COMPARATIVE STUDY ON THE MECHANICAL STRENGTH PROPERTIES OF LAMINATED BAMBOO (*Bambusa vulgaris*) WITH OTHER WOOD LAMINATES.

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ABSTRACT
Bambusa vulgaris (Bamboo) is a material gaining recognition globally due to the production of glued laminated panels. Its diverse use in construction and beautification cannot be overemphasized. It can also be a substitute to other wood species due to its tensile strength. This study examined the mechanical properties of laminated bamboo using glue as adhesive treatment. It was done by calculating the Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) using fifty replicates of laminated bamboo. The bamboo was harvested and cut into strips thereafter, glued with a measurement of 50 x 50 x 6 mm of length, width and thickness respectively. The bamboo laminates were adhesively glued in fours and tested in the Wood Testing Laboratory. The results showed some tested laminates with their respective load (KN) and deflection (MM) which was used to calculate MOE and MOR of laminated bamboo. The mean MOR and MOE of the laminated bamboo was 46.45N/mm² and 259.53N/mm respectively. When compared with other laminates, laminated bamboo has a higher MOR than Wood Plastic Composites (WPC) and Laminated Wood Composite (LWC); and low MOE than WPC and LWC. This was concluded that bamboo laminates can withstand stress, however it can be difficult to bend when being stretched.
Keywords: *Bamboo, laminates, WPC, LWC, Mechanical strength, MOE, MOR*

INTRODUCTION
The diversity of species of bamboo, both in Nigeria and in the world at large, can be an alternate supply to the market of wood products, which is directed towards the reducing deforestation, bush burning and the development of technologies that encourages sustainability of forest products (Chaowana, 2013). Recently, the use of bamboo has been expanded to include its manufacture into several structural composite products. As well, bamboo is a naturally occurring grass that is available worldwide, nevertheless, it is a type of grass that is the largest and matures at a period of five years in which the return is always three times higher when compared with timber (Zhang *et al*. 2002). It is important to note that Bamboo is fast becoming a promising wood substitute and one of the chief reasons for this is that usable bamboo can be harvested in 3 – 4 years from the time of plantation as opposed to timber which takes decades (Chaowana, 2013). Notably, bamboo stalks reach maturity in a short time, strength is comparable to that of wood. As such, it makes an appealing material as a structural material. It is projected therefore, that bamboo could become a sustainable alternative to current building materials (Egbewole *et al*. 2020). Furthermore, bamboo has an appearance and workability as compared to wood of native tree species, being valued in the European and American markets, can be used in its natural form and also for the manufacture of veneers (Rusch *et al*. 2019). According to Rosa *et al.,* 2016, the panel type with the most widespread production technology is the glued-laminated bamboo (GLB), which began in China in the 1980s (Berndsen *et al.,* 2013). As the availability of resources declines and demands increase in today's modern industrialized world, it is becoming indispensable to explore opportunities for new, sustainable building materials. The effective and judicial use of laminated bamboo will mitigate the pressures on the depleting natural forest in developing countries and thus, conserve the global environment which is the major constraint the world faces today caused by deforestation (Chung and Yu 2002). Bamboo based laminates are therefore, needed to be investigated thoroughly so that the full potential of bamboo as a functionally graded composite could be utilized. This study revealed the mechanical strength properties of laminated bamboo as comparison to other wood composite products.

METHODOLOGY
Study area
The experiment was carried out in the wood workshop and the test of the sized laminated bamboo boards was done at the wood testing laboratory of the Department of Forestry and Wood Technology, Federal University of Technology, Akure, Ondo State, Nigeria. Federal University of Technology Akure (FUTA) is located on the north-western part of Akure and it occupies an area of about 5km². It lies between the latitude 7°17′ - 7°19′N and longitude 5°7′-5°9′E. The area shows a gentle slope with locomotive increase in elevation from the east and

south towards the north-western part and elevation ranging between 372m and 405m above the sea level. The vegetation of FUTA is characterized as a tropical rain forest with thick forest. FUTA has a mean annual rainfall between 1000mm and 1500mm. The annual mean temperature ranges from 21.9°C to 30.4°C. The area's humidity is relatively high during the wet season and low during dry season with values ranging from 39.1% to 98.2% (Akinbode *et al*., 2008).

