J. Bamboo and Rattan, Vol. 13, Nos. 3&4, pp. 81-89 (2014)
Special Issue: Proc. First Bamboo Colloquium, Kumasi, Ghana, April, 2014

Investigating the mechanical properties of some bamboo species for efficient utilization in Ghana

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Abstract: The use of bamboo is advocated to reduce pressure on dwindling commercial timber species, around the world. To extensively utilize bamboo in various forms such as housing, their properties need to be known. But little information exist on these properties especially their mechanical properties. In this study, the mechanical properties viz. static bending strength (MOR), Modulus of Elasticity (MOE) and compressive strength, of laminated bamboo boards produced from three plantation managed bamboo species namely *Bambusa vulgaris, Dendrocalamus brandisii* and *Guadua chacoensis* were determined. The bamboo species were obtained from Kade which is located at the moist semi-deciduous ecological zone in Ghana. The bamboo culms were prepared and glued into boards after they were air dried to about 13% moisture content. The lamination was done with three different glue types available on the Ghanaian market. The test specimens were prepared as required by the British Standard BS 373:1957. Tests revealed that *Bambusa vulgaris* laminated with a 5-minute hardening polyurethane adhesive had a mean MOR of 62.58N/mm^2 and MOE of 9915 N/mm^2. *Dendrocalamus brandisii* laminated boards had mean MOR of 99.73N/mm^2 and MOE of 11594 N/mm^2. *Guadua chacoensis* with the same adhesive had a mean MOR of 80.25N/mm^2 and MOE 7861N/mm^2. The laminated boards from these three species exhibited properties that make it suitable to be used as boards for housing.

Key words: strength properties, bamboo species, utilization, modulus of rupture, modulus of elasticity

INTRODUCTION

Bamboo has a lot of features that differ from the other woody plants and grasses (Yulong, 2001). The strength of bamboo, its lightness, straightness, flexibility, extra-ordinary hardness, range in size, abundance and ease of propagation make it suitable for a variety of purposes and hundreds of different end- uses (Jayanetti, 2001). It is a viable alternative to the dwindling tropical timber resources that are used for furniture and building/construction. 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, 1985; Schaur, 1985; Hidalgo, 1996). The hollow tube shape gives a strength factor of almost two times more than a solid wood beam. Some species of bamboo have twice the compression strength of concrete and roughly the same strength-to-weight ratio of steel (Hidalgo, 1996; Adewuyi *et al*., 2015). Bamboo as a building material in comparison with

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concrete, steel and wood has four major advantages according to Janssen (1987). These include the 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 of material.

Ghana is endowed with vast areas of natural bamboo resources and has formed part of everyday lives of the rural people. Ghana is reported to have about 200,000 ha of bamboo land (UNIDO, 2001). Some of the common species available include *Bambusa vulgaris, B.vulgaris* var. *vittata, Dendrocalamus strictus, B. bambos* and *Oxytenanthera abyssinica.* These bamboo species occur mainly in the wild mostly the wet and moist evergreen; the dry and moist semi-deciduous forests of Ghana (Hall and Swaine, 1981). They are also found in river catchment areas and are mainly used for fences, scaffolding, ladders, musical instruments, baskets, construction of barns and huts, etc. The species has an enormous potential for alleviating both environmental and housing problems facing Ghanaians.

Lack of knowledge on the properties of bamboo species and the low level of processing has hindered its extensive use especially as building and construction material in Ghana. The government of Ghana was seeking to ensure that by the year 2015 at least sixty percent of materials used in the building and construction industry would be indigenous raw materials (MESTI, 2011). As part of the housing policy programme on the utilization of local building material, the technological properties of bamboo and some selected lesser utilised timber species for housing needed to be established. Over the years, few studies have been conducted on some bamboo species in Ghana. Ebanyele & Oteng-Amoako (2007) and Tekpetey *et al*. (2007) have worked on selected physical and morphological properties of bamboo species in Ghana. Essien *et al*. (2011) also worked on the susceptibility of bamboo to termite and fungi decay. Although bamboos have been used in various forms for a long time, knowledge on their physical and mechanical properties is scarce (Lwin *et al*., 2006). Information on these properties is of utmost importance especially its use as structural elements in construction and furniture where strength and stiffness are warranted. Over the years, several bamboo species have been introduced to diversify and expand its utility. These species including *Dendrocalamus membranaceus, B. heterostachya, D.barbatus, Guadua chacoensis* and *D. brandisii* are performing well in plantation trials.

