EFFECTS OF THERMAL TREATMENT ON THE PHYSICAL AND MECHANICAL PROPERTIES OF IROKO (*MILICIA EXCELS*) WOOD

BY

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ABSTRACT

The aim of this research is to investigate the effects of thermal treatment on the physical and mechanical properties of a selected indigenous Nigerian wood. In order to achieve the research aim, Iroko (*MiliciaExcels*) wood samples obtained from Ala forest in Akure, Ondo state, Nigeria were subjected to heat treatment at varying temperatures (80 ^oC, 100 ^oC, 120 ^oC, 140 ^oC and 160 ^oC) with constant treatment duration of 6 hours and for varying time durations at constant temperature of 120 ^oC. The following characteristics: moisture contents, density, dimensional shrinkages, shearing strength, compression strength, tensile strength, modulus of rupture in bending static (MOR) of the Iroko (*Milicia excels*) wood were studied. The results showed that all the values of the characteristics studied decreased with increasing treatment temperature and treatment time, except hardness that behaved otherwise. At 120 ^oC the Iroko wood has the best physical and Mechanical properties similar to that of Teak that makes it suitable for technological applications such as Handles of Agricultural implements and tools, its durability makes it suitable for boat building piles, other marine work and rail road crossties. Iroko wood is also found suitable in many and most carpentry and joinery, flooring, furniture, veneer and cabinet works.

CHAPTER ONE

1.0 INTRODUCTION

This chapter provides the background information, the motivation for embarking on the thermal processing of Iroko wood (*Milicia excels*), the aims and objectives of this research, the limitation to this study, as well as the outline of this thesis.

1.1 Background

According to Korkut and co-investigators (2008), heat treatment of wood is considered as a viable alternative on ecological basis in comparison to chemically impregnated wood. Moreover, Rapp, (2001) reported that heat treated wood are suitable for fabricating garden, kitchen and sauna furniture, floors, ceilings, inner and outer bricks, doors and windows. A search through the available literature as well as a survey of the wood research activities carried out at Forest Research Institute of Nigeria (FRIN) in Ibadan and other Nigerian Universities revealed that there are no information on the effect of heat treatment on the mechanical and physical properties of Iroko wood (*Milicia excels*).

1.2 Problem statement

Jayeola *et al.*, (2009) reported that only very few (e.g. *Milicia excels* – Iroko, *Afzelia Africana* – Apa, *Anogeissusleiocarpus* – Ayin, *Antiaristoxicaria* – Oro, *Khayaivorensis* – Oganwo, *Mansoniaaltissima* – Ofun, and *Disopyros* – Kanran) of the different species of trees in the Nigerian forests had been exploited economically on commercial scale. Most of the few that are exploited are large trees which are among the highly priced hardwood timbers of tropical Africa and are well known all over the world. An attempt to identify other species that are not exploited as well as the reason behind that is a subject to be research on. In an effort to draw the attention of the anatomists to engage in wood quality study, Jane (1967) recommended that the aspects of variation in wood structure are of practical importance in the industrial production sense. However, Bamiro (2004), pointed out that many Nigerian production engineers using wood know very little or nothing about its structure and properties. Jayeola, (2009) stressed that there is no doubt that the information obtained from the wood structures could provide a credible alternative for identification of timber species, even after processing. He believed that although there is a lot of promise in the use of wood structural information for timber identification in Nigeria, it could not be achieved as the level of information remains scanty. For the purpose of supplying more information and making Nigerian wood literature more available rather than scanty, the study of the properties of heat treated Nigerian wood is therefore unavoidable. Considering these points, it is important that characterisation studies about heat treated Nigerian woods are carried out in an attempt to create a knowledge database to guide production engineers in the application of wood for appropriate technological purposes.

1.3 Aims and Objective of the Study

The aims and objectives of the study are summarised as follows: -

1. To determine the effect of heat treatment processing parameters (temperature and time) on the physical properties, and mechanical properties, of Iroko (*Milicia excels*) wood.
2. To determine the optimum processing parameters as well as optimum technological properties of the Iroko wood.
3. On the basis of the results obtained from 1 and 2, the Iroko (*Milicia excels*) wood will be characterised for suitable technological applications.

