International Journal of Research in Agriculture and Forestry
Volume 1, Issue 1, November 2014, PP 44-54
ISSN 2394-5907 (Print) & ISSN 2394-5915 (Online)

The Influence of Age and Location on Selected Physical and Mechanical Properties of Bamboo (Phyllostachys Pubesces)

F. R. Falayi[1], B. O. Soyoye[2]

Agricultural and Environmental Engineering Department,
School of Engineering and Engineering Technology,
Federal University of Technology, Akure Ondo State Nigeria
[2]*soyoye2002@yahoo.com*

T. O. Tehinse

Rural Access and Mobility Project,
Federal Ministry of Agriculture and Rural Development, Abuja Nigeria

Abstract: *With the continued rapid development of the global economy and constant increase in population, the overall demand for wood and wood-based products will likely continue to increase in the future. However, modern applications are being discovered, several of which are based on bamboo's unique physical and mechanical properties. Bamboo is currently being looked upon as a low-cost panacea for the enormous housing problems faced by several developing countries. Some physical and mechanical properties of bamboo were determined using standard procedures. A completely randomized block design (CRBD) with three treatments and three replicates was adopted. The results of the study showed that the specific gravity of the selected bamboo base on location had the mean values of 0.67, 0.67 and 0.64 for top, middle and base respectively and base on age series it had the mean specific gravity of 0.51, 0.71 and 0.76 for ages one, three and five years respectively. The moisture content ranged between 0.51 to 0.76 % and 33.26 to 58.51 % respectively depending on age and height on the culm. The mechanical properties of bamboo showed that the bending strength varies between 117 and 190 MPa for modulus of rupture and 8380 and 13188 MPa for modulus of elasticity. There was a significant effect in the relationship between specific gravity and bending properties with r^2 value of 0.91 for modulus of rupture and 0.75 for modulus of elasticity. This result indicated that increase in specific gravity of bamboo have a bearing effect on its mechanical properties. The compressive strength of bamboo parallel to the grain was higher (78.4 MPa) compared to when the load was perpendicular to the grain (27.38 MPa). The height of bamboo culm had no significant effect on the compressive strength while the effect of age was significant. From these results, bamboo possesses a higher mechanical properties compared with timber and could be used in varieties of applications including furniture, building construction (farm sheds), poultry feeding lines and other engineering purposes as a result of its availability and affordability.*

Keywords: *Moisture content, specific gravity, modulus of rupture and modulus of elasticity.*

1. Introduction

Bamboo is a naturally occurring composite material which grows abundantly in most of the tropical countries. It is considered a composite material because it consists of cellulose fibers imbedded in a lignin matrix. Cellulose fibres are aligned along the length of the bamboo providing maximum tensile flexural strength and rigidity in that direction [1]. Over 1200 bamboo species have been identified globally [2]. Bamboo has a very long history with mankind. Bamboo chips were used to record history in ancient China. Bamboo is also one of the oldest building materials used by mankind [3]. It has been used widely for household products and extended to industrial applications due to advances in processing technology and increased market demand. In Asian countries, bamboo has been used for household utilities such as containers, chopsticks, woven mats, fishing poles, cricket boxes, handicrafts and chairs. It has also been widely used in building applications, such as flooring, ceiling, walls, windows, doors, fences, housing roofs, trusses, rafters and purlins. It is also used in construction works as structural materials for bridges, water transportation facilities and skyscraper scaffoldings. There are about 35 species now used as raw materials for the pulp and paper industry.

Massive plantation of bamboo provides an increasingly important source of raw material for pulp and paper industry in China [4].

There are several differences between bamboo and wood. In bamboo, there are no rays or knots, which give bamboo a far more evenly distributed stresses throughout its length. Bamboo is a hollow tube, sometimes with thin walls, and consequently it is more difficult to join bamboo than pieces of wood [5].

1.1. Objectives of the Research Work

The overall objective of this study is to evaluate the physical and mechanical properties of the bamboo species *phyllostachys pubesces* as a substitute for wood for the construction of farm structures and other related works. The specific objectives include;

1. to evaluate the influence of age on some physical and mechanical properties of bamboo,
2. to determine the physical and mechanical properties of bamboo with respect to its variation in height **and**
3. to assess the relationship between the specific gravity and bending strength of bamboo and its effect on utilization.

