DENSITY AND SHRINKAGE CHARACTERISTICS OF APA (*Afzelia africana* sm. Ex. Pers.) IN TARABA STATE

BY

MAIGURU, A. ABEL
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A THESIS SUBMITTED TO THE DEPARTMENT OF FORESTRY AND WILDLIFE MANAGEMENT, SCHOOL OF AGRICULTURE AND AGRICULTURAL TECHNOLOGY, FEDERAL UNIVERSITY OF TECHNOLOGY, YOLA, IN PARTIAL FULFILMENT OF THE
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DECLARATION

I declare that this work was carried out in its original form by MAIGURU, A. Abel of the Department of Forestry and Wildlife Management, Federal University of Technology, Yola, Nigeria.

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Sign Date

APPROVAL PAGE

This thesis entitled: "Effects of Human Activities on the Status of Mammals in Wildlife Park of the University of Agriculture, Makurdi, Benue State." meets the regulations governing the award of degree in M.Tech. Wildlife Conservation and Management, Federal University of Technology, Yola and is approved for its contribution to knowledge and literary presentation.

1.____________________________ ________________

Prof. C. Akosim — Date

Supervisor

2.____________________________ ________________

Prof. E.I. Arifalo — Date

Internal Examiner

3.____________________________ ________________

Dr. E. I. Inah — Date

External Examiner

(UNICAL)

4.____________________________ ________________

Dr. Michael Akpan — Date

Head of Department

5.____________________________ ________________

Prof. A. Nur — Date

Dean, School of Postgraduate Studies

DEDICATION

This Thesis is dedicated to the Almighty God, my wife and children.

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ABSTRACT

This study evaluates the physical characteristics of *Afzelia africana* wood in Taraba State, Nigeria with the hope of ascertaining its utility as a construction material. Due to increasing wood demand that overshoots supply, timber has gradually become scarce and expensive especially in Northern States of the Country. In this regard, alternative wood species with rooted provenance to the local climatic conditions of North-eastern Nigeria, particularly Taraba State, was examined. Apa (*Afzelia africana)* is widely and successfully grown in Taraba State and was chosen for the research. Three study locations were randomly selected from defined senatorial zones of Taraba State, for the study. These are Northern Zone, Central Zone and Southern Zone. From each of the study locations 5 matured tree samples of *Afzelia* were randomly selected, from which a total of 45 wood specimens were prepared for the physical characteristics determination. The parameters of interest that were determined using standard methods include Density and Shrinkage. The test-data were subjected to analysis of variance (ANOVA) statistics to test for the level of significance between the parameters, senatorial zones, trees, and their respective sections. Results of the research revealed that at an average moisture content of 13.51%, *Afzelia africana* has a density of 718.16 kg/m^3, and volumetric shrinkage of 18.70%. Findings also revealed that there was significant difference of *Afzelia* wood density across the zones at 1% level of significance ($P<0.01$). Also, significant difference of density was obtained between the trees and their sections. However, there was no significant difference of the wood species shrinkage across the zones, as well as the trees, and their sections. The determined physical characteristics of Afzelia wood compare favourably with those of common wood species used for timber in Nigeria. Thus, Afzelia wood could be suitable for timber production, since its density is higher than many wood species that are used for timber production. Examples of such species are *Eribroma oblonga* (670 kg/m^3), *Khaya ivornsis* (485 kg/m^3), *Pycnanthus angolensis* (480 kg/m^3), *Mitragyna ciliate* (560 kg/m^3), and *Gossweilerodendron balsamiferum* (497 kg/m^3).

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ACRONYMS

ANOVA	-	Analysis of Variance
cm	-	Centimeter
Dw	-	Dry Weight
Et al	-	*Eta lia*
FPL	-	Forest Products Laboratory
FPRL	-	Forest Products Research Laboratory
FSP	-	Fibre Saturation Point
kg	-	Kilogramme
kg/m^3	-	Kilogramme per Cubic Meter
Lgs	-	Longitudinal Shrinkage
LSD	-	Least Significant Difference
MC	-	Moisture Content
mm.	-	Millimeter
mm/s	-	Millimeter Per Second
RCBD	-	Randomized Complete Block Design
STAS	-	Romanian Standard Institution
Tgs	-	Tangential Shrinkage
US	-	Ultimate Strength
USDA	-	Unites States Department of Agriculture
USFPL	-	United States Forest Products Laboratory
Vs	-	Volumetric Shrinkage
Ww	-	Wet Weight

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Wood is an organic material. It is also a renewable forest resource. It is the most naturally occurring polymeric material. Under appropriate conditions, it has adequate structural and dimensional stability. It also has high strength and load bearing capacity in relation to its density (Youngquist, 1989). Timber could be treated to resist wood worms and fungal attacks, as well as provide an attractive natural appearance. Fire resistance of wood can also be improved upon by appropriate chemical treatments. Its thermal insulation, acoustic value, seasoning and processing have shown wood to be an excellent constructional material (Porter, 2001). Consequently, timber is extensively utilized in all sorts of architectural and building structures, such as beams, rafters, and purlins. Other attractive areas of timber utilization include furniture and interior decorations required in residential buildings, offices, recreational camps, hospitals, schools, churches etc. Wood has a long history of being used as fuel, which continues to this day, mostly in rural areas of the world. Nearly all boats were made out of wood until the late 19th century, and it remained in common use today in boat construction.

However, as a result of advanced technology and population increase, there has been a phenomenal rise in demand and use for wood. In view of this, wood is gradually becoming scarce and expensive in Nigeria, particularly in Taraba State. There is need therefore, to find alternative wood species to augument the existing economic wood species commonly in use as timber in the State. It is against this background that the researcher wishes to explore the utilization potentials of a lesser used wood material as timber. This research becomes particularly important in Taraba State, as the economic wood species commonly used for construction purposes are very limited. In the state, timber for furniture production and interior decorations is obtained from Southern Nigeria (Akpan *et al.*, 2006).

The procurement and transport arrangements of these economic trees from the South to the North are beset with some obvious difficulties that must be overcome to reduce the escalating prices. On this note, alternative wood species that grow successfully in northern Nigeria, with particular reference to Taraba State should be examined.

Afzelia africana is one of the most widely distributed tree species in Taraba State and it is the species of choice for this research. According to Houerou and Petit (1980), it is a large tree with spreading crown. The height varies between 10m – 20m with corresponding average diameter of 36cm (Houerou and Petit 1980). Nevertheless, despite the wide information based on the utilization of the wood species' bark, leaves, foliage, root, fruit, pod and seed for medicinal purposes, not much work has been done as to the documentation of its properties in relation to timber utilization in Taraba State. The focus of this research is to explore the potentials of the tree species in relation to utilization as timber, by carrying out a quantitative analysis of the density and shrinkage properties of the wood species growing in Taraba State, Nigeria.

1.2 Statement of the Problem

The major wood species converted into timber for constructional purposes in Taraba State is obtained from Southern Nigeria. As a result of high cost of fuel, poor road network, labour cost, as well as vehicle purchase and maintenance, the transportation of these wood products becomes very tedious and expensive. Consequently, the high cost of transportation increases the cost of timber used for furniture and other wood based products in Taraba State, Nigeria.

It is the researcher's opinion that, if alternative wood species prevalent in Taraba State could substitute the generally used ones from the South, the present high cost of timber in Taraba State could be reduced. *Afzelia africana* which is abundantly grown in Taraba State is easily adaptable to the environmental conditions of Taraba state and is the selected species for this research.

1.3 Scope of the Study

The study is to cover the three senatorial zones in the state, viz: Taraba North, Central, and South. The representative study locations of the zones were randomly selected from each of these senatorial zones. The study also covered two physical properties of *Afzelia africana*, viz: density and shrinkage relevant to its utilization as a constructional material.

1.4 Significance of the Study

If the understudied physical properties of *Afzelia africana* wood compares favourably with other economic trees used for timber in Nigeria, a new source of locally available wooden raw material for timber will be introduced into the market; particularly in Taraba State, where timber is scarce. Also, the determined physical properties of the wood species will serve as database for utilization and performance.

1.5 Aim and Objectives of the Study

The major aim of this study is to evaluate the physical properties of *Afzelia africana* in relation to its utilization as timber.

The specific objectives of the study are:

1. To determine the density of *Afzelia africana* wood.
2. To determine the shrinkage of *Afzelia africana* wood.
3. To compare the investigated properties of the wood species with those of locally used wood species for timber in Nigeria.

CHAPTER TWO

LITERATURE REVIEW

2.1 Brief Description of the Wood Species under Study.

Afzelia africana, sm, Ex Pers is the scientific nomenclature of the wood species under study, and it is classified under the family *Caesalpiniodeae*. It is one of the many species that grow in tropical Africa. Its common names according to Houerou and Petit (1980) are African Oak, Afzelia, Apa, and Papao.

The species occurs in Republic of Benin, Burkina Faso, Cameroon, Central African Republic, Chad, the Republic of Congo, Ivory-cost, Ghana, Guinea Bissau, Mali, Niger, Nigeria, Senegal, Sierra –Leon, Sudan, Togo and Uganda. The wood is hard, heavy, durable, termite resistant, light brown to red brown in colour scaly grey-brown (Houerou and Petit, 1980). Its glabrous wigs, with lenticels leaves are up to 30cm long, with 7 – 17 pairs of leaflets, having elliptical shapes. The petioles are 0.4 – 1.0cm long in length. The seeds are characterized with sweet edible aril.

