Thermo-Physical and Mechanical Properties of Five Wood Species Grown in Abeokuta, Ogun State, Nigeria

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Abstract

Thermal conductivity, toughness, cleavability tensile and bending strengths of *Khaya senegalensis* (Oganwo), *Nauclea diderrichii* (Opepe), *Triplochiton scleroxylon* (Arere), *Pycnanathus angolensis* (Akomu), *Albizia zygia* (Ayunre) grown in Ogun State, Nigeria were investigated to obtain preliminary data on these properties to guide utilization. The thermal conductivity was measured using fully automated unitherm 6000 Guarded Hot Plate (-170 to 550^{0}C) while the tensile and bending strengths of the woods were evaluated using INSTRON 5500 series Electromechanical Testing Machine configured with the 2820 series base beam and three-point anvil settings based on ASTM 52188 and ASTM 52186 recommendation respectively. The toughness analysis was carried out in accordance to ASTM D6110-97 using Charpy Notched method while the cleavability of the wood was determined using a static testing arrangement. Results indicated that the thermal conductivity of these five wood species ranged from 0.20-0.26 W/m.k. with Opepe and Arere having the lowest thermal conductivity of 0.21W/m.k. The toughness of Oganwo (73.16 J/cm) and Opepe (67.27 J/cm) was the highest and lowest respectively thereby making Opepe the most amenable to splitting and use for firewood. The values obtained for tensile and bending strengths are in increasing order from Opepe, Akomu, Arere, Ayunre to Oganwo. Oganwo has the maximum values for all the properties investigated. This study was able to generate data on specified properties for Opepe, Akomu, Arere, Ayunre and Oganwo grown in Abeokuta, Ogun State while also establishing the need to be conservative in the use of these five wood species.

Keywords: Wood properties, Strengths, Thermal conductivity, Toughness, Cleavability.

Introduction

Wood is a natural resource that is complex in nature yet it is often most preferred to other alternative materials in the production of structural and non-structural items. Renewability, abundance, accessibility, versatility, less energy input required for processing and relative cheapness are particularly responsible for its preference (Lucas, 2006). Up till now wood remain the most sought tangible forest resources in many African countries. Forests in Africa are still largely dependent upon for continuous production of different wood species. The scarcities of fine quality wood often obtained from the most familiar economic trees have since been reported (Lucas, 1983). The issue of sustenance therefore requires strong ecological forest management practices combined with wood utilization guided by sufficient and up-to-date properties knowledge.

The scarcity of fine quality woods has forced into the markets species that ten years ago were considered only acceptable for low-end construction type uses. One case in point is the patronage recently given to the use of *Pycnanathus angolensis* (Akomu), *Triplochiton scleroxylon* (Arere) and *Albizia zygia* (Ayunre) as general purpose wood in Abeokuta area of

Ogun State. These wood species, though had been in use before ten years ago, had only exclusively used for special end purpose. Recently the use has been extended as they are sought for any end uses including structural and non-structural use. Again, *Khaya senegale* a species of Mahogany, recently classified as vulnerable due to insufficient information c growing status in the wild in the locality like Cameroon, Central African Republic, Ga Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Nigeria, Senegal, Sudan, Togo, Burkina Faso (The Wood Explorer, 2011). The same situation holds for the *Nauclea dideri* (Opepe) that has been listed alongside of other most common economic wood species th fast thinning out of forests located in the South West Nigeria (Lucas, 1983). To promote sustainability of these five wood species, it is expedient to make available loca information on their mechanical and physical properties to the would-be users to guide selection for desire end uses.

Wood being a biological material with complex nature has its mechanical properties influe by growth, environmental and experimental conditions (FPL, 1999). Since these condi vary from place to place, it is expected that the characteristic properties of wood wi location biased. Value is often assigned to each wood property using standard experim method under prescribed condition with appropriate testing equipment.

