FLEXURAL STRENGTH OF LAMINATED BAMBOO BEAMS

James Kariuki[1], Richard A. Shuaibu[1]*, Timothy Nyomboi[2] and Siphila Mumenya[3]
[1]Department of Civil Engineering, Pan African University, Institute for Basic Science, Technology and Innovation (PAUISTI), JKUAT, Kenya
[2]Department of Civil and Structural Engineering, Moi University, Kenya
[3]Department of Civil and Construction Engineering, University of Nairobi, Kenya

ABSTRACT
The need to discover new and sustainable building materials has necessitated research in different parts of the world. This study presents a comparative performance of bamboo laminated beams with cypress beams of the same dimensions. Six laminated bamboo beams and three cypress beams were tested in this study. The dimensions of each specimen was 45mm x 95mm x 600mm and tested under two point loading. Experimental results revealed that bamboo laminated beams resisted higher load than cypress beams and had a higher flexural strength of 39kN/mm2 against that of cypress beam of 34kN/mm2. Also, while cypress beams failed in flexure with major cracks, bamboo laminated beams however failed in tension on the lower part of the beams and shear along the grains. In addition, it was observed that bamboo laminated beams took longer duration than cypress beam to fail completely. The study hereby concluded that bamboo laminated beams showed better load carrying capacity than cypress beams.

KEYWORDS: *Bamboo, Cypress, Lamination, Beams, adhesive, failure pattern*

I. INTRODUCTION

In recent times, it has become more and more essential to discover opportunities for new and sustainable building materials due to drop in level of resource availability [1]. Some factors however influence the choice of building materials. These factors include price, appropriateness and design knowledge of those materials. Issues such as renewability of resources, energy efficiency and eco-friendliness are also becoming progressively vital. Studies have shown that bamboo in comparison to timber, which takes years, have the benefit of been harvested in 3-4 years from the time of plantation [2,3]. The anatomy of bamboo internode cross-section also revealed that the strength properties of bamboo increase from inner to outer layer of the culm [4]. Bamboo has been used in various forms to determine its suitability as a construction material. For instance, the potential of bamboo as reinforcement in concrete was investigated by [5] and found that if bamboo reinforced concrete beam is reinforced with steel stirrups, it improves its load carrying capacity. On the other hand, different studies have characterised bamboo composites based on bamboo fibres in polymeric matrix [6] [7] [8] [9]. Recently, [10] arranged bamboo stripes in different orientations and investigated the effects of orientation on strength of laminated bamboo beams. Their observations showed that, for face loaded beams, the elasticity had a decreasing influence on longitudinal tensile strength. However, the flexural strength of the beams were found to improve while loaded on the face and edges. Another study conducted by [11] established that laminated bamboo possess greater allowable and average strength values in flexure and tension and comparable stiffness values, with much less variability to a commonly used structural species of wood, Douglas fir. They also affirmed that, it is possible to use laminated bamboo in framing applications. This material can be utilized as structural members such as structural beams, roof structures and curtain walls as shown in Figure 1.

Figure 1: Application of laminated bamboo materials

Different researchers have also investigated the properties of laminated bamboo [12] [13]. The results of [14] showed that the dimensional stability of Moso bamboo is dependent on layer, referring to the location within the wall of the culm between the inner and outer radii. Despite the fact that various researches investigated the suitability of using bamboo as a replacement for wood in structural applications, the cylindrical form of bamboo is still a major challenge. Lamination is therefore a process in which materials are glued in various forms to produce a member. A study was conducted by [15] on layered laminate bamboo composite and their mechanical properties. Their results showed that the mechanical properties evaluated of LLBCs are resembling with the properties of teak wood. This study compares the structural performance of bamboo laminated beams with cypress beams of the same sizes. This paper starts with introduction, which shows the background knowledge of laminated bamboo and relevant reviewed literatures. Followed by various experimental procedures used and then results and discussion. Finally, conclusion, recommendation for further research followed by list of references.

