

Investigation into the Physical and Mechanical Properties of Structural Wood Commonly Used in Nigeria: A Case Study of Benin City

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Abstract An experimental study of the structural and mechanical properties of some selected tropical timber species available locally in Nigeria was carried out. The fundamental aim of this paper is to establish the properties of timbers currently used in Benin City, since manufacturing and preservation processes affect the properties of timber. Four chosen species, Albizia (*Albizia ferruginea*), Dahoma or Ekhimi (*Piptadeniastrum africanum*), Ekki (*Lophira Alata*) and Opepe (*Nauclea diderichii*), were obtained, and tests for their mechanical properties (compressive strength, modulus of rupture and modulus of elasticity) and physical properties (moisture content and density) were conducted. The mechanical properties of these species were compared to data published by international organisations. It was observed that woods from Benin City had lower strength values, compared to average values published for these species. From the results, Albizia showed much lower strength properties than Ekhimi and Opepe. Ekki exhibited very high values of all mechanical properties, at 12% moisture content. It also had a very high density. Albizia had a low density and moisture content at its basic state, while Ekhimi and Opepe had medium moisture contents and densities at their basic states, respectively. From these results, their suitability as structural members was inferred, after having compared their mechanical properties.

Keywords Tensile test, Strength, Moisture content, Density, Elastic

1. Introduction

Timber is a major construction material that can be used in almost every facet of construction [1]. Timber in its simplest form can be said to be the hard, tough substance that forms the trunks of trees [2]. The Nigerian code of practice, NCP2 1973, defines timber as wood in a form suitable for construction of carpentry, joinery, or for manufacturing purposes [1, 2]. Basically, timber is a biological and organic material often used in its natural state; anisotropic and hygroscopic, with widely varying properties depending on species, geographical area where the tree grows, the growth conditions, size of the tree at harvest, sawing and any other manufacturing processes [3].

As a structural element, timber is usually used in areas in a structure where load-bearing is at the minimum or virtually non-existent, to maximize the workability, and minimise cost [4]. However, in some countries where timber is the major construction material for most structures, design of these structures is done with regard to timber, and special treatment is given to the wood before or after construction

[5]. Also, particular species are used in construction, depending on the property required. Some species possess high resistance to bending and compression stresses, chemical or insect attack, or resistance to fire than others, which makes them desirable when these properties are needed [6].

In the tropics, timber abounds, and is one of the cheapest and highly available materials. In Nigeria, a wide range of species of timber are available, and selection of the appropriate species for a particular use is of utmost importance [7-9].

Significant reduction in compressive and static bending strength of these species could be attributed to many factors, among which are premature felling of the trees before they reach maturity; presence of defects in the wood; improper drying (seasoning) of the wood, and improper timber conversion processes; poor growth conditions (e.g. poor soil and nutrients for tree growth, etc.); position along the tree trunk from which the specimen was obtained (strength properties are usually greater towards the bottom of the trunk, and reduce as one travels upwards); discrepancies in the moisture content and density of the samples, which in turn, due to swelling and shrinkage, have a great influence on the moduli of elasticity of the samples; and the different locations of origin of the wood from which the different specimens used to undergo these tests were obtained [9-12].

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Thus, this work intends to address the possible variation in properties of timber as a result of current manufacturing and production process in Nigeria. Thus, complementing the work of other researchers [9, 14, 15]. Table 1 to 3 show the mechanical properties of timber, which are not from Benin, published in literature.

The aim of this research is to ascertain the inherent physical and mechanical characteristics/properties of some selected species of tropical timber available in Nigeria, using Benin City, Edo State. It has been shown that the location, climate, planting technique and specie could have significant impact on the physical and mechanical properties of timber [12-14].

