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Manufacturing laminates from sympodial bamboos — an Indian experience

A. K. BANSAL* and T. R. N. PRASAD

Indian Plywood Industries Research and Training Institute, Tumkur Road, P. O. Box 2273, Bangalore 560 022, India

Abstract—In recent years bamboo has been rediscovered as an important renewable material with great potential. Industrial bamboo products will also result in alleviating the pressure on forests, as well as creating employment opportunities for rural/tribal poor, particularly women. Considering this, the Government of India has launched an important national initiative for promotion of bamboo products in mission mode. Laminated bamboo boards are closest to wood both in appearance and properties and are generally manufactured from the monopodial bamboo, namely Phyllostachys pubescens. The material is highly suitable for flooring and furniture. Working on a project funded by the Ministry of Environment and Forests, Government of India, IPIRTI has evolved a process for making bamboo wood (laminates) from a sympodial bamboo found in several states of India, namely *Bambusa bambos*. Strength properties of bamboo wood are comparable to those of *Tectona grandis* (teak). A flat-pack table and a wall stand were also designed and fabricated, indicating the suitability of the material for furniture.

Key words: Laminates; bamboo-wood; wood substitute; sympodial bamboo.

INTRODUCTION

The development of wood substitutes is one of the important interventions enunciated in the 1988 National Forest Policy of India aiming at the conservation of natural forests [1]. Such substitution has necessarily to be done by the use of renewable fibres, due to the fact that wood alternates made from non-renewable resources will not be sustainable. More over alternates based on plastics, metals and such other materials are highly energy consuming, non-biodegradable and are not conducive to our environment [2, 3]. Of the several renewable fibre resources bamboo is being rediscovered throughout the world as a futuristic material. Bamboo is perhaps one of the fastest growing plants on the earth and sequesters atmospheric carbon most

*To whom correspondence should be addressed. E-mail: bansalka@vsnl.com

efficiently. Several panel products have been developed or are under development using bamboo in different form including strips/laths, slivers and particles [4, 5]. India has rich resources of bamboo both in terms of extent and variety. In fact, several species of bamboos occur naturally in the country and have been part of Indian culture with more than thousand traditional uses. IPIRTI has been associated with development of several useful products from woven bamboo mats that are not only environment-friendly but also people friendly [6, 7].

A new generation product made from bamboo strips, known as bamboo laminate, has gained importance in Europe and America, particularly as flooring material in place of hardwoods, due to the fact that it resembles wood in appearance and has similar workability [8]. Bamboo laminate can replace timber in many other applications, such as doors and windows, frames, partitions and furniture. These laminates are manufactured from a temperate zone monopodial bamboo, namely *Phyllostachys pubescens*, referred to in the international technical literature also as moso bamboo (Ref. [9] and data not shown).

Working under a project funded by the Ministry of Environment and Forests, Government of India, IPIRTI screened a number of Indian sympodial or clump forming bamboo species and developed the technology for the manufacturing bamboo laminates from *Bambusa bambos*, one of the common bamboo species in several parts of the country covering around 15% of the total bamboo bearing forest areas. The species is also raised as plantations outside forests.

MATERIALS AND METHODS

A generalized process flow chart for manufacturing bamboo laminates is given in Fig. 1. In simple terms, the process involves conversion of bamboo into strips having uniform rectangular cross-section, drying them to reduce the moisture to desirable level, application of adhesive and hot pressing using both vertical and side pressure to achieve proper bonding. Some of the bamboo processing machines were imported as they are not available in the country. One of the available hydraulic hot presses was modified so as to provide both vertical and side pressure required for making bamboo laminates.

The bamboo strips are required to have a uniform rectangular cross-section. The strips are put side by side in two different fashions and accordingly they are termed as vertical and horizontal laminates (Fig. 2). The normal minimum size (the lesser dimension of the cross-section) for use in furniture is 18–20 mm. Moreover, such strips are made from bamboo splits having a cross-section as shown in Fig. 3. From such a cross-section strips of rectangular cross-sections are cut by removing the extra material in two stages of planing. This specific processing requirement puts a constraint on minimum diameter and wall thickness of bamboos that can be economically used for making laminates.