1.2. Project Justification

The cost of wood, wood products and construction with imported raw materials or production cost with foreign machinery make product cost very high, thereby seriously contributing to the rate of homelessness for many people and making the construction of farm sheds almost impossible for some people. While individuals are badly affected by the high cost of construction materials, government and corporate bodies take the lion share of this unfortunate situation. It is therefore imperative for us to conduct an in-depth research work into the available local alternatives such as bamboo which could be used as standard and acceptable construction materials that will bring about affordable and available local construction materials adjudged suitable and safe materials as substitute for expensive imported materials.

1.3. Description of Bamboo

Bamboo is a tall grass, fast-growing and typically woody. The bamboo plant is a complex system, consisting of two sets of similarly structured vegetative axes: one above the ground and the other below the ground and the features are shown in Figure 1. The portion between two successive nodes is called an internode. Internodes are invariably, but not always, hollow. They are covered by sheaths at the initial stages of growth, which fall off as the plant matures. The inter-nodal length varies considerably across bamboo species, ranging from 0.05 to over 0.60 metres [6]. In general, the inter-nodal length increases upwards along the culm from the lower portion to the middle, and then decreases as shown in Figure1. Bamboo has been neglected or ignored in the past by tropical foresters, who tend to concentrate on timber trees at the expense of traditional multi-purpose woody species such as bamboo and rattan [7]. Literature on the dynamics and productivity of natural bamboo stands is meagre, and reports from plantation stands are almost non-existent [8]. Bamboo has been used for handicrafts and building material in India and China for thousands of years, yet its potential contribution to sustainable natural resource management has only recently been recognized [9].

1.4. Economic Importance of Bamboo

The shortage of housing in developing countries motivates the search for low cost materials that can be applied in the construction of affordable houses, especially in earthquake regions of the world. Building materials are commonly selected through functional, technical and financial requirements. However, with sustainability as a key issue in the last decades, especially in western countries, the environmental load of building materials has also become a more important criterion. In the year 1987, [10] introduced their relationship of sustainability with the world population, average welfare rate and environmental impact of welfare commodities, demonstrating the need of achieving a factor 20 environmental improvement by the year 2040. Many organisations and institutions have adopted this target. The building industry, directly or indirectly causing a considerable part of the annual environmental damage, can take up the responsibility to contribute to sustainable development by finding more environmentally benign ways of construction and building. One of the directions for solutions is to be found in new material applications: recycling and reuse, sustainable production of products, or use of renewable resources.

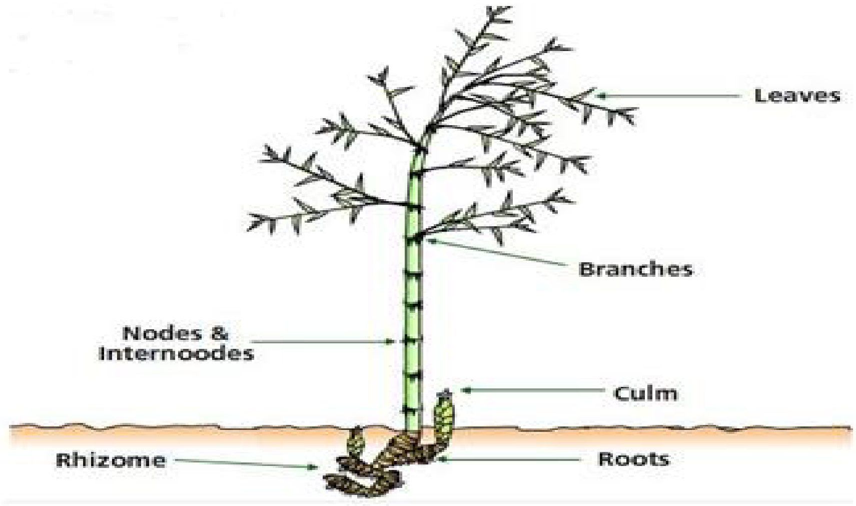

Figure 1. *Structure of Bamboo Plant*

2. MAIN BODY

2.1. Material and Methods

The experimental locations for this study were the Plantation Research Farm, Civil and Mechanical Engineering Departments of the Federal Polytechnic Ado Ekiti, Ekiti State. The concluding part of the experiment was carried out at the Forestry and Wood Technology Department, Civil Engineering Department and Agricultural Engineering Department of the Federal University of Technology Akure, Ondo State. Bamboo of ages; one, three and five years were used for this study. The ages of bamboo were monitored by the forest officers through replacement factors that is, (cutting off the aged ones and planting new ones).

