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Products development of laminated panel doors from plantation grown bamboo species in Ghana

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Abstract: The level of awareness and acceptance of products from native bamboo species from many countries is low. Efficient promotion through establishment of its working properties is essential. In this study, bamboo culms from plantations in Ghana were extracted, processed, dried, planed and glued. Test samples were prepared using ASTMD 143- 94 and 1666-87. These were planed with two cutting angles and three feed speeds at a spindle speed of 5,200rpm. The surface qualities of the planed samples were evaluated and graded according to ASTM D 1666-87. The samples were further used for sanding tests using five grit sizes of sand papers and belt sander. A second sanding operation with grit size 250 was performed manually to finally prepare the surfaces of the prototype products for the application of wood finishes. Results revealed that surface planing quality increased with decreasing cutting angle and feed speed. Sandpaper P60 eliminated all torn/chipped grain defects while the highest percentage surface quality for each species was recorded with P150 followed by P120 and P100. The ease of planing and sanding was classified as moderately easy to slightly difficult. Laminated wood members for panel door production were prepared and sanded and fixed together using dowels and 'Woodchem' adhesive. A good quality laminated bamboo panel door was produced. Bamboo utilization for door manufacturing is recommended for enhanced marketing.

Key words: Bamboo species, laminated panel door, planing, product development

INTRODUCTION

The bamboo resources of tropical Africa covers about 2.5 million hectares from about 20 genera and 50 species out of the world's total of 14 million hectares with 75 genera and 1250 species. In Ghana, there are four species of bamboo from three genera, which are the most commonly exploited (Irvine 1963; Hawthorne 1990). These include *Bambusa vulgaris, Dendrocalamus strictus, Bambusa bambos* and *Oxytenanthera abyssinica.* The bamboo species occur in the wild mostly from the wet and moist evergreen and the dry and moist semi-deciduous forests of Ghana (Hall and Swaine, 1981).

According to Janssen (1987), four major advantages of bamboo as a building material over concrete, steel and wood include the lower energy needed for production of structures, safety of material in construction, of which bamboo is next to steel, strength and stiffness per unit area of material and the ease of production with bamboo. Jayanetti (2001) has reported that bamboo can be used to address three major global

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challenges. These include livelihood security by generating employment in planting and primary processing for manufacturing of basic products; ecological security through conservation of forests through timber substitution, efficient carbon sequestration potential, alternative material to non-biodegradable and high embodied energy materials such as plastics and metals; and sustainable food security through bamboo based agro-forestry systems, maintaining the fertility of adjoining agricultural lands (nitrogen fixing) and bamboo shoots.

Bamboos are important part of the forest resource. The colourful culms and evergreen leaves of bamboos make them beautiful plants for landscaping. Their extensive rhizome-root system is very useful for soil conservation (Zhu, 1987). Due to its fast growth, easy propagation, soil binding properties and short rotation, bamboo is an ideal plant for use in afforestation, soil conservation and social forestry programme (Gaur, 1987; Zhou *et al.*, 2013). Bamboo is used in the fishing industry, housing sector, fuel wood, transport system both on land and water. It is also used for the manufacture of coffin, shoes, clothing, paper, agricultural implements, horticultural pursuits, basket, handicrafts and production of edible shoots. According to Sharma (1987), bamboo, which used to be called poor man's timber worldwide, is now a term of the past in some countries like China and India.

The strength of bamboo culms, their straightness, lightness, combined with extra-ordinary hardness, flexibility, range in sizes, hollowness, long fibre, its abundance, ease of propagation and easy working qualities, make them suitable for a variety of end-uses (Gaur, 1987; Jayanetti, 2001). It is one of the strongest plant-based building materials, and there are bamboo structures that have been in existence for hundreds of years. The properties of the bamboo plant are advantageous especially in tensile and bending strength where they supersede man-made materials (Dunkelberg, 1987; Schaur, 1987; Hidalgo, 1996). The hollow tube shape gives a strength factor of almost two times more than a solid wood beam (ZERI, undated; Jayanetti, 2001). Some species of bamboo have twice the compression strength of concrete and roughly the same strength-to-weight ratio of steel. Certain bamboo withstands up to 52,000 pounds of pressure per square inch and that due to its flexibility, bamboo structures have withstood hurricane winds in excess of 170 mph (ZERI, undated)

