorbing pollutants and excessive moisture (World bamboo resources A Thematic Study Prepared in The Framework of the Global Forest Resources Assessment 2005). In its turn of events, China is a pioneer. Japan, the Republic of Korea and the Chinese territory of Taiwan are at present the significant purchasers, however their imports are progressively extending in Europe and North America. Compared to tree species, bamboo becomes quicker and has a more limited pivot; bamboo charcoal's calorific worth and ingestion properties are tantamount to or better than those of wood

charcoal; and It is less expensive and simpler to make.

n) **Bamboo Based Gasifier for Electricity**

It is possible to provide energy and a variety of useful by-products by bamboo gasification. A commitment to renewable and sustainable power and thermal energy is being reinforced. It can take advantage of waste produced by processing activities, substitute the use of fossil fuels and reduce operating costs. The bamboo can be cut into small pieces in the gasifier and used. A small proportion of the total availability is the requirements of the gasification machine. For a 100 kW gasifier, just about 1000 tonnes per annum will be needed, the equivalent of a truckload every three days on average . An additional advantage of bamboo gasification is that 15% of the biomass can also be used in the form of high-grade charcoal as a by-product. In the case of a 100 kW gasifier, approximately 135 tons of charcoal will be available per year to fulfill local fuel needs. It is an energy source that is clean, cheap & sustainable. In addition, the quality, species, and maturity of bamboo does not depend on it..

o) **Bamboo based fibre and fabric**

The processing of fibre for the manufacture of yarn and various fabrics is a new development in bamboo. There are several spinning mills that use 100% bamboo yarn, and Indian companies such as Raymond, BSL Ltd of the Bilwara group, and Paramount Textile Mills Ltd, Madurai, have already launched fabrics made from bamboo. Naturally, bamboo fabrics are anti-microbial because they absorb three times more moisture than cotton due to the presence of micro pores in the fiber, making it a superior product. Apart from those mentioned above, bamboo extracts contain valuable elements which can also be used in many industrial products. For example, in pharmaceuticals, creams, and beverages, bamboo can be used. Bamboo extracts are used in traditional medicines like Chawanprash.

p) **Food Products**

Bamboo shoots bring the potential for value-added economic activity by production, processing and packaging at the entrepreneurial and community level. It goes way back in history to its use in food and cooking. Annually, China receives US$130 million from exports of edible bamboo shoots. Around 200 bamboo species can provide edible and palatable shoots of bamboo. In Chinese grocery stores and restaurants worldwide, bamboo vegetables can be found. The shoots are always crisp after cooking, as cooking doesn't destroy their texture. It is possible to store cooked bamboo shoots in containers and export them globally.

q) **Construction and Structural Applications**

Advances in structural engineering and the development of bamboo composites have opened new avenues for lightweight, durable and aesthetic products made out of bamboo for a variety of applications including for housing, community and functional structures. Commonly used bamboo includes *Bambusa balcooa, B. brandisii, Dendrocalaimus giganteus, Dendrocalaimus hamiltonii, Dendrocalaimus strictus, Meloccana bambuisodes* etc. Bamboo Shoots available from *D. tulda, D. hamiltonii, M. Bacifera* (Muli) are also of good quality. Bamboo constructions are easy to build, resilient to wind and even earthquake forces, and readily repairable in the event of damage. Associated products such as bamboo based panels and bamboo reinforced concrete also find applications in the construction process. In spite of these clear advantages, the use of bamboo has been largely restricted to temporary structures and lower grade buildings due to limited natural durability, difficulties in jointing, a lack of structural design data and exclusion from building codes. However, in order to exploit fully the potential of bamboo as a construction material, development effort should be directed at the key areas of preservation, jointing, structural design and codification (Raj & Agarwal, 2014).

Some species of bamboo have ultimate tensile strength same as that of mild steel at yield point and this coupled with other merits boosts the usage of bamboo as construction material. Bamboo needs to be chemically treated due to their low natural durability. It can be used in different ways for roof structure as purlins, rafters and reapers, for flooring, doors and windows, walling, ceiling, man-hole covers etc. Bamboo is strong and lightweight and can often be used without processing or finishing.

Construction-relevant bamboo uses include its use as scaffolding, water piping and as shuttering and concrete reinforcement. In addition, the recent production of a variety of bamboo based panels has increased the potential number of construction applications.

r) **Bamboo Trusses**

The power of the bamboo is equal to that of teak and salt. An experiment with the construction and testing of a 4 m span truss made of round bamboo and various web-chord link jointing techniques

Fig 3. Bamboo housing - a changeover from traditional to contemporary

yielded results that suited the strength of the timber.

s) **Bamboo Housing**

There are three major styles of bamboo housing: (a) traditional houses using bamboo culms as the primary building material; (b) traditional bamboo barbeque houses with a cement or clay bamboo frame; and (c) modern prefabricated houses constructed of laminated bamboo boards, veneers and panels. Generally, these buildings are cheaper than wooden houses, light, solid and earthquake resistant, unlike brick or cement constructions. New types of prefabricated houses made of engineered bamboo have distinct advantages. At a fair rate, they can be packed flat and transported. They are better built and more eco-friendly. Bamboo products are widely available and can be grown at a low cost.