The samples were of three sub-groups with three different categories; top, middle and base;

Sample A: Top A_T, Middle A_M and Base A_B (5 replicates each)
Sample B: Top B_T, Middle B_M and Base B_B (5 replicates each)
Sample C: Top C_T, Middle C_M and Base C_B (5 replicates each)

A completely randomized block design (CRBD) with three treatments and three replicates was adopted. The samples used for moisture content determination were also used for the bending properties. This gives a total of 45 samples. Compressive strength samples makes a total of 90 samples; 45 samples for compression parallel or longitudinal to the grain and 45 samples for compression perpendicular to the grain.

2.2. Determination of Moisture Content of Bamboo

The tests were carried out in accordance with the ISO D22157 (2000). The bamboo specimen were cut into 120 mm long and each of them were marked with a maker such as $M_{1,}$ $M_{2,}$ ---------- $M_{n.}$ An empty can weighing X mm was attached to each of the marked specimen. The cans and the wet samples were weighed and recorded as Y, the can with the wet samples were transferred into the oven, and allowed to dry for 48 hours at temperature of 110^0C. They were removed from the oven and kept in the dessicator and allowed to cool for 30 minutes. The weight of the can (container) with the dried bamboo was determined and recorded as Z.

$$M_c = \frac{Y - Z}{Z - X} \times 100 \, {}^0\!/_0 \quad (1)$$

Where;

M_c = Moisture content of bamboo (%) dry basis

X = Mass of container (g)

Y = Mass of container with wet bamboo (g)

Z = Mass of container with dried bamboo (g).

2.3. Determination of Density of Bamboo

The bamboo specimens were cut into 120 mm long with each marked D_1, D_2, ---, D_n. the masses of the bamboo specimens were determined using the electric weighing balance provided and recorded as X (g). The ureka can was filled with water to the brim and the bamboo specimen was gently lowered into it. As the specimen went down the ureka can, the quantity or amount of water displaced was collected in a measuring cylinder placed by its side as shown in Figure 2. The volume of the displaced water was taken and recorded as Y (ml); this represents the volume of the tested bamboo.

$$D_B = \frac{X}{Y} = \frac{mass}{volume}\left(g/ml\right) \tag{2}$$

Where;

D_B = Density of bamboo (g/ml)

X = Mass of bamboo (g)

Y = Volume of bamboo (ml)

Figure 2. *Determination of the Density of Bamboo*

2.4. Compressive Strength Test

The following apparatus were used in the determination of the compressive strength of bamboo; marker, standard hydraulic compressive testing machine and saw. The length of the bamboo was taken and recorded as L (mm), the external and internal diameters of the bamboo were also taken and recorded as (D and d) mm respectively. The new length of the bamboo after the test was taken and recorded as *l* (mm) and then the change in length was also noted and recorded as Δl (mm). The bamboo specimen to be tested was put between the jaws of the compressor and the machine was electrically switched on as shown in Figure 3.

$$\text{Area of bamboo specimen} = \frac{\pi D^2}{4} - \frac{\pi d^2}{4} = \frac{\pi}{4}\left(D^2 - d^2\right)\ \text{mm}^2 \tag{3}$$

$$\text{Compressive stress} = \frac{F}{A}\left(kN/mm^2\right) \tag{4}$$

Where;

D = External diameter of the bamboo specimen (mm)

d = Internal diameter of the bamboo specimen (mm)

F = Compressive force at fracture of the bamboo specimen (kN)

A = Area of the bamboo specimen (mm^2)

Figure 3. *Determination of the Compressive Strength of Bamboo*

2.5. Determination of Modulus of Rupture

The following equations as stated by [11] were used for the determination of modulus of rupture;

Modulus of Rupture = $\frac{\sigma}{\delta}\left(MN/mm^2\right)$

$$\delta = \frac{\Delta l}{L}$$

Where;

σ = Compressive stress of bamboo MN/mm^2
δ = Compressive strain of bamboo
Δl = Change in length of bamboo (mm)
L = Original length of bamboo (mm)

3. Results and Discussion

3.1. Specific Gravity

The result of mean specific gravity of the tested bamboo is shown in Table 1. Samples of bamboo selected from the top, middle and base had a mean specific gravity of 0.67, 0.67 and 0.64 respectively. The result of the analysis of variance in Table 2 revealed a significant difference ($p<0.05$) in the effect of locations of selected samples and age series of bamboo on specific gravity. In all the age series of samples selected, specific gravity was highest in bamboo of age five and decreased as the age decreases (Figure 4). The specific gravity of any structural material has been identified as an important indicator of its strength. The result of this study indicated that the specific gravity of bamboo examined at different ages were significantly different among the age series. This showed that there was a difference in the variability of the materials in terms of mass of dry woody substance per volume of the bamboo examined as they grow older. Specific gravity also varied with different positions from which the samples were selected (top, middle and base). Highest density was recorded at the top and lowest density was recorded at the base. The same trend of result was obtained by [12] and [13]. Although the study by [14], showed that specific gravity at different height was not statistically different, the top portions consistently had higher specific gravity than the samples at the base for the age groups of bamboo examined.