The foliage is good cattle forage, particularly before the growth of grass in the early rainy seasons, wild animal browse the arils, and antelope eat the young shoots. As the leaves are rich in nitrogen, they are used to enrich the soil(Houerou and Petit, 1980).

2.2 Wood Density

Wood density is one of the important factors that influences the strength of timber (James, 1975; Desch, 1992; Akpan, 2001; Akpan, 2006); but there are many other variables. Some of these variables are anatomical in origin such as knots, slope of grain, tension wood, compression wood, and microfibrillar angle (Haygren and Bowyer, 1982; Leary *et al.*, 1982; Peterson *et al.*, 1984; Anon, 1992; Anon, 1993; Minor and

Peterson, 1997); while some factors are environmental such as moisture content and temperature (Mclain *et al.,* 1984; Green *et al.,* 1986; Larry and Joseph, 1988; Green and Evans, 1996). All these factors play a significant role in determining the strength and stiffness of wood.

It is usual to speak of the weight of wood in terms of a standard volume or relative density. Wood density is therefore defined as the mass per unit volume of wood, and is obtained by dividing the mass of the wood by its volume. The weight is determined on a balance to accuracy depending on the purpose for which the determination is required. There are several ways of determining the volume. The simplest is a calculation based on the direct measurement of length, width, and thickness of the squared or rectangular shaped sample. For irregular shape, Baker (1980) advanced that a beaker of water is placed on the pan or balance and counter balanced by sand or weights. Then the test block, suspended by a needle, damped in a stand is lowered into the beaker and completely immersed in the water. Arrangements are made so that this can be done without any of the water running over. Also, when the block is immersed, it is not in contact with the sides or bottom of the beaker. Weights are then added to the pan until equilibrium is restored. The weights in grams added to restore balance are equal to the volume of the test block in cubic centimeters. As wood is a porous substance, it is necessary to coat the test block with an impervious material, such as paraffin wax, if its volume is to be determined by the immersion method. According to him, the block is dipped in a bath of melted wax and quickly removed. When the coating has set, the surplus wax is scrapped off. The ratio of the weight of block in grams over the weight in grams added to restore balance, gives the density of the wood at particular moisture content.

The specific gravity of a substance is merely the relative density of that substance. Water is a particularly useful standard because the weight of one cubic centimeter is one gram. In consequence, provided the oven dry weight of wood is determined, density and specific gravity of the wood are numerically equal though the former (density) will be in units of kg/m^3.

A piece of perfectly dry wood is composed of both the solid material comprising the cell walls and the cell cavities, which contain air and small quantities of gum and other substances (Akpan, 2006). Different timbers, however, vary in weight from about 160 kg/m^3 to 1250 kg/m^3. This variation is caused by differences in the ratio of cell wall to air space in different timbers. Desch (1992) and Bendtsen *et al*., (1994) reported that this ratio is controlled by both the relative proportions of the thinner-walled vessel and parenchyma cells, and the thicker fibres, as well as the extent of development of the secondary walls of the fibres. Generally, both factors operate to produce this very wide range in density among timbers. Variations in density among timbers are clearly depicted in Table 1, according to Desch (1992). From Table 1, it is noted that the range in densities of the softwood timbers is much lower than that for hardwood timbers, and equally as important, the density range of the softwood is encompassed by that of the hardwoods. That is, some of the hardwoods are less dense than the softwoods. Therefore, the term "softwood" and "hardwood" are technical terms to distinguish between the timbers obtained from trees belonging to two major plant groups. Generally at moisture contents of 12% - 15% density values of wood species are grouped into five classes, ranging from very light to very heavy. Table 2 shows that classification of wood densities into the various classes.

Table 1: Density Values at 12% - 15 % M.C. for some Common Hardwoods and Softwoods

SOFTWOODS		HARDWOODS
	1300	
		- Lignum vitae
	1200	- African Blackwood
		- Ebony
	1100	
		- Ekki
		- Greenheart
	1000	
		- Muhuhu
	900	-
		- Hickory
	800	- Jerray
		- Kapur
		- Beech, oak, utile
Pitch pine -		
	700	
Yew -		- Afromosia
		- Iroko, teak
		- Sapele
European larch -	600	- Abura
Douglas fir -		- Elm
		- Mahogany
Scots pine	500	- Agba, Ranim
Norway spruce -		- Jelulong
Sitka spruce -	400	- Obeche
Western red cedar - -		
	300	
	200	
		- Balsa
	100	

Source: Desch (1992).

Table 2: Classification of Wood Densities in kg/m^3 at 12%-15% Moisture Content

Class	Very Light	Light	Moderate	Heavy	Very Heavy
Density	<400	≥400	>600-800	>800-1000	>1000≥1500

Source: STAS 6085:72

In addition to the range in density that occurs among timbers of different species, there is considerable variation in density between different samples of the same species. According to Desch (1992), this variation can be as high as four fold and occurs between timbers from different trees and in timber from different part of any one tree. In the former, variation is influenced by such factors as rate of growth, site conditions, and genetic composition (Akpan *et al.,* 2006). In the latter, systematic patterns of variation occur, as general rule with the heaviest wood found at the base of the tree, and there is a gradual decrease in density in samples from successively higher levels in the trunk. At any given height in the trunk there is usually a general increase in density outwards from the pith, fairly marked in the rings near the pith, but slowing down considerably thereafter. Super imposed on this systematic outwards variation of density from the pith is the effect of growth rate. Barnes and Mitchel (1994) showed how the composition and hence the density of the growth ring is influenced by the rate of growth, and how this effect is different in conifers, ring-porous and diffuse porous hardwoods. According to them, as the width of ring tends to decrease towards the bark, the effect of ring width on density tends to be additional to the systematic trends as far as softwood are concerned, and density increases towards the bark. On the other hand, in the case of ring-porous hardwoods, the effect of decreasing ring width is to reduce density and hence detract from the systematic pattern in such that density may decrease slightly in the outer rings. In diffuse-porous hardwoods, ring width has little effect on density subject to the reservation of the general systematic pattern (Barnes and Mitchel, 1994). The density of wood is of practical interest because it is a reliable determinant of strength. This generalization, however, requires qualification. Meyer (1991) reported that density is of limited value in evaluating the strength properties of individual piece of wood, because of the influence of other factors such as moisture content, and other anatomical factors. Wood density is useful, however, for indicating the lower limit for a species, below which a specimen will invariably be weak, compared with average material of that species.

A relationship exists between relative density and strength because these properties depend on the thickness of the walls of individual cells, and on the proportions of the different kinds of tissue in each piece of wood. Two other factors according to Desch (1992) modify the importance of relative density as a criterion of strength; namely the arrangement of the individual cells, and the physico-chemical composition of the cell walls. If for example, the parenchyma is distributed in broad layers, these may constitute planes of weakness along which the timber will shear, despite a relatively high density for the sample as a whole. It has now been established that the physico-chemical composition of the cell wall is the major influence in determining the strength properties of individual piece of wood; in particular, the visco-elastic behaviour of S_2 microfibrillar secondary wall layer. Also, the degree of lignifications of the cell walls has a direct bearing on most strength properties and stiffness (Desch, 1992).

2.3 Wood Shrinkage

The absorption and desorption of water in wood is accompanied by volume changes. Below the fibre saturation point, the relationship may be simple merely because, the absorbed water adds its volume to that of the wood, or the desorbed water subtracts its volume from that of the wood. Haygreen and Bowyer (1982) reported that this relationship may be complicated by the development of stresses. Theoretically, above the saturation point wood volume is not affected by moisture content. Actually, changes in volume or shape may occur because of the development of moisture gradients and stresses below fibre saturation point. Such stresses are minimized by drying wood under carefully controlled and empirically established conditions (Udegbe, 1991). In the absence of drying stress (with small specimens and extremely slow dryings, the degree of shrinkage from green to oven dry conditions is, as a first approximation, proportional to the specific gravity of the wood (Desch, 1992). The slope of the linear relationship is also equal to the average fibre saturation point of the wood (Stanish *et al.*, 1986). Substantial deviation from the linear relationship may occur with species high in extractives (Woldstein and Nicolas, 1993). As with all wood properties, shrinkage is highly anisotropic. Tangential swelling or shrinking (occurring tangential to the rings) is 1.5 to 2.5 times greater than radial shrinkage or swelling (occurring along the radius of the rings). Tangential shrinkage from green to dry ranges from 6 to 8%. Longitudinal shrinkage (occurring in the direction of the tree growth) is usually very small, 0.1 to 1.5%. (Wagenfuhr and Steiger, 1972; Akpan *at al.,* 2001). Table 3 shows the classification of wood shrinkage into five groups. However, in certain abnormal (reaction) woods, such as compression, or tension wood, longitudinal swelling or shrinkage may be relatively high, up to 1 – 2% for tension wood and 5 – 6% for compression wood (Rietz and Page, 1991).