1.4 The Significance of the Study

It is expected that the outcome of this study would form part of database that would help students of wood technology, wood merchants, and production engineers to gain basic knowledge of Iroko wood (*Milicia excels*) with regards to its suitability for various applications in joinery, interior, furniture products and structural products. Furthermore, investigation of the heat treatment parameters would help determine the optimum physical and mechanical properties of Iroko (*Milicia excels*) wood. It is anticipated that this knowledge would help the Nigerian wood processing industries in the development of process parameters for their woods. An attempt to find out the physical and mechanical properties of wood in Nigeria, would not only help in establishing the level of the Nigerian woods quality but also assist in making an adequate, accurate and timely decision on the nature and quality of wood species available, which could lead to the effective utilisation of wood and its product in Nigeria.

Based on the argument that Nigeria does not export wood and wood products due to the high supply and demand gap being experienced. This study would be of great importance in suggesting ways of increasing its supply to at least meet the high demands in Nigeria and probably lead to its exportation to other parts of the world and provide opportunity for Nigerian wood industrialists to invest their resources into the production of high quality wood products for exportation. This is expected to increase Nigeria's foreign earnings.

1.5 Limitations of the Study

The study is generally about the effect of heat treatment parameters on the physical and mechanical properties of *Iroko* wood (*Milicia excels*). There are two basic techniques of identifying the effects of physical and mechanical properties of a wood. However, for the purpose of this study, thermal processing technique was used. Moreover, there are many timbers species in Nigeria but this study is specifically concerned about the Iroko (*Milicia excels*) species being one of the available timber species in Nigeria. The choice of Iroko (*Milicia excels*) was based on its availability, durability, easy workability in addition to the fact that it does not require regular treatment with oil or varnish. Sampling and observation techniques are the most crucial methods and techniques of carrying out this research study. The iroko (*Milicia excels*) wood sample will be subjected to different temperatures (80 ^oC, 100 ^oC, 120 ^oC, 140 ^oC and 160 ^oC) with constant treatment duration of 6 hours and for varying durations (2 hr, 4 hr, 6 hr and 8 hr) with constant temperature of 120 ^oC while the physical, and mechanical properties are to be systematically observed, prior and after the processing conditions.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter presents the review of related literature to this study. It begins with the function and various species of wood in Nigerian society, then describing the structure and function of a wood. Moreover, wood chemistry, moisture properties of wood, mechanical properties of wood and wood processing are also considered in this chapter. These issues are looked at in order to provide insight into the structure and behaviour of wood during both processing and service conditions as relevant to the interest of production engineers. Moreover, it is expected this literature review would help in identifying areas worth exploring for further research in this study with a view to improving the quality of *Iroko* wood product and make it available for exportation.

2.2 The functions of Wood

Wood has played an important role in the development of human race from the early ages up till now. Wood is the major source of cooking and heating fuel for the world. According to Food and Agricultural Organization (FAO, 2004), world consumption of fuel wood and charcoal totalling 1,838,218,860 cubic meters in 2002. This represents nearly 54% of the world’s consumption of wood. Table 2.1 presents the amount of fuel wood consumed by various regions of the world.

Table 2.1: Fuel wood consumption by various world regions (Source: FAO, 2004)

World Region	Consumption of fuel wood (%)
Asia	43.0
Africa	31.0
United States	4.0