Table 1. *Mean specific gravity of bamboo samples selected at different locations on the stem*

Location	Mean Specific Gravity
BASE	0.6413
MIDDLE	0.6667
TOP	0.6733

Table 2. *Analysis of variance for specific gravity based on and age series*

Source	Sum of Squares	*df*	Mean Square	F	Sig.
LOCATION	.009	2	.004	18.707	.000
AGE	.497	2	.249	1088.352	.000
Error	.009	40	.000		
Total	**.515**	**44**			

Table 3. *Mean values for moisture content based on age series of bamboo*

Age (years)	MC
One	0.5180
Three	0.3713
Five	0.4620

Table 4. *Mean values of moisture content based on location of selected samples*

Location of selected samples	MC
Base	0.4300
Middle	0.4347
Top	0.4867

3.2. Moisture Content

The moisture content of the bamboo is shown in Tables (3 and 4) and Figure 5.The results showed that moisture content value ranged from 47.03 to 58.51%, 33.26 to 37.89% and 39.34 to 48.51% for ages one, three and five respectively. Figure 5 showed that bamboo of age three has the lowest moisture content and age one with relatively high moisture content. The Figure also showed that the moisture content in age one has the highest value at the top and the lowest value at the middle. Sample of age three also shown similar trend of result, except for those of five years where the top and the middle had the same moisture content. The analysis of variance showed that there were significant differences within the age series, the location of the selected samples and the interaction between the age series (Table 5). Green bamboo used in the study had an average of 45.0% and it increased along the longitudinal direction fron the base to the top. Results in Figure 5 further showed that the moisture content reduces with maturity of bamboo.

This effect would be an important indicator for increase in strength properties of bamboo as it grows older. There was a great disparity in the result of bamboo test carried out by [15] and that which was obtained in this study. The moisture content of the samples were stabilized to 20% at the time of his test which consequently affected the strength values. At 20%, the average values obtained for compressive strength, MOE and MOR were 80 MPa, 15, 600 MPa, and 84±34 MPa respectively compared to what was obtained in this study as 60 -70 MPa, 10, 000 – 13,000 MPa, and 159 – 190 MPa for compressive strength, MOE and MOR respectively.Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) were the bending properties examined for bamboo. Results showed that the mean MOR of samples selected at different locations i.e. Top, middle and base were 157.74, 155.95 and 153.39MPa respectively (Table 6). MOE also varied with the age of bamboo. Bamboo of age one had a mean MOR of 117.74 MPa, 159.53 MPa for age three and 190.06 MPa for age five (Table 7). A significant difference exist ($p<0.05$) in the effect of location of samples and age series on the MOR of bamboo (Table 8). MOR values also varied with age as shown in Figure 6. Higher values of MOR was obtained with bamboo of age five and lowest values in age one. A similar result was obtained for MOE values in the tested bamboo Figure 7. MOE values varied with the location of the selected samples. Samples at the top had a mean MOE of 10766.80 MPa, 10653.87 MPa at the middle and 10210.53 MPa at the base (Table 9). MOE values for the age series was highest with bamboo of age five (13188.80 MPa) and lowest in age one series with MOE values of 8380.87 MPa (Table 10, Figure 7).

Table 5. *Analysis of variance for Moisture Content*

Source	Sum of Squares	Df	Mean Square	F	Sig.
Age series	0.164	2	.082	172.732	**.000***
Location of selected samples	0.030	2	.015	31.166	**.000***
Age series * Location	0.053	4	.013	27.606	**.000***
Error	0.017	36	.000		
Total	**0.264**	**44**			