II. EXPERIMENTAL PROCEDURES

2.1. Materials and preparation

2.1.1 Bamboo

The key material used in this study was bamboo; *Yushania alpina* species. This material was sourced from Kamae, Kenya. Erect and straight culms diameter larger than 80mm and wall thickness greater than or equal to 10mm in the lower section of the culm were selected and utilised in the study.

2.1.2 Adhesives

High strength Polyvinyl Acetate Adhesive was used for the lamination of bamboo strips. The adhesive was bought directly from the market and applied. This adhesive is mostly used for structural and furniture works in Kenya furniture industry.

2.1.3 Cutting and splitting

The culms were cut using the cross cutting machine to sizes of 2m to get shorter and workable pieces to suite the dimensional requirements of the pressing machine. Splitting machine was also used to concert round hollow bamboo poles into flat strips of 22mm.

2.1.4 Bamboo strip shaping

Bamboo strips were flattened and pre-shaped before being boiled and dried; shaping was done using the 2-side removal machine. This involved removal of the shiny and silky outer skin and the inner knot of the strips. However, care was taken not to remove the culm epidermis as it is the strongest part of the bamboo culm.

2.1.5 Preservation and drying

The strips were boiled in a tank for 3 hours to decolourise them and guard them against pests in a single process using the chemicals mentioned in Table 1.

Table 1: Chemicals for preservation and treatment

Chemical Composition for preservation and Bleaching of Bamboo Strips		
Chemical Agent	**% in Solution**	**Quantity per 1000 L of Water**
Hydrogen peroxide (80%)	0.5	5 L
Borax oxide	0.8	8 Kg
Boric acid	0.2	2 Kg

Bleaching was achieved by boiling the strips for three hours in a solution containing hydrogen peroxide. Hydrogen peroxide is a strong oxidizer in both acid and alkaline media, and also functions as a reducing agent that extracts starch, protein and other nutrients. The preservative agent was the mixture of boric acid and borax oxide which resulted in the formation of disodium octaborate. Boron salts were dissolved in water and are effective against borers, termites and fungi. After treatment, the water evaporated, leaving the salts inside the bamboo. The bleached and treated bamboo strips were dried in air for 3 months, and the moisture content was monitored until 12% was achieved.

2.1.6 4-Side planning

Strip size and moisture content are very important factors to achieve stable laminated beams. The moisture content of the bamboo strips was re-checked to confirm that it was below 12%. A 4-side moulding machine was used to shape the strips into fixed width and thickness to ensure that they bonded into a solid beam after lamination.

2.1.7 Assembling and pressing

The laminated bamboo beams were cold pressed at 200 tons top pressure and 100 tons side pressure and left overnight to bond at a room temperature of 22°C.

2.2. Beam specimen details and setup

A total of six laminated beams of dimensions 45mm x 95mm x 600mm were tested. These beams were compared with three beams made with cypress timber. Strain gauges were attached at the bottom centre of the beams to measure the induced flexural strains at the extreme fibres of the beam. Figure 2 and 3 show experimental set up and laboratory testing of the beam specimens.

