

DEVELOPMENT OF A COMPOSITE BOOKSHELF WITH BAMBOO (*Bambusa vulgaris*) STRIPS, LUMBER AND PLYWOOD

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Abstract:

This study investigated the potential of bamboo strips as a partial substitute for wood products in furniture manufacture. Five matured *Bambusa vulgaris* culms (4 years old) were harvested from a natural stand. On harvest, the inter-nodal length, wall thickness and outer diameter of the green culms were measured. The culms were then cut into 4.5m lengths, separated into top, middle and bottom portions. The percentage strip recovery was determined. The bottom and middle portions only were selected and air-dried for six weeks followed by one-week sun-drying. The strips were then treated with borax and boric acid at concentrations of 0%, 5% and 8%. A set of the 500mm (l) x 30mm (b) x 7.9mm (d) treated strips were used as slabs, a set of 800mm (l) x 80mm (b) x 20mm (d) pieces of *Gmelina arborea* lumber were used as framing beams and columns, while 6.2mm plywood was used as the covering/sheathing material in the design and construction of a 1150mm(l) x 500mm (b) x 800mm (d) bookshelf. It was concluded that treated bamboo strips could be a partial substitute for lumber and plywood in furniture production.

Key words: bamboo strips; *Gmelina arborea*; lumber; plywood; furniture.

INTRODUCTION

Bamboos are one of the most abundant non-woody grasses naturally occurring in many parts of the tropical regions in Africa, Asia and Latin America. As shown in Figure 1, bamboos vary in color around the world. Solid colors found include green, yellow, brown, black, red and blue; while the striped colors include green with yellow, pink, brown or black. With a maturity cycle of three to four years, bamboo is regarded as one of the fastest growing plants. Although there are about 115 genera and over 1400 species of bamboos in the world, there are five indigenous species in Nigeria. These are *Bambusa arundinacea*, *Bambusa tulda*, *Dendrocalamus giganteus*, *Oxyanthera abyssinica* and *Bambusa vulgaris*- the most common. *Bambusa vulgaris* can grow to a height of 14-20 metres and attain a girth of 20cm (Olorunnisola 2006, Gutu 2013, Ogunwusi 2014).

It has long been recognized that bamboos have multipurpose uses (Lucas 1972, Liese 1987, Hunter 2003). The culms (hollow stems) are, however, the most economically important part of the plant. Given the special structure of bamboo, its processing and utilization methods are different from those of wood. For example, bamboo stems are smaller in diameter, thin-walled, and tapered. The cylindrical and hollow structure of bamboo with its rigid cross walls gives it resistance to collapse from bending. The culm is jointed and has a very hard external surface which contributes to its strength and impermeability to water. These admirable characteristics notwithstanding, there are major challenges associated with bamboo processing and use in natural form for modern furniture production. Prominent among these challenges are the non-straightness, roughness, existence of the nodal plates, non-uniformity of the stalk diameters; jointing problems, strength and durability, and the vulnerability of the bamboo culm to splitting (Lucas and Ogedengbe 1987, Janssen 2000, Omobowale and Ogedengbe 2008).

Many of the challenges associated with bamboo utilisation in the natural form can be alleviated by creating laminates of bamboo strips (Adewole *et al.* 2017) The strips are generally produced by first cross-cutting the bamboo culm into desired lengths and then splitting the culm along the length into individual strips. Traditional bamboo furniture makers use natural round or split bamboo, while modern bamboo furniture items are produced largely with laminated or un-laminated bamboo strips. There have been little or no research reports on the combination of treated bamboo with other wood products including lumber and plywood in the manufacture of furniture items.



Fig. 1.
Bamboo species of different colours.