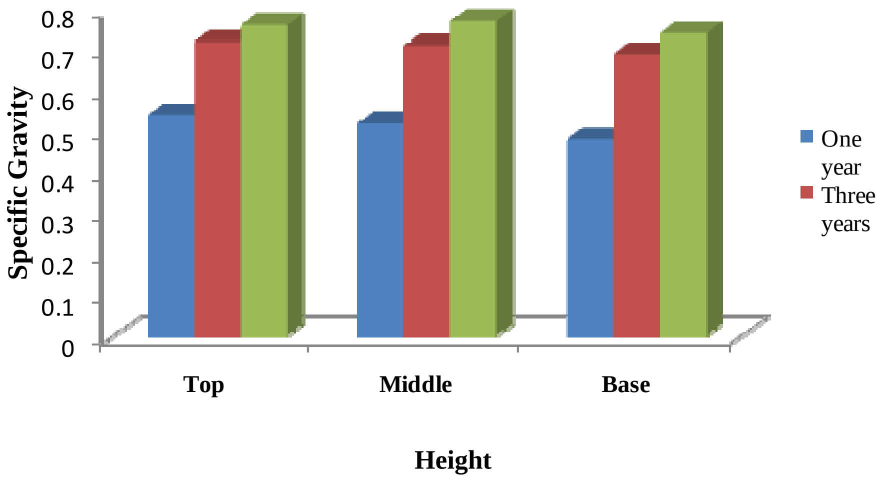

Figure 4. *Influence of Age and Location of selected samples on specific gravity of bamboo*