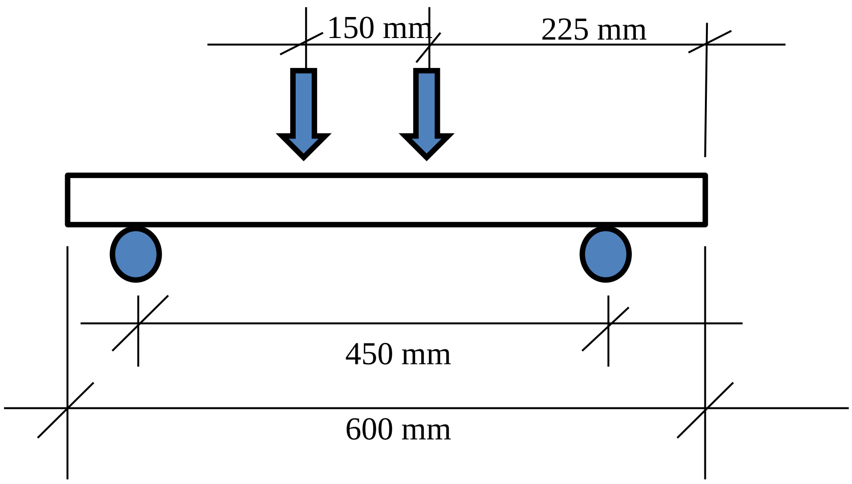

Figure 2: Beam setup

Figure 3: Experimental testing

III. RESULTS AND DISCUSSION

3.1 Load-deflection characteristics

Load-deflection characteristics of laminated bamboo and cypress beams are shown in Figure 4. From Figure 4, it can be seen that bamboo laminated beam deflected more than cypress beam under applied load. Laminated bamboo beams also exhibited almost a linear load-deflection characteristics up to a load application of 35 kN and a deflection of about 7mm after which the load increased with constant deflection until total failure.

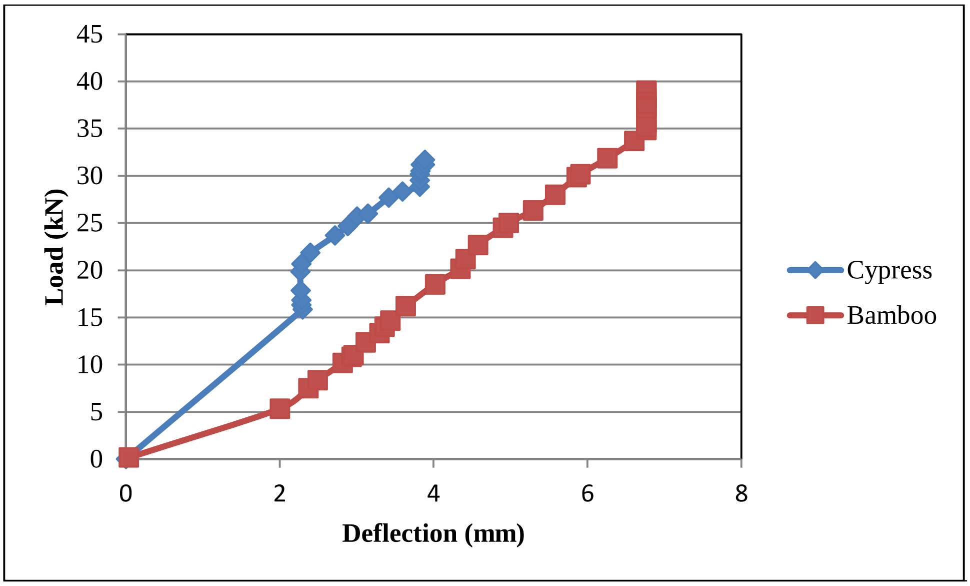

Figure 4: Load-deflection characteristics of beams

On the other hand, after 15kN, cypress laminated beams maintained a constant deflection up to 20kN and then exhibited deflection increase as the load increased. It is therefore concluded that bamboo laminated beams showed greater resistance than cypress beams.

3.2 Flexural strength

Flexural strength of laminated bamboo beams was observed to be 39kN/mm^2 and that of cypress beams was found to be 34kN/mm^2. This value was a mean of all the tested specimens. This shows that laminated bamboo beam is more rigid than cypress beam. This strength was carried out in accordance to EN 408 2003.

3.3 Load-time relationship

The study also investigated the behaviour over time of laminated bamboo beams in comparison to cypress beams under applied load. From Figure 5, it can be observed that bamboo laminated beam showed higher load resistance with time. Cypress beam snapped after about 200 seconds of loading while bamboo laminated beam resisted loading until over 800 seconds. The loading was applied at the same rate.