Bamboo building construction is characterized by a structural frame approach similar to that applied in timber frame construction. In this case, the floor, wall and roof elements are interconnected and often one dependent on the other for overall stability.

In certain conventional types of construction, in particular, there is a need to monitor lateral deformation. The adequacy and suitability of the building for occupancy would also rely to a great extent on good data, such as helping to avoid ingress of water and moisture, fungal attack and infestation of vermin.

Hot and cold creosote treatment will treat parts of bamboo columns that are in direct contact with the soil and below the soil. For all structural frame work (trusses, beams etc.) & columns above the plinth, inter nodal preservative injection is used. Split bamboo slivers used for cement mortar-plastered infill wall panels can be processed using boron chemicals via the diffusion process.

Of all the advantages of bamboo housing technology, the most important is that its low-cost without sacrificing quality and durability. A 400 sq ft house in a village, which costs Rs. 1.75 to Rs. 2 lakh with conventional materials, can be built for Rs. 1.25 lakh if bamboo is used. Furthermore, a bamboo house takes very little time for assembly. This becomes critical especially in times of disaster management, providing quick relief or rehabilitation.

t) **Techno-economic cost evaluation of Bamboo w.r.t Steel as Reinforcement in Concrete**

Use of bamboo as reinforcement has gain popularity due to cheap, natural and also readily available. The Analysis of the replacement of steel with bamboo as reinforcement shows that reinforcement with bamboo is quite cheaper than that of steel reinforcement. Bamboo as reinforcement in concrete can increases the load carrying capacity of the structure. Bamboo possesses low modulus of elasticity compared to steel and it is stronger than steel as it has a tightly packed molecular structure than steel (Dange *et al*., 2017). So, it cannot prevent cracking of reinforced concrete under ultimate load. Rahman et.al (2011) evaluated the performance evaluation of bamboo as reinforcement in concrete beam. They have conducted tensile test for bamboo species and flexural strength test for bamboo reinforced concrete beam. The load carrying capacity of singly bamboo reinforced concrete beam can be increased about 2.2 times and that for doubly bamboo reinforced beam about 3.0 times than plain concrete beam having same dimensions. The ultimate load carried by slab is 78 kN with corresponding deflection 2.17 mm. Bamboo's small weight and relative flexibility make it an especially appealing option for home building in earthquake-prone areas. Bamboo is second only to concrete in terms of strength and first in terms of stiffness when compared to concrete, steel, and wood on a mass-per-volume basis. One inch of bamboo can support up to 7 1/2 tonnes of weight and is as strong as mild steel with the compressive strength of concrete. Bamboo has some engineering features similar to steel used in construction, but unlike wood, it has a more evenly distributed yield stress strength due to the absence of rays and knots in its stem. Today, bamboo is used in building construction not only because of its strength, but also because of other features such as pest resistance, sturdiness, flexibility, and availability.

In general, techniques used in conventional reinforced concrete construction need not he changed when bamboo is to be used for reinforcement. The same mix designs can be used as would normally be used with steel reinforced concrete. Concrete slump should be as low as workability will allow. Excess water causes swelling of the bamboo. High early-strength cement is preferred to minimize cracks caused by swelling of bamboo when seasoned bamboo cannot be waterproofed.

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But there are some negative attributes of Bamboo due to its tendency to absorb water. the bonding between the Bamboo and concrete is considered the biggest problem due to absorption of water and smooth wall of the Bamboo Culm. In addition, Bamboo is week at node section and major failure occurs at node point. In the green material concept, the replacement of steel reinforcement can be possible by using bamboo for low cost construction. Moreover, there is a need to establish more characteristic strength of bamboo for design purpose based on experimental and rigorous statistical analysis. Also, there is a need for the development of a simple design code for the application of Bamboo as a Construction material.

u) **Bamboo Composites Vs. Synthetic Composites**

Composites have become indispensable in a variety of industries due to their improved qualities, lower manufacturing costs, and applicability for a variety of applications. Among the several classifications, polymeric composites are primarily focused on their usage as structural components, and the reinforcement selection and composition play a critical role in determining the composite's features. Currently, most research is focused on the utilization of various natural fibers in various forms as reinforcements in polymeric composites (Kamrun *et al*., 2019, Md Shah *et al*., 2016, Pramud *et al*., 2020).

Fiber reinforced polymer composites are made composed of high-strength fibres that act as load-bearing components and offer strength and stiffness, while polymer matrices keep the fibres aligned

(position and orientation). They also shield them from the elements and other potential harm. The addition of high-strength fibres to the polymer gives it significantly improved mechanical properties, making fibre reinforced polymer composites suitable for a wide range of applications. Synthetic fibres such as glass, carbon, aramid, Kevlar, and others are used to make fibre reinforced polymer composites.