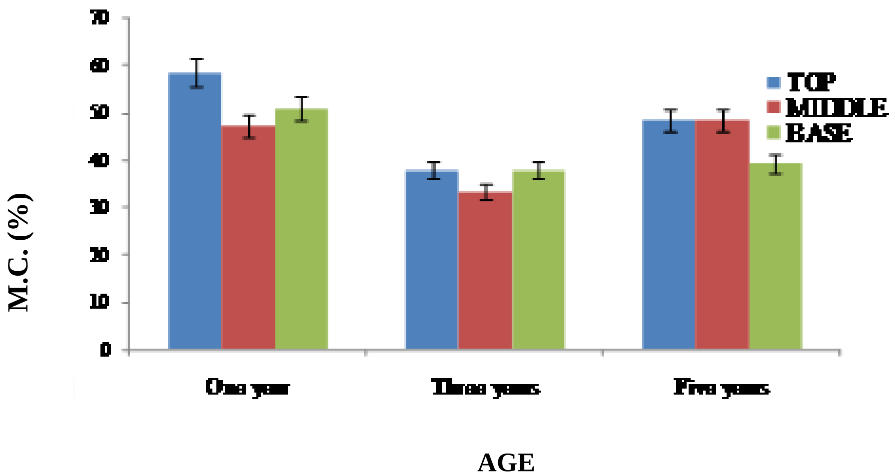

Figure 5. *Influence of Age on Moisture content of bamboo*

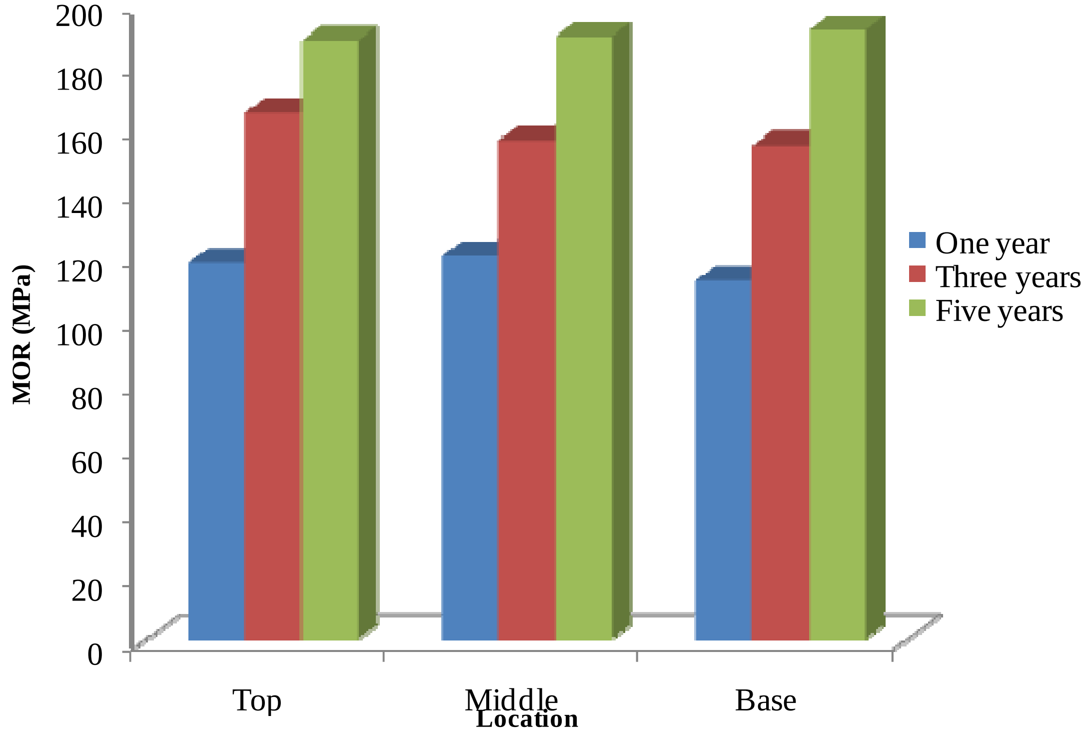

Figure 6. *Influence of Age and location on the MOR of bamboo*

3.3. Bending Strength

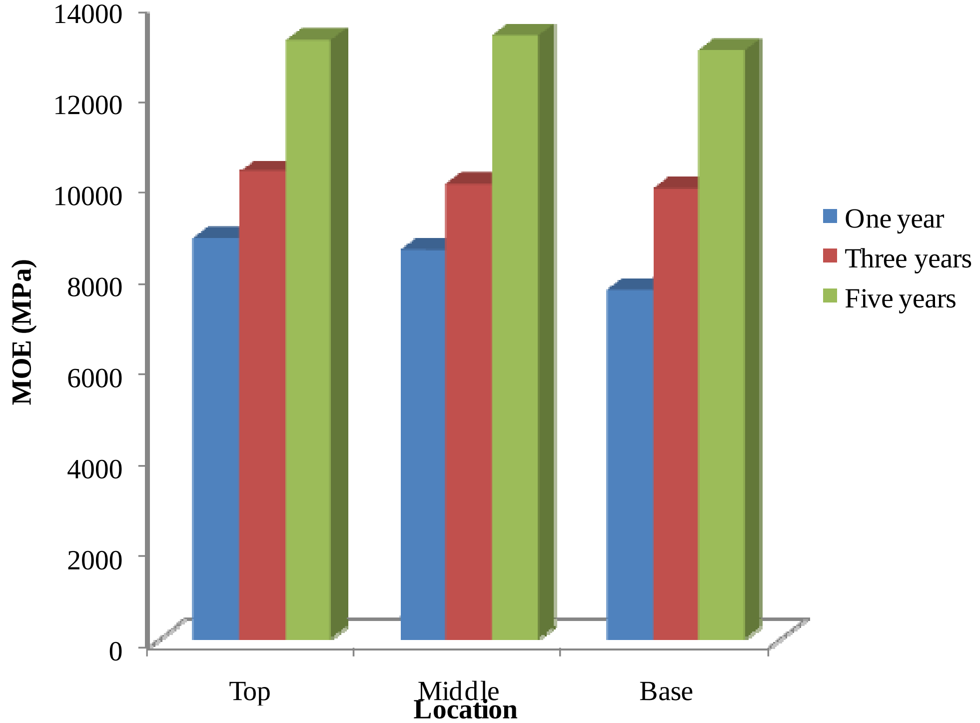

Figure 7. *Influence of Age and Location on MOE of bamboo*

Results from this study have shown that the bending properties of bamboo vary with age (Table 7). The properties also increased from bottom to the top of bamboo stem as observed by [16]. The bending properties of bamboo reduce gradually from the top to the base of bamboo stem. It could also be observed that MOE and MOR values were higher at the top but lower at the base. The higher bending properties of bamboo obtained from the age series in this study indicated that there is an increase in specific gravity of bamboo during its period of growth which consequently results in its higher strength properties as it matures. [17] Asserted to this fact that increase in weight of bamboo is cumulative and directly related with age. The stiffness of bamboo is in the same range as in timber (15,000 – 17, 000 MPa). Reinforced concrete is approximately four times stiffer while steel is approximately thirteen times stiffer than bamboo. [18] observed that during bending, bamboo fibres are usually in good condition despite the strain on its lignin content although the value of MOE drops dramatically. If the load is removed, bamboo will return to its straight form. This property serves as an advantage in case of hurricane or an earthquake.