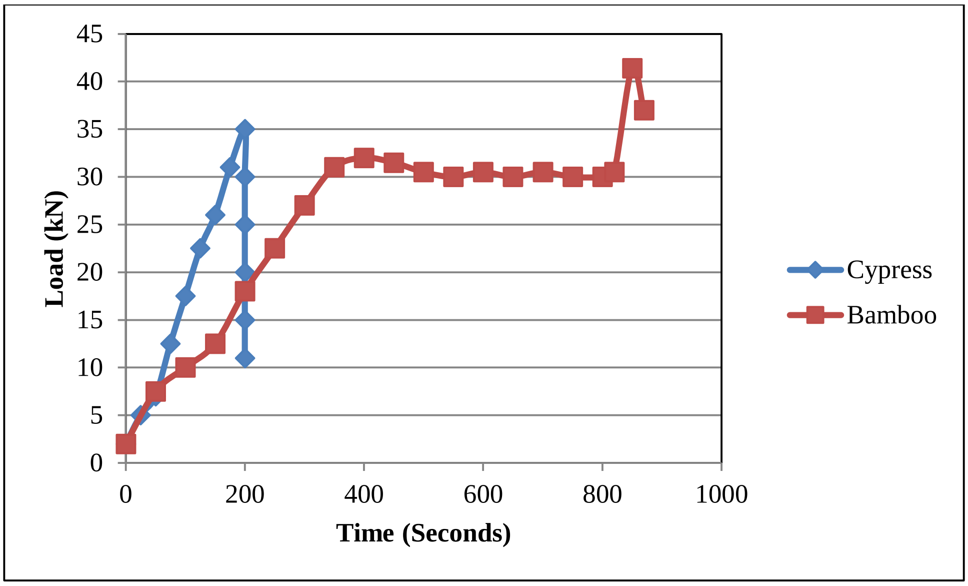

Figure 5 Load-time curve

3.4 Load-strain relationship

Figure 6 shows the relationship between applied load and flexural strains induced at the extreme bottom fiber of the beams. Comparative behavior of bamboo laminated bamboo beams and cypress beams showed that cypress beam induced more strain at the extreme bottom fiber of the beams than bamboo laminated beam. This was actually expected due to difference in resistance of the two beams. However, the maximum strains induced in both beams at 25kN for cypress beam and 40kN for bamboo laminated beam was about 0.0038%, which finally confirms the superiority of bamboo laminated beams in terms of rigidity.