The main objective of this study was to determine the mechanical properties of laminated bamboo species using adhesives available on the Ghanaian market. The study of these properties would enhance the promotion and utilization of bamboo as construction materials in Ghana.

MATERIALS AND METHOD

Feasibility studies

Desk study was undertaken to identify sites in six regions in Ghana where bamboo species are grown both in the natural and plantations, and the types of bamboo species.

This made it possible for some bamboo sites to be selected for the reconnaissance study. One of the bamboo plantations is located at Kade in the Kwaebibirem District, Eastern Region of Ghana. Its geographical coordinates are 6° 5' 0" North, 0° 50' 0" West. The plantation was set up by the Oil Palm Research Institute (OPRI) of the Council for Scientific and Industrial Research (CSIR), in the moist semi-deciduous ecological zone. An assessment was carried out at the plantation to identify the species; their availability and conditions of the stands/clumps and culms. Based on this, three species were selected for the study.

Extraction of selected bamboo species

The selected bamboo species include the following: *Dendrocalamus brandisii, Bambusa vulgaris* and *Guadua chacoensis*. For each species five bamboo culms from different clumps of the selected bamboo species were harvested at the age of 7 years. A mini-chainsaw and a cutlass were used in extracting the culms. Each culm was measured for its length. Depending upon the full length of the culms, it was cross-cut into two parts as bottom and top and were labeled. This was done for easy identification of the various culms and their parts during processing. Prophylactic treatment was done by brushing culm ends as well as other exposed surfaces with preservatives (Dursban) to prevent fungi and borers (insects) attack. The materials were then transported to woodworking laboratory at CSIR-FORIG for further processing into various sample sizes for testing.

Processing of Culms

A circular saw, Wadkin AGS 250/300 – Tilting Arbor Saw bench was used in ripping the bamboo culms. The bamboo culms were ripped into four to six pieces depending upon their diameters to facilitate drying of the samples. These were dipped into a mixture of chemical preservative (Dursban) and water in a container for treatment in batches for five to ten minutes, and stacked to permit air drying after the excess solution was allowed to drain off. When the moisture content of 18% and below were attained, all the stacked bamboo strips were further ripped into smaller strips to make them easier for planing and production of laminated boards.

Lamination of bamboo strips and preparation of samples

The lamination technique investigated by Sulastiningsih and Nurwati (2009) and Rittironk and Elnieiri (2007) was adapted for the lamination of bamboo. The bamboo culms were split into slender strips and all the surfaces of the strips were scraped and planed to remove wax and silica. The strips were finally planed to rectangular cross sections. The strips were air-dried to moisture content of about 13%. The adhesive was then applied to the strips and neatly placed on top of one another. Strips of 5 or 6 were then clamped together to form bigger planks of 25 mm x 30 mm cross sections. Lamination was done using three different types of adhesives: Polyvinyl acetate emulsion white wood glue (PVA), Formaldehyde based adhesive resin, WoodChem (FWC) and 5-minute curing Polyurethane wood adhesive (5PU). Samples for the mechanical tests were then prepared based on dimensions prescribed by the BS 373:1957. The tests were carried out using an 'Instron' Universal Testing Machine.

RESULTS AND DISCUSSION

Tables 1 and 2 show the mean values of the machanical properties tested. *Dendrocalamus brandisii* (DB) had the highest mean MOR of 99.73 N/mm^2 with the application of the polyurethane glue and *Bambusa vulgaris* (BV) had the least mean MOR with the application of the same glue. *Bambusa vulgaris* recorded a good mean MOR of 94.3 N/mm^2 with the application of the polyvinyl acetate white glue and 91.54 N/mm^2 with the use of the formaldehyde adhesive. *Guadua chacoensis* seemed to have consistent results with all the 3 different adhesives. For PVA and FWC, which are available and popular in the Ghanaian market, *Bambusa vulgaris* recorded the best results in terms of the MOR (Figure 1).