This study had considered some elements of information being required for the five sel wood species in the study area to includes tensile, bending and cleavability stren toughness and thermal conductivity. The choice of these properties for investigati dependent on equipment availability and desired end uses for these species in the study are

Methodology

Wood samples used were extracted from trees fell around the University of Agricu Abeokuta, Ogun State. Three discs each were cut from different location along tree bole: below breast height, log middle and top. By annual ring count, none of the samples were than 25 years of age. The wood test samples were machined from the cut dicks and conditi in room atmospheric conditions before the test is carried out. The values reported averages of all the values for each species since the study was designed to yield prelim data. The INSTRON 5500 Electromechanical Testing Machine (ETM) configured with series base beam and three-point anvil was used for tension strength test. Minimum sp depth of 14in was used in accordance with ASTM 52188. The data was interpreted using hill 2 Flexure software module. For bending test strength, the only modification carrie was that yoke deflectometer was added to the set up and procedure for the test w accordance to ASTM 52186. In accordance with ASTM D6110-97, Charpy impact resis method was used for toughness test. Wood sample of 1.27 x 1.27 x 12.7 cm was no before used. A Fully automated Unitherm 6000 Guarded Hot Plate (-170 to 550^{0}C) desi for insulating materials was used to determine thermal conductivity of 3mm square sample size. A special device consisting of two hooks with one suspended at the centre an other extended above the movable head was designed set up for cleavage test. A 1inch was bored at the centre while another 0.25 inch hole from each end of each of the 5 x 5 cm wood sample used thus reducing the sample cross section been tested to 2 x3 inch. The ends of the hooks are fitted into the notch at the specimen ends while the movable head machine was made to descend at the rate of 0.25 inches/ minute, pulling apart the hooks splitting the block. Samples used for this test were prepared taken into consideration principal planes of wood.

Results and Discussion

The results of all the tests conducted were presented for each wood species separately before merging corresponding data for wood properties comparison.

Khaya senegalensis **(Mahogany)**

K. senegalensis is a species of a Mahogany that is called Oganwo in the study area. Oganwo refers to a heavier African mahogany with more similarities to *K. grandifoliola* and less to *K. ivorensis*. It has excellent wood quality with a firm texture and a natural dark reddish-brown color (CAB International, 2005). Its trees and logs, are liable to attack by longhorn and buprestid beetles; resistant to termites. Once dry, the wood is fairly stable in service (The Wood Explorer, 2011; Wood Technical Fact Sheet, 2011). At green moisture content, the bending and tensile strengths are 86.00N/mm² and 93.00N/mm² respectively while the average value recorded for its cleavability is 61.00N/mm. Details of the mechanical properties for 20mm standard is presented in Table 1 alongside with the thermo-physical property tested. These values were found to fall within the range of values found in the literature (Matbase, 2011).

Table 1: Average Values Obtained for Tested Properties of Mahogany

S/n	Sample Description	Test Results	*Range
1	Tensile Strength (N/mm²)	93.00	32.5 - 101
2	Bending Strength (N/mm²)	86.00	36 - 126
3	Thermal Conductivity (W/m.K)	0.26	0.14 - 0.31
4	Toughness (J/cm)	73.16	unavailable
5	Cleavability/Max.Crushing strength (N/mm)	61.00	52 – 63

*Existing range found in the literature green to dry (**Sources: Matbase, 2011; The Wood Explorer, 2011)**

The wood is sought for general use and particularly for furniture, joinery, dug-out canoes, mortars, spoons, fuel wood and structural members' production in the study area. There are over-exploitation of *Khaya senegalensis* for timber and medicine and this poses serious threat for its sustenance in Ogun State. It is expedient to fashion out sustainable methods of harvesting with prompt implementation.

Nauclea diderrichii **(Opepe)**

Nauclea diderrichii is given the same common name, Opepe, in the study area as generally called in Nigeria. Visual examination of its heartwood colour shows that it conformed to the ITTO (1986) description that the heartwood of Opepe is golden-yellow with a copper luster that get darkens upon exposure to air. The striking color of the wood together with the figure gives it a very attractive appearance. The bending and tensile strengths are 75.00N/mm² and 80.00N/mm² respectively while the average value recorded for its cleavability is 58.00N/mm. These values also falls within the established range found in literature (The Wood Explorer, 2011; Matbase, 2011). Details of all other properties measured are contained in Table 2.