Table 3: Classification of Shrinkage at 12% – 15% Moisture Content

Negligible	Small	Moderate	Large	Very Large
Lgs ≤ 0.10	>0.10-0.20	>0.20-0.40	>0.40-0.50	>0.50
Rds ≤ 1.00	>1.00-3.00	>3.00-5.00	>5.00-6.50	>6.50
Tgs≤ 3.00	>3.00-5.00	>5.00-9.00	>9.00-13.00	>13.00
Vs ≤ 9.00	>9.00-11.00	>11.00-14.00	>14.00-19.50	>19.50

Source: STAS 6085:72

Additional water or other liquids to the cell wall substance, causes the microfibrillar net to expand in proportion to the amount of liquid which has been added. This continues until the fibre saturation point is reached. Further addition of water to the wood produces no changes in volume of the wall substance. Conversely, the removal of moisture from the cell wall below the fibre saturation point causes the wood to shrink, such dimensional changes are traditionally expressed as a percentage of the maximum dimension of the wood, and since the green size is a condition at which no reduction in dimension has yet occurred, the shrinkage is expressed as a percentage of the green volume (Rowell and Banks, 1985). The shrinkage curves shown in Figure 1 according to Panshin and Dezeeuw (1980) are typical of wood in general. It is observed from these curves that shrinkage does not begin until the fibre saturation point (25-30%) is reached. It is also observed that the tangential shrinkage for air-dried wood is about twice as large as the radial, at the same moisture content. The volumetric shrinkage is roughly the sum of the tangential and radial shrinkages, since the longitudinal shrinkage of normal wood from the green to oven dry condition is almost negligible (Akpan, 2006). It is noted from the curves in Figure 1 that the portions of the curves between 6 and 18 percent moisture content are approximately straight lines, and for this reason, shrinkage or dimensional changes in wood; for any moisture conditions between these points, are assumed to conform to straight line relationship (Sushcland and Woodson, 1986).

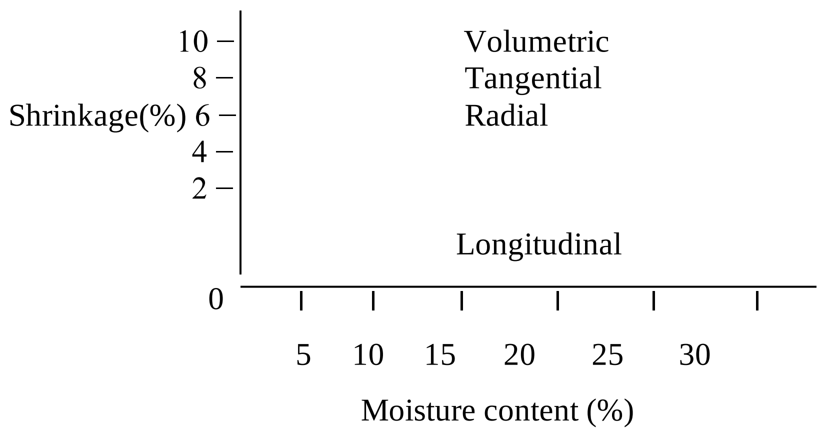

Figure 1: Shrinkage curves for wood
Source: Panshin and Dezeeuw (1980).

Dimensional changes that occur in wood are a function not only of the quantity of moisture in the wood, but also of the amount of the cell wall substance. The greater the amount of material present, the larger the dimensional change that is possible for the same percentage moisture content change. This must be considered as a rough indicator only, since the correlation does not hold well for all wood; as is evident from the work of Harris *et al.,* (1995). Accordingly Honduras Mahogany (*Swietenia macrophylla)* with approximately the same amount of material in the cell wall with Sweetgum (*Liguidambar styraciflua*) is nearly twice as stable dimensionally (Harris *et al*., 1995). The volumetric shrinkage from green to oven dry condition is 7.7% for mahogany, as against 15.0% for the Sweetgum. Collapse, a defect which may develop in the drying of some woods, is an exception to the rule that green wood does not shrink above the fibre saturation point (Speilman, 1980). Collapse is characterized by irregular and abnormal shrinkage which occurs above the fibre saturation point. It is due to buckling and crushing of the cells; for this reason, the amount of shrinkage resulting from collapse can not be predicted on the basis of the normal dimensional changes in wood. According to Speilman (1980), collapse is common in Western Red Cedar (*Thujalcata*), redwood (*Sequoia simpervirens*), and a number of hardwoods such as Oak (*Quercus spp*), Black walnut (*Juglans nigra*) and most species of the genus eucalyptus. Swelling of wood is the dimensional change expressed as a percentage of the dry dimension of wood swelling in wood cannot be taken as a reciprocal of the shrinkage values since two different reference bases are used in their calculations. Furthermore, an irreversible change occurs in the dimensional response of wood to moisture changes when it is first dried from the green condition. As a result, all the subsequent dimensional changes with moisture content are smaller than those which occur during the first drying cycle. This permanent change in dimensional response to moisture varies markedly from species to species. The total dimensional changes that may occur in a piece of wood, in drying from the green condition are an important consideration in manufacture. Even more important, however are the change in dimensions that accompany the usual fluctuations of relative humidity after wood has been placed in service. This behaviour is known as movement and cannot be predicted from the dimensional change based on shrinkage from the green condition (Conner *et al.,* 1986). It is useful index to the employment of wood under the range of atmospheric conditions that affect wood in service.

As an example, Bass wood (*Tilia spp*), exhibits very high shrinkage from the green to oven dry conditions for its specific gravity, and on the bases of these values, it would be unsuitable for exterior use.

Maloney (1986) reported that the magnitude of dimensional changes in wood is directly related to the amount of cell wall material that is present. In general, shrinkage and swelling in wood increase with increasing specific gravity. This is true both between pieces of wood of different kinds and within single pieces in which there are local differences in specific gravity, such as those between early wood and late-wood bands in the hard pines (Panshin and Dezeeuw, 1980). However, this relationship may be masked by the presence of large amounts of extractives which serve as bulking agents in the cell wall spaces, and reduce dimensional changes below that expected for the apparent specific gravity of the wood. Also, abnormally high lignin fractions in wood may reduce dimensional changes, at least in the longitudinal axis of wood.

As mentioned earlier, the observed dimensional changes in wood are unequal along the three structural directions because wood exhibits anisotropy. These dimensional changes include both the swelling associated with the addition of water to wood, and shrinkage which results from the removal of liquid from wood. The large difference between the directions parallel and perpendicular to the grain can be explained by considering the following ideas according to Panshin and Dezeeuw (1980); (1) the cell walls wood consist of reinforcing micro fibrils of high tensile strength along their axes, embedded in an essentially amorphous metric of lignin and hemi-cellulosic material. With the addition or removal of water, the micro fibrils change very little in length, at the same time, the matrix tends to change dimensions more or less equally in all directions and to a much larger extent than the micro fibrils. The strong reinforcement of the micro fibrils deforms the matrix and produces unequal strains in the length, width and thickness of the cell wall; causing small longitudinal and considerable lateral dimensional changes. The magnitudes of the longitudinal and transverse components of dimensional changes in the cell walls are functions of (a), the mechanical properties of the composite wall, that is, the ratio between the effective modulus of elasticity of the micro fibrils and the shear modulus of the matrix for a given moisture condition of the wood and (b), the mean angle of the micro fibrils with the cell axis. Increasing microfibrillar angle in the cell wall, causes increase in longitudinal changes in decrease in transverse changes. The magnitude of these rates is increased by increasing moisture content up to the fibre saturation point. (2) The majority of cells in wood are arranged with their long axes in the longitudinal direction, that is, parallel to the grain; and because of the effect of the microfibrils discussed in the preceding section, they change little in the longitudinal dimensions and considerably in the lateral directions with fluctuations in the moisture content of the wood.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Description of the Study Area

This study was carried out in Taraba state. The state was created in august, 27th 1991 when the Babangida's Military Administration carved it out of the defunct Gongola State. It derives its name from one of the three major rivers, and covers a land area of 59,400 square kilometers (Ministry of Land and Survey, 2009). At inception, the state comprised only Ten Local Government Areas, namely: Jalingo, Donga, Zing, Lau, Karim Lamido, Sardauna, Bali, Gashaka, Wukari and Takum. The state currently has sixteen local government areas as a result of the creation of additional six local government areas, namely: Ibi, Yorro, Ardo Kola, Kurmi, Ussa and Gassol in 1996.

Taraba State lies between latitude 6^0 30^1 and 9^0 36^1 North and longitude 9^0 10^1 and 11^0 East (Ministry of Land and Survey, 2009). It is bounded on the north by Bauchi and Gombe States. In the north-east by Adamawa state; and Plateau State in the north-west. The state is further bounded to the west by both Nasarawa and Benue States, while it shares an international boundary with the Republic of Cameroon to the south and south-east. According to National Population Commission (NPC) (2006), Taraba State has a population of two million, three hundred thousand, seven hundred and thirty six (2,300,736) people.

There are over eighty (80) ethnic groups found in Taraba State, each with its distinct historical and cultural heritage co-habiting with one another. Some of these tribes include Mumuye, Ichen, Wurkum, Jukun, Mambila, Kuteb, Yandang, Tigun, Ndoro, Munga and Banbuka. Hausa is commonly spoken by most indigenes of Taraba State irrespective of ethnic grouping. The state agrarian nature and rich alluvial tract of soil found in most parts of the state makes it conducive for growing various foods and cash crops.