Dendrocalamus brandisii had the highest mean MOE of 11797 N/mm^2 with the application of the formaldehyde adhesive whilst *Guadua chacoensis* had the least MOE of 7861 N/mm^2 with the application of the PVA (Figure 2). The mean MOE results of *Bambusa vulgaris* were consistent for all the three different adhesives [9794 – 9923 N/mm^2]. With the application of the PVA and FWC adhesives, which are readily available in the Ghanaian market, *Dendrocalamus brandisii* recorded the best mean MOE results.

Literature reveals that species features have effect on the properties of bamboo (Liese,1998). Among the species sampled in this research, *D. brandisii* , a sympodial bamboo and exotic to Ghana, is reported to produces one of the strongest and largest of bamboo used for construction. The highest value of strength properties for *D.brandisii*

Table 1: Mean Modulus of rupture (MOR) and Modulus of elasticity (MOE) values for the species with 3 different glue types

Species	PVA		FWC		5PU	
	MOR N/mm^2	MOE N/mm^2	MOR N/mm^2	MOE N/mm^2	MOR N/mm^2	MOE N/mm^2
Bambusa vulgaris	94,3 (17,22)	9794 (2967)	91,54 (20,08)	9923 (1098)	62,58 (11,95)	9915 (1647)
Dendrocalamus brandisii	84,52 (13,17)	9778 (1162)	90,19 (13,04)	11797 (1669)	99,73 (20,62)	11594 (1433)
Guadua chacoensis	78,2 (17,09)	6629 (747)	81,26 (12,93)	7787 (1137)	80,25 (18,12)	7861 (872)

Note: figures in parenthesis are standard deviations from the sample mean

Table 2: Mean Compressive strength Results for the three species with 3 different glue types

Species	PVA N/mm^2	FWC N/mm^2	5PU N/mm^2
Bambusa vulgaris	50,71 (6,55)	52,41 (6,57)	47,71 (5,66)
Dendrocalamus brandisii	47,79 (4,07)	49,6 (4,98)	52,51 (5,24)
Guadua chacoensis	37,89 (3,82)	37,21 (3,22)	37,78 (4,84)

PVA = Polyvinyl acetate emulsion white wood glue, FWC = Formaldehyde based adhesive resin, WoodChem, 5PU = 5 minute curing Polyurethane wood adhesive

may be related to superior anatomical features of vascular bundle types and vessels size which is related to vascular bundle sizes and thicker cell wall. It is also an edible bamboo species from southwest China and south Asia (Wang *et al*., 2016). The physical and mechanical properties of bamboo species are correlated to the anatomical characteristics. Abd Latif *et al*. (1993) indicated that vascular bundles size is proportional to modulus of elasticity (MOE) but negatively with modulus of rupture (MOR). Earlier research on the anatomical properties of bamboo genera like *Bambusa*, *Dendrocalamus, Gigantochloa* are classified as having vascular bundle types III and IV (Abd Latif *et al*., 1993). Formaldehydes based adhesives (FWC) are more effective than water based adhesives like PVA. The results of the studies indicated that the strength properties of the bamboo species were higher in most cases with the FWC than the others.

Bambusa vulgaris had the highest compressive strength with the application of the FWC (52.41 N/mm^2) and PVA (50.71 N/mm^2). However, *Dendrocalamus brandisii* had the highest compressive strength with the application of the 5PU glue out of the three species. The effect of the three different adhesives type on the MOE, MOR, Compressive strength could not fully be ascertained but in terms of MOE and MOR, FWC glue performed better for all the bamboo species then followed by 5PU. For compressive strength , FWC gave better results for all the three bamboo species.