Ghana is endowed with vast areas of natural bamboo resources. The pressures of population on the dwindling supply of commonly used timber species for housing in Ghana calls for research and development efforts on the use of non-timber forest products, particularly bamboo. Currently, Ghana faces an acute housing deficit of about one million, seven hundred thousand (1,700,000) units (Appiah-Kubi, 2013). This represents an average of about 13% increase for the year 2011.

To make housing affordable, the increase use of the available local raw materials, which include bamboo species, cannot be over emphasized. This will reduce the import bill on building materials and retain capital, generate revenue to the state, provide employment for the youth and hasten infrastructural development in the rural communities.

According to Haryanto (1987) there are several methods of processing bamboo from its original form and condition into finished products. Lamination is the technique of manufacturing a material in multiple layers, so that the composite material achieves improved strength, stability, sound insulation, appearance or other properties from the use of differing materials. A laminate is usually permanently assembled by heat, pressure, welding, or adhesives (Haryanto, 1987). The materials used in laminates can be the same or different, depending on the processes and the object to be laminated.

In machining operations, according to Cus and Zuperl (2006), the production rate, cost, and product quality are three incompatible objectives. They have added that as the machining industry welcomes the introduction of new materials and cutting tools, it finds itself undergoing rapid development which is giving rise to processes of highly complex and non-linear phenomena. Machining properties relate to the behaviour of wood when planed, sanded, turned, shaped or put through any other standard woodworking operation.

Surface roughness has been defined by Benardos and Vosniakos (2003) as the superimposition of deviations from a nominal surface from the third to the sixth order where the orders of deviation are defined by international standards, DIN 4760 (1982). Correa *et al.* (2009) have also defined surface roughness as the functional behavior of a part. Unlike metal, wood, which is a non-homogenous material, has its machined surface consisting of not only the processing irregularities but also the anatomical irregularities such as fuzzy grains and deep valleys (Gurau *et al.*, 2007). In view of this, the measured surface roughness values are not the true reflection of the actual processing irregularities, hence giving rise to a misinterpretation of the processing performance (Gurau, 2004). In order to evaluate the machining performance and obtain an accurate processing roughness of the machine wood surfaces, deep valleys caused by the vessels and other cellular structures must be removed (Fujiwara *et al.*, 2003).

Sanding, reduces the roughness of a previously machined workpiece to a relatively smooth and flat surface to prepare it for subsequent application of finish materials. The preparation of the wood surface helps to decrease the depth of sanding scratches and to create a uniform surface into which stains will penetrate as evenly as possible (Owusu *et al.*, 2012).

Unfortunately the limited knowledge on the properties and use of the bamboo species, which include machining and lamination have hindered its use as building and construction material in Ghana. Studies into them will generate results to facilitate the efficient processing, utilization and promotion of bamboo as raw material for housing and construction.

The main objective of the research was to determine some machining properties of laminated boards produced from bamboo species grown in Ghana. The specific objectives were to: a) determine the planing and sanding properties of the laminated board produced from bamboo species grown in Ghana and b) manufacture a prototype product from the bamboo laminated boards produced.

MATERIALS AND METHODS

Bamboo culms from plantation clumps were extracted from Daboase, Kusi/Kade and Amantia in southern Ghana for the research work. The selection of the bamboo species was based on the availability in the plantations at the three locations. The selected bamboo species from the three sites are shown in Table 1. Some bamboo culms from different clumps of the selected bamboo species were harvested using a mini-chainsaw machine and a cutlass. Each of the culms, depending upon the full length and tapering nature, was cross-cut into two parts as butt and top (to obtain uniform diameter per portion) and these were labeled accordingly. Each end of a cross-cut culm was treated by dipping the cross-cut end into a solution of Dursban and Anti-blue 37-37 to prevent fungi and insects attack. The materials were then transported to CSIR-FORIG wood workshop for further processing into various sample sizes for the machining tests.