Collection of bamboo

The matured bamboo culms were harvested in the forest using chainsaw and transported to the factory site. The bamboo was air-dried to a moisture content of about 12% and later processed by using the circular saw to cut them into strips, removing the inner knots to form straight bamboo strips which was repeated until all the bamboo were converted into strips. They were later measured using the tape rule into the required length of 50 x 50 x 6 mm of length, width and thickness respectively. Thereafter, the measured strips of bamboo were joined in fours using the glue as an adhesive forming bamboo laminates. Fifty replicates of laminated bamboo were produced, laid up and pressed together. Each bamboo laminates were pressed using the wood press machine and left for seven days to cure. Standard sizes are cut from the laminated bamboo and the following strength tests were determined:

Modulus of Rupture (MOR)

Modulus of Rupture is defined as the maximum load capacity of a wooden member. The modulus of rupture (MOR) of the laminated bamboo is determined using test specimens of the required standard sizes. The test specimens were supported by two rollers at both ends and loaded at the middle of the span until failure occurred. At the point of failure, the force exerted on the specimens that caused the specimens (the laminated bamboo) to crack was recorded and the modulus of rupture was calculated using the formula below:

MOR = $\frac{3PL}{2bd^2}$ ……………………………..equation (i)

Where;

MOR= modulus of rupture (N/mm²)

P= the ultimate failure load (N)

L= the board span between the supports (mm)

b= width of the board sample (mm)

d= thickness of the board sample (mm)

Modulus of Elasticity (MOE)

Modulus of Elasticity (MOE) is defined as the measure of the stiffness properties of the board. This was determined from the bending test carried out on the laminated bamboo. The modulus of elasticity of the board was calculated using the formula below;

MOE= $\frac{PL^3}{\Delta 4bd^3}$ ………………………equation (ii)

Where:

MOE= modulus of elasticity (N/mm²)

P= load (N)

L= the span of load of board samples between the machine supports (mm)

b= width of the board sample (mm)

d= thickness of the board sample (mm)

Δ= slope of the graph

RESULTS AND DISCUSSION

Comparison between the means of the load and deflection analysis of bamboo

Table 1 revealed the result of some tested laminated boards with their appropriate load (KN) and deflection (mm) which were used to analyze the results of the means of the modulus of elasticity and modulus of rupture in comparison to other studies in literature.

Table 1: Results of some load and deflection measured

Load (KN)	Deflection (mm)
3.504	18.49
4.598	22.30
4.879	16.28
4.615	23.27
4.737	22.61

Comparing laminated bamboo boards with other wood laminates in literature

According to researches on some WPC, it was revealed that the MOR and MOE were 13.1-46.3N/mm² and 1781-3170N/mm² respectively (Arab and Islam 2015; Yang *et al.*, 2015; Srivabut *et al.*, 2018). In this study, it was revealed that the mean MOR and MOE for laminated bamboo was 46.45N/mm² and 259.53N/mm². In comparison, this showed that the laminated bamboo has a high Modulus of Rupture than the Wood Plastic Composites. This revealed that the tendency of laminated bamboo to break as compared to WPC is low as it can withstand the stress of breakage. This is justified by Pereira and Faria (2009) who reported that bamboo laminates show higher strength and stiffness which helps them to be suitable for construction and design of structural elements compared to those made of wood. However, the MOE is higher than the laminated bamboo. In Laminated Poplar Wood Veneer, the MOR was 37.52-51.12N/mm² and the MOE was 8880N/mm² to 11.490N/mm² (Yue *et al*., 2019).

CONCLUSION

The study focused on the mechanical strength of laminated bamboo with other wood composites. the mean MOR and MOE for fifty (50) laminated bamboo in this study is 46.45N/mm² and 259.53N/mm². In comparison to other wood laminates, laminated bamboo can be used as an alternative to wood composites due to its high strength properties. It is therefore imperative to be used in place of other wood laminates.

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