The results obtained compares favourably with most tropical hardwood species such as *Khaya ivorensis* with an MOR of 73.9N/mm^2 and MOE of 9113 N/mm^2 (Addae-Mensah, 1978; Appiah-Kubi, 2015), *Sterculia rhinopetala* with an MOR of 81.7 N/mm^2 and an MOE of 13382 N/mm^2 (Appiah-Kubi *et al*., 2012; Brunner *et al*., 2008), *Combretodendron africanum* with an MOR of 103.7 N/mm^2 and an MOE of 9739 N/mm^2 (Ofori *et al*., 2009). The above wood species are used for various forms of construction. With similar properties, the bamboo species can be used for similar construction works especially when laminated with the FWC adhesive.

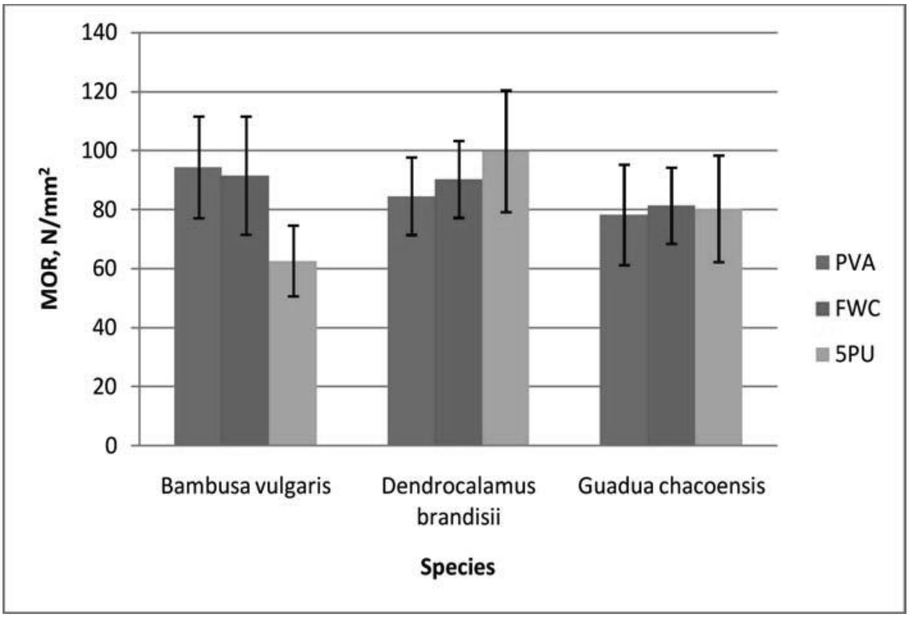

Figure 1: Chart showing the Modulus of Rupture (MOR) of the species for each glue type