Table 2: Average Values Obtained for Tested Properties of Opepe

S/n	Sample Description		Test Results	*Range
1	Tensile Strength	(N/mm^2)	80.00	122 -140
2	Bending Strength	(N/mm^2)	75.00	86.6 – 121.7
3	Thermal Conductivity	(W/m.K)	0.21	unavailable
4	Toughness	(J/cm)	67.27	unavailable
5	Cleavability/Max.Crushing strength	(N/mm^2)	58.00	47.86 -68.05

Existing range found in the literature from green to dry (Sources: Matbase, 2011; The Wood Explorer, 2011)

***Albizia zygia* (Ayunre)**

Albizia genus generally occurs throughout Africa both in the high forest and secondary forests (The wood Explorer, 2011) In the study area, it is common to find *Albizia zygia* as an ornamental, shade and roadside trees. It is often branded as one of the commonest urban tree species in the area. The heartwood is yellowish brown or pinkish brown to dark brown and is sometimes with red tinge but is distinctly demarcated from the wide pale yellow to grey sapwood. With visual inspection the grain appears sometimes straight or interlocked while its texture range from fine to coarse. Sawn lumber from *Albizia zygia* most often appear woolly and according to the test conducted, the green bending and tensile strengths are 81.00N/mm² and 86.00N/mm² respectively. The cleavability and toughness is experimentally determined as 55.00N/mm and 66.80lb respectively while the value obtained for the thermal conductivity is presented in Table 3.

Table 3: Average Values Obtained for Tested Properties of Ayunre

S/n	Sample Description		Test Results	*Existing Range
1	Tensile Strength	(N/mm^2)	86.00	unavailable
2	Bending Strength	(N/mm^2)	81.00	55.51-86.00
3	Thermal Conductivity (W/m.K)		0.24	unavailable
4	Toughness	(J/cm)	65.51	unavailable
5	Cleavability/Max.Crushing strength (N/mm^2)		55.00	29.81- 59.32

Existing range found in the literature from green to dry (Sources: Matbase, 2011; The Wood Explorer, 2011)

***Triplochiton scleroxylon* (Arere)**

The wood from *Triplochiton scleroxylon* is considered too soft for general joinery use, but it is highly suitable for small accurate mouldings (ITTO, 1986). It is commonly called Arere or Obeche and usually available in large sizes with relatively inexpensive prices range in the study area. The heartwood has no distinguishable colour from the sapwood and the test result shows that the bending and tensile strengths are 79.00N/mm² and 84.00N/mm² respectively.

The values obtained for the bending and tensile strengths were comparable with that wood species in the N_6 strength group listed in NCP (1973). Values of other properties determined were presented in Table 4.

Table 4: Average Values Obtained for Tested Properties of Arere

S/n	Sample Description	Test Results	*Existing Range
1	Tensile Strength (N/mm^2)	84.00	unavailable
2	Bending Strength (N/mm^2)	79.00	unavailable
3	Thermal Conductivity (W/m.K)	0.21	unavailable
4	Toughness (J/cm)	63.94	unavailable
5	Cleavability/Max.Crushing strength (N/mm^2)	53.00	unavailable

Pycnanathus angolensis **(Akomu)**

The wood from Akomu as it is called in the study area had been reported as having lower bending strength when compared with Mahogany (The Wood Explorer, 2011). The wood is whitish while its heartwood is hardly distinguishable from its sapwood. The texture may be medium to coarse with generally straight grain without luster. When freshly sawn it sometimes have an unpleasant odor which readily disappears on drying. The bending and tensile strengths are 77.00N/mm^2 and 82.00N/mm^2 respectively while the wood cleavability is 54.00N/mm (Table 5).