Presently, the state is made up of 3 senatorial zones, namely: Taraba north, Taraba central, and Taraba south. Variations of climatic conditions across these zones have been documented by Udo and Mamman (1993). In the southern zone, the geology is dominated by quart marble granites and partially bima stones. The dominant soils include sand, silt, and clay. Although, some traces of alluvial soil is found along the riparian vegetation. The most dominant soil colour is reddish dark-brown (Udo and Mamman, 1993). The topography of the southern zone is hilly with the plain rising between 300m to 600m in altitude. The zone's temperature ranges form 10^0C to 28^0C depending on the season of the year (Udo and Mamman, 1993). The temperature is usually colder at higher altitudes, especially between the months of December and January. The vegetation is montane forest, which is as a result of the rainfall in the zone with a mean of 1200mm. The vegetation supports mixed woodland rather than the grass land savanna characterized by the central and northern zones.

The vegetation of the central zone of the state takes the form of highly diverse and dry deciduous woodland and savanna grassland. It is marked by dry and rainy seasons. Mean annual rainfall rises up to 800mm, while mean annual temperature ranges from 20^0C-30^0C. The zone lies between latitude $7^0 00^1$N – $11^0 00^1$N and longitude $7^0 00^1$E – $10^0 00^1$E of Greenwich Meridian. The climate of the northern zone is comprised of two distinct seasons similar to the southern and central zones. The rainy season spans from the months of April and October, while the dry season is between November and March. It is situated between latitude $9^0 00^1$N – $9^0 30^1$N and longitude 10^0E. The vegetation type falls under sudan savanna type. The geology of the area is dominated by bima sand stone, consisting of fine sand, clayish sand, silt iron stone, and alluvium deposits which consist of both clay and silt clay (Dombe, 1997). The average rainfall is 700m. The wettest months are August and September. According to Udo and Mamman (1993), the relative humidity drops from 82% - 92% between June and October to 25% - 36% between December and March. Daily maximum temperature may rise as high as 35^0C, and the minimum may fall as low as 11^0C during the harmattan periods (November – February). Each senatorial zone has at least five local governments. From the various local government areas of each senatorial zone, one was randomly selected for the study. Thus, 3 study locations were isolated to reflect the 3 senatorial zones. Fig. 2 shows the map of Taraba State indicating the 3 senatorial zones and the study locations.

Fig. 2: Map of Taraba State indicating the study locations.
Source: Ministry of Lands and Survey, 2009

3.2 Density Determination

Eighteen (18) matured *Afzelia africana* trees of 20 years and above were chosen by selective random sampling using diameter of at least 60cm as a basis for selection for the research from the three senatorial zones of the state. Out of this number, five (5) tree samples were selected and felled in each of the zones. Their growth rings were counted with additional 2-3 rings to confirm the ages of the trees. To ensure clear visibility of rings, the samples were stained with silver nitrate solution.

Each felled tree from the study locations was divided into three (3) sections, that is, bottom, middle and top in accordance with the conventional sampling strategy of 0%, 20%, and 40% of the total tree height (STAS6085:72). Each of these sections was labeled for the test. All samples were obtained from defects free areas of the trees. Thus, a total of 45 specimens were collected from the three zones and labeled for the density test. Each wood specimen was further cut to a sizeable dimension of 100mm x 60mm x 40mm in accordance with STAS6085:72. The tests were carried out in the departmental laboratory.

Prior to density determination, the moisture contents of the test pieces (wood specimens) were determined. This was done by recording the samples' wet weight, and thereafter drying the wood samples at a temperature of $103^0C \pm 2^0C$ for 24 hours. At intervals of 30 minutes, each sample was removed and weighed, using the electronic weighing balance until a constant mass was obtained for each of the wood samples. The moisture content of the wood samples was then determined based on their oven dry weights, using the equation.

$$MC = \frac{Ww - Dw}{Dw} \times 100\ (\%) \quad \text{--- (1)}$$

where: MC = Moisture content (%)
Ww = Wet weight (kg)
Dw = Dry weight (kg)

Thereafter, the specimens were cut to standard sizes of 75mm x 45mm x 20mm in accordance with STAS 6085:72. Plate 1 shows the cutting of the samples to standard sizes using the circular saw machine. Based on these standard sizes their masses were recorded using the electronic weighing balance. Plate 2 shows the measurement of the wood specimens' masses with the electronic weighing balance. In the same vein, the wood specimens' volumes in terms of their lengths, widths and heights were also measured, using the micrometer screw gauge. Densities of the wood samples were then calculated with the relationship.

$$\text{Density} = \frac{\text{Mass of oven dry wood sample}}{\text{Volume of oven dry wood sample}} \quad (kg/m^3) \quad \text{----} \ (2)$$

Mean densities of the 45 wood samples were obtained from the three different vegetation zones. The obtained data were analysed with the ANOVA statistical tool, using Randomized Complete Block Design (RCBD) experiment. The ANOVA was used to test the level of significance of density between the different zones, and also between the sampled trees and their respective sections. The Fisher's Least Significant Difference (LSD) was used to analyze the established variation. In addition, relationship between density and mass, as well as moisture content were examined. Further more, the variation of density along the tree trunk was also examined.

Plate 1: Cutting of the wood samples to standard sizes with the circular-saw machine.

Plate 2: Weighing the wood specimens' masses with the electronic balance.

3.3 Shrinkage Determination

Fifteen (15) tree samples were used for this experiment by randomly selecting 5 trees from each of the 3 zones. Each felled tree was cross cut into three sections from base to top that is, bottom, middle, and top. Thus, 45 test pieces were selected from defects free areas of the trees and prepared according to STAS 6085:72. Accordingly, the wood species were cut to sizeable samples of 100mm x 60mm x 40mm for the purpose of drying to constant weights. After which, each specimen was extracted from the seasoned samples by cutting to a standard dimension of 30mm x 20mm x 20mm. The specimens were cut in such a way that the wood rays in the radial axis were parallel to the fibres in the tangential and longitudinal axes.

Thereafter, the test pieces were completely immersed in water for 60 minutes. This is to attain the fibre saturation point (FSP) of wood at which shrinkage begins to occur. Immediately, by means of a micrometer screw gauge, the initial (maximum) dimension of the three axes of the wood will be taken. The wood specimens were dried at a temperature of $103^0C \pm 2^0C$ for 24 hours. At intervals of 30 minutes, the specimens were weighed with the electronic weighing balance, until a constant weight was obtained for each of them.

s Their final (dry) moisture contents were also calculated. Similarly, the final (minimum) dimensions of the specimens, viz: longitudinal, radial and tangential were recorded using the micrometer screw gauge. On the bases of these dimensions, tangential, radial and longitudinal linear shrinkages of the 45 wood specimens were calculated with the respective relationship.

$$Tgs = \frac{Dt - dt}{Dt} \times 100\% \qquad \text{--(3)}$$

$$Rds = \frac{Dr - dr}{Dr} \times 100\% \qquad \text{--- (4)}$$

$$Lgs = \frac{Dl - dl}{Dl} \times 100\% \qquad \text{--- (5)}$$

where:

Tgs	-	Tangential linear shrinkages (%)
Rds	-	Radial linear shrinkages (%)
Lgs	-	Longitudinal linear shrinkage (%)
Dt	-	Initial dimension (mm) along the tangential axis at green moisture content of 30%
Dr	-	Initial dimension (mm) along the radial axis at green moisture content of 30%
D1	-	Initial dimension (mm along the longitudinal axis at green moisture content of 30%
dt	-	Final dimension (mm) along the tangential axis at dry moisture content of 30%
dr	-	Final dimension (mm) along the radial axis t dry moisture of 30%
dl	-	Final dimension (mm) along she longitudinal axis at dry moisture content of 30%

The mean values were obtained as the linear shrinkages of the three asymmetrical axes of the wood species under study. At the same time, volumetric shrinkages (VS) of each of the 45 wood specimens were computed with the relationship.

$$VS = 100 - \frac{(100 - Lgs)(100 - Rds)(100 - Tgs)}{10^4} \% \qquad \text{--- (6)}$$

The mean values were obtained. With the zones, as well as the tree samples, and their respective sections being the sources of variation and volumetric shrinkage as parameter, ANOVA was used to analyze the data, by testing the level of significance of shrinkage between the different zones and also between the sampled trees and their respective sections. The Fishers Least Significant Difference (LSD) was used to test the established variation. Relationship between volumetric shrinkage and drying (at 15 minutes interval of drying) in the three zones were examined.

CHAPTER FOUR

RESULTS

4.1 Wood Density

The densities of the 45 wood specimens of *Afzelia africana* were computed based on the wood specimens' masses as contained in Appendix 1, and volume of 6.75 x 10^{-5} m^3 for each of the specimens. The results in the three study locations are contained in Table 4. In the northern zone of the state, the mean density varies from 667.75kg/ m^3 to 715.80kg/m^3, with an average value of 695.77kg/ m^3. The tree samples in this zone also recorded density variation along their trunks. Tree sample no I has a variation of 645.48 kg/m^3 to 729.93 kg/m^3, while tree sample no 2 has a variation of 639.56kg/m^3 to 687.85kg/m^3. The density of Tree sample no 3 ranges from 670.82 kg/m^3 to 692.88 kg/m^3. Tree samples 4 and 5 have density variation of 701.04 kg/m^3 to 729.33 kg/m^3 and 708.44 kg/m^3 to 716.30 kg/m^3 respectively (Table 4).

In the central zone of Taraba State, the mean density varies is from 682.19 kg/m^3 to 720.59 kg/m^3, with a mean of 701.32 kg/m^3. In the same vein, the tree samples in this zone recorded density variation along their trunks, with Tree 1 having a range of 655.11 kg/m^3 to 735.70 kg/m^3. Tree samples 2 and 3 have density variation of 658.22 kg/m^3 to 699.30 kg/m^3 and 678.82 kg/m^3 to 696.30 kg/m^3 respectively. Tree 4 has a density range of 706.96 kg/m^3 to 732.00 kg/m^3, while Tree 5 has a variation of 696.15 kg/m^3 to 724.24 kg/m^3 (Table 4).