Since culm diameter and wall thickness are two very important parameters that limit the conversion of bamboo into strips of suitable sizes for making laminates,

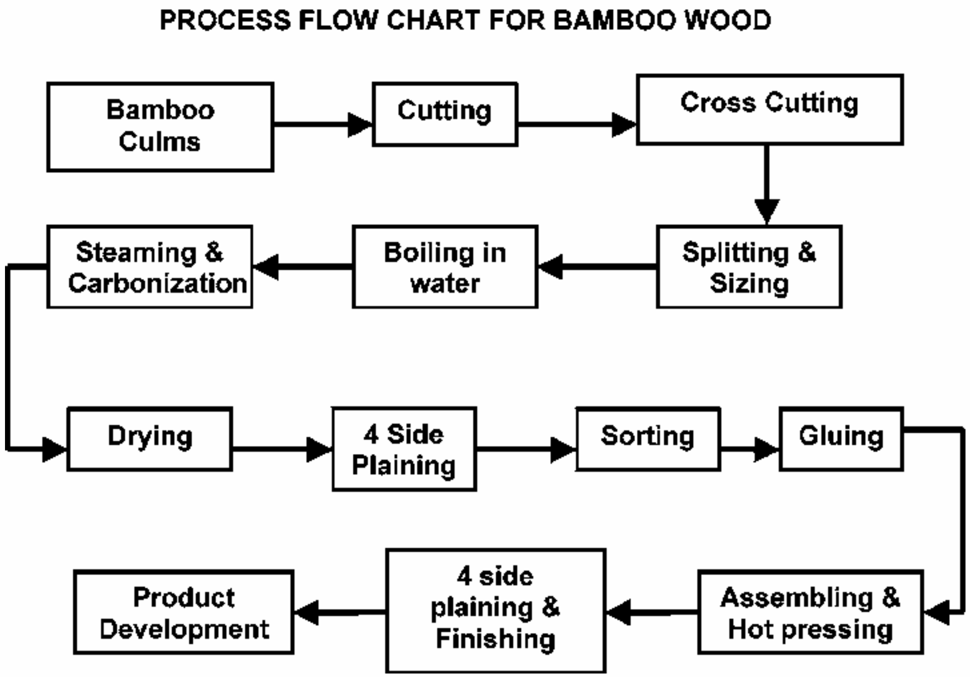

Figure 1. Process flow chart for manufacturing bamboo laminates.