Table 1. Properties for selected group of species [9]

Specie	Density(kg/m ³)	Compressive strength (N/mm ²)	Modulus of Elasticity (N/mm ²)
Albizia	734.2	35	9800
Ekhimi	776.7	60	10,600

Table 2. Properties for selected group of species [14]

Specie	Density (kg/m ³)	Compressive strength (N/mm ²)	Modulus of Elasticity (N/mm ²)
Ekhimi	700	57	15,190
Ekki	1060	96	21,420
Opepe	760	63	14,660

Table 3. Properties for selected group of species [15]

Specie	Density (kg/m ³)	Compressive strength (N/mm ²)	Modulus of Elasticity (N/mm ²)
Albizia	592-720	32.6	7523
Ekhimi	900-1100	57	12,300
Ekki	950-1100	-	18,500
Opepe	740-760	-	13,400

2. Materials and Methods

All the samples were sawn and/or planed to the sizes required for each test, as required by BS 373: 1957 [16], and the diagrams of each sample shape and dimensions are shown along with the tests. However, there were slight variations in dimensions, due to poor machining operations by the operators, non-uniformity of the wood sold, the thickness of the blade used in cutting and the calibration of the Universal Testing Machine (UTM) used, calibrated in kN, which only reflects failure readings of sections of more than 5mm thickness. Regardless, all these variations in the dimensions were within the permissible variations stated in Clause 13 of BS 373: 1957.

2.1. Moisture Content Determination

In determining the moisture content of a timber specimen, several methods abound. However, the oven-drying method was chosen for use in this study due to its ease of conduction and relatively moderately high accuracy. The test was

conducted according to Clause 2 of BS 373: 1957, and calculations made according to Appendix A of the same code. The test specimen was prepared as shown in Figure 1.

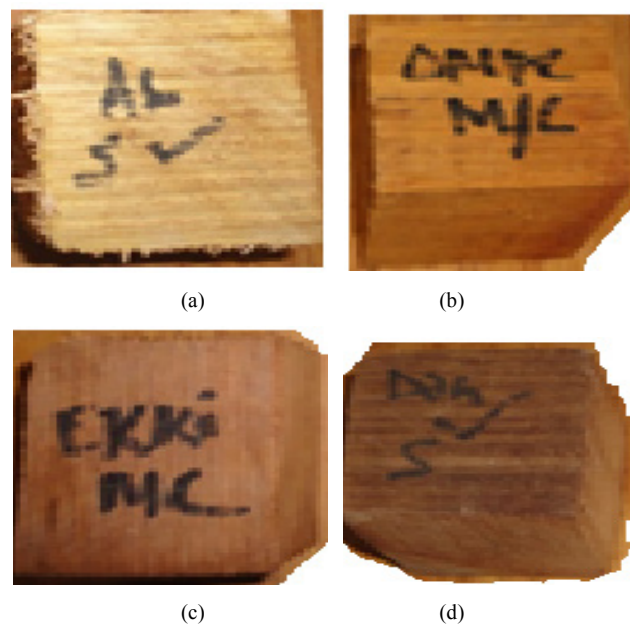
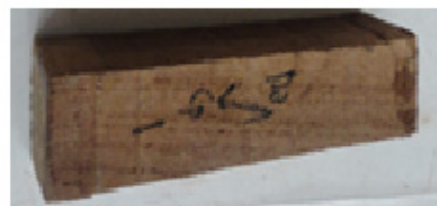
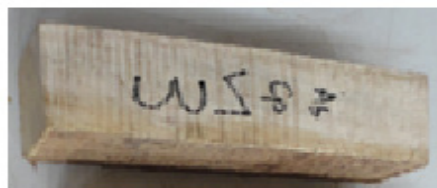


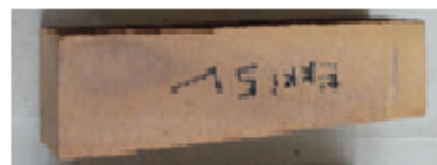
Figure 1. (a) Albizia (b) Opepe (c) Ekki (d) Ekhimi



(a)



(b)



(c)



(d)

Figure 2. (a) Ekhimi (b) Albizia (c) Ekki (d) Opepe

2.2. Compressive Strength Determination

The compressive strengths of the different species studied, in parallel and perpendicular direction to the timber grains, were obtained from test procedures according to Clauses 8a and 8b of BS 373: 1957. The shapes and sizes, as shown in Figure 2 were prepared according to the 2-inch standard for both tests stated in the code. Afterwards, each sample in turn, was placed under the compression chamber of an Avery-Denison Universal Testing Machine (as shown in Figure 3), and load was applied at a rate of 0.01cm/s. The failure load (in KN) of each sample was observed, read off the dial gauge and recorded.



