Investigation of Some Mechanical Properties of 'Agaraba' - A Native Nigerian Bamboo

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Abstract

*The investigation of some mechanical properties of 'Agaraba', a native Nigerian bamboo (*Bambusa vulgaris*) was carried out. The moisture content of the sample, which is a basic requirement for effective analysis of its mechanical properties, was first examined. The compressive and tensile properties and hardness of the top, middle and bottom locations of the bamboo culm were investigated. The result shows that the strength of bamboo increases with length of the culm. The average values for the compressive strength, tensile strength and hardness number were 75.69 MPa, 295.33 MPa, and 3.96, respectively. The results of the compressive and tensile strength of Nigerian-grown bamboo were comparable to that of timber, concrete, plastic and mild steel, while the hardness test was comparable to that of softwood and some hardwood. Due to the results of the tests carried out, it was found that bamboo that has been under-utilized in Nigeria, could be used as an alternative material to wood, plastic and concrete in applications such as housing, construction and piping and also for use in some engineering applications.*

Keywords: *Culm, compressive strength, tensile strength, hardness, alternative material.*

Introduction

'Agaraba' *(Bambusa vulgaris)* is one of the most common species of the bamboos in Nigeria. It is self-propagating plant that takes two to six years to mature. Other common species of the bamboos in Nigeria are: *Bambusa arundinacea*, *Bambusa tulda*, *Dendrocalamus giganteus*, and *Oxynanthera abyssinica* (RMRDC 1996; Ogunsile and Uwajeh 2009). Bamboo species across Nigeria have similar morphological characteristics though there is variation in size, suggesting influence of age and perhaps the soil condition. Bamboo is particularly adapted in the rain forest belt of Nigeria where it is found in abundance along river banks and other relatively marshy areas (RMRDC 1996).

'Agaraba' is a moderately-sized bamboo not densely tufted, jointed woody stems up to 20 m high, 5-10 cm in diameter with bright green, glossy walls 7-15 mm thick. It is the most widespread member of its genus and has long been cultivated across the tropics and subtropics. It prefers low land, humid habitats, but tolerates wide range of climatic conditions and soil types. It commonly naturalizes forming mono-specific stands along river banks, roadsides and open ground. Although it is taxonomically a grass, its habit is tree-like. It forms dense stands of cylindrical, jointed woody stems up to 20 m in height and 4-10 cm in diameter, leafy branches at nodes with narrow leaves up to 30 cm long. The motivation behind this work is based on the fact that 'Agaraba', which possesses a good strength to weight ratio, fast growing rate and takes only about one quarter of the time taken by trees to reach maturity, may be used as a substitute to timber in engineering applications (Mohmod and Mustafa 1993).

The choice of ‘Agaraba’ out of few other species of the bamboo in Nigeria was due to its strength and availability in almost every part of Nigeria. The sample which was sound and free from defects for the purpose of effective analysis was collected from the swampy and water-logged area of Ogbogbo in Idah Local Government Area of Kogi State. It was about 430 cm in length with external diameter of the culm ranging between 3.1-6.4 cm. The length of the internodes ranged from 26-38 cm. The sample was cut at about 30 cm above the ground level. Each specimen was marked and cut at about 60 cm intervals into the basal, middle, and top parts. The specie was identified at the Department of Botany and Microbiology, University of Ibadan, Ibadan, Oyo State, Nigeria.

Bamboo is a plant with a great range of applications in the landscape, either as a living plants or building material and finished products from harvested bamboo. It has been used extensively as a building material in regions where it normally occurs. There are up to 1,500 bamboo species distributed worldwide with the greatest species diversity in Asia, especially China, central and South America. In addition, Asian species have been brought to the western hemisphere for horticultural purposes and cultivation for other uses. The use of bamboo is expected to remain strong and perhaps increase, especially in areas where there is shortage of timber supply (Grosser and Liese 1971).

Bamboo is a perennial, giant, woody grass. Most of the bamboos need a warm climate, abundant moisture, and productive soil, though some do grow in reasonably cold weather (below -20^{o}C). Bamboos are also adaptable to various types of habitat. They grow in plains, hilly and high altitude mountainous regions, and in most kinds of soils, except alkaline soils, desert, and marsh. Mohmod and Mustafa (1993) mentioned that bamboo could grow from sea level to as high as 30 m. Bamboo is suitable on well-drained sandy to clay loom or from underlying rocks with pH of 5.0-6.5. The culm is the primary material used in bamboo product. Culm growth rates and heights vary among species and environmental conditions, and can be impressive.