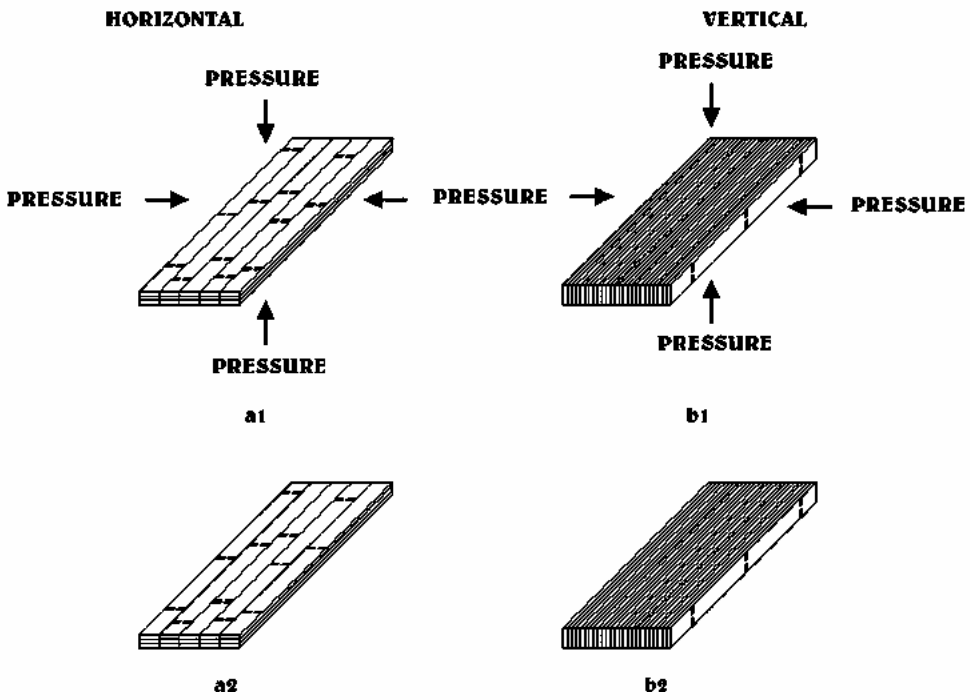

Figure 2. Bamboo laminates.

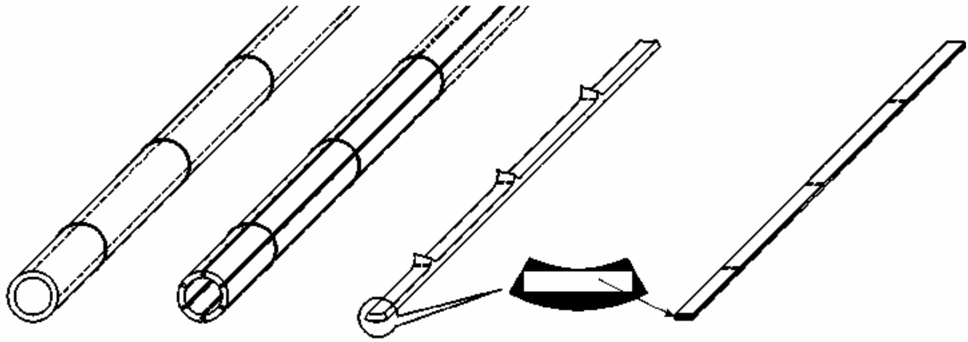

Figure 3. Bamboo splitting and sizing for laminates.

of the several Indian bamboo species, *viz.*, *Bambusa balcooa*, *B. nutans*, *B. bambos* and *B. tulda* appear to be suitable. Of these, *B. bambos* was taken up for the study due to its availability close to the Institute's main research laboratory at Bangalore. The utilizable proportion of bamboo strips will greatly depend upon the diameter and wall thickness of the bamboo. A preliminary estimation of yield of strips was also carried out.

Conversion of bamboo into strips

Mature bamboo culms with outer diameter more than 100 mm and wall thickness in the range of 10–15 mm were cross-cut to 1-m lengths using a cross-cutting machine. External bulging at the nodes was removed manually. A special splitting machine that splits bamboo into strips with parallel edges was used to convert round bamboos into strips. The strips were then immersed in boiling water to which some preservative chemical was also added to remove the starch and enhance durability of bamboo strips. The colour of the strips can be darkened by steaming them under 5–6 kg/cm^2 pressure for 2–4 h. The intensity of the colour developed depends on the temperature and duration of the steaming, the higher the temperature and longer the time, the darker the colour. These strips are then dried to 8–10% moisture content in a hot air chamber at $80 \pm 2°$C. After drying the strips are passed through four side planing machine equipped with two side (vertical) and two face (horizontal) cutters to get strips with predetermined and uniform rectangular cross-sections with plane surfaces. However, some strips may have defects like blue stains, cutter marks, reining, dents and ripples. Defect-free strips were selected for further processing.