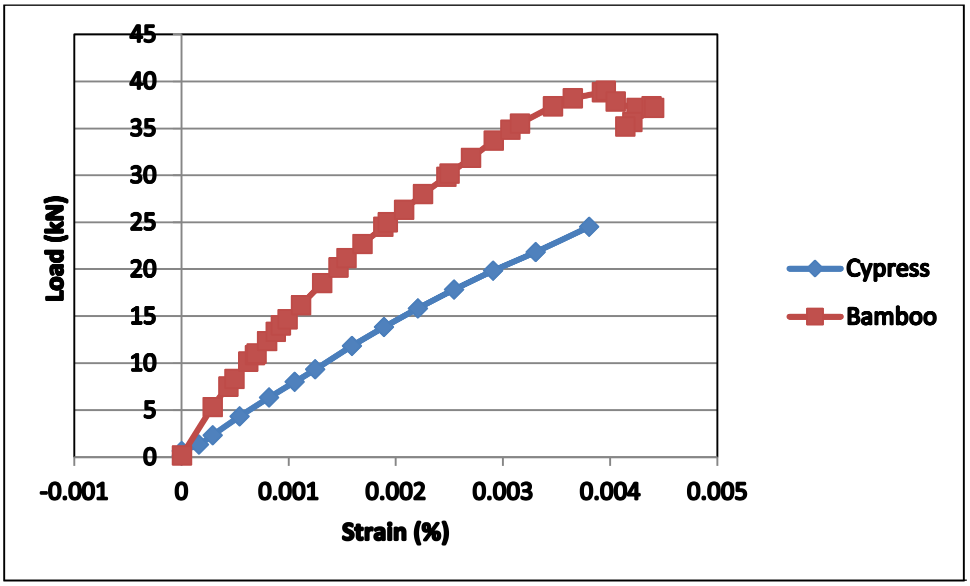

Figure 6 Load-strain curve

3.5 Failure pattern

Figure 7 shows sample failure patterns of laminated bamboo and cypress beams. Cypress beams failed by cracking across the grains and was less elastic compared with bamboo laminated beams. The failure mode in cypress was flexural with major cracks. It also failed abruptly by snapping. Failure mode for laminated bamboo beams on the other hand was by tension on the lower part of the beams and shear along the grains. Shear occurred by separation of fibres from the inner faces of bamboo culms that were strongly bonded on the outer faces of the culms. Due to low concentration of fibres in the inner side of the culms and more lignin, the fibres tend to peel off under load. However, this created two separate beams, parallel to each other and the beams were able to take more load after cracking of bottom strips under tension, and as well contributed to the elastic behaviour as the beam returned back to its original state after the load was removed. Both laminated bamboo beams and cypress beams buckled at the upper compression layer forcing the neutral axis to move downwards, so that ultimately the lower part of the specimens failed in tension. Figure 8 shows the edge failure of laminated bamboo beam.

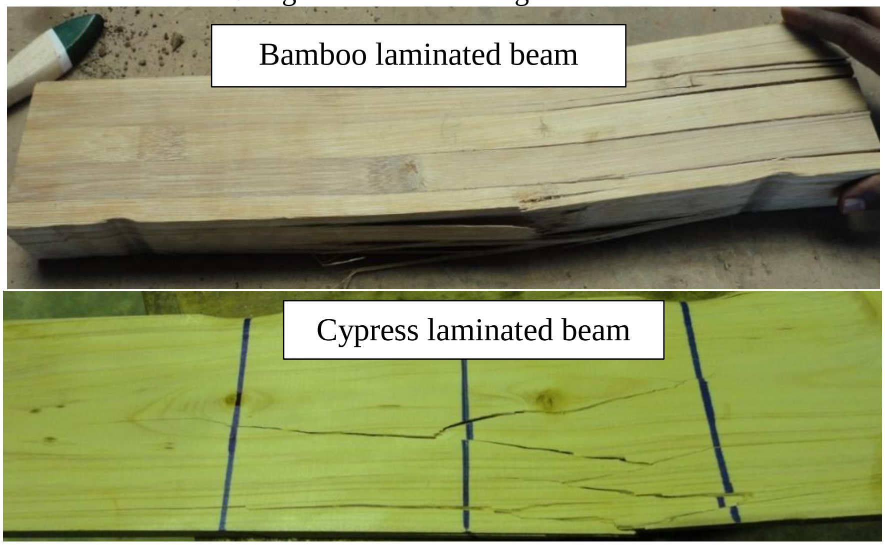

Figure 7 Failure patterns of laminated bamboo and cypress beams

Figure 8 Failure pattern at the edge of bamboo laminated beam

IV. CONCLUSIONS

From experimental tests carried out on laminated bamboo beams and cypress beams, it can be concluded that;

a. Laminated bamboo beams exhibited better load carrying capacity than cypress beams.
b. Laminated bamboo beams under similar load rate application took more time to fail completely than cypress beams.
c. The failure mode of laminated bamboo beams was primarily by tension at the lower part of the beams and shear along the grains while those of cypress beams were flexural with major cracks. This shows that the failure patterns of the beams were different.

Therefore, it can be concluded that laminated bamboo beams appear to be more elastic than cypress beams, hence a superior building materials.

V. RECOMMENDATIONS FOR FUTURE WORK

Further research is therefore recommended to investigate durability of bamboo laminated beams when exposed to moisture and chemical attacks. It is also recommended that possible application of bamboo laminated beams to produce trusses be investigated.

ACKNOWLEDGMENTS

The first and second authors will like to appreciate Pan African University for their scholarship and funding of this research work.

REFERENCES

[1] D. H. Meadows, D. L. Meadows and J. Randers, "Beyond the limits: confronting global collapse, envisioning and sustainable future," Chelsea Green Purblishing, White River Junction, VT, 1992.

[2] S. Lakkad and J. Patel, "Mechanical properties of bamboo, a natural composite," Fiber Sci Technol 1980, vol. 14, pp. 319-322, 1980.

[3] S. Amada, Y. Ichikawa, T. Munekata, Y. Nagase and K. Shimizu, "Fiber texture and mechanical graded structure of bamboo," Composites Part B , vol. 28, p. 13–20., 1997.