Bamboo traditionally is processed as either cut poles (culms), large culms split lengthwise and flattened into boards, or split culms woven into panels. Bamboo poles and boards are used in structures such as pavilions, bridges, scaffoldings and in fencing, gates, screens, trellises, furnishings, and accessories or decorative items. Woven bamboo panels have been used as screens and decorative fence or façade treatments. Because bamboo is a rapidly renewable and versatile material with characteristics similar to woods, its use as an alternative to wood has expanded rapidly in recent years, particularly in building interiors, for example laminate flooring and panels, chipboard, and fiberboard (Wong 1995). The aim of this work is therefore to investigate the mechanical properties such as compressive test, tensile test and hardness test of ‘Agaraba’ and to also determine the moisture content of the sample, which is a basic requirement for effective analysis of its mechanical properties and to also find out based on the result, if it can serve as a substitute or alternative to materials such as wood, plastic and even metal in some engineering applications.

Materials and Methods

Determination of Moisture Content

The principle of weighing the loss in mass of the test piece on drying to constant mass was adopted to determine the moisture content in which the calculation of the loss in mass as a percentage of the mass of the test piece after drying was carried out. The apparatus used were weighing balance, electric oven and desiccator. The test was conducted in an environment of 23^{o}C temperature and 60% relative humidity. The test piece of approximately 30 mm wide, 30 mm long and 10 mm thick was weighed to an accuracy of 0.01 g and then dried in an oven at a temperature of 103 ± 2^{o}C. The mass was recorded at regular intervals of two hours. Care was taken to prevent increase in moisture content between removal from the oven and subsequent determinations of the weight by putting the specimen inside a desiccator when out of the oven. The drying was considered complete when the difference between the successive determinations of the weight did not exceed 0.01 g.

Determination of the Hardness

The hardness test of ‘Agaraba’ was carried out based on ASTM D1037 (1999) by applying a load of 100 g on the specimen of minimum thickness of 10 mm with a rectangular cross section and right angle corners on a Brinell hardness machine. A 10-mm ball diameter ball was used for the purpose. The apparatus used to conduct the hardness test were Brinell hardness machine, micrometer microscope, hand file, hacksaw, venier caliper and adhesive.

Specimens were cut from the top, middle, and bottom locations of the culm using a hack saw to a rectangular cross section with right angle corners and were designated with letters *T*, *M* and *B*, respectively. The top and middle part of the specimens whose thickness were less than the minimum thickness of 10 mm were stacked together with an adhesive and filed to shape to attain the minimum thickness. It was also ensured that the surfaces of the specimens were made smooth for accurate measurement. The top (*T*) labeled specimen which represented the upper part of ‘Agaraba’ was placed on the anvil of the Brinell hardness machine, the hand wheel was rotated so that the specimen along with the anvil moved up until it contacted the 10-mm diameter steel ball. The load was then applied mechanically (by a gear driven screw) until the desired load of 100 g was attained and ball formed an impression on the specimen in the process. The diameter of the indentation made on the specimen by the pressed ball was measured by the use of a micrometer microscope which has a transparent engraved scale in the field of view. The same procedures were repeated for the middle (*M*) and bottom (*B*) labeled specimen of ‘Agaraba’ and the Brinell hardness number was calculated using the load applied and the indentation diameter of the specimens.

Determination of the Compressive Strength

The compressive strength of ‘Agaraba’ was evaluated using the specimen made parallel to the fiber direction. AC162 (2000) test technique was used for the evaluation of the compressive strength properties. The specimens were tested on a universal testing machine of capacity 100 kN with a loading rate of 0.9 mm/min. The apparatus used were universal testing machine, venier caliper and hacksaw.

The test specimens were cut from the top (*T*), middle (*M*), and bottom (*B*) locations of ‘Agaraba’ using a hacksaw and the dimensions of the specimens were measured accurately by a vernier caliper. The top marked specimen which represented the upper location of the culm was placed parallel to the fiber direction on the compressive plate of the Universal Testing Machine and the specimen was placed so that the centre of the moveable head of the Universal Testing Machine was vertically above the center of the cross section of the specimen. A small load of not more than 1 kN was initially applied to set the specimen, a continuous load was then applied to cause the moveable head of the Universal Testing Machine to travel at a constant rate until failure occurred. The displacements at various load intervals were recorded and the same procedures were repeated for the middle and bottom locations of the culm sample. The ultimate compressive strength was calculated using the data from the failure load and cross sectional area of the specimens.

