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Bamboo: Technology Innovations Towards Value-added Applications: A Review

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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 can substitute not only wood, but also plastics, steel, cement and other materials in structural and product applications through improvements in processing technologies, product innovation with the application of scientific and engineering skills. The sector has vast potential for generating income and employment, especially in the rural areas. Towards promoting the usage of bamboo into value-added products, the National Mission on Bamboo Applications has been a major initiative by the Govt. of India under the 10th five year Plan. Primary processing of bamboo *i.e.* cross-cutting, splitting, knot removal, sliver making, strip making and round stick making may be carried out at rural cluster zones. After primary processing of bamboo, a lot of waste is generated. This waste may be effectively converted into value-added products such as activated carbon, charcoal etc. Efforts are underway for converting bamboo into usable form of energy by gasification. These gases can replace diesel up to 70% thus catering to energy needs (Tripathi, 2008). The by-products of biomass gasification in the forms of volatiles are rich sources of chemicals. The conversion of bamboo waste into charcoal is also being explored for catering to rural energy needs. The low-cost technology could be taken up for commercial production particularly in rural areas. This review paper discusses in detail about the properties and application of bamboo as wood, primary and secondary processing of bamboo and preservation of bamboo. The paper brings out technology overview of the products and associated business opportunities.

Key words: Bamboo, Composite, Green grass, Poaceae.

Bamboo is a grass, the most diverse group of plants in the grass family. It belongs to the sub-family Bambusoidae of the family Poaceae (Graminae). Bamboo occurs naturally on every major continent except Europe, with over 1200 species, distributed in seventy genera Europe (Gupta *et al* 2008). It is an enduring, versatile and highly renewable material, one that people and communities have known and utilized for thousands of years. Bamboo has been an integral part of the cultural, social and economic traditions of many societies. Millions of people depend on it for their livelihood and for household and functional uses. In return, communities have nurtured and protected bamboo and are repositories of vast knowledge and skills related to the propagation, processing and usage of bamboo. They are among the fastest growing plants on the planet. For most purposes bamboo can be harvested in 2-3 years, making it a truly renewable resource. Bamboo contributes to the soil and environment, giving back as much as it takes. A pivotal element in the balance of oxygen and carbon dioxide in the atmosphere, bamboo produces 30% of its volume in biomass. Its unique root and rhizome structures act as binders, controlling erosion and rejuvenating soil. Bamboo, in plantations or on the periphery of homesteads, acts as a windbreaker, a noise and climate buffer (ICFRI, 2017). Bamboo based household plantation and agro-forestry can enhance food security, assist in soil conservation, watershed development and the reclamation of wasteland.

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Bamboo has many new uses too, developed through the application of science and technology. It can substitute technologically and commercially not only wood, but also plastics, steel and cement and composite materials in structural and product applications through improvements in processing technologies, product innovation and the application of scientific and engineering skills (Ray *et al.*, 2005).

Bamboo: The Indian context

Bamboo grows profusely in the North East, which accounts for almost two-thirds of growing stock and considerable variety. Bamboo occurs in major concentrations as well in the Himalayan foothills, the Western Ghats and wide swathes of central, peninsular and northern India, as well as in the Andaman and Nicobar islands. Four fifths of the growing stock comprises of three species: *Dendrocalamus*

strictus (53%), *Bambusa arundinacea* (15%) and *Melocanna bambuisodes* (15%). Most Indian bamboo is sympodial (clump forming); the singular exception is Phylostacchus bambuisodes, cultivated by the Apa Tani tribe on the Ziro plateau in Arunachal Pradesh.

Bamboo is currently in the process of being 'rediscovered' in India. Its attributes and potential are increasingly recognised. Bamboo has much to do with people. In many parts of the country the use of bamboo is ubiquitous. With communities putting the material to aesthetic yet functional use, their skills having evolved over centuries of usage. People are also repositories of knowledge, which can be extremely useful for the development of the sector. The sector has vast potential for generating income and employment, especially in remote areas and amongst communities, which have tended to be economically and socially disadvantaged.

The expectation is that bamboo can be an important vehicle for sustainable and widespread development, augmenting economic opportunity, income and employment, in particular in relatively underdeveloped areas. Bamboo is an eco-friendly alternative to many currently used materials. It is a material that lends itself easily to simple processing technologies. At the same time it is capable of high-end and high-value products and applications. The development of diverse bamboo applications would have environmentally beneficial impacts, through substitution and conservation of timber resources and enhancement of green cover.

Applications of bamboo

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

Wood substitutes and composites

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 Moulded 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, November 2007) and Mohanty *et al* (2015).