Table 6. *Mean values for Modulus of Rupture of bamboo based on location of selected samples*

Location	Mean MOR (MPa)
BASE	153.3980
MIDDLE	155.9453
TOP	157.7373

Table 7. *Mean values for MOR based on age series of bamboo*

Age (Year)	Mean MOR (MPa)
ONE	117.4947
THREE	159.5253
FIVE	190.0607

Table 8. *Analysis of variance for MOR*

Source	Sum of Squares	*df*	Mean Square	F	Sig.
POSITION	142.650	2	71.325	7.872	.001*
AGE	39824.039	2	19912.020	2197.744	.000*
Error	362.408	40	9.060		
Total	**40329.098**	**44**			

Table 9. *Mean values for Modulus of Elasticity based on location of selected samples*

Location	Mean MOE (MPa)
BASE	10210.5333
MIDDLE	10653.8667
TOP	10798.8000

Table 10. *Mean values for MOE based on Age series of bamboo*

Age (Year)	Mean MOE (MPa)
ONE	8380.8667
THREE	10093.5333
FIVE	13188.8000

3.4. Compressive Strength of Bamboo

The result of compressive strength in two major directions of test is shown in Table 11. Results showed that compression value was higher for the samples loaded longitudinally to the grain of bamboo stem. A compression value of 74.84 MPa was obtained for bamboo loaded longitudinally to the grain while 27.39 MPa was obtained for those loaded perpendicular to the grain. Mean compressive strength of different age series of bamboo is shown in Table 12. Samples of age one had a mean compressive strength of 33.71 MPa and 58.32 MPa and 61. 31 MPa for ages three and five respectively. Samples selected from different locations showed the values of 50.01, 51.36 and 51.9 MPa for middle, base and top respectively (Table 13). There exists a significant difference ($p<0.05$) in compressive strength of bamboo based on age but no significant difference ($p>0.05$) in compressive strength of bamboo based on location of selected samples. The result obtained revealed that strength in compression parallel to the grain is higher compared to when the direction of loading is perpendicular to the grain. This is an indication that bamboo is a material that has directional properties as observed by [14]. This directional property describes the use of bamboo either as column or a beam in any construction. Bamboo could bear more loads when used as column than a beam. Although results from previous studies [10]; [13]; [19] and [20] found the compressive strength to increase with height, results from this study showed that compressive strength increased but not statistically significant as shown in Table 13 and 14. Compressive strength also increased with age as observed in the bending strength of bamboo.

Table 11. *Mean values for Compressive strength in direction of test for bamboo*

Direction of test	Mean Compressive Strength (MPa)
Longitudinal to the grain	74.840
Perpendicular to the grain	27.387

Table 12. *Mean values for compressive strength for age series of bamboo*

Age (Year)	Mean Compressive Strength (MPa)
One	33.7103
Three	58.3207
Five	61.3097

Table 13. *Mean values for compressive strength based on location of selected samples*

Location of Samples	Mean Compressive Strength (MPa)
Middle	50.01
Base	51.36
Top	51.97

Table 14. *Analysis of variance for Compressive stress of bamboo*

Source	Sum of Squares	df	Mean Square	F	Sig.
Test direction	50665.924	1	50665.924	2004.079	.000*
Age	13763.258	2	6881.629	272.201	.000*
Position	60.197	2	30.098	1.191	.309^{ns}
Error	2123.638	84	25.281		
Total	**66613.016**	**89**			

4. Conclusions

The physical and mechanical properties such as specific gravity, moisture content, bending strength and compressive strength are important properties that determine the utilization of bamboo in construction and for structural purposes.

- Results of this study have shown the effect of age and its variation along the height of the culm of bamboo on the specific gravity, moisture content, bending strength and compressive strength of bamboo.
- The moisture content was found to decrease as bamboo attains maturity which also has a corresponding effect on the strength properties.
- Properties such as bending and compressive strength increase with age of bamboo. Compressive strength was higher when bamboo was loaded longitudinally to the grain than when perpendicular to the grain. This showed that it could bear more loads when used in column than as a beam.

Bending properties of bamboo (MOE and MOR) had a strong relationship with specific gravity of bamboo. This implies that since age had a great influence on specific gravity, the bending properties of bamboo increased as the specific gravity increased.

References

[1] Lakkad, S. C. and J. M. Patel. (1981). Mechanical properties of bamboo, a natural composite. Fiber Sci. and Tech. 14(3): 319-322.

[2] Ahmad, M. (2000). Analysis of calcutta bamboo for structural composite materials. Dissertation, Wood Sci. and Forest Products, VT. pp. 210.