Wood has remained an important material for production engineers throughout history because of its unique properties such as recyclability, renewability and biodegradability. Wood can further be converted to many useful industrial chemicals such as ethanol and plastics. Wood can also be treated to resist decay and with proper construction techniques, and stains or paint. Wood building can last hundreds of years. Today, production engineers use wood in the construction of roofs and doors, boats and lorry bodies, electric poles, bridges, and packaging, manufacturing of crutches, pulp and paper, handles of tools, furniture, railroad, tiles, and many other engineering components for daily use (Adeleke, 2008). Wood's functions are versatile and because of its versatility, many wood products can be made recyclable. The simplest of this recycling was the burning of used wood (charcoal) for heat, whether in a wood stove, fire place, or furnace. New technologies are improving the efficiency to which the used or scrap wood can generate electricity and heat. Other recycling opportunities for wood, which are of interest to production engineers, include the manufacture of wood fiber and plastic composite material, in wood polymer composites, wood fibers improve the strength to weight ratio over that of plastic, this performance characteristics has strong appeal in the automotive industry, among others. Wood's chemical make-up is largely carbon, hydrogen, and oxygen arranged as cellulose, hemicelluloses and lignin. As such wood presents an appetising feast for a variety of fungal species that can metabolise either the sugar- like cellulose or the more complex lignin. By this fungi in the presence of air and water, wood rots, or in environmental terms, is biologically degraded (Risbrudt, 2005).

2.3 Wood in the Nigeria society pre-historical

In Nigeria, dendrology (the study of trees and other woody plants) had been an integral of part of our societies since the ancient times when we largely depended on trees as a means of providing for our basic needs such as food, housing, clothing, and security (Nigeria Information Portal, 2011). According to Keay and Stanfield (1964), Nigerian forests are naturally blessed with over nine hundred different species of trees such as Mahogany, Iroko and Obeche which are main sources of timber products. The abundances of these trees in Nigeria is attributed to prolonged rainy season, resulting in high annual rainfall (above 2000mm), which ensures adequate supply of water and promotes perennial tree growth (Nigeria Information Portal, 2004).

Table 2.2 shows some of the most promising of these woods

Table 2.2: List of commonly used timber species of Nigeria

Name of species	Local Common Names	Wood characteristics	Family	Availability
Afzelia Africana	Bin: arinyan, orodo Hausa: Kawa Ibo: akpalata, aja Yoruba: olutoko, Apa Igbo	Hard, tought and heavy, coarsely grained with lighter streaks, banded light and dark brown. Diffuse porous, aliformparatracheal parenchyma	Caesalpinaceae	Common in the savannah secondary forest, and in the high forests
Anogeissusleiocarpus	Ayin	Grayish outside, dark brown at the heart and very hard. Wood is ring porous, surface crystals and traumatic ducts	Combretaceae	Found at the edges of the rainforest
Antiarisleiocarpus	Oro	Wood is ring porous tyloses, and septatefibresrous.	Moraceae	Common in tropical and subtropical regions
Khayaivorensis	Mahogany, Hausa: male Igbo :ono Yoruba: oganwo	Wood of two bands of axial parenchyma, first class mahogany.	Maliaceae	Found in low land rain forests
Mansoniaaltissima	Ofun	Semi-ring porous wood, slash soft, dull white with brown streaks. Semi-ring porous wood, solitary vessels and storied fibers	Sterculiaceae	Common in swamp forests
Milicia excels	Hausa: Lokoibo: ojiNupe: rook Bini: ulokoitsekiri: uroko Yoruba: Iroko	Huge compound tyloses present in all vessels, wood peel turns dark brown	Moraceae	Common in rain forests and forest outliners in savanna wood land areas
Aistonia (booneicongensis)	Bini: ukhuEfiki: ukpoijaw: ndondoibo: egbu Yoruba: awun	The wood is creamy white and indistinctly demarcated from the up to 20 cm wide sapwood.	Apocynaceae	Common in the damp shigh forests.
Disopyros	Bini: abokopo, Isahiame Hausa: Kanyan, Kaiwa Yoruba: Kanran, Igidudu	hard wood, there is the pure black ebony, and the striped ebony or Calamander wood	Ebenaceae	Restricted to Benin, Abeokuta and Ijebu areas

(source: Jayeola, 2009)