Table 1: Some bamboo species extracted from plantations in three sites in Ghana

Daboase	Kade	Amantia
Dendrocalamus latiflorus	*Guadua chacoensis*	*Bambusa bambos*
Bambusa bambos	*Dendrocalamus brandisii*	*Bambusa vulgaris*
Guadua angustifolia	*Bambusa vulgaris* var. *vittata*	*Bambusa vulgaris* (from the wild)
Guadua chacoensis	*Bambusa vulgaris*	

Bamboo ripping

A circular saw, of type – Wadkin AGS 250/300 – Tilting Arbor Saw-bench was used in ripping the bamboo culms on species basis (Figure 1). The bamboo culms were ripped into four or more pieces, depending upon their diameters (Figure 1), to facilitate air drying of the samples.

Figure 1: Ripping and re-ripping of bamboo culms with Arbor saw-bench

Prophylactic treatment with Dursban and Anti-blue 37-37 was undertaken for these ripped specimens to prevent fungi and insects attack (Figure 2). These bamboo samples were then stacked for air drying. When the moisture content attained below 18%, all the stacked bamboo samples were further ripped into smaller strips to make them easier for the removal of the diaphragms from the samples at the nodes and for effective planing.

Figure 2: Chemical treatment of bamboo strips through dipping method

Planing of bamboo

A narrow bandsaw machine was used to remove the diaphragm and or other knots at the nodes from each smaller strip of the bamboo (Figure 3). A thicknesser planing machine of type 610 x 230 mm "D.A.A" was then used in planing both sides of all the bamboo strips on species basis (Figure 4).

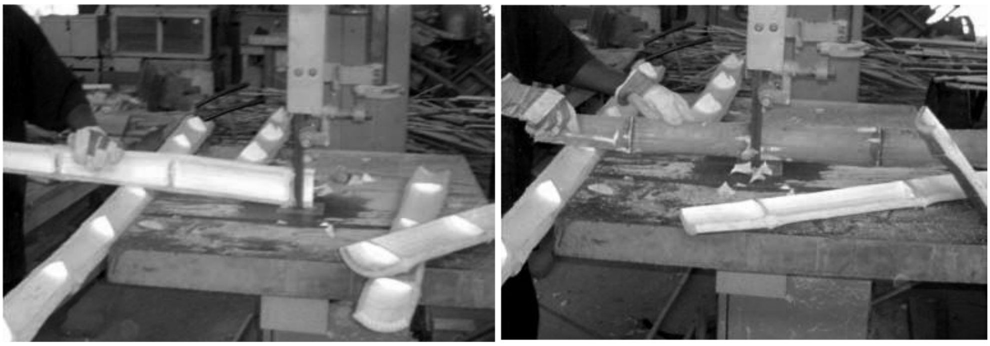

Figure 3: Removal of diaphragms and other knots from bamboo strips

These planed bamboo strips were sorted out based on their thicknesses, widths, lengths and butt or top of the culms in order to obtain uniform dimensions of laminates (strips) for the production of the laminated boards.

Figure 4: Bamboo strips being planed and labeled

Laminates from each group of uniform dimensions were manually applied with Woodchem adhesive (multi-purpose white adhesive) width-wise at both faces using blushes of width 25.4 mm. With the help of sash and "G" clamps as shown in Figure 5, each glued strips attaining a width of 152.5 mm (6 inches) were clamped manually together and was left for six hours for the glue to cure before the clamps were loosened. This process was repeated until all the strips for the different bamboo species were finished. For wider boards, two or more of the 152.5 mm lumber were clamped together with the same glue. Both insects and fungi preservatives were applied to treat the laminated boards to prevent infestation.

Figure 5: Bamboo strips being laminated-A and Laminated bamboo board-B

Having produced the laminated boards, some of the butt, and top portions were randomly selected and planing samples tests were prepared in accordance with ASTM

D 1666-87 and ASTM D 143-94. Two cutting angles (15 and 20 degrees) and three feed speeds (6, 9 and 14 m/min) were used for the planing tests.