In the southern zone, the mean density varies from 718.62 kg/m^3 to 770.30 kg/m^3, with a mean value of 757.38 kg/m^3. Similarly, the various tree samples showed variation of density along their trunks, with Tree 1 having a range of 759.11 kg/m^3 to 770.37 kg/m^3. Tree 2 has a range of 758.52 kg/m^3 to 766.76 kg/m^3, while Tree 3 has a range of 704.44 kg/m^3 to 737.04 kg/m^3. Trees 4 and 5 have variation of 767.70 kg/m^3 to 769.77 kg/m^3, and 766.76 kg/m^3 to 773.77 kg/m^3 respectively (Table 4). The overall mean density of the wood species across the three zones is 718.16 kg/m^3 (Table 4). Table 5 shows the result of the analysis of variance (ANOVA) of the wood density while Table 6 shows the Fisher's Least Significant Difference for density. The result shows that there is significant difference between the tree samples' densities as well as between the tree regions at 5% level of probability ($P<0.05$). In addition, the density of the trees is highly significantly different in the various zones at 1% level of probability ($P <0.01$) (Table 5). The follow-up analysis reveals that there is significant difference between each of the means of the three zones, as each mean difference is greater than the LSD value (Table 6). Further more, Figures 3a, 3b, and 3c show the graphical relationship between density and mass of the sampled trees, and Figures 4a, 4b, and 4c show the relationship between density and moisture content of the trees, while Figure 5 shows the variation of density along the trunks of the trees in the three study locations.

Table 4: Density (kg/m^3) of *Afzelia africana* Wood in the Three Senatorial Zones of Taraba State

Tree Samples	Northern Zone Wood Specimens				Central Zone Wood Specimens				Southern Zone Wood Specimens				
	1*	2*	3*	Mean	1*	2*	3*	Mean	1*	2*	3*	Mean	Overall Mean
1	729.93	717.48	645.48	697.63	735.70	718.66	655.11	703.16	770.37	769.19	759.11	766.22	722.34
2	687.85	675.85	639.56	667.75	699.30	689.04	658.22	682.19	766.76	763.70	758.52	962.99	704.31
3	692.88	685.63	570.82	683.11	696.30	692.15	678.82	689.09	737.04	714.87	704.44	718.62	696.94
4	729.33	713.33	701.04	714.57	732.00	722.82	706.96	720.59	769.77	768.88	767.70	768.78	734.65
5	716.30	722.66	708.44	715.80	724.24	714.37	696.15	711.59	773.77	770.37	766.76	770.30	732.56
Mean	711.26	702.99	673.07	695.77	717.51	707.41	679.05	701.32	763.54	757.30	751.31	751.38	718.16

*1-bottom, 2-middle, 3-top

Table 5: ANOVA Table of *Afzelia african* Wood Densities in the Three Senatorial Zones of Taraba State

SV	SS	Df	MS	F	P-Value
Trees	298872.60	4	285671.30	1.03*	0.0496
Zones	468287.78	2	283686.89	1.02**	0.0036
Tree Sections	4564576.63	2	278818.88	1.00*	0.0251
Error	18402550.84	14	269514.44		
Total	22316287.85	22			

* - Significant (P<0.05)

**- highly significant (P< 0.01)

Table 6: Fisher's Least Significant Difference for Density in the Three Senatorial Zones of Taraba State

Alpha		0.05
Error Degree of Freedom		14
Error Mean Square		269514.44
Critical Value of t		2.31
Least Significant Difference		2.21 Kg/m^3
Zone	Sample Size	Mean Density (kg/m^3)
Northern Zone	45	695.77 a
Central Zone	45	701.32 b
Southern Zone	45	757.38 c
Tree Sections	Sample Size	Mean Density (kg/m^3)
Bottom	45	730.77 a
Middle	45	722.56 b
Top	45	701.14 c

N.B. Means with the same letter are not significantly different.

4.2 **Wood shrinkage**

Appendix 2 containing the data of the linear shrinkages shows that at average green moisture contents of 31.61% in the northern zone, 32.42% in the central zone, and 32.02% in the southern zone; the mean initial dimensions of the specimens are 21.32mm (northern zone), 21.29mm (central zone), and 21.44mm (southern zone) along the tangential axes (Dt) (Appendix 2). At similar green moisture contents, the mean initial dimensions of the wood specimens along the radial axes (Dr) in the northern, central, and southern zones are 21.23mm, 21.02mm, and 21.32mm respectively. Also, the longitudinal axes (Dl) of the specimens have mean initial dimensions of 30.25mm in the northern zone, 30.26mm in the central zone, and 30.22mm in the southern senatorial zone at the same green moisture contents.

At moisture contents of 13.12% in the northern zone , 13.77% in the central zone , and 13.65% in the southern zone; the average final dimensions of the test pieces along the tangential axes (dt) are 18.69mm, 18.64mm, and 18.76mm respectively. At the same oven dry moisture contents, the average dimensions of the wood samples along the radial axes (dr) in the northern, central, and southern zones are 19.80mm, 19.81mm, and 19.89mm respectively. Longitudinally (dl), at the same oven dry moisture contents, the mean final dimension of the specimens are 29.78mm in the northern zone, 29.91mm in the central zone, and 29.88mm in the southern zone (Appendix 2).

Accordingly, linear shrinkage along the tangential axes in the northern zone range from 11.32% to 14.08%, with a mean value of 12.01%. Similarly, linear shrinkage along the tangential axes in the central zone range from 12.09% to 13.74 % (mean of 12.34%); while those of the southern zone vary from 11.68% to 13.69% (mean of 12.38%). In the same vein, the linear shrinkage along the radial axes in the northern zone range from 5.29% to 7.01% (mean of 6.16%); and those of the central zone vary from 5.29% to 7.04%, having a mean of 6.68%. In the southern zone, the linear radial shrinkage range from 5.29% to 7.01%, with a mean of 6.22%. Along the longitudinal axes, in the northern zone, the linear shrinkage range from 1.00% to 1.32%, with an average of 1.06%. While the longitudinal linear shrinkage in the central zone range from 0.66% to 1.65%, having a mean of 1.23%; the longitudinal linear shrinkage in the southern zone vary from 1.00% to 1.32%, having a mean of 1.13%(Appendix 2).

Results of the volumetric shrinkage of the 15 sampled trees in the northern senatorial zone as contained in Table 7 show that this property varies from 18.33% to 18.98% with a mean of 18.77%. In the central zone, the property varies from 18.65% to 19.02%, having a mean value of 18.85%; while in the southern senatorial zone, volumetric shrinkage of *Afzelia africana* varies from 18.22% to 18.85%. The mean volumetric shrinkage in this zone is 18.49%; while the overall mean volumetric shrinkage across the three zones is 18.70%. Table 8 contains the results of the analysis of variance (ANOVA) of volumetric shrinkage, and Table 9 contains the Fisher's Least Significant Difference of volumetric shrinkage. The results indicate that none of the three different zones showed significant difference in shrinkage values at 5% probability level ($P>0.05$). In the same vein, significant difference of shrinkage was not attained between the tree samples and the sections at 5% level of probability ($P>0.05$). The follow-up analysis confirms that none of the means of the three different zones, as well as the sections showed significant difference of shrinkage. Figures 6a, 6b, and 6c show the relationship between drying and volumetric shrinkage in the three zones.

Table 7: Volumetric Shrinkage (%) of *Afzelia africana* in the Three Senatorial Zones of Taraba State

Tree Sample	Northern Zone Wood Specimens 1*	2*	3*	Mean	Central Zone Wood Specimens 1*	2*	3*	Mean	Southern Wood Specimens 1*	2*	3*	Mean	Overall Mean
1	18.52	18.40	18.06	18.33	18.66	19.21	19.20	19.02	18.24	18.20	18.22	18.22	18.52
2	18.89	19.05	19.00	18.98	18.86	19.06	19.01	18.96	18.55	18.57	18.20	18.44	19.80
3	18.83	19.30	18.39	18.84	18.20	18.60	19.15	17.65	19.13	18.71	18.70	18.85	18.78
4	19.06	18.98	18.71	18.92	19.02	18.80	18.50	18.77	18.21	18.96	18.78	18.65	18.78
5	18.70	18.60	18.97	18.76	18.60	18.98	18.90	18.83	18.50	18.15	18.21	18.29	18.63
Mean	18.80	18.87	18.63	18.77	18.67	18.93	18.95	18.85	18.53	18.52	18.42	18.89	18.70

*1 – bottom, 2 – middle, 3 – Top

Table 8: Results of ANOVA of *Afzelia african* Wood Shrinkage in the Three Senatorial Zones of Taraba State

SV	SS	Df	MS	F	P-Value
Trees	5.58864148	4	0.39918868	1.45 ^{ns}	0.1504
Zones	0.38864148	2	0.19432074	0.70^{ns}	0.4974
Tree Sections	0.55758370	2	0.27879185	1.01^{ns}	0.3685
Error	23.18147111	14	0.27596989		
Total	29.716338	22			

ns- not significant (P<0.05)

Table 9: Fisher's Least Significant Difference for Volumetric Shrinkage in the Three Senatorial Zones of Taraba State

Alpha		0.05
Error Degree of Freedom		14
Error Mean Square		0.27596989
Critical Value of t		2.61
Least Significant Difference		0.1 %
Zone	Sample Size	Mean Shrinkage (%)
Northern Zone	45	18.77 a
Central Zone	45	18.85 a
Southern Zone	45	18.49 a
Tree Sections	Sample Size	Mean Shrinkage (%)
Bottom	45	18.66 a
Middle	45	18.77 a
Top	45	18.66 a

N.B. Means with the same letter are not significantly different.