In the present day Nigerian society, woods are being sculpted into handles for farm implements such as hoes, sickles, and rakes; shaped into kitchen cabinet, wardrobes, drawers, cushion ,interior, peg for plants, doors and even beds by production engineers. Furthermore, Nigerian societies also use wood in the field of education. For instance, woods are used in producing writing tables for the Arabic and Islamic schools, chalkboard for Western and secular schools. Woods are also used in the production of instructional materials and infrastructures in Nigerian schools. Elekwe, (1999) observed that modern civilisation and technology expertise had led to the sophisticated utilisation of wood in the contemporary Nigerian societies. This could probably be attributed to the increasing demand for wood by the Nigerian architects, artisans and production engineers in carrying out construction of buildings culverts, and bridges, fabrication of automobile bodies and advertising bill boards, and electrification of towns and villages. In the Nigerian manufacturing sector, Adeleke (2008) reported that woods are used in the production of papers, pulp and crutches, crates for packaging eggs and soft/hard drinks. Oyetola (2001) also pointed out that the increasing demand for wood products in the various sectors of the Nigerian economy had led to commercialization of wood. According to Oyetola (2001), less attention was being paid to wood utilization in various technological applications by the designers because woods are easily destructible in case of fire-out-break. Despite Oyetola's claim, it is evident that various segments of the Nigerian society attached so much value and relevance to the wood and timber in specific, based on the availability of a number of saw-mills in places like Akure, Ibadan, Ondo, Benin, e.t.c. Therefore, wood is, a source of income generation to many Nigerians and Government.

2.4 The Structure of Wood

Wood is composed of hollow, elongated, spindle- shaped cells that are arranged parallel to each other along the trunk of a tree. A growing tree has two main domains, the shoot and the roots. The roots are underground part of the tree that is responsible for water uptake, mechanical support of the shoot, and storage of the biochemical. The shoot comprises the trunk or bole of the tree, the branches, and the leaves (Raven, Evert and Eichhorn, 1999). The trunk is composed of various materials present in the concentric bands. From the outer part of the tree to the inner part there are six layers: outer bark, inner bark, vascular cambium, sapwood, heartwood, the pith and the rays (Figure 2.1). The outer bark provides mechanical protection to the softer inner bark, and also helps to limit evaporative water loss. The inner bark (phloem) is the tissue through which sugars produced by photosynthesis (photosynthate or "food") are translocated from the leaves to the roots or growing portions of the tree. The vascular cambium is the layer between the bark and the wood.

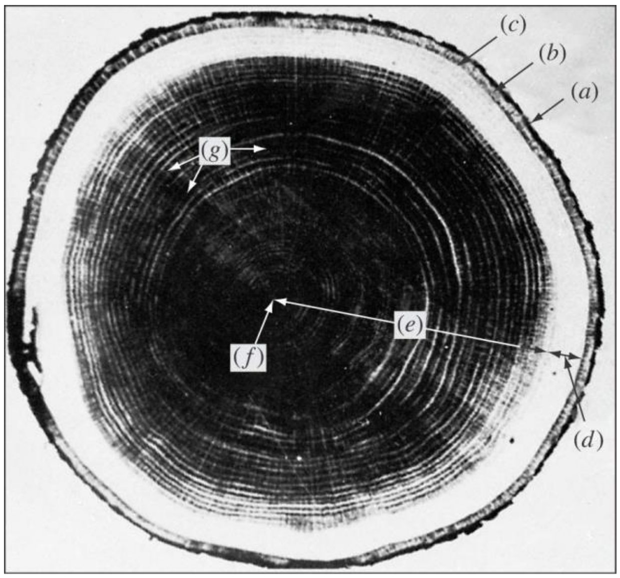


Figure 2.1 Macroscopic view of a transverse section of a *Quercusalba*trunk. Beginning at the outside of the tree, there is the outer bark (a), the inner bark (b), and then the vascular cambium (c), Interior to the vascular cambium is the sapwood (d), which is easily differentiated from the heartwood (e) that lies to the interior. At the center of the trunk is the pith (f), which is barely discernible in the center of the heartwood. The fine radiating “spokes”, (g) are the wood rays (Source: Regis, 1999)