One hundred and fifty (150) samples of dimensions 2.5 x 10 x 100 cm were used, hence twenty-five (25) samples per operation for six planing operations. For each operation, both sides of each specimen were planed and assessed, evaluated and graded, which was based on their smoothness of cut (degree of generation of machining defects). The assessment and evaluation of the planing quality were also in conformity with ASTM D 1666-87, with some adjustments, on the basis of three quality grades. These include Grade 1 = excellent or defect-free, grade 2 = defective but possible to be remedied with sanding and grade 3 = defective beyond remedy. In addition, performance rating was introduced to specify surface quality classification based on the percentage excellent samples (without any planing defect as fuzzy, chipped/torn, splits or chip marks) per species.

After grading of the planed samples, they were used for the sanding operations. To eliminate the defects (chipped/torn grains, fuzzy grain and raised grain) that were generated on the samples, two sand papers, P60 and P80 were used on a belt sander. The samples were then assessed, evaluated and graded after which P100, P120 and P150 were also applied to finish the surfaces of the samples. These three sand papers were tested to assess the one that would generate the best surface quality (with minimal scratching tendencies) with the help of a hand lens.

To enable potential users of bamboo to appreciate products that could be generated from bamboo, a four-panel door, which is made up of different machining profiles, was produced (Figure 6).

Figure 6: Laminated bamboo four-panel doors

They were then assembled as a unit using dowels and glue. The product was sprayed with a sanding sealer after which manual sanding with sand paper of grit size P250 was performed. To protect the surfaces of the panel door against scratches, insects and fungi attack, wood lacquer with some Dursban and Anti-blue 37-37) were applied using a spraying machine.

RESULTS AND DISCUSSION

Table 2 shows the surface qualities of eight different laminated bamboo species after planing with three feed speeds (6, 9, and 14 m/min) and two cutting angles (15° and 20°). At 6m/min with 15° cutting angle, the percentage quality was 100% for all the eight species. On the other hand, the percentage surface quality at the same cutting angle ranged between 92 – 100% and 72 – 88% for feed speeds 9m/min and 14m/min respectively. Similar trend was observed with 20° cutting angle. This indicates that feed speed affects surface quality in planing laminated bamboo boards. Again, from Table 2, *Bambusa vulgaris* from the wild, registered the lowest percentage surface planing quality with all the three feed speeds and two cutting angles. This could be attributed to the poor management of the species (sivilcultural practices), which might have affected the quality of the culms. Some sparks were also observed during the planing of *Bambusa vulgaris* from the wild, may be attributed to the presence of silica content and thick walled fibers.

The planing quality of *Guadua chacoensis* and *Bambusa vulgaris* var. *vittata* recorded the same percentage surface quality for all the operational conditions. The densities and internodal lengths of these species were comparatively lower than the others. The results showed some significant differences between the three feed speeds at $P \leqslant 0.05$ among the species. The differences in percentage surface qualities for all the bamboo species were higher for feed speeds between 6m/min and 14m/min than 6m/min and 9m/min as well as 9m/min and 14m/min for both cutting angles. For instance, *Bambusa bambos* at feed speeds 6m/min and 14m/min with 15° cutting angle, recorded percentage surface qualities of 100% and 80%, respectively (Table 2). The same species at 15°, also recorded 96% and 80% for 9m/min and 14m/min, respectively. The trend was the same with a cutting angle of 20°. These indicate that surface planing quality decreases with increasing feed speeds.

The surface quality for all the bamboo species did not show any significant differences between the two cutting angles (15° and 20°) for all the three feed speeds ($P \geqslant 0.05$). In some cases, some of the species recorded the same percentage surface quality (Table 2). For instance, *Dendrocalamus latiflorus* (100%), *B. bambos* (100%), *Guadua chacoensis* (100%) *and B. vulgaris* from wild (100%), were similar in surface quality at 6m/min with the two cutting angles. The record for 9m/min, as shown in Table 2, were *B. bambos* (96%), *B. vulgaris* (96%) and *B. vulgaris* from wild (92%). The following species at 14m/min also recorded the same percentage surface quality from the 15° and 20° cutting angles: *B. bambos* (80%), *Guadua angustifolia* (80%) *and Dendrocalamus brandisii* (84%). Consistently *B. bambos*, for the two cutting angles, scored the same grade per feed speed. These indicate that any of the cutting angles could be used to plan the laminated boards of the bamboo species stated.