CHAPTER FIVE

DISCUSSION

5.1 Wood density

The result of the *Afzelia africana* wood density at average of 718.16 Kg/m^3 shows that the wood species falls under the density class of 'moderate' wood species (Table 2) (STAS 6085:72). The density result also agrees with the general range of wood densities as published by Desch (1992), who recorded a density variation of 160kg/m^3 to 1250kg/m^3 among tree species. This density value compares favourably with majority of known economic trees commonly used for timber in Nigeria. These tree species are contained in Table 10. Examples of these tree species according to Desch (1992), Hall (1998), Ghelmeziu (1981), Kwame (2001), and Akpan (2006) include *Eribroma ablonga* (670 kg/m^3), *Khaya ivorensis* (485 kg/m^3), *Chlorophora excelsa* (660 kg/m^3), *Mansonia altissima*(615 kg/m^3), and *Terminalia superba*(580 kg/m^3). Others are *Entandrophragma cylindricum* (620 kg/m^3), *Pycnanthus angolensis* (480 kg/m^3), *Mitragyna ciliate* (560 kg/m^3), *Tectona grandis* (660 kg/m^3), *Triplochiton scleroxylon* (368 kg/m^3), *Gossweilerodendron balsamiferum* (497 kg/m^3), *Entandrophragma candollei* (670 kg/m^3), and *Terminalia ivorensis* (550 kg/m^3).

Based on the wood species classification as a moderate density wood, it therefore implies that it will be particularly attractive for general timber utilisation. However, in selecting areas of optimum utilization of the wood species, it is considered that very light species are relatively weak; resulting into possible failures when subjected to stresses (NDSWC, 1992). In addition, insects, and fungi easily attack light wood species (Raven *et al*, 1997). For these reasons, light density wood species are mostly used for light constructional purposes e.g crates and form-work constructions. On the other hand, very heavy species are difficult to process, requiring considerable energy that will result into excessive heat generation between the cutter and wood. This heat causes the wooden material to tend to char. It also causes the cutter to loose its sharpness, or correct geometry and by so doing perform poorer. Consequently, very large density woods are attractively required only where extremely high strength is of prime importance. Thus, based on its density class, Afzelia wood will be a promising tree species for timber utilization, especially for general woodwork and joinery, since it has a moderate density.

The ANOVA shows that there is significant difference between the tree samples' densities as well as between the tree regions at 5% level of probability ($P<0.05$) (Table 5). In addition, it was found that the densities of the trees is highly significant in the various senatorial zones at 1% level of probability ($P <0.01$) (Table 5). The follow-up analysis reveals that there is significant difference between each of the means of the three zones, as each mean difference is greater than the LSD value (Table 6). Also, at the sections, significant differences of density were obtained between the bottom, middle, and top, as their mean differences are greater than the LSD value (Table 6). These results agree with the works of Panshin and Dezeeuw (1980) and Desch (1992), who recorded considerable variation in wood density between different samples of the same tree species. According to Desch (1992), this variation can be as high as four fold and occurs between timber from different trees of the same species, and in timber from different parts of any one tree. Factors such as rate of growth, site conditions and genetic composition influence the density variation within and between species (Panshin and Dezeeuw, 1980). It was also observed from the results of the density determination in line with the work of Desch (1992) that the heaviest wood is found at the base (bottom) of the tree, and there is gradual decrease in density in samples from successively high levels in the trunk (Figure 5). Another reason that might be responsible for the variation of density within the tree species could be attributed to the findings of Barnes and Mitchel (1994). They reported that at any given height in the trunk, there is usually a general increase in density outwards from the pith towards the bark.

The density results further show that the densities are higher with higher values of masses, because of the free water in the wood samples. These relationships are graphically represented in Figures 3a, 3b, and 3c. The graphs confirm the linear progression of the wood densities with higher masses. This phenomenon is in total agreement with similar works on wood density as carried out by Desch (1992) and Akpan *et al*. (2006). Furthermore, the higher the moisture contents of the wood samples, the higher the values of the wood densities, because below the fibre saturation point (FSP), the excess water adds to the mass and volume of the wood (Figures 4a, 4b, and 4c).This relationship between wood density and moisture content is in line with similar works carried out by Desch (1992).

5.2 Wood shrinkage

Results obtained from the studies of shrinkage characteristics of *Afzelia africana* show that the wood species at an average volumetric shrinkage of 18.70% falls into the class of wood species with 'large' shrinkage. This inference is based on the classification of STAS 6085:72, which classified shrinkage of wood species from green to oven dry moisture contents into five categories, viz: negligible, small, moderate, large, and very large (Table 3). Thus, shrinkage qualities of Afzelia wood, even though compares favourably with some shrinkage values of some locally used timber, tend to be on the high side when compared with majority of the Nigerian used timber (Table 10). Examples of locally used timber that Afzelia wood shrinkage compares favourably with are *Uapaca guineensis* (19.9%), *Strombosia pustulata* (19.7%), *Terminalia ivorensis* (18.8%), *Sterculia rhinopetala* (20.9%), *Distemonanthus benthamianus* (20.6%), and *Lophira alata* (19.8%) (Ghelmeziu, 1981; Kwame, 2001). Table 10 shows shrinkage values of the commonly used timber vis-à-vis that of Afzelia wood.

Results of the shrinkage studies also indicate that the tangential shrinkage at 12.74% is about twice as large as the radial shrinkage with a value of 6.26% at the same moisture content of 13.05%. Also observed from the shrinkage results is the fact that the volumetric shrinkage is approximately the sum of the tangential and radial shrinkages, since the longitudinal shrinkage from green to oven dry condition is almost negligible. These observations are in accordance with the works of Suchsland and Woodson (1986), Harris *et al* (1995), Kellog and Wangaard (1989), Akpan *et al.* (2001), and Wagenfuhr and Steiger (1972) (Appendix 2, Table 7). In addition, the obtained range of shrinkage values of Afzelia wood as applied to the tangential, radial, and longitudinal directions are in line with the general ranges of wood shrinkages in those directions as published by Wagengfuhr and Steiger (1972), Akpan *et al.* (2001), and Panshin and Dezeeuw (1980). Also observed in the course of the shrinkage experiment is the concept that shrinkage of the wood samples did not begin until the fibre saturation point was attained. This observation also agrees with the principles of Panshin and Dezeeuw (1980), Akpan *et al.* (2001), and Kwame (2001) that shrinkage only occurs at moisture contents equals to or above fibre saturation point. With regard to the relationship between moisture content and volumetric shrinkage, it was observed that shrinkage did not occur when the wood samples were fully saturated with water. However, as the moisture content in the wood samples reduces from green to dry condition, the volumetric shrinkage increases (Figures 6a, 6b, and 6c). This scientific concept is explained by the fact that wood begins to shrink only when it attains fibre saturation point; and the more moisture that leaves the wood, the higher the volume of shrinkage. The shrinkage finally ceases when the wood is completely dried, attaining equilibrium moisture content (EMC). These findings agree with similar works conducted by Rowell and Banks (1985); Akpan *et al*. (2001); as well as Suchsland and Woodson (1986).

It suffices to state that this large shrinkage value of *Afzelia africana* will restrict the tree species to be particularly applicable as timber for interior utilization, as there is little fluctuation of relative humidity and temperature in the interior, than outside. If, however, the wood species is to be used outside in its fresh stage (due to the high variation of humidity and temperature), the wood will, exhibit considerable shrinkage, resulting into warping; with a corresponding high degree of distortion. In order to circumvent this disadvantage, Afzelia wood, on account of its large shrinkage characteristics, should be immediately subjected to carefully controlled seasoning conditions after conversion. The purpose is to bring the moisture content of the wood to Equilibrium Moisture Content (E.M.C).

The analysis of variance (ANOVA) reveals that none of the three different zones showed significant difference in shrinkage values at 5% probability level ($P>0.05$). In the same vein, significant difference of shrinkage was not attained between the tree samples and the sections at 5% level of probability ($P>0.05$) (Table 8). The follow-up analysis confirms that none of the means of the three different senatorial zones, as well as the sections showed significant difference, as each of their mean differences was found to be less than the least significant difference (LSD) value (Table 9).