Adhesive formulation

Three types of resin adhesives, namely (1) urea formaldehyde (UF) fortified with melamine (the melamine is added after manufacturing of UF resin), (2) melamine urea formaldehyde (MUF, the melamine is added during the resin manufacturing process, before co-condensation stage) and (3) phenol formaldehyde (PF), were

Table 1.
Adhesive formulations (parts)

	UF resin	MUF resin	PF resin
Resin	100	100	100
Melamine	2.5		
GNCP	10	10	
CSF			8
Hardener	0.5	0.6	

GNCP is Ground nut cake powder; CSF is Coconut shell flour.

Table 2.
Pressing conditions

	UF resin	MUF resin	PF resin
Temperature (°C)	115	125	145
Pressure perpendicular to glue-lines (kg/cm^2)	10	12	14
Pressure parallel to glue lines (kg/cm^2)	2.5	2.5	2.5
Pressing time (min)	12	15	20

used in the investigations. Various parameters of the three resins are given in Table 1.

Adhesive application, assembly and hot pressing

Adhesive was applied to the four side planed strips through brush coating. Adhesive coated strips were assembled to make the desired thickness, keeping in mind the compression losses during hot pressing, using two stacking types as depicted in Fig. 2 to make vertical and horizontal laminates. The assembly was hot pressed in a hydraulic hot press generally used for making plywood modified to provide side pressure in addition to the vertical pressure. The pressing conditions for three adhesive resins are given in Table 2.

Finishing or surface coating

Laminates manufactured in the pilot plant were planed in a planing machine to get a smooth finish. The board is then filled with putty prepared with bamboo dust to fill the gaps and crevices, and primer coating was given followed by coating with melamine clear finish or polyurethane.

Testing of bamboo laminates

Five samples each of the three types of vertical and horizontal laminates were tested at the Institute's testing lab for block shear strength, modulus of rupture (MOR), modulus of elasticity (MOE), screw withdrawal strength, compression strength and abrasion resistance. The first five properties were tested according to Indian Standard IS 1708-1986, the last one according to IS 12823-1990. These properties were compared with those of teak (*Tectona grandis*), as it is a well-known and widely used timber through out India for all sorts of work such as beams, columns, roof work, flooring, planking, paneling, doors and windows, furniture, etc. Teak is recognized as a standard species for evaluation of suitability indices of timber species in India [10–12].

RESULTS AND DISCUSSION

Yield

From the investigation carried out during the conversion of bamboo into strips average yield came to 17%. This utilisable portion of bamboo for manufacturing laminates is rather low; the remaining portion can be used for particle board or as fuel; the outer layer can be used for basketry. Proportions of residues, not-utilizable for making laminates, in different stages, are given in Table 3.

Strength properties

One of the important properties of any composite material using resin or any adhesive material is the bond integrity. The bamboo laminates were tested for their bond strength through cyclic wetting in hot water at $60 \pm 2°C$ for 3 h followed by drying for 16 h. It was seen that the laminates manufactured with the three types of resins namely urea formaldehyde, melamine urea formaldehyde, and phenol formaldehyde remained intact without any signs of de-lamination after 3, 6 and 12 cycles, respectively. These results conform to expected quality of bonding for the respective resins and indicate that only PF-bonded laminates can be suitable for exterior applications, and UF- and MUF-bonded laminates are suitable for interior uses.

The physical and mechanical properties of laminates made from *B. bambos*, as well as the relevant values for teak wood, are given in Table 4. From Table 4 it is clear that the strength properties of bamboo laminates compare well with those

Table 3.
Waste during conversion of bamboo culms into strips

Process	Waste (%)
Cross-cutting	17
Splitting	16
Internal knot removing	36
Shrinkage during drying	4
Four side planning	10
Total	83

of teak wood. Bamboos are generally understood to be not a strong material, but there are several species of bamboo which are quite strong. Comparing various Indian bamboo species with a view to classify and grade them for structural utilization. Rajput and Sharma [13] have observed that average strength of bamboo is about 16% less than that of average wood, but the MOR and MOE of some bamboo species, including *B. bambos*, reported in the study, are higher than those