Several years of R and D at Indian Plywood Industries Research and Training Institute (IPIRTI), Bengaluru have resulted in the development of cost-effective and eco-friendly technology for the production of several products based on bamboo (Pandey 2019) and IPIRTI, Development of Improved and New Products from Bamboo Mats. 100p, 1983). Final products can be graded as follows, based on the preliminary processed bamboo.

Bamboo mat based product

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 Moulded Skin Board (BMMSB)
f) Bamboo Mat Ridge Cap (BMRCS)

A detailed product flow chart is shown in Fig 1.

Bamboo strip based products

The list includes the following:

a) Bamboo Wood [Laminates]
b) Bamboo Flooring Tiles
c) High Density Transport Flooring

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

Bamboo in round/split/composite form

The product list includes

a) Bamboo Based Housing System
b) Bamboo Match Splint

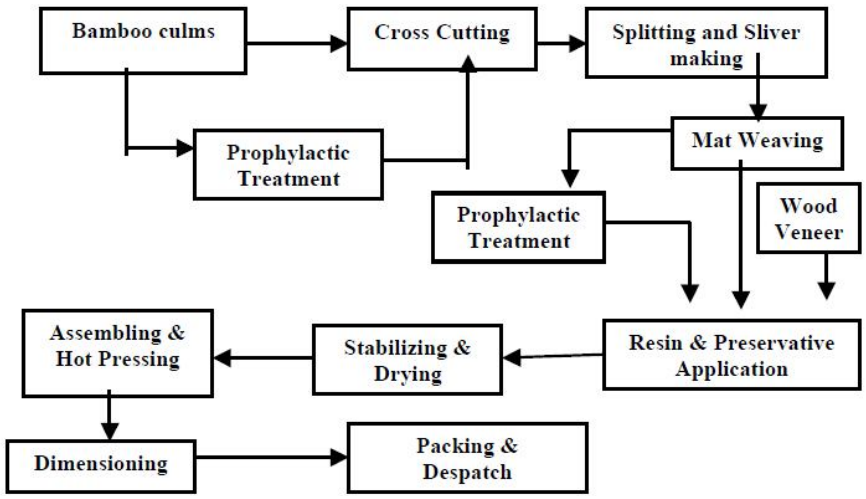

Fig 1: A generalized process flow chart for Bamboo mat composites. Source: Mohanty *et al.* (2015).

Bamboo mat based products

The details of these products are given hereunder.

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. 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

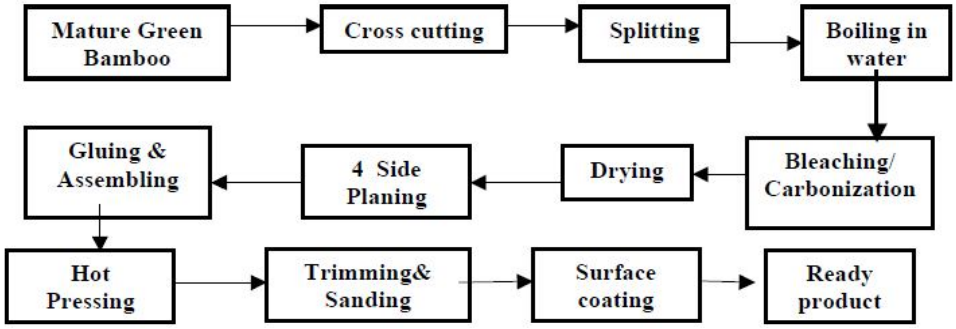

Fig 2: Flow chart for the manufacture of bamboo wood. Source: Mohanty *et al.* (2015).

Table 1: Physical and mechanical properties of BMB of different thickness.

Property					
Thickness of the panels	3 mm	6 mm	6 mm*	8 mm	9 mm
Density, Kg/m^3	766	711	935	790	892
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
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
Tensile strength N/mm^2	22.69	26.59	89.17	29.54	31.4
Compressive strength N/mm^2	16.77	30.35	50.60	35.30	57.5
Mod. of rupture N/mm^2	50.74	56.31	102.57	59.35	68.8
Mod. of elasticity N/mm^2	3678	3220	12033	3114	3930
Mod. of rigidity, N/mm^2	5881	6050	3527	6066	5750

*Pattern of waving is rectangular.

Source: Mohanty *et al.* (2015).

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. 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 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 of HB/MDF skin board doors.

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 × 0.43 m for the normal production of bamboo mat ridge caps.

Table 2: Physical and mechanical properties of BMVC.