Table 10:Pooled Data on Density and Volumetric Shrinkage Values of Commonly Used Nigerian Trees

S/N	Local Name	Scientific Name	Density (kg/m^3)	Volumetric Shrinkage (%)
1	Afromosia	*Pericopsis elata*	690	10.0
2	Afara	*Terminalia superba*	580	10.1
3	Mahogany	*Khaya ivorensis*	485	9.1
4	Obeche	*Triplochiton scleroxylon*	368	9.7
5	Eiong	*Eribroma oblonga*	670	18.3
6	Sapele	*Entandrophragma cylindricum*	620	12.6
7	Mansonia	*Mansonia altissima*	615	10.3
8	Ilomba	*Pycnanthus angolensis*	480	14.5
9	Iroko	*Chlorophora excelsa*	660	9.4
10	Omu	*Entandrophragma candollei*	670	15.8
11	Richio	*Uapaca guineensis*	678	19.9
12	Agba	*Gossweilerodendron balsamiferum*	497	7.6
13	Teak	*Tectona grandis*	660	15.0
14	Abura	*Mitragyna ciliate*	560	13.1
15	Idigbo	*Terminalia ivorensis*	550	18.8
16	Danta	*Nesogordonia papaverifera*	760	18.4
17	Ceiba	*Ceiba pentandra*	300	10.4
18	Ekki	*Lophira alata*	1070	19.8
19	Faro	*Daniellia klainei*	560	15.9
20	Sipo	*Entandrophragma utile*	615	12.6
21	Afina	*Strombosia pustulata*	850	19.7
22	Emien	*Alstonia boonei*	300	11.5
23	Opepe	*Nauclea diderrichii*	700	14.1
24	Oro	*Antiaris Africana*	480	12.1

Continuation of Table 10

25	Coto	*Pterygota macrocarpa*	605	17.9
26	African walnut	*Lovoa trichilioides*	600	10.4
27	Lotofa	*Sterculia rhinopetala*	700	20.9
28	Esia	*Combretodendron macrocarpum*	700	18.4
29	Tiama	*Entandrophragma angolense*	550	13.6
30	Guarea	*Guarea thompsonii*	580	11.0
31	Chitola	*Oxystigma oxyphyllum*	630	11.0
32	Avodire	*Turraeanthus Africana*	550	11.6
33	Ayan	*Distemonanthus benthamianus*	700	20.6
34	Ayo	*Holoptelea grandis*	650	14.4
35	Berlinia	*Berlinia confuse*	665	14.0
36	Canarium	*Canarium schweinfurthii*	470	14.2
37	Dahoma	*Piptadeniastrum africanum*	675	14.1
38	Ebony	*Diospyros crassiflora*	1050	15.0
39	Tali	*Erythrophleum ivorense*	970	13.5
*	Papao	*Afzelia Africana*	718.16	18.70

Sources: Desch (1992), Hall (1998), Ghelmeziu (1981), Kwame (2001) and Akpan (2006).

*Field work (2010)

CHAPTER SIX

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

6.1 Summary

Due to technological advancement and population increase, there has been rapid growth of wood based industries in Nigeria. In view of this, timber has gradually become scarce and expensive, especially in the northern states of the country. Furthermore, the economic wood species that are commonly used for constructional purposes in northern Nigeria are significantly obtained from southern Nigeria. Timber procurement from the south to the north is associated with some pertinent problems, including high cost of transportation. In this regard, alternative wood species that is adaptable to the local climatic conditions of northern Nigeria, with particular reference to Taraba State was examined. *Afzelia africana* is widely grown in many parts of the state, and it's the species of choice for the research, to explore its utilisation potentials as timber.

In the realisation of this broad objective, three study areas were randomly selected from each of the three senatorial zones of Taraba State for the study. In each of the study areas, 5 matured tree samples of Afzelia wood were randomly selected for the research. The parameters that were examined in the course of the research include density and shrinkage. Findings from the research reveal that the measured parameters generally compared favourably with those of local species used for timber in Nigeria.

6.2 **Conclusion**

Owing to the species' moderately large size in terms of its density, it will provide an attractive workability characteristic with both hand and machine tools, as the wood species will not be too soft to be attacked by insects, and too hard to be processed with difficulty. In addition, its density value favourably compares with many locally used Nigerian timber. Even though, Afzelia wood has high shrinkage value, it compares favourably with some locally used timber; and therefore is quite suitable for timber utilisation, as long as it's seasoned under controlled conditions. Thus, with this high utilization potential of Afzelia wood for timber; a new source of locally available and renewable raw-material for the building and architectural industries in Nigeria, with particular reference to Taraba State is introduced into the market.

6.3 **Recommendations**

In order to have a data-bank on the wood species, further researches should be carried out on the following aspects of the wood: fibre size, holo-cellulose content, alpha-cellulose content, lignin content, tannin content, resin content, ash content. Other recommended areas of further research are microscopic properties, such as descriptive characteristics of annual rings, pores, medullary rays, and parenchyma cells.

REFERENCES

Akpan M. (2001). Socio-economic values of neem (*Azadirachta indica):* an overview; in proceedings of the National conference on the Revitalization of Agriculture in the Nigerian Economy; organized by SAAT, Federal University of Technology, Yola, Pp. 186 – 189.

Akpan, M.; Anametemkfiok, V. and Ijoma, J.U. (2001). Dimensional changes of wood in science: Potential of *Eribroma oblonga* for interior decorations. Journal of science and Technological Research, Vol. 7 (1&2), Pp. 6-11.

Akpan, M. (2006). Physical and mechanical properties of neem (*Azadirachta indica*) wood for structural utilization in north eastern Nigeria. PhD Thesis, Department of Forestry and Wildlife Management, Federal University of Technology, Yola, p.211.

Akpan, M.; Olufemi, B. and Apagu, V. (2006). Quantitative studies on density of neem wood in north eastern Nigeria. *Nigeria Journal of Construction Technology and Management*, Vol. 7, No1, Pp. 6 – 12.

Baker, B.K. (1980). Research paper STP 691. American Society of Testing and Materials, Philadelphia pg. 981.

Barnes, H.M. and Mitchel, P. (1994). Density variation in wood. *Forest products Journal*, Vol. 34, (6), 29 pp.

Anon, (1992). Selecting ash by inspection. Princes Rishborough Laboratory, Technical Note No 84, Madison, 18 pp.

Anon, (1993). The natural durability of timber. Princes Rishborough Laboratory Technical Note No 87, Madison, 123 pp.

Bendtsen, B.A.; Gjovik, L.R. and Veril, S.P (1994).Anatomical structure of wood. Research paper FPT 343.
United State Department of Agriculture (USDA) Forest products laboratory, modison, pg. 486.

Conner, A.H.; Wood, B.F.; Hill, C.F. and Harris, J.F. (1986). Cellulose structure, modification, and Hydrolysis. John Wiley and sons Publications, New York, Pp. 282 – 296.

Desch, H.E. (1992). Timber: Its structure, properties and utilization. Macmillan Educational Publications, London, 401 pp.

Dombe, D. (1997). Geological evaluation of clays in Vinikilang area, Yola, Adamawa State. Unpublished Project Report, Department of Geology, Federal University of Technology, Yola, p. 6.

Ghelmeziu, N. (1981). Lemnul exotic-Lemnul African, proprietati si utilisari. Editura Tehnica, Bucuresti, pp. 426.

Green, D.W.; Link, C.L.; DeBonis A.L. and Mclain, T.E. (1986). Change of strength properties of pine according to moisture contents. *Journal of wood and Fibre Sc.*, 18 (1), pp 134 – 143.

Green, D.W.; and Evans, J.W. (1996). Effect of ambient temperature on bending strength of Lumber. *Forest products Journal*, 43 (3): Pp. 17 – 26.

Hall, F.F. (1998). Tropical Trees and Forests. Springer publications, Berlin, pp. 431.

Harris, J.F.; Saeman, J.F. and Locke, E.G. (1995). The chemistry of wood. Wiley Interscience, New York, pp. 585.

Haygreen, J.G and Bowyer, J.L (1982): Forest Products and wood science: an introduction, 1st Edition Iowa State university Press, Ames. Iowa, pp 81.

Houerou, H. and Petit, S. (1980): A*fzelia africana* short description. Forest Products Outlook No 24. Food and Agricultural organization of the United Nations, Rome, pg. 2.

James, W.L (1975). Research Paper FPL 245. USDA, Forest Service, Forest products Laboratory, Madison. Pg. 239.

Kellog, R.W. and Wangaard, F.F. (1989). Wood fibre. United States Department of Agriculture (USDA), Forest Products Research Laboratory, Bulletin No 180, vol. 1, No 3, Madison, pp. 18-36.

Kwame, J.B. (2001). Timbers of west Africa: an overview of their physical and strength properties. *International Journal of Environ. Sc*. 54(3): 30-39.

Larry, W.D. and Joseph, W.N`. (1988). Agricultural sustainability and nematode integrated pest management, *Journal of Nematode Interactions*, Vol. 36, pp 251 – 287

Leary, G.J.; Sawtell, D.A. and Wong, H. (1982), Factors Influencing strength properties in wood. *Holforschung*, 37 (1), Pp. 1 – 17

Maloney, T.M. (1986). Terminology and Products definitions – a suggested approach to uniformity worldwide, in 18th international Union of Forest Research Organization World Congress, Organized by IUFRO World congress organizing committee, Ljubljana, 177 pp.

Mclain, T.E.; DeBonis, A.L.; Green, D.W. Wilson F.J and Link C.L. (1984). Research Paper FPL 447. USDA Forest Service, Forest products Laboratory, Madison, pg. 118.

Meyer, J.A. (1991). Within tree variation of wood densities. *Journal of wood science*, 14 (2): Pp. 49 – 63.

Minor, J.L. and petterson, R.G. (1997). Anatomical structure of timber. *I.J. Agric Food Chem.*, 35: Pp. 996 – 1001.

Ministry of Land and Survey (2009). Ministry of Information, Jalingo, p.11

NDSWC (National Design Specification for Wood Construction) (1992). National Forest Products Association, Washington, D.C., p. 22.