Table 5: Average Values Obtained for Tested Properties of Akomu

S/n	Sample Description	Test Results	Existing Range
1	Tensile Strength (N/mm^2)	82.00	unavailable
2	Bending Strength (N/mm^2)	77.00	unavailable
3	Thermal Conductivity (W/m.K)	0.22	unavailable
4	Toughness (J/cm)	67.67	unavailable
5	Cleavability/Max.Crushing strength (N/mm^2)	54.00	unavailable

General Overview of the Determined Properties for all the Wood Species

The results of all the mechanical properties examined for all the five wood species were summarized graphically in Figure1. It shows that the tensile strength values for the studied species decreases from *Khaya, Albizia, Triplochiton, Pycnanathus* to *Nauclea*. Since wood generally exhibits greatest strength in tension parallel to the grain (Faherty and Williamsonm 1994; Chadnoff, 1984), it is not of necessity to be conservative in giving preference to a particular species from among the five wood species in the consideration for the production of wooden item that is to support load in tension. However, it is observed that wood from the *Nauclea diderrichii* harvested from the study area has the least tensile strength.

The bending strength describes the deflection characteristics of wood. It very important in the consideration of wood species required to be produce wooden beam among others. The order of increasing value for the five wood species coincides with tensile strength

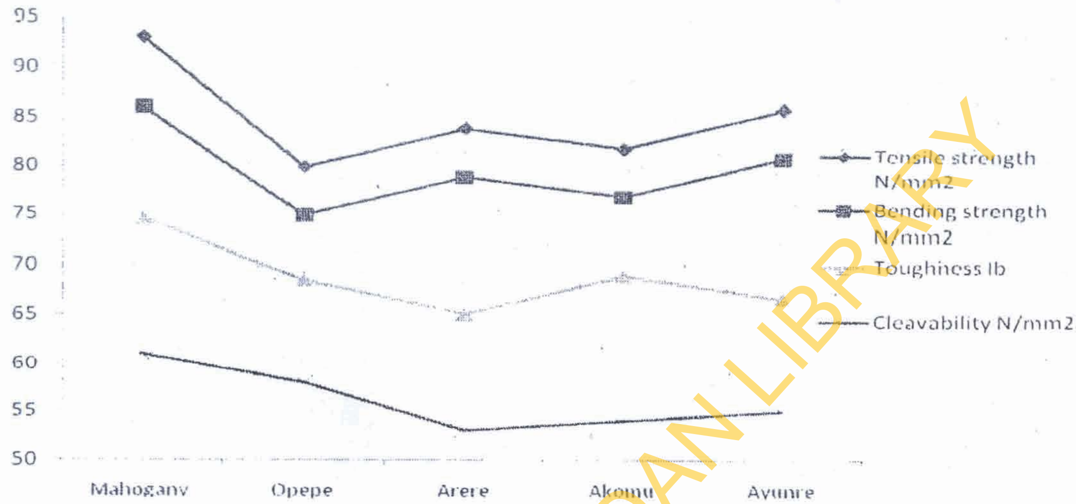

Figure 1: Summaries of the Tests Results for the Five Wood Species

trend. Unlike tensile strength, there may be need to replace Opepe with Oganwo or Ayunre when selecting wood species for making bottom cord of wooden truss from among the five wood species considered in the study area.

The average values obtained for maximum crushing strength test (wood cleavability) increases from Arere, Akomu, Ayunre, Opepe and Mahogany. This result show that energy required to split each of the five wood species increase from Arere to Oganwo in the order stated. This property influences the adaptability of wood to its use as firewood (), hence, Arere, Akomu and Ayunre are better suited for the purpose than Opepe and Oganwo because of relative ease of splitting. However, Mahogany and Opepe wood will be more useful among the five species for producing tool handle because of the higher energy required for splitting.

Ayunre has the least value of toughness of all the five wood species. The implication of is that it has highest tendency to break suddenly with a clean instead of a splintery fracture without warning (FPL, 1999). Therefore baring all other reasons, mortal, pest, wooden bridge among the likes made with Ayunre may not perform as well as that made with any other five species considered in the study area. This is because any of this wooden material will be expected to support impact loading.