As an engineering material, bamboo has a higher specific compressive strength than wood, brick or concrete and a specific tensile strength that rivals steel (Huang *et al.* 2018). However, it is biodegradable and susceptible to attack by fungi and especially by insects, particularly beetle and termites (Liese 1987). Bamboo durability depends on environmental and climatic conditions. Untreated bamboos have an average life of less than 3 years when exposed to either weathering elements and/or the soil. Under cover, they may be expected to last 4-7 years depending on the nature and conditions of use. This makes bamboo treatment of utmost concern especially when used as a structural material. An alternative to treatment is frequent replacement which may be time consuming. Treatment is necessary to increase the service life and improve the overall performance of bamboo products. Traditional methods of preserving bamboo include leaching, smoking and lime-washing. These methods generally do not require sophisticated technology and are usually cost-effective although not effective for long-term preservation. Chemical methods, on the other hand, involve the use of chemical preservatives which may be water-based, oil-based, organic solvent - based, or natural toxicants to protect bamboo from degradation. The chemicals have a more lasting effect and therefore increase the service life of bamboo products (Gnanaharan and Mohanan 2002).

Current uses of bamboo in Nigeria include scaffolding in building sites, stakes in farms, fuel wood, poles for aerial antennae, electricity and rafters. When the utilization pattern in Nigeria is compared with what obtains in South East Asia, it is clear that bamboo is being grossly under-utilized in the country. The aim of this study was to investigate the potentials of producing a bookshelf from a combination of bamboo strips, lumber and plywood.

MATERIALS AND METHODS

Matured (about 4-year old) culms of *Bambusa vulgaris* were harvested from a natural stand at the University of Ibadan. The length, diameter and inter-nodal lengths were also measured. On harvest, the moisture content was determined. The culms were cut into 3 parts: top, middle and bottom. The top and bottom portions were discarded. The bottom and middle portions, each of which was 4.5 meters long were selected for utilisation. They were stacked on concrete blocks to prevent termite infestation and air-dried for a period of six weeks under a shed to minimise rapid shrinkage. This was followed by sun-drying (Fig. 1) for a period of one week at a temperature of 25^oC-30^oC.

After sun-drying, the culms were split into four parts manually by applying force on the nodal point of the bamboo, which is the strongest part, using wood mallet. The bamboo strips were planned on both sides using the disc planer to remove the waxy layer and the diaphragm. The strips were then cut to 170 cm long pieces with a portable circular saw.

Three concentrations of boric acid and borax were used for preservative treatment, i.e., 0% (control), 5% and 8%. The constituents of the borax powder are listed in Table 1. The boric acid, obtained in its pure form as a whitish-crystalline powder, was a weak acid with p^H of 11 constituted largely of boron and other elements like hydrogen and oxygen in minute quantities. To obtain the required concentrations of 5% 103g of boric acid and 165g of borax were diluted in 12 litres of water. To obtain the 8% concentration, 203g of boric acid and 325g of borax were diluted in 20 litres of water.



Fig. 2.
Bamboo strips laid out for sun-drying.

Table 1

Chemical Composition of the borax powder

Constituents	Percentage by mass
$Na_2B_4O_7 \cdot 10H_2O$	M. wt. 381.37
Assay (min)	99%
p^H (5% Solu)	9.0-9.6
Chloride %	0.01 (max)
Sulphate %	0.02 (max)
Iron %	0.002 (max)
Heavy metals %	0.001 (max)



Fig. 3.
Soaking the bamboo strips in boric: borax solution.

After dilution, the bamboo strips were soaked in the boric acid: borax solution in an improvised tank for 72 hours (Fig. 3) and air-dried.