The sapwood is the active, "living" wood that is responsible for conducting the water (or sap) from the roots to the leaves. The pith at the very center of the trunk is the remnants of the early growth of the trunk, before wood was formed. The branches of a plant perform three functions. The first is simply to support the weight of the foliage and extended branch growth results in leaves gaining maximum possible exposure to light. Secondly, as with the roots, branches are able to store nutrients ready for when they are required. The third function is to provide a conduit for water and nutrients from one part to another. Leaves are the place where the tree processes sugars in a process known as photosynthesis. These sugars take the form of glucose (carbohydrates) which in turn provides growth energy to the plant. A second function of leaves is to allow water to evaporate through their surface in order to keep a constant flow of water throughout the whole tree. In the next section, the two types of woods (softwoods and hardwoods) used by production engineers are described.

2.5 Softwoods and Hardwoods

Botanically, softwoods are those woods that come from gymnosperms (mostly conifers), and hardwoods are woods that come from angiosperms (flowering plants). In the temperate region of the Northern Hemisphere, softwoods are generally needle-leaved evergreen trees such as pine *(Pinus)* and spruce *(Picea)* (Figure 2.2a), whereas hardwoods are typically broadleaf, deciduous trees such as maple *(Acer)* and birch *(Betula)* (Figure 2.2b).

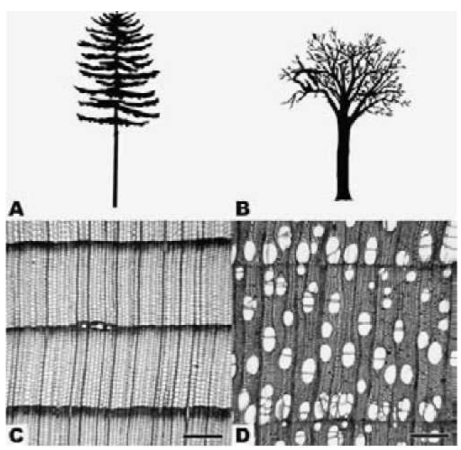


Figure 2.2 Softwood and hardwood. (a) The general form of a generic softwood tree. (b) The general form of a generic hardwood tree. (c) Transverse section of *Pseudotsugamensiezii,* a typical softwood. The three round white spaces are resin canals. (d) Transverse section of

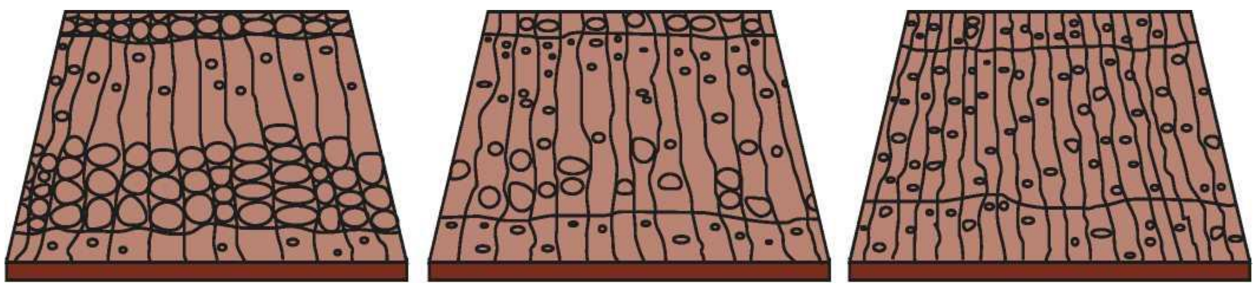
Betulaalleghenensis, a typical hardwood. The many large, round white structures are vessels or pores, the characteristic feature of a hardwood (Source: Wiedenhoeft and Miller, 2005)

Not only do softwoods and hardwoods differ in terms of the types of trees from which they are derived, but they also differ in terms of their component cells. The single most important distinction between the two general kinds of wood is that hardwoods have a characteristic type of cell called a vessel element (or pore), whereas softwoods lack these (Figures 