Thermal conductivity is the property of a material that indicates its ability to conduct heat. For any material including wood thermal conductivity is inversely proportional to its thermal resistivity. Thermal conductivity depends on many properties of a material, notably its structure and temperature. For instance, pure crystalline substances exhibit very different thermal conductivities along different crystal axes, due to differences in phonon coupling along a given crystal axis. The thermal conductivity of most wood is much less than the conductivity of metals with which wood often is mated in construction (Okeke et.al, 1969).

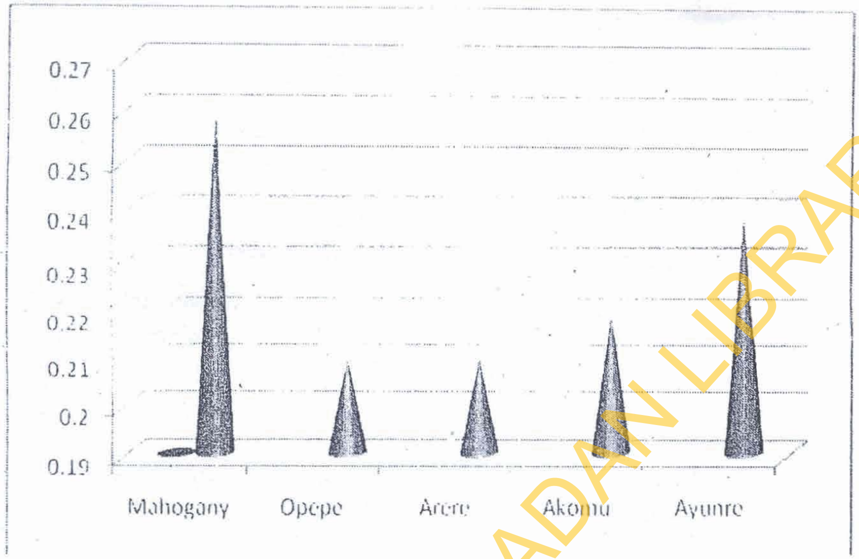

Figure 2: Summaries of Thermal Conductivity Test Results for all the Wood Species

Hence most wood is regarded as having low thermal conductivity and it varies from 0.04-0.4$Wm^{-1}k^{-1}$ depending on the species (FPL, 1999; Goyal, 1979). From the result of the test carried out, all the five species had their thermal conductivity within the 0.2 to 0.26 Wm^{-1} k-1 ranges as shown in Figure 2. Thus any of them can be used interchangeably for same insulating requirement.

Conclusion

This study established the need to be conservative in selecting wood for particular use among *Khaya senegalensis* (Mahogany), *Nauclea diderrichii* (Opepe), *Triplochiton scleroxylon* (Arere), *Pycnanathus angolensis* (Akomu), *Albizia zygia* (Ayunre) grown in Abeokuta Ogun State, Nigeria. For tensile and bending strengths the average values decreases from Oganwo, Ayunre, Arere, Akomu to Opepe. The average maximum crushing strength (wood cleavability) increases from Arere, Akomu, Ayunre. Opepe and Mahogany. The toughness decreases from Oganwo, Akomu, Opepe. and Ayunre to Arere. The thermal conductivity values of the five species ranges from 0.2 to 0.26 W/m.k. There are over-exploitation of *Khaya senegalensis* for timber and medicine and this poses serious threat for its sustenance in Ogun State. This study also observed that many hitherto un-familiar wood species are daily been introduced to plank markets in Abeokuta, Ogun state.

As a result of these findings, it is expedient to fashion out sustainable methods of harvesting *Khaya senegalensis* with prompt implementation. Because of the abuse of use of the wood species which properties were investigated and the new wood species just entering into the plank market in the study area, it is necessary to initiate full blown research on all the properties of wood species growing in Abeokuta, Ogun State.

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