The composite book shelf was constituted of four members: a set of 500mm x 30mm x 7.9mm bamboo strips acting as the slabs, a set of eight 800mm x 80mm x 20mm *Gmelina arborea* lumber pieces acting as the beams, another set of four *gmelina* lumber pieces acting as the beam-column and 6.25mm thick pieces of plywood acting as the side covering. The choice of the lumber species was based on availability, strength, nailability and cost. The design parameters considered for the slabs and beams were

bending strength, deflection and shear strength. It was assumed that each slab of bamboo strip would be loaded flat-wisely, each Gmelina lumber beam would be loaded on edge, and that the load would be uniformly distributed over the span. The density of the *Bambusa vulgaris* was determined to be 350kg/m³. Its Modulus of Elasticity, maximum bending stress and maximum shear stress per density were assumed to be 680N/mm², 7.4N/mm² and 0.003N/mm² respectively (Jayanetti *et al.* 2008). The density and Modulus of Elasticity of *Gmelina arborea* were assumed to be 512kg/m³ and 7500N/mm² respectively in dry service condition (Nigeria code of practice for timber design 2005). The allowable deflection was assumed to be $l/240$.

On completion of the structural design based on standard design equations, the bookshelf components were assembled together. The bottom and middle parts of bamboo strips were used for the fabrication. They were joined to the *Gmelina arborea* using the end-to-end butt joint techniques. Although, this type of connection is not so strong, it was reinforced with nails after the application of a wood adhesive. The plywood pieces, which acted as the cladding member was joined to the built-up slab sheath using nails. They were connected using face-to-end butt joint technique.

RESULTS AND DISCUSSION

Green dimensions of the bamboo culms

The measured green dimensions of the five bamboo culms are shown in Table 2. The maximum inter-nodal length, wall thickness and outer diameter of the bamboo culms were 425mm, 18mm and 279mm respectively. The corresponding average inter-nodal length, wall thickness and outer diameter values were 306.8mm, 12.6mm and 188.6mm respectively.

Table 2

Geometric dimensions of the green culms

Culm	Inter-nodal length (mm)	Wall Thickness (mm)	Outer diameter (mm)
1	215-406	10 -15	91 – 279
2	222 -419	9 – 13	101 – 285
3	177 – 419	10 – 16	120 -247
4	158 – 425	11 – 18	133 – 260
5	215 - 412	11 – 14	119 -251

Strip recovery

The percentage strip recovery is presented in Table 3. The whole length of the culms could not be effectively converted to strips. This was largely due to the tapering nature of bamboo and also manual mode of conversion to strips using wood mallet and chisel. Theoretically, a total 120 strips were expected from the five culms harvested. However, 98 strips were recovered giving a recovery efficiency of about 82% which is relatively high.

Table 3

Percentage strip recovery

Parameter	Value obtained
No. of culms	5
No. of expected strips	120
No. of recovered strips	98
Percentage recovered	81.6%
Percentage loss	18.3%

Planing loss

To obtain flattened strips, the curvature of the bamboo was removed with a surface planer. The planing and trimming operation accounted for about 30% loss in width and thickness of the strips as shown in Table 4. This level of loss is relatively high, though the waste is unavoidable since the planing and trimming processes are mandatory requirements for bamboo furniture production. The bamboo particles could be used for stuffing in upholstered bamboo furniture production, particleboard manufacture, bamboo charcoal briquette production etc.

Table 4

<i>Percentage Loss due to Machining</i>			
Parameter	Before planing	After planing	Average % loss
Width	36-45mm	27-30mm	27.9-31.5
Thickness	6-12mm	4-8mm	31.5-35.7

The composite bookshelf

The bookshelf fabricated from pieces of lumber and strips of bamboo measured 1150mm x 80mm x 50mm. The stability of the shelf was further improved by bracing with wedge-like corner pieces as shown in Fig. 4. The inclusion of the plywood enhanced the appearance of the shelf. Since the strips of bamboo were effectively treated with boric acid/borax solution, the strips are expected to resist attack from micro-organisms. The cost of producing the bamboo bookshelf estimated at about USD 70 was at par with the cost producing the same size of bookshelf with lumber and plywood of the same dimensions. However, the bamboo shelf has a higher strength-to-weight ratio which gives it an added advantage over an equivalent wooden shelf.