Property	Structural plywood	BMVC (67%)
Thickness		21mm
Density Kgs/m^3	750	602
I.B. Strength N/mm^2	-	
Dry		2.30
Wet		1.65
Surface strength N/mm^2	-	
Dry		8.00
wet		6.80
Tensile strength N/mm^2||⊥	5434	36.4035.80
Compressive strength N/mm^2||⊥	3429	43.9040.20
Mod. of rupture N/mm^2||⊥	4929	68.5055.40
Mod. of elasticity N/mm^2||⊥	73553923	78203210
Mod. of rigidity, N/mm^2	588	3316

Source: Mohanty *et al.* (2015).

Bamboo strip board

During assembly, bamboo strips are arranged in one and the same direction and then bidirectionally 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 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, 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

Table 3: Strength properties of bamboo laminates.

Property	Vertical laminates		Horizontal laminates	
	UF	MUF	PF	MUF
Density Kgs/m^3	728	745	796	782
MOR, N/mm^2	122.5	149.1	145.2	164.4
MOE N/mm^2	12028	16570	16800	17300
Compressive strength N/mm^2	61.7	84.7	96.0	87.9
Block shear strength, N/mm^2	11.89	12.8	12.7	9.6
Screw withdrawal strength, N				
Face	4999	4006	4683	3235
Edge	2333	3659	3216	5375

Source: Mohanty *et al.* (2015).

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.

a) 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.

Table 4: Properties of bamboo strip board.

Property	Values obtained
Density Kgs/m^3	921.00
Moisture content, %	3.9
Modulus of rupture, N/mm^2	
Along	118.56
Across	59.47
Modulus of elasticity N/mm^2	
Along	12383
Across	3556
Block shear strength, N/mm^2	5.67

Source: Mohanty *et al.* (2015).

Sector-wise applications of bamboo boards/ laminates

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

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

b) Bamboo flooring

Bamboo flooring is a premium product that has a large global consumer market. It has advantages over floors made of wood from trees due to its smoothness, brightness, stability, high resistance, insulation qualities and exibility. Bamboo flooring has a soft natural lustre and maintains the natural gloss and elegance of the bamboo-bre. 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.

Table 5: Physical and mechanical properties for bamboo composite laminates.

Physical properties	Bamboo composites with resin content		Teak
	5.5%	9.3%	
Moisture	8.60	6.60	9.7
Density g/cm^3	0.99	0.62	0.596
% water absorption, 24 hrs soaking	16.27	46.50	15.7
% volumetric shrinkage, AD to OD	4.36	4.61	5.05
% swelling in water after 24 hrs. soaking			
i) Breadth	0.89	1.47	0.88
ii) Thickness	3.62	3.12	1.09
iii) Volumetric	4.51	4.59	1.97
Mechanical properties			
Modulus of rupture, kg/cm^2	1169	1062	959.0
Tensile strength parallel to grain, kg/cm^2	1048.8	698.6	-
Compressive strength parallel to grain, kg/cm^2	1057.4	675.5	632.0
R A Impact, Kg-cm	343.2	186.0	68.0
Shear strength, Kg/cm^2	201.9	127.9	102.0
Modulus of elasticity 1000 × kg/cm^2	247.0	155.0	119.6
Screw holding strength (kg)	348.5	361.4	326.0

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.

a) 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 living spaces. Mechanized blind making units may be companies that are economically viable. Again, 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. It can be found in match sticks as well.

b) Bamboo furniture

Traditional bamboo furniture uses natural round or split bamboo. A new type of 'pack-flat,' 'knockdown' furniture uses glue-laminated bamboo panels. Unlike the traditional design, the new design overcomes many of the problems of traditional bamboo furniture, such as high labour and transportation costs, low productivity, instability, varying quality and susceptibility to insects and fungi. At the same time, it retains the distinct physical, mechanical, chemical, environmental and aesthetic features of bamboo. Export of laminated bamboo furniture is growing rapidly. However, trade statistics currently do not capture the value, owing to the absence of a special code for bamboo furniture. It is usually classified as wooden furniture.

Industrial products

Bamboo's industrial goods basically involve the conversion into fuel or electricity by gasification. Bamboo can be processed into three useful items by pyrolysis - bamboo charcoal, oil and gas. Depending on the intent and market conditions, changing the pyrolysis parameters will change product shares. Bamboo-based production gases may be used as a petroleum alternative. Bamboo charcoal is a perfect barbecue and cooking fuel. The use of activated charcoal can also occur. This is used as a waste and unnecessary moisture deodorant, purifier, disinfectant, medication, farm chemicals and absorber. Industrial usage includes the use of bamboo waste for gasification and hence producing electricity.

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 Samir Jamatia (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.