Panshin, J.A. and Dezeeuw, C. (1980). Text book of wood Technology:

Structure, identification, uses and properties of the commercial woods of the United States, 4th edition. McGraw Hill, New York, 705 pp.

Peterson, B.G. Swchwandt, V.H. and Effland, M.J. (1984). Factors affecting Strength and Stiffness of Timber. *J. Chroma togr. Sci*, Pp.258-

Porter, B. (2001). Carpentry and Joinery 3, Butterworth Heinemann Publication, Oxford, 228 pp.

Raven, P.H.; Evert, R.F. and Eichhorn, S.E. (1997). Biology of woody plants, 4th edition. Worth publishers Inc., New York, p. 104.

Rietz, R.G. and Page, R.H. (1991). Agricultural Handbook 402: U.S.Department of Agriculture, U.S. Government Printing Office, Washington, D.C. pg. 9.

Rowell, R.M. and Banks, W.B. (1985). General Technical Report FPL 50. USDA, Forest Service, Forest Products Laboratory, Madison, pg 112.

Spielman, P. (1980). Working green wood with PEG. Sterling Press, New York. Pg. 31

Stanish, M.A.; Shajer, G.S. and Kayihan, F. (1986). Effect of moisture content on physical properties of woody and non-woody plants. *AIChE J*. 32(8): 1301.

STAS 6085:72. Romanian Standard Institution (1972). Studiul lemului:indrumar pentru lucrari practice. Universitatea din Brasov, Brasov, pp. 240.

Suchsland, A. and Woodson, G.E. (1986). Agricultural Handbook 640 on timber-drying. U.S. Department of Agriculture, Washington, DC. Pg 61.

Udegbe, J. (1991). Design and Construction of a Solar-heated wood Kiln, M.Sc. thesis. Department of Agricultural Engineering, University of Ibadan, Ibadan, 98 pp.

Udo, R.K. and Mamman, A.B. (eds.) (1993). Nigeria: giant in the tropics, vol. 2. Gabumo Publ. Co. Ltd, Lagos, pp. 598.

Wagenfuhr, R. and Steiger, A. (1972). African Species. Holz Technology Bulletin No 3 FPL, Washington, D.C.; Pg 37.

Woldstein, T.S. and Nicolas, D.D. (1993). Degradation protection and Seasoning of Wood, Syracuse University Press, Syracuse, 307 pp.

Youngquist, J.A. (1989). Wood-based Panels: their properties and uses (a review). The Food and Agricultural Organization of the United Nations, Rome, Pg 45.

APPENDICES

Appendix 1: Mass (kg) of *Afzelia africana* Wood in the Three Senatorial Zones of Taraba State

Tree Samples	Northern Zone Wood Specimens 1*	2*	3*	Central Zone Wood Specimens 1*	2*	3*	Southern Zone Wood Specimens 1*	2*	3*
1	0.04927	0.04843	0.04357	0.04966	0.04851	0.04422	0.05200	0.05192	0.05124
2	0.04643	0.04562	0.04317	0.04720	0.04651	0.04443	0.05175	0.05155	0.05120
3	0.04677	0.04628	0.04528	0.04700	0.04672	0.04582	0.04975	0.04822	0.04755
4	0.04923	0.04815	0.04732	0.04941	0.04879	0.04772	0.05196	0.05190	0.05182
5	0.04835	0.04878	0.04782	0.04892	0.04822	0.04699	0.05223	0.05200	0.05175

*1– bottom, 2 – Middle, 3 – top

Appendix 2: Linear Shrinkages of *Afzelia africana* Wood in the Three Senatorial Zones of Taraba State

No of Specimens	Dimensions of Specimens (mm)						M.C (%)		Linear Shrinkages (%)		
	Initial			Final							
	Dt	Dr	Dl	dt	dr	dl	Green	Ovendry	Tgs	Rds	Lgs
Northern Zone											
1	21.33	21.22	30.22	18.82	19.81	29.93	33.21	13.15	11.74	6.50	1.00
2	21.21	21.05	30.12	18.41	19.94	29.91	32.05	13.55	13.21	6.19	1.00
3	21.44	21.22	30.34	18.91	19.81	29.92	22.99	14.80	11.68	6.60	1.32
4	21.33	21.22	30.23	18.55	19.82	29.93	33.44	13.50	13.15	6.60	1.00
5	21.53	21.33	30.33	18.82	20.02	30.01	33.96	14.84	12.56	6.10	1.00
6	21.50	21.41	30.30	18.90	19.90	29.92	33.90	19.00	12.09	7.01	1.32
7	21.42	21.22	30.22	18.52	19.93	29.92	33.62	14.11	13.55	6.12	1.00
8	21.32	21.15	30.24	18,33	19.85	29.90	32.41	13.50	14.08	6.16	1.00
9	21.52	21.30	30.32	18.74	19.94	29.95	32.61	13.12	13.02	6.57	1.32
10	21.24	21.13	30.21	18.82	19.83	29.91	31.04	14.85	11,32	6.16	1.00
11	21.12	20.84	30.12	18.43	19.92	29.83	31.96	14.20	12.80	5.29	1.00
12	21.22	21.00	30.11	18.43	18.83	29.84	31.46	14.11	13.21	5.71	1.00
13	21.60	21.30	30.46	18.89	2.00	30.08	33.13	14.56	12.50	6.10	1.32
14	21.32	21.14	30.25	18.34	19.83	29.92	33.55	12.33	14.00	6.16	1.00
15	21.44	21.23	30.24	18.53	19.92	29.92	31.50	12.90	12.55	6.12	1.00
Mean	21.32	21.20	30.25	18,69	19.80	29.78	31.61	12.12	12.01	6.16	1.00

Central Zone											
16	21.45	21.26	30.33	18.62	19.83	29.90	33.71	14.30	13.04	6.60	1.32
17	2.21	21.00	30.22	18.43	19.7	29.83	31.96	13.36	12.21	6.19	1.32
18	21.33	21.14	30.22	18.50	19.81	29.81	31.73	12.99	13.21	6.16	1.00
19	21.32	21.22	30.20	18.50	19.82	29.80	30.52	13.00	13.15	6.60	1.33
20	21.44	21.21	30.30	18.82	19.93	29.90	33.80	14.65	12.18	6.13	1.32
21	21.30	21.20	30.11	18.41	19.82	29.93	31.54	13.66	13.62	6.60	0.66
22	21.33	21.22	30.32	18.71	1.84	29.94	32.45	13.50	12.20	6.60	1.32
23	21.62	21.42	30.41	18.90	20.00	30.00	33.99	14.81	12.50	6.54	1.32
24	21.42	21.33	30.33	18.82	19.81	29.83	33.08	13.75	12.15	7.04	1.65
25	21.54	21.44	30.32	18.92	19.90	30.00	33.87	14.80	12.09	7.01	1.00
26	21.44	21.23	30.32	18.70	19.94	20.93	32.66	13.59	12.65	6.13	11.32
27	21.12	20.81	30.11	18.22	1971	29.83	31.33	12.33	13.74	5.29	1.00
28	21.33	21.12	30.15	18.42	19.80	29.81	31.73	12.99	12.21	6.16	1.00
29	21.50	21.31	30.33	18.82	20.00	30.00	33.55	14.20	12.50	6.10	1.32
30	21.50	21.30	301.2	18.62	19.93	30.30	33.60	14.33	13.49	6.51	0.66
Mean	21.29	21.02	30.26	18.64	19.81	29.91	32.42	13.77	12.34	6.68	1.23

Southern Zone											
31	21.23	20.80	30.11	18.44	19.72	29.82	33.44	14.19	12.83	5.35	1.00
32	21.65	21.40	30.41	18.90	20.00	30.05	32.92	15.00	12.50	6.54	1.32
33	21.41	21.22	30.32	18.93	19.84	29.91	33.60	14.20	11.68	6.60	1.32
34	21.33	21.23	30.23	18.52	19.82	29.90	31.50	13.00	12.15	6.60	1.00
35	21.22	21.03	30.13	18.44	19.82	29.85	31.40	12.45	13.21	5.71	1.00
36	21.13	20.80	30.13	18.43	19.72	29.82	33.80	14.10	12.80	5.29	1.00
37	21.53	21.42	30.32	1892	19.90	29.93	31.22	14.80	12.09	7.01	1.32
38	21.12	20.81	30.14	18.41	19.72	29.94	31.50	13.98	12.80	5.29	1.00
39	21.53	21.42	30.32	18.92	19.90	29.93	31.22	14.80	12.09	7.01	1.32
40	21.23	21.03	30.15	18.44	19.80	29.82	33.10	13.05	13.21	5.11	1.00
41	21.40	21.23	30.32	18.83	19.92	29.91	32.25	15.00	12.15	6.13	1.32
42	21.55	21.33	30.35	18.73	19.94	29.92	32.85	13.00	12.04	6.57	1.32
43	21.24	21.13	30.24	18.82	19.83	29.92	31.55	14.70	11.32	6.16	1.00
44	21.45	21.22	30.33	18.80	19.92	29.90	34.00	14.90	12.15	6.13	1.32
45	21.53	21.33	30.34	18.81	20.00	30.00	31.70	12.85	12.56	6.10	1.00
Mean	21.44	21.32	30.22	18.76	19.89	29.88	32.02	13.65	12.38	5.22	1.13