From Table 3, the mean percentage surface qualities for the two cutting angles at feed speeds of 6m/min, 9m/min and 14m/min ranged from 98-100%, 92-98% and 70-86% respectively. The bamboo species with the least surface quality at 6m/min were *Guadua angustifolia / Dendrocalamus brandisii/ B. vulgaris* while *B. vulgaris* (from the wild) recorded the minimum surface quality for both 9 and 14m/min. These indicate that the percentage defect-free bamboo samples generated with the three feed speeds ranged from 70-100%. Therefore any wood planing machine with either of these three feed speeds and a cutting angle from 15° to 20° could perform better on the bamboo species studied.

The major defects observed were: chipped grain, raised grain, torn grain and fuzzy grain. These defects were of lower degree and were eliminated during sanding. Chip marks defect was not observed. Generally, the planing action on the laminated boards of all the bamboo species was classified as fairly easy, except *B. vulgaris* (from the wild), which was moderately easy to plane (Table 4).

Table 2: Surface planing qualities of bamboo laminated boards with three feed speeds and two cutting angle

Feed speed m/min	Bamboo species	15° cutting angle		20° cutting angle	
		% defect-free samples	Defective samples	% defect-free samples	Defective samples
	Dendrocalamus latiflorus	100	-	100	-
	Bambusa bambos	100	-	100	-
	Guadua angustifolia	100	-	96	4
	G. chacoensis	100	-	100	-
	D. brandisii	100	-	96	4
	Bambusa vulgaris var. *vittata*	100	-	100	-
	B. vulgaris	100	-	96	4
6	*B. vulgaris* (wild)	100	-	100	-
	D. latiflorus	100	-	96	4
	B. bambos	96	4	96	4
	G. angustifolia	96	4	92	8
	G. chacoensis	100	-	96	4
	D. brandisii	96	4	92	8
	Bambusa vulgaris var. *vittata*	100	-	96	4
	B. vulgaris	96	4	96	4
9	*B. vulgaris* (wild)	92	8	92	8
	D. latiflorus	84	16	80	20
	B. bambos	80	20	80	20
	G. angustifolia	80	20	80	20
	G. chacoensis	88	12	84	16
	D. brandisii	84	16	84	16
	Bambusa vulgaris var. *vittata*	88	12	84	16
	B. vulgaris	80	20	76	24
14	*B. vulgaris* (wild)	72	28	68	32

Table 3: Mean percentage surface quality of some laminated bamboo species with three feed speeds.

Feed speed m/min	Bamboo species	Mean % defect-free samples	Mean % defective samples
6	*Dendrocalamus latiflorus*	100	0
	Bambusa bambos	100	0
	Guadua angustifolia	98	2
	G. chacoensis	100	0
	D. brandisii	98	2
	B. vulgaris var. *vittata*	100	0
	B. vulgaris	98	2
	B. vulgaris (wild)	100	0
9	*D. latiflorus*	98	2
	B. bambos	96	4
	G. angustifolia	94	6
	G. chacoensis	98	2
	D. brandisii	94	6
	B. vulgaris var. *vittata*	98	2
	B. vulgaris	96	4
	B. vulgaris (wild)	92	8
14	*D. latiflorus*	82	18
	B. bambus	80	20
	G. .angustifolia	80	20
	G. chacoensis	86	14
	D. brandisii	84	16
	B. vulgaris var. *vittata*	86	14
	B. vulgaris	78	22
	B. vulgaris (wild)	70	30

Table 4: Classification of the ease of planing of laminated boards produced from eight bamboo species