Table 4.
Properties of vertical bamboo laminates

Sl. No.	Property	Teak wood[a]	Horizontal laminates MUF[b]	Vertical laminates UF[c]	Vertical laminates MUF[b]	Vertical laminates PF[b]
1	Density (kg/m^3)					
	a. Average	645	782	728	745	796
	b. Standard deviation	40.9	23.3	44.3	62.6	38.0
	c. Variation coefficient (%)		3.0	6.1	8.4	4.8
2	Modulus of rupture (N/mm^2)					
	a. Average	86.6	164.4	122.5	149.1	145.2
	b. Standard deviation	9.4	17.8	22.8	34.6	25.4
	c. Variation coefficient (%)		10.8	18.6	23.2	17.5
3	Modulus of elasticity (N/mm^2)					
	a. Average	10 752	17 300	12 028	16 570	16 800
	b. Standard deviation	1102	2330	1311	2560	2060
	c. Variation coefficient (%)		13.5	10.9	15.5	12.3
4	Compressive strength (N/mm^2)					
	a. Average	47.7	87.9	61.7	84.7	96.0
	b. Standard deviation	4.3	9.5	4.7	12.6	7.9
	c. Variation coefficient (%)		10.9	7.6	14.8	8.3
5	Block shear strength (N/mm^2)					
	a. Average	9.98	9.65	11.9	12.8	12.7
	b. Standard deviation		2.3	2.2	3.5	1.7
	c. Variation coefficient (%)		23.5	18.3	27.4	13.2
6	Screw withdrawal strength (N)					
	i. Face					
	a. Average	3900	3235	4999	4006	4683
	b. Standard deviation		396.5	370	793	692
	c. Variation coefficient (%)		12.3	7.0	19.8	14.8
	ii. Edge					
	a. Average	2881	5375	2333	3659	3216
	b. Standard deviation		563	464	878	669
	c. Variation coefficient (%)		10.5	20.0	24.0	20.8

[a] At 12 % moisture content.
[b] Made from *B. bambos* culms obtained from Bangalore University Campus.
[c] Made from *B. bambos* culms obtained from MM hills, Karnataka.

Figure 4. Magazine holder.

of teak. Moreover, strength of split bamboo is found to be more than round bamboo [14]. The strength properties of bamboo are known to increase with age being the maximum at maturity and decrease along the length within a culm. In the present study only mature bamboo culms were used and in the course of processing generally the bottom portions of the culms were selected, due to the requirement of minimum wall thickness for making laminates. All these factors contribute in enhancing the strength properties of the laminates. This also suggests that bamboo species and selection of lower thick walled portions from mature culms is likely to have significant effect on the properties of the laminates.

Figure 5. Centre table.

The vertical bamboo laminates manufactured at the Institute's facilities were used for making consumer products and a centre table, and a magazine holder were designed and fabricated at the Institute (Figs 4 and 5).

CONCLUSIONS AND RECOMMENDATIONS

From this it is seen that bamboo wood or laminates made from the Indian clump forming or sympodial bamboo species *Bamusa bambos* has properties comparable to those of teak wood. They are also suitable for making furniture. The study also indicates that, whereas UF and MUF resin bonded laminates are suitable for interior uses, for exterior applications PF resins are required to be used. Further work is in progress to screen other sympodial bamboo species for manufacturing bamboo wood.

Considering that bamboo wood has properties comparable to teak, a highly demanded furniture wood, and the fact that India has sizable quantities of bamboo species suitable for processing into laminates, the Institute is working in collaboration with the National Mission on Bamboo Applications for evolving a technology package encompassing critical aspects of the processing technology in terms of characterization of bamboos, primary processing including cross-cutting, splitting, four-side planing and yield of utilizable splits, characterization of adhesive and its application, hot pressing, finishing and evolving standards, to facilitate industrial adoption of the technology.

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