Figure 3. Arrangement of sample for compression test



Figure 4. Avery-Denison Universal Testing Machine

2.3. Tensile Strength Determination

The tensile strength parallel to the grain was determined for each specie, according to clause 12 of the BS 373: 1957 code. Each sample was mounted in the tension chamber of an Avery-Denison Universal Testing Machine shown in

Figure 4. The tensile load was applied at a constant head speed of 0.02cm/s, and the failure loads of the samples were recorded. The tensile strength of each sample was obtained by dividing the cross-sectional area of the gauge length under test by the maximum load.

2.4. Bending Strength Test

Figure 5 shows the test specimen shape and size employed in the determination of the static bending strength (i.e. determination of the modulus of elasticity of a small clear specimen of timber). The sample size was obtained and tests were carried out according to the provisions of Clause 6 and Appendix A of the BS 373: 1957 code, using the 2 cm standard and the central loading method.



Figure 5. Static bending test specimen shapes and sizes (a) Albizia (b) Ekimi (c) Ekki (d) Opepe

The samples were cut to 20 mm x 6 mm x 500 mm, and finished for straight edges. The apparatus for the test, including a spirit level (to check for horizontality), clamps for holding down the specimen, a dial gauge to measure the deflection, and a hanger and weights for applying load at mid-span of each specimen.

3. Results

The moisture contents and dry densities results are presented in Table 4. Table 5 shows the compressive strength of studied timbers with respect to the direction of grain (i.e. parallel and perpendicular strength computations were obtained), while Table 6 shows the tensile strength of these timbers.

Table 4

Specimen tested	Moisture Content (%)	Dry Density (kg/m ³)
Albizia	32.52	690
Ekimi	43.23	912
Ekki	13.57	997
Opepe	23.87	776

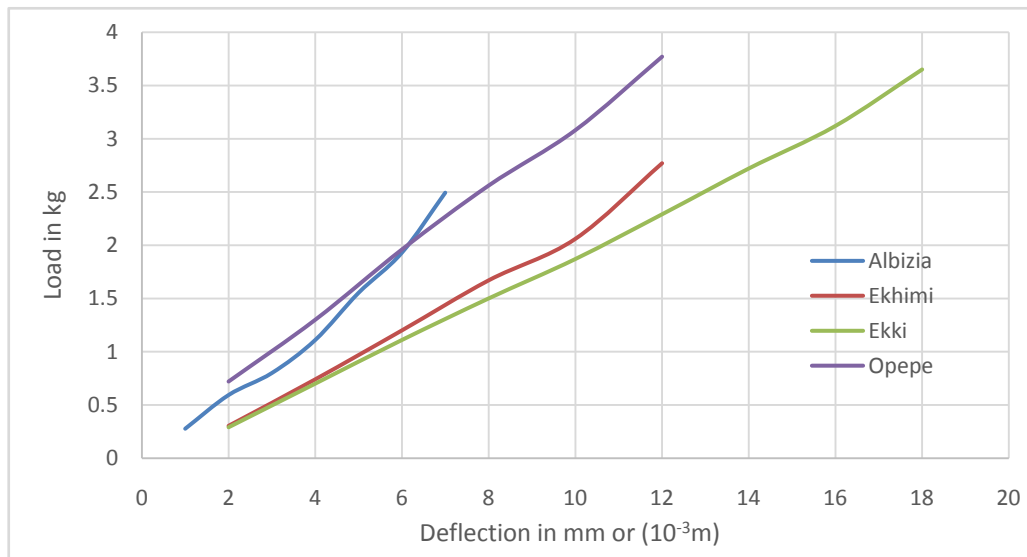


Figure 6. Load deflection curves

Table 5. Compressive Strength

Specimen tested	Average Compressive Strength in kN/m^3 (parallel to grains)	Average Compressive Strength in kN/m^3 (perpendicular perpendicular)
Albizia	35300	19600
Ekhihi	49470	32130
Ekki	62000	51200
Opepe	45070	39400

Table 6. Modulus of rupture

Specimen tested	Modulus of rupture in N/m^2
Albizia	6.76×10^7
Ekhihi	8.7×10^7
Ekki	1.11×10^8
Opepe	9.22×10^7

Applying a point load at mid-span to the specific timber beams, load-displacement curves were obtained as shown in Figure 6. Subsequently, the Young's modulus of the selected timbers were obtained as shown in Table 7.