Bamboo is a natural fibre with mechanical qualities similar to those of conventional fibres. The performance of bamboo fibre reinforced polymer composites (BFRP) is influenced by a number of elements. Bamboo fibres contain a significantly higher amount of lignin than other natural fibres, which contributes to their high strength. Stronger fibres result in more robust culm structures. However, bamboo fibres' high lignin concentration hinders the efficacy of resin impregnation into the fibres. To ensure that the maximum quantity of lignin is extracted from the fibres, appropriate extraction methods are required. Some bamboo-based composites are now commonly utilised in everyday life, such as ply bamboo and bamboo medium density fiberboard (MDF). Several factors influence the qualities of bamboo composites, and the three primary elements that must be properly addressed to differentiate bamboo composites are types of fibres, types of matrices, and fabrication process. These three criteria are intertwined in the production of good bamboo composite characteristics.

Synthetic fibers reinforced polymer composites (SFPCs) have excellent properties over NFPCs. Mechanical properties of SFPCs such as tensile strength, flexural strength, impact energy and tensile modulus have higher end value. But when the comparison is made in terms of specific properties (property/specific gravity), because of lower densities of natural fibers, NFPCs have comparable specific properties to that of SFPCs. The mechanical behavior of the NFPCs are mostly influenced by the large number of parameters like volume fraction of fibers, fibers length, fibers aspect ratio, fiber-matrix adhesion, fiber orientation, and stress transfer at the interface. Hence to improve the overall mechanical behavior of the composites, the properties of matrix and fibers have to be improved first. Table 6 gives the comparison of mechanical properties of bamboo and glass fibre composites.

The tensile strength of bamboo fibres is generally stochastic, with a wide range in strength. As the strength of the reinforcements fluctuates, the stochastic character of bamboo fibres will have a

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v) **Bamboo Composites Vs. Synthetic Composites**

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Fiber reinforced polymer composites are made composed of high-strength fibers that act as load-bearing components and offer strength and stiffness, while polymer matrices keep the fibers aligned

substantial impact on the mechanical properties of the composites. Taking into account the BFRP's thermal and mechanical qualities, it offers a lot of promise for making lightweight, long-lasting final products that can save a lot of energy in the aerospace industry.

Bamboo fiber, like other hydrophilic natural fibres, has weak interfacial adhesion with the majority of hydrophobic matrices. To improve the compatibility of fibers and matrix, high hydroxyl groups in cellulose must be changed. Different fibre treatments result in significant increases in tensile and flexural strength, ranging from 10 to 120 percent (https://www.guaduabamboo.com/blog/advantages-of-building-with-bamboo),while improvements in tensile and flexural modulus can range from 80 to 214 percent. The chemical treatment of fibres can significantly minimize moisture absorption. Various chemicals, such as alkali (sodium hydroxide), isocyanate, KMnO4 (permanganate), CTDIC (cardanol derivative of toluene di-isocyanate), peroxide, enzyme, and others, were utilized to treat the composites, resulting in a significant change in the mechanical and physical properties.

Conclusion

While India has the world's second-largest bamboo resources and many people rely on it for their livelihood, there is a pressing need to encourage bamboo use to its full potential. Bamboo's diverse applications, such as building materials, activated carbon, useful form of energy, bamboo shoots, and so on, have prompted people to consider it as a better alternative to wood and other materials. Bamboo products with added value have a lot of potential for producing money and jobs, especially in rural regions. The waste generated could also be turned into value-added goods like activated carbon, indicating that bamboo is being used to its maximum potential. Other factors include minimal capital investments, the need for semi-skilled personnel, and the availability of raw materials locally etc. should be considered when adopting processing procedures at the rural level. Composite materials, such as FRP doors and doorframes, are more cost-effective than wooden items and are more robust for long-term use. This low-cost composites technique could be used for commercial production, especially in rural areas.

The standardization of bamboo structural goods reflects society's and policymakers' rising interest in the material, and it offers up new avenues for long-term economic growth. Comprehensive codification of structural bamboo products may be unavoidable in the near future, but without deliberate participation from interested stakeholders, including academia, industry, and politicians, the process will be slow and inefficient. While the production of standards and rules for bamboo products is booming around the world, there is a growing demand for bamboo-based goods that must be met. The growing economic and environmental interest in a sustainable material like bamboo will be aided by multilevel contributions, which will be a critical step toward the standardization of structural and engineered bamboo products.

Table 6. Comparison of mechanical properties of bamboo fibre composites and glass fibre composites

No.	Fiber	Volume Fraction (vf:%)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation (%)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Density (g/cm^3)
1	BF		500-575	27-40	1.9-3.2	100-150	10-13	1.2-1.5
2	GF		124-150	7-10	2.5-4.8	110-150	5-9	2.35-2.5
Composite materials								
3	BE+Epoxy	65	87-165	3-15	1.7-2.2	107-140	10-12	1.16-1.25
4	GF+Epoxy	65	180-220	5-10	2.7-3.5	195-220	7-12	1.96-2.02

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