[3] Abd.Latif, M., Wan Tarmeze, W.A. and Fauzidah A. (1990). Anatomical features and mechanical properties of three Malaysian bamboos. Journal Tropical Forest Science 2(3): 227-234.

[4] Heng, X., C. Tanaka, T. Nakao, and H. Katayama. (1998). Mechanical properties of plywood reinforced by bamboo or jute. . Forest Prod. J.. 48(1): 81-85.

[5] Oyebode, Y. O. and Ogedengbe, K. (2001). Some mechanical properties of bamboo (*Bambusa vulgaris, schrad)*. African Journal of Environmental Studies vol. 2, No 1, pp 108-112.

[6] Satjapan, L., Suthon, S. and Nirundorn, M. (2010). "Compressive strength and ductility of short concrete columns reinforced by bamboo", Songklanakarin J. Sci. Technol. 32 (4), 419-424.

[7] Kassim, J., A. J. Hj.Ahmad, and A. A. Jalil. (1992). Utilization of bamboo for pulp and paper and medium density fiberboard. In: (W.R.W. Mohd and A.B. Mohamad, eds.). Proceedings of the Seminar towards the Management, Conservation, Marketing and Utilization of Bamboos, FRIM, Kuala Lumpur. pp. 182-195.

[8] Hanafi, I., M. R. Edyham, and B. Wirjosentono. (2002). Bamboo fiber filled natural rubber composites: the effects of filler loading and bonding agent. Polymer Testing. 21: 139-144.

[9] Hinkelmann, K. (1997). Selected SAS Documentation for STAT 5615/5616: Statistics in Research. Department of Statistics, Virginia Tech.

[10] Lucas, E. B. and Ogedengbe, K. (1987). Shrinkage Charaeteristics of Bamboo (*Bambusa vulgaris, schrad).* Journal of Forestry , vol. 17 Nos 1 and 2 pp 7-11.

[11] Haygreen, J. G., and J. L. Bowyer. (1998). Forest products and wood science. An Introduction, Iowa State University Press/Ames. Third Edition.

[12] Sattar, M. A., M. F. Kabir, and D. K. Battacharjee. (1994). Effect of age and height position on muli (*Melocanna baccifera*) and borak (*Bambusa balcooa*) bamboos on their physical and mechanical properties. In Bamboo in Asia and the Pacific. Proceedings of the 4th International bamboo Workshop, Chiangmai, Thailand, 27-30 November, 1991. pp. 183-187.

[13] Sattar, M. A., M. F. Kabir, and D. K. Bhattacharjee. (1991). Effect of age and height position of muli (*Melocanna baccifera*) and borak (*Bambusa balsooa*) bamboo on their physical and mechanical properties. Proceedings: 4th International Bamboo Workshop. Bamboo in Asia and the Pacific. Chiangmai, Thailand.

[14] Li, X. (2004). Physical, Chemical and Mechanical properties of bamboo and its utilization potential for fibre board manufacturing. A Thesis Submitted to the Graduate Faulty of the Louisiana State University and Agriculture and Mechanical College In Partial Fulfillment of the Requirements for the Degree of Master of Science.

[15] Alisto, M. (2005). Bamboo reinforcement as structural material for the construction of low cost houses in Ethiopia. A thesis submitted to the School of Graduate Studies, Addis Ababa University for M. Sc Degree in Civil Engineering (Structures). 84p.

[16] Chauhan, L., S. Dhawan, and S. Gupta. (2000). Effect of age on anatomical and physic-mechanical properties of three Indian bamboo species. J. of the T.D.A.. 46:11-17.

[17] Zhou, F.C.. (1981). Studies on physical and mechanical properties of bamboo woods. J. of Nanjing Technology College of Forest Products. 2: 1-32.

[18] Janssen J. A. A. (2000). Designing and building with bamboo. Technical report No. 20. Technical University of Eindhoven, Eindhoven, the Netherlands. 211p.

[19] Espiloy, Z. (1987). Physico-mechanical properties and anatomical relationships of some Philippine bamboos. In: (A. N. Rao, et al., eds.). Recent research on bamboo. Proceedings of the international bamboo workshop, Hangzhou, China, 6-14 October. Chinese Academy of Forestry, Beijing China; International Development Research Center, Ottawa, Canada. pp. 257 264.

[20] Kabir, M. F., D. K. Bhattacharjee, and M. A. Sattar. (1991). Effect of age and height on strength properties of *Dendrocalamus longispathus.* BIC India Bulletin. 3(2):11-15.