Table 7. Modulus of Elasticity Results

Specie	Length (m)	Moment of Inertia, $I (\text{m}^4)$	Slope of load-deflection, $dP/d\Delta (\text{N/m}^2)$	Modulus of Elasticity, $E (\text{N/m}^2)$
Albizia	0.5	0.036	0.87×10^6	6.3×10^9
Ekhihi	0.5	0.036	1.5×10^6	1.09×10^{10}
Ekki	0.5	0.036	1.6×10^6	1.2×10^{10}
Opepe	0.5	0.036	1.08×10^6	7.8×10^9

4. Discussion of Results

Comparing the results obtained from the tests to those

presented in previous researches, it was observed that properties varied slightly, and sometimes, greatly. (Compare Tables 1, 2 and 3 to Tables 4-7)

Changes in mechanical properties, as observed in the results, can be attributed to site specific factors in Benin City. The average annual precipitation of 2025mm and average temperature of 27.5°C can be inferred to have significant effect on the properties of timber sourced from Benin City. Other research have shown that the property of latewood, for example, has a strong correlation with climatic variables. In fact, it was observed that specific months of intense precipitation and temperature have significant correlation with properties of latewood. Rainfalls in the month of May and August were found to be very important [17]. Thus, the substantial rainfall between the months April to September, in Benin City, could have significant effect on the varied properties observed.

Thus, in this regard, the results from this work for timbers in Benin complements the results obtained from other studies. Also, comparing the compressive strength and modulus of elasticity values to those presented in other reports [15, 16], it was observed that the obtained compressive strength of Ekhihi was a bit lower than values presented in other works, and the same was the case with Ekki and Opepe. Albizia was within the same range. However, in the modulus of elasticity values, all the obtained results differed greatly, the obtained results being substantially less than those presented in the reports (this can be seen from comparing Tables 3 to 7).

Fundamentally, the mechanical properties of woods tested falls below international values of published properties. In all cases, the specific gravities at 12% moisture content were higher in all samples tested in Benin City, compared to internally published values.

The average values for the modulus of rupture (MOR) for Ekki, Albizia, and Ekhihi and Opepe species, at 12% moisture content, grown in Benin City were below average

values, which have been published internationally. This shows that species in Benin City can sustain less bending strains and stresses before rupture. Thus, in designing for such local specie, care needs to be taken to apply a conservative factor of safety to account for the reduced bending strength.

An average of 50% reduction in the elastic modulus (Young's modulus) of species found in Edo State was also observed as shown in Tables 8-11. This implies that stiffness's are lower for species found in Edo State. In comparison to other species, locally and international, the Ekki wood gave the highest elastic modulus. This values makes it a material of choice, internationally.

Table 8. Comparison between experimental and published mechanical properties of Ekki

Ekki, Azobe (<i>Lophira alata</i>)		
	Published Average Values*	Experiment
Source	West Africa	Specie in Benin
Specific Gravity (12% MC)	1.06	0.99
Modulus of rupture	$1.96 \times 10^8 \text{ N/m}^2$	1.11×10^8
Elastic Modulus	$1.9 \times 10^{10} \text{ N/m}^2$	$1.2 \times 10^{10} \text{ N/m}^2$
Crushing strength (Parallel)	$9.6 \times 10^7 \text{ N/m}^2$	$6.2 \times 10^7 \text{ N/m}^2$
Characteristics	Rot resistant, no odour and hard	

* Data source: Wood Database [18]

Table 9. Comparison between experimental and published mechanical properties of Albizia

Albizia (<i>Albizia ferruginea</i>)		
	Published Average Values*	Experiment
Source	Tropical Africa	Specie in Benin
Specific Gravity (12% MC)	0.6	0.69
Modulus of rupture	$8.3 \times 10^7 \text{ N/m}^2$	$6.8 \times 10^7 \text{ N/m}^2$
Elastic Modulus	$1.1 \times 10^{10} \text{ N/m}^2$	$0.63 \times 10^{10} \text{ N/m}^2$
Crushing strength (Parallel)	$4.9 \times 10^7 \text{ N/m}^2$	$3.53 \times 10^7 \text{ N/m}^2$
Characteristics	Used in furniture making, no odour and hard	