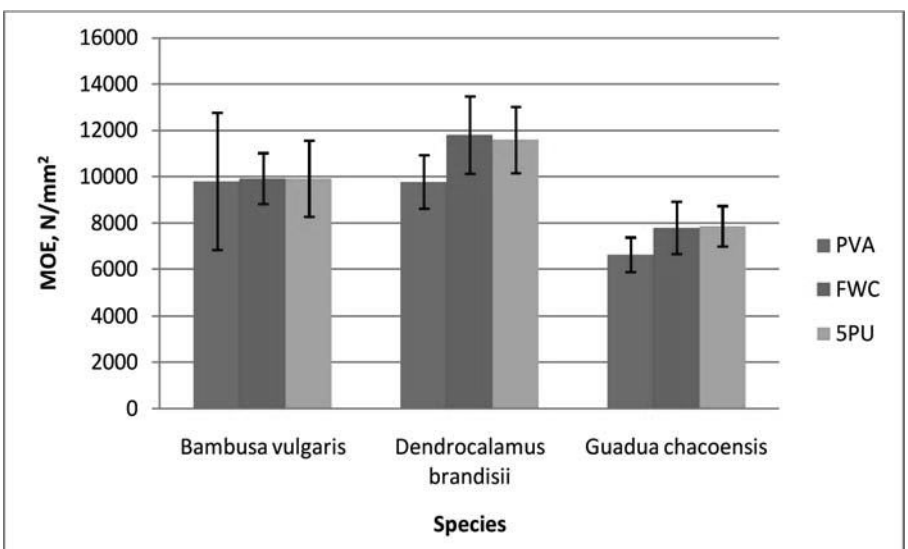

Figure 2: Modulus of Elasticity (MOE) of the species for each glue type

CONCLUSION

Bambusa vulgaris and *Dendrocalamus brandisii* recorded good strength properties with the application of the PVA and FWC adhesives. Results were relatively lower for *Bambusa vulgaris* with the application of the 5PU adhesive whilst *Dendrocalamus brandisii* recorded the best results with the application of the 5PU for both MOR and compressive strength. *Dendrocalamus brandisii* also had the highest MOE with the application of the FWC adhesive. *Guadua chacoensis* consistently had the lowest strength values out of the three species. *Bambusa vulgaris* laminates attains the highest MOR when PVA adhesive is used in the lamination and attains the highest compressive strength when FWC is used in the lamination. *Dendrocalamus brandisii* attains both the highest MOR and compressive strength when the 5PU adhesive is used in the lamination. It is evident from the results that both *Bambusa vulgaris* and *Dendrocalamus brandisii* can be laminated into boards and beams using the readily available adhesives, FWC and PVA, for constructional purposes. With the dwindling wood resources, the use of laminated bamboo boards and beams should be promoted.

REFERENCES

Abd Latif, M., Amin, A.H., Kasim, J. and Jusuh, M.Z. 1993. Effects of anatomical characteristics on the physical and mechanical properties of *Bambusa blumeana*. Journal of Tropical For. Scie 6(2) 159-170.

Addae-Mensah, A. 1978. Über den Einsatz von tropischen Hölzern im Ingenieurholzbau der Ursprungs-länder am Beispiel von Abachi (*Triplochiton scleroxylon*) und Khaya (*Khaya ivorensis*). Dissertation, Munchen.

Adewuyi, A., Otukoya, A., Olaniyi, O. and Olafusi, O. 2015. Comparative Studies of Steel, Bamboo and Rattan as Reinforcing Bars in Concrete: Tensile and Flexural Characteristics. *Open Journal of Civil Engineering*, 5, 228-238. doi:10.4236/ojce.2015.52023.

Appiah-Kubi, E. 2015. Investigating the engineering properties of plantation grown *Khaya ivorensis* and its suitability as a construction material. PhD Thesis. Kwame Nkrumah University of Science and Technology, Kumasi. November 2015.

Appiah-Kubi, E., Kankam, C.K. and Adom-Asamoah, M**.** 2012. Bending and Modulus of Elasticity properties of ten lesser used Ghanaian timber species using structural size dimensions. Ghana Journal of Forestry, Vol. 28 (1), 2012. pp. 15-28.

B.S. 373. 1957. Method of testing small clear specimens of timber. British Standards Institution, London.

Brunner, M., Appiah-Kubi, E., Zurcher N., Reinhard M., and Kankam, C. K. 2008. WAWABIMA: Outstanding mechanical properties of some lesser known timber species in Ghana. World Conference on Timber Engineering, WCTE, Japan, June 2008.

Dunkelnerg, K. 1985. Bamboo as a building material. Bambus – Bamboo IL 31. Stuttgart: In Institute for lightweight structures, University of Stuttgart. No. 38

Ebanyenle, E. and Oteng-Amoako, A.A. 2007. Site differences in morphological and physical properties of Bambusa vulgaris grown in Ghana. *Discovery and Innovation*, volume 19 (Afornet Special Edition No.3) ISSN 1015- 0798. 222-225

Essien, C., Oteng-Amoako, A.A., and Tekpetey, S.L. 2011. Morphological Assessment and Susceptibility of Bamboo o Bio-degrading agents in Ghana. *Journal of Bamboo and Rattan* 10 (3&4): 103-110.

Hall, J.B. and Swaine, M.D. 1981. Geobotany - Distribution and Ecology of Vascular Plants in a Tropical Rainforest. Forest Vegetation in Ghana. Dr. W. Junk Publishers. The Hague pp. 382

Hidalgo, O. 1996. Study of mechanical properties of bamboo and its uses as concrete reinforcement: Problems and solutions. Proceedings of the 4th International Bamboo congress held in Bali, Indonesia, June 1995, vol 3: 76 - 91. New Delhi: The International Network for Bamboo and Rattan (INBAR).