Bamboo charcoal for fuel

Bamboo charcoal is traditionally used as a substitute for wood charcoal or mineral coal. It can serve as a fuel, absorbent and conductor. The calorific value of bamboo charcoal is almost half that of oil of the same weight. Activated bamboo charcoal can be used for cleaning the environment, absorbing excess moisture and producing medicines. The absorption capacity of bamboo charcoal is six times that of wood charcoal of the same weight. Bamboo charcoal is excellent for cooking and barbequing. Activated charcoal is used as purier, disinfectant, medicine, in the pharmaceutical industry and in industrial processes for absorbing pollutants and excessive moisture (Jamatia 2012). Compared to tree species, bamboo grows faster and has a shorter rotation; bamboo charcoal's calorific value and absorption properties are comparable to or better than those of wood charcoal; and It is cheaper and easier to manufacture.

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 (Jamatia 2012). 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 and sustainable. In addition, the quality, species and maturity of bamboo does not depend on it.

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.

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.

Construction and structural applications

Advances in structural engineering and the development of bamboo composites have opened new vistas for lightweight, durable and aesthetic construction for a variety of applications, enabling informed choices for housing, community and functional structures. Commonly used bamboo includes *Bambusa balcooa, Dendrocalaimus 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 *et al.* 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 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 yielded results that suited the strength of the timber.

Bamboo housing

There are three major styles of bamboo housing: (a) traditional houses using bamboo culms as the primary building material; (b) traditional bamboo bahareque houses with a cement or clay bamboo frame; and (c) modern prefabricated houses constructed of laminated bamboo boards, veneers and panels (Fig 3). 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

Fig 3: Bamboo housing – a changeover from traditional to contemporary.

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. Furthermore, a bamboo house takes very little time for assembly. This becomes critical especially in times of disaster management, providing quick relief or rehabilitation.

Techno-economic cost evaluation of Bamboo w.r.t Steel as reinforcement in concrete

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. High early-strength cement is preferred to minimize cracks caused by swelling of bamboo when seasoned bamboo cannot be waterproofed.

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.

Bamboo composites vs. synthetic composites

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 utilisation of various natural fibres in various forms as reinforcements in polymeric composites (Kamrun *et al.* 2019), Md Shah *et al* (2016) and Pramudi *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

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

Fiber	Volume fraction (vf:%)	Tensile strength (MPa)	Tensile modulus (GPa)	Elongation (%)	Flexural strength (MPa)	Flexural modulus (GPa)	Density (g/cm^3)
BF		500-575	27-40	1.9-3.2	100-150	10-13	1.2-1.5
GF		124-150	7-10	2.5-4.8	110-150	5-9	2.35-2.5
Composite materials							
BE+Epoxy	65	87-165	3-15	1.7-2.2	107-140	10-12	1.16-1.25
GF+Epoxy	65	180-220	5-10	2.7-3.5	195-220	7-12	1.96-2.02

specific properties to that of SFPCs. The mechanical behaviour 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 behaviour 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.

Bamboo fibre, like other hydrophilic natural fibres, has weak interfacial adhesion with the majority of hydrophobic matrices. To improve the compatibility of fibres 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 and Pandey *et al* (2019), while improvements in tensile and flexural modulus can range from 80 to 214 per cent. The chemical treatment of fibres can significantly minimise moisture absorption. Various chemicals, such as alkali (sodium hydroxide), isocyanate, $KMnO_4$ (permanganate), CTDIC (cardanol derivative of toluene diisocyanate), peroxide, enzyme and others, were utilised to treat the composites, resulting in a significant change in the mechanical and physical properties.

CONCLUSION

Today's world calls for sustainability in its development. The requirement of biodegradable and natural origin is mandated primarily. While India has second largest bamboo resources in the world and many people are dependent on it for their livelihood, there is a substantial need to promote the utilization of bamboo to the extent possible. Value added bamboo products would have vast potential in generating income and employment, especially in the rural areas. The waste so generated could also be converted into value added products such as activated carbon *etc.* This indicates the utilization of bamboo to the fullest extent. Other aspects such as low capital investments, requirement of semi-skilled workers, abundant availability of raw materials locally etc. would merit attention in adopting the processing methodologies at rural level. The cost-effective composite products *viz.*, FRP doors and doorframes are better alternatives to wooden products and these products are durable for long term usage. This low-cost technology of composites could be taken up for commercial production particularly in rural areas.

The standardization of bamboo structural goods represents the growing interest of society and policymakers and opens up new possibilities for sustainable industrial growth. While the production of standards and codes for bamboo products is booming globally, the increasing demand for goods based on bamboo needs to be addressed. Multilevel contribution will lead the growing economic and environmental interest on a sustainable material like bamboo and will be a key step towards the standardization of structural and engineered bamboo products.

Conflict of interest: None.

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