[4] Z. P. Shao, L. Zhou, Y. M. Liu, Z. M. Wu and C. Arnaud, "Differences in structure and strength between internode and node sections of moso bamboo," *Journal of Tropical Forest Science,* vol. 22, no. 2, pp. 133-138, 2010.

[5] M. Adom-Asamoah and O. R. Afrifa, "A comparative study of bamboo reinforced concrete beams using different stirrup materials for rural construction," *International Journal of Civil and Structural Engineering* , vol. 2, no. 1, pp. 407-423, 2011.

[6] A. Rajulu, S. Baksh, G. Reddy and K. Chary, "Chemical resistance and tensile properties of short bamboo fiber reinforced epoxy composites," *J Reinf Plast Compos 1998;17:1507–11,* vol. 17, pp. 1507-1511, 1998.

[7] X. Chen, Q. Geo and Y. Mi, "Bamboo fiber-reinforced polypropylene composites: a study of mechanical properties," *J Appl Polym Sci* , vol. 69, no. 10, pp. 1891-1899, 1999.

[8] U. Jindal, "Development and testing of bamboo–fibers reinforced plastic composites," *J. Compos Mater,* vol. 20, pp. 19-29, 1986.

[9] M. Thwe and K. Liao, "Durability of bamboo–glass fiber reinforced polymer matrix hybrid composites," *Compos Sci Technol* , vol. 63, pp. 375-387, 2003.

[10] J. Kariuki, T. Nyomboi and S. Mumenya, "Effect of orientation and arrangement of bamboo strips on structural strength of laminated bamboo beam," *International Journal of Engineering Sciences & Emerging Technologies*, vol. 7, no. 2, pp. 555-567, 2014

[11] A. Sinha, D. Way and S. Mlasco, "Structural Performance of Glued Laminated Bamboo Beams," *Journal of sStructural Engineering* , vol. 140, no. 1, pp. 1073-1087, 2014.

[12] M. Mahdavi, P. L. Clouston and S. R. Arwade, "Development of laminated bamboo lumber: review of processing, performance, and economical considerations," *Journal of Materials in Civil Engineering,* vol. 23, no. 7, pp. 1036-1042, 2011.

[13] F. Shin, X. Xian and M. Yipp, "Analysis of the mechanical properties and microstructure structure of bamboo–epoxy composites," *J Mater Sci* , vol. 24, pp. 3489-3490, 1989.

[14] H. Q. Yu, Z. H. Jiang, C. Y. Hse and T. F. Shupe, "Selected physical and mechanical properties of bamboo (Phyllostachys pubescens)," *Journal of Tropical Forest Sciences,* vol. 20, no. 4, pp. 258-263, 2008.

[15] C. Verma and V. Chariar, "Development of layered laminate bamboo composite and their mechanical properties," *Composite part B,* vol. 43, pp. 1063-1069, 2012.

AUTHORS

James Kariuki, currently student in Master in Civil Engineering, (Structural Option) at Pan African University, Institute for Basic Science, Technology and Innovation (PAUISTI), JKUAT, Kenya.

Richard A. Shuaibu is a Facilities Manager at Federal Inland Revenue Service, Nigeria. He is currently pursuing his master degree in civil engineering (structural option) at the Pan African University Institute for Basic Sciences, Technology and Innovation, hosted by Jomo Kenyatta University of Agriculture and Technology, Kenya. He has four paper publications in referred journals. His areas of interest are but not limited to structural engineering and design, sustainable building materials, concrete technology, finite element modelling and geopolymer concrete.

Timothy Nyomboi is a part time senior lecture at Pan African University Institute for Basic Sciences Technology and Innovations (PAU), Senior Lecturer Moi University (on leave of absence), Design and Construction Manager Kenya Urban Roads. Has 10 publications in refereed journals and Conferences. His areas of interest are in Construction, Sustainable construction material, Structural Engineering, and Design

Siphila Mumenya is a part time Thesis Supervisor at Pan African University Institute for Basic Sciences Technology and Innovations (PAUISTI), Senior Lecturer University of Nairobi. She has several publications in refereed Journals and Conferences. Her areas of interest are in Concrete, Sustainable Construction material, Structural Engineering, and Design.