Bamboo species	*Dendrocalamus latiflorus*	*Bambusa bambos*	*Guadua angustifolia*	*G. chacoensis*	*D. sbrandisii*	*B. vulgaris* var. *vittata*	*Bambusa vulgaris*	*Bambusa vulgaris* (wild)
Classification of ease of planning	Fairly Easy	Fairly Easy	Fairly Easy	Easy	Fairly Easy	Easy	Fairly Easy	Moderately Easy

Sanding

The sanding results, from Table 5, show that sandpaper of grit size P60 was able to remove the planing defects that were generated on the surfaces of the laminated boards for all the species, hence surface quality score of 100%. The percentage defect-free boards recorded for all the bamboo species with sand paper P80, ranged from 76% (*B. vulgaris* (from the wild)) to 92% (*Guadua chacoensis* and *B. vulgaris* var. *vittata*). This indicates that sand paper P80 could not remove all the defects on the surfaces of some of the laminated boards. These defects were mostly torn grain. Therefore, lower grit sizes of sand papers are more capable of eliminating planing defects, especially torn grain, from laminated bamboo boards.

The degree of surface scratches on the laminated boards of the different bamboo species, after sanding with three grit sizes of sand papers (P100, P120 and P150), is shown in Table 5. Sanding with P100 rendered most scratches on the surfaces of the test samples for all the species, hence graded as low surface quality. This means that P100 cannot be used to finish the surface preparation of any of the species for the application of finish materials. With sand paper of grit size P120, the test samples were graded as medium surface quality, which means that the degree of scratches on the various laminated boards was minimal as compared to that with P100. *B. vulgaris* (from the wild), recorded the lowest surface quality with P120 and medium quality with P150. Comparatively, scratching tendency was observed to be higher on the boards of this species than the others with these sand papers. Owusu *et al.,* (2012) have indicated that scratching tendency is comparatively higher on high-density species. Hence the density of *B. vulgaris* (from the wild) is expected to be higher than the rest of the bamboo species studied.

High graded surface quality was recorded for all the laminated bamboo species with P150, except *B. vulgaris* (from the wild) as indicated in Table 5. This indicated that P150 can effectively prepare the surfaces of the boards for finish materials. Sanding of the laminated bamboo of each of the species was classified as fairly easy while *B. vulgaris* (wild) was moderately easy to be sanded.

Table 5: Sanding effect on some bamboo laminated boards with different grit sizes of sand paper

Bamboo species	% defect-free specimens		Surface finish/quality		
	P60	P80	P100	P120	P150
Dendrocalamus latiflorus	100	88	L	M	H
Bambusa bambos	100	88	L	M	H
Guadua angustifolia	100	84	L	M	H
G. chacoensis	100	92	L	M	H
D. brandisii	100	88	L	M	H
B. vulgaris var. *vittata*	100	92	L	M	H
B. vulgaris	100	84	L	M	H
B. vulgaris (wild)	100	76	L	L	M

Low surface quality = L; Medium surface quality = M; High surface quality = H

CONCLUSION

Planning of the laminated bamboo boards was moderately easy and surfaces generated were smooth. Also cross-cut surfaces were moderately smooth. There was no significant difference between 15° and 20° cutting angles. High surface quality of laminated boards was generated with feed speeds of 6m/min and 9m/min. The percentage surface qualities of the laminated boards for all the bamboo species increased with decreasing feed speed. The major defects generated were chipped grain, fuzzy grain and raised grain. Sanding with sand paper P60 removed all machining defects from the boards of every bamboo species. Final preparation of the surfaces of the boards for the application of finish materials was best achieved when P150 sand paper was used. Generally, the planing and sanding bamboo laminated boards were classified as fairly easy and comparable to those of medium to high density wood species.

RECOMMENDATIONS

Treatment of bamboo at various stages of development is recommended and that both insecticidal and fungi preservatives should be used. Care must be taken in using adhesives that cure very fast when manual gluing is applied for production of laminated boards. In planing of bamboo laminated boards, 15 and 20 degree cutting angles could be used with 6m/min and or 9m/min. Sand paper P60 is recommended for use to remove any planing defect while P150 could be applied to prepare surfaces of bamboo laminated boards for the application of finish materials. It is recommended that all the bamboo species studied could be used to produce laminated boards.

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