Determination of the Tensile Strength

The apparatus used were universal testing machine, venier caliper, hacksaw, surface planer, hand file, metal plate and adhesive**.** The tensile test specimens were prepared to shape with the use of file and surface planer. A 1.5-mm thick metal plate was glued to the specimens in order to avoid slip during the test. The cross sectional dimensions of the gauge portion (length of exposed portion) of the top (*T*) location of the culm was measured and recorded. The specimen was placed in the upper grip of the moveable cross-head of the Universal Tensile Machine and the moveable cross-head was operated to move downward so as to fix the lower portion of the specimen to the lower grip on the table of the universal testing machine. Load was applied continuously at rate of 0.01 mm/sec until failure occurred and displacements at various load intervals were recorded until failure occurred. The same procedures were repeated for the middle and bottom locations of the culm and the ultimate tensile strengths were calculated using the data gotten from the failure load and cross sectional area of the gauge length of the specimens.

Determination of Moisture Content

The moisture content of the test piece was determined by

$MC = [(M - M_O) / M_O] \times 100,$ (1)

where:

M = original mass of specimen before drying (g); and M_O = mass of specimen after drying (g).

Determination of the Brinell Hardness Values

The Brinell hardness number of the top (T), middle (M) and bottom (B) locations for 'Agaraba' was determined by (ASTM 1999):

$HB_{avg} = (HB_T + HB_M + HB_B) / 3,$ (2)

where:

HB_{avg} = Average Brinell hardness number;
HB_T = Brinell number of the top location;
HB_M = Brinell number of the middle location; and
HB_B = Brinell number of the bottom location.

Determination of the Ultimate Compressive Strength

The ultimate compressive strength for the top, middle and bottom locations of 'Agaraba' could be determined by (Bhadari 2001):

$\sigma_{ultC} = F_{ultC} / A,$ (3)

$A = \pi / \{4[D^2 - (D - t)^2]\}$, and (4)

$\sigma_{avg\ ultC} = (\sigma_{ultC\ T} + \sigma_{ultC\ M} + \sigma_{ultC\ B}) / 3,$ (5)

where:

F_{ultC} = maximum load at which specimen failed when compressed (KN);
σ_{ultC} = ultimate compressive strength of the bamboo material (MPa);
$\sigma_{ultC\ T}$ = ultimate compressive strength of the top position (MPa);
$\sigma_{ultC\ M}$ = ultimate compressive strength of the middle position (MPa);
$\sigma_{ultC\ B}$ = ultimate compressive strength of the bottom position (MPa);
$\sigma_{avg\ ultC}$ = average compressive strength of the material (MPa);
A = cross sectional area of the specimen (mm^2);
D = outer diameter of the specimen (mm); and
t = thickness of the specimen (mm);

Determination of the Ultimate Tensile Strength of the Material

The ultimate tensile strength for the top, middle and bottom locations of 'Agaraba' could be determined by:

$\sigma_{ultT} = F_{ultT} / A,$ (6)

$A = W \times t$, and (7)

$\sigma_{avg\ ultT} = (\sigma_{ultT\ T} + \sigma_{ultT\ M} + \sigma_{ultT\ B}) / 3,$ (8)

where:

F_{ultT} = maximum load at which specimen failed at tension (KN);
σ_{ultT} = ultimate tensile strength (MPa);
$\sigma_{ultT\ T}$ = ultimate tensile strength of the top position (MPa);
$\sigma_{ultT\ M}$ = ultimate tensile strength of the middle position (MPa);
$\sigma_{ultT\ B}$ = ultimate tensile strength of the bottom position (MPa);
$\sigma_{avg\ ultT}$ = average tensile strength of the material (MPa);
A = cross-sectional area of the gauge length (length of exposed portion of specimen) (mm^2);
W = width of the gauge length (mm); and
t = thickness of the gauge length (mm).

Results and Discussion

The mass of the specimen during and after drying is shown in Table 1. For effective comparison of result and effect of moisture content to the mechanical properties of bamboo and other wood-based plant, the moisture content of 'Agaraba' was determined using Eq. (1) to be 19% which was the weight of the water in the culm expressed as a percentage of dry weight of the culm. It was observed that during the drying process, that there was reduction in the thickness of the specimen which was due to loss of moisture.

Table 1. Results of mass of the specimen during and after drying.