Hsiung, W. 1991. Prospects of bamboo development in the world. Bamboo society of America, No 1-2: 168 – 178. Republished in Bamboo Research, 1993, (Sum no. 47. No. 1. Nanjing: Nanjing Forestry University.

Janssen, J.J.A. 1987. The mechanical properties of bamboo. *In* Rao, A.N., Dhanarajan, G. and Sastry, C.B. (Eds) Recent Research on Bamboos: Proceedings of the international bamboo workshop organized jointly by MOF - China, IDRC – Canada and IUFRO and held in Hangzhou, China on October 6 – 14, 1985. 250-256

Jayanetti, L. 2001. Bamboo housing: TRADA's work in India. *In* Proceedings of the 3rd International seminar on Bamboo cultivation, processing and utilization. Held in Yibin city, Sichuan, China from 20th – 22nd October 2001 and sponsored by International Network for Bamboo and Rattan (INBAR), Provincial Forestry Administration of Sichjuan and Yiobin Municipal Peoples' Government. 125-137

Liese, W. 1998. Anatomy of bamboo culms. INBAR Technical Reports (book 18) International Network for Bamboo and Rattan, Beijing China.

Lwin, K.M., Sint, K.M., Than, S.M. and Myint, C.C. 2006. Investigation on chemical, physical and mechanical propeorties of some Myanmar bamboo species. Proceeding of the annual Research Conference, May 2006, Yangon, Myanmar.

Ministry of Environment, Science, Technology and Innovation. 2011. Action plan for implementing the policy on the utilization of local building materials in the construction industry in Ghana. Ministry of Environment, Science and Technology. 1-8

Ofori, J., Mohammed, A. I., Brentuo, B., Mensah, M. and Boamah-Tawiah, R. 2009. Properties of 10 Ghanaian high density lesser-used species of importance to bridge construction – Part 2: Mechanical strength properties. *Ghana Journal of Forestry*, 25: 77-91.

Schaur, E. 1985. Bamboo a material of the future. Bambus – Bamboo IL31, Stuttgart: Institute for lightweight structures, University of Stuttgart No. 418.

Tekpetey, S.L., Frimpong-Mensah, K. and Darkwa, N. A. 2007. Thermogravimetric behaviour and physical properties of *Bambusa vulgaris* in Ghana. *Journal of Bamboo and Rattan.* vol. 6 (3 &4). 199-203.

Sulastiningsih, I. M. and Nurwati 2009. Physical and mechanical properties of laminated bamboo board. *Jour. Trop. For. Sci*., 21 (3), 246 -251.

Rittironk, S. and Elnieiri, M. 2007. Investigating laminated bamboo lumber as an alternate to wood lumber I residential construction in the United States. Proceedings of 1st International Conference on Modern Bamboo Structures. Taylor & Francis, Abingdon, U.K., 83-96.

United Nations Industrial Development Organization 2001. The European Flooring market and Prospects for bamboo and industrial products from Ghana.

Wang, Y., Zhan, H., Ding, Y., Wang, S. and Lin, S. 2016. Variability of anatomical and chemical properties with Age and Height in *Dendrocalamus brandisii*. Bioresources 11(1) 1202-1213.

Wang, S.G., Pu, X.L., Ding, Y.L., Wan, X.C. and Lin, S.Y. 2011. Anatomical and chemical properties of *Fargessia yunnensis*. Journal of Tropical Forest Science 23(1) 73-8.

Yulong, D. 2001. Bamboo Anatomy: Today and Tomorrow. A paper presented at the 3rd International seminar on Bamboo cultivation, processing and utilization. Held in Yibin city, Sichuan, China from 20th – 22nd October 2001 and sponsored by International Network for Bamboo and Rattan (INBAR), Provincial Forestry Administration of Sichjuan and Yiobin Municipal Peoples' Government. Proceedings compiled on December, 2001, 30-33