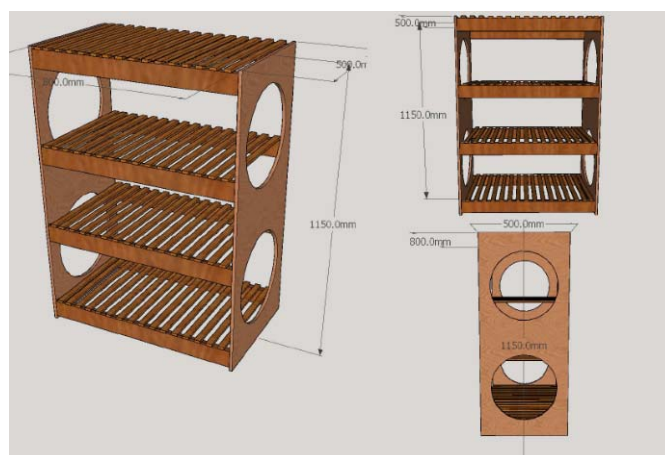


Fig. 4.
Different views of the composite bookshelf.

CONCLUSION

Based on the findings of this study, it can be concluded that the percentage of bamboo strip recovery is relatively high but the planing loss is also relatively high. Nevertheless, it is possible to diversify from the traditional lumber and plywood to modern bamboo based furniture products. *Bambusa vulgaris* strips treated with borax and boric acid can serve as partial and/or full replacement for solid wood in furniture production. The use of bamboo as wood substitute in furniture manufacture will help develop and promote high value-added products from bamboo. It is envisaged that modern bamboo-based furniture products will enjoy market acceptance in Nigeria and other African countries as they have done in Asian countries.

REFERENCES

- Adewole NA, Etta PN, Ibor BB (2017) Characteristics of selected properties of parquet laminate produced from *Bambusa vulgaris* (Schrad) harvested from Akamkpa Local Government Area, Calabar, Nigeria. International Journal of Emerging Trends in Engineering and Development 3(7):183-192.
- Gnanaharan R, Mohanan C (2002) Preservative treatment of bamboo and bamboo products. Kerala Forest Research Institute, Handbook No. 16, 19 pp.
- Gutu T (2013) A Study on the mechanical strength properties of bamboo to enhance its diversification on its utilization. International Journal of Innovative Technology and Exploring Engineering 2(5):1-4.
- Huang X, Li F, De Hoop CF, Jian Y, Xie J, Qi J (2018) Analysis of *Bambusa rigida* bamboo culms between internodes and nodes: anatomical characteristics and physical-mechanical properties. Forest Prod. J. 68(2):157-162.
- Jaynetti DL, Follett PR (2008) Bamboo Construction in: Modern bamboo structures, Xiao, Y., Inoue, M., and Paudel, S.K., eds., London, UK, pp. 23-32.

Janssen JJA (2000) Designing and building with bamboo: INBAR Technical report 20. International Network for Bamboo and Rattan, Beijing, China, pp. 211.

Liese W (1987) Research on bamboo. Wood Science and Technology. 21:189-209.

Lucas EB, Ogedengbe K (1987) Shrinkage Characteristics of Bamboo (*Bambusa vulgaris*, Schrad). Nigerian Journal of Forestry, Vol. 17(1-2):7-11.

NCP2 (2005) Nigeria standard code of practice; the use of timber for construction, Nigeria Standard Organisation, Federal Ministry of Industries, Lagos, Nigeria. 75 pp.

Ogunwusi AA (2014) Unlocking the potential of bamboo in Nigeria. Published by Venus Multimedia Development Services Ltd., Abuja, Nigeria.

Olorunnisola AO (2006) The potentials of bamboo as a novel building and furniture production material in Nigeria. Proc. 5th Nigerian Materials Congress, NIMACON 2006, Organised by Materials Society of Nigeria, Held at Merit House, Maitama District, Abuja, Nigeria, Nov. 15–18:180-185.

Omobowale MO, Ogedengbe K (2008) Trends in fiber characteristics of nigerian grown bamboo and its effect on its impact and tensile strengths. Bamboo Sci. Culture 21(1):9-13.