* Data source: Wood Database [19]

Table 10. Comparison between experimental and published mechanical properties of Opepe

Opepe (<i>Nauclea diderrichii</i>)		
	Published Average Values*	Experiment
Source	Africa	Specie in Benin
Specific Gravity (12% MC)	0.65	0.78
Modulus of rupture	$1.27 \times 10^8 \text{ N/m}^2$	$9.2 \times 10^7 \text{ N/m}^2$
Elastic Modulus	$1.38 \times 10^{10} \text{ N/m}^2$	$0.78 \times 10^{10} \text{ N/m}^2$
Crushing strength (Parallel)	$5.9 \times 10^7 \text{ N/m}^2$	$4.5 \times 10^7 \text{ N/m}^2$
Characteristics	Rot resistant, no odour and hard	

* Data source: Mat Web [20]

Table 11. Comparison between experimental and published mechanical properties of Ekimi

Ekimi (<i>Piptadeniastrum africanum</i>)		
	Published Average Values*	Experiment
Source	Africa	Specie in Benin
Specific Gravity (12% MC)	0.7	0.91
Modulus of rupture	$1.37 \times 10^8 \text{ N/m}^2$	$0.87 \times 10^8 \text{ N/m}^2$
Elastic Modulus	$1.5 \times 10^{10} \text{ N/m}^2$	$1.1 \times 10^{10} \text{ N/m}^2$
Crushing strength (Parallel)	$5.7 \times 10^7 \text{ N/m}^2$	$5 \times 10^7 \text{ N/m}^2$
Crushing strength (Perpendicular)	-	$3.2 \times 10^7 \text{ N/m}^2$
Characteristics	House framing and construction	

* Data source: TROPIX CIRAD [21]

Ekki also gave the highest value of crushing strengths. Though the values obtained for Ekki wood found in Benin City was lower than average values which have been published internationally, it was found to be the hardest wood in terms of compressive strength in Benin City.

The relatively high values of compression and tensile strengths of Ekki wood found in Benin City, compared to other species from Benin City, makes it a material of choice in the construction of footbridges, piles and decks in Nigeria.

The specific gravities of woods found in Benin City correlated well with averaged values that have been published. Also, Ekki was found to have the highest value of specific gravity, i.e. most dense.

The significant reduction in compressive, static bending strength and Young's Modulus of these species found in Benin City when compared to similar species elsewhere could be attributed to many factors, among which are premature felling of the trees before they reach maturity; presence of defects in the wood; improper drying (seasoning) of the wood, and improper timber conversion processes; poor growth conditions.

Values obtained for the mechanical properties of locally sourced Ekki are similar to those of the Red woods, which are commonly found in the U.S. For example, the Red Oak has a modulus of rupture of $9.9 \times 10^7 \text{ N/m}^2$ compared to $1.11 \times 10^8 \text{ N/m}^2$ obtained for locally sourced Ekki. Red Oak has an average elastic modulus of $1.2 \times 10^{10} \text{ N/m}^2$ while locally sourced Ekki has a value of $1.16 \times 10^{10} \text{ N/m}^2$. However, Ekki from Benin City had much higher crushing strengths of $6.2 \times 10^7 \text{ N/m}^2$ when compared to Red Oak's $4.7 \times 10^7 \text{ N/m}^2$ [22].

5. Conclusions

The following conclusions can be drawn from this work:

1. This research shows that Ekki, being of high strength, can be used for major structural work. Ekki showed superior properties in terms of modulus of elasticity, crushing strength and modulus of rupture.

2. The mechanical properties of timber can vary significantly depending on its manufacturing process and the climate of the location from which it is obtained.
3. It was found that the mechanical properties of woods obtained from Benin City, at 12% moisture content, fell below the average values that have been published for similar species, internationally.
4. Ekimi from Benin City can be used but must be properly seasoned and protected against absorbing moisture due to its highly hygroscopic nature.
5. Opepe from Benin City can also be used in structural works, but only for moderately-loaded members.
6. It is inadvisable to use Albizia for any sound load-bearing structural member. It should be restricted to light construction and bracing.

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