Original mass (g)	Mass after 2 hr (g)	Mass after 4 hr (g)	Mass after 6 hr (g)	Mass after 8 hr (g)	Mass after 10 hr (g)
20.39	17.24	17.19	17.15	17.12	17.12

This justifies the fact that the mechanical properties of ‘Agaraba’ could be influenced by the amount of water present, surrounding relative humidity and temperature. It was also observed that the hardness of ‘Agaraba’ varied with the length of the culm. These results showed that the hardness of bamboo plant reduces from the top to the bottom of the culm. The average Brinell hardness number of the top, middle and bottom locations of the specimen was determined using Eq. (2) to be 3.96 (Table 2); this indicated that ‘Agaraba’ could be comparable favorably with the hardness of soft and hard woods as shown in Table 3.

It was observed from the load-displacement compression data (Table 4) that there was a roughly linear relationship between the load and displacement when load was applied during the test. It was also observed (Table 4) that the bottom location of ‘Agaraba’ experienced the highest displacement at critical load followed by the middle and the top location. This indicated that the harder the material, the lower the displacement experienced. From Table 4, it was obvious that there were significant differences between locations along the culm height for the compressive strength with the highest value located at the top. The average ultimate compressive strength of ‘Agaraba’ was determined using Eq. (5) to be 75.69 MPa (Table 2), this high value was comparable to that of mild steel, wood, concrete and plastic as in Table 5 and this also shows that bamboo could also serve as a good substitute to wood in some engineering applications. The average ultimate tensile strength of ‘Agaraba’ was determined using Eq. (8) to be 295.33 MPa (Table 2). This value is higher than that of wood, concrete and plastic as shown in Table 5. The higher value of the ultimate tensile strength of bamboo enables its usage as reinforcement for concrete slabs.

The trends of the tension data from Table 6 showed that the displacement increases with increase in load. It was also observed from Tables 4 and 6 that ‘Agaraba’ specimen experienced higher displacement when under tension than compression.

Table 2. Summary of the mechanical properties of ‘Agaraba’.

Locations	Ultimate compressive strength (MPa)	Ultimate tensile strength (MPa)	Hardness (HB 10/100)
Top	83.75	313	4.55
Middle	79.68	297	4.02
Bottom	63.65	276	3.3
Average	75.69	295.33	3.96

Table 3. Hardness test results for some selected materials.

Materials	Hardness (HB)
Softwood	1.6
Hardwood	2.6-7.0
Aluminum	15
Copper	35
Mild Steel	120
Glass	1,550

Table 4. Load-displacement compression data for the top, middle and bottom locations.

Top		Middle		Bottom	
Force (KN)	Displacement (mm)	Force (KN)	Displacement (mm)	Force (KN)	Displacement (mm)
5.00	0.05	5.00	0.06	10.00	0.07
10.00	0.14	10.00	0.09	20.00	0.14
13.00	0.18	20.00	0.16	30.00	0.19
17.00	0.26	35.00	0.34	40.00	0.25
20.00	0.38	40.00	0.41	50.00	0.34
		46.00	0.51	60.00	0.43
				70.00	0.58

Table 5. Typical strength values of timber, plastic, concrete and mild steel.

Material	Ultimate compressive strength (MPa)	Ultimate tensile strength (MPa)
Wood (16% Mc)	50-100	20-110
Plastic	10-90	7-70
Concrete	25-55	-
Mild Steel	-	400-570

Table 6. Load-displacement tension data for the top, middle and bottom locations.

Top		Middle		Bottom	
Force (KN)	Displacement (mm)	Force (KN)	Displacement (mm)	Force (KN)	Displacement (mm)
2.00	0.32	5.00	0.62	5.00	0.70
4.00	0.52	10.00	1.21	10.00	0.92
6.00	0.93	13.00	1.75	15.00	1.10
8.00	1.42	15.00	1.92	20.00	1.47
11.52	1.95	17.82	2.12	25.00	1.96
				27.60	2.44

Conclusion

In this work, some mechanical properties of ‘Agaraba’ were evaluated. Hardness, compressive and tensile test were conducted on the bamboo culm. Samples were taken from the top, middle and bottom locations for all the tests carried out.

The results showed that the average compressive strength, tensile strength and hardness are 75.69 MPa, 295.33 MPa, and 3.96, respectively (Table 2).

It was also found that the strength varies along the length with the highest recorded at the top location followed by the middle and bottom location. Due to the compatibility of these results to that of engineering materials like wood, mild steel, plastic and concrete, it could therefore be concluded that the potential of ‘Agaraba’, which has been under utilized in Nigeria despite its affordability and availability, could be used as an alternative to other materials in applications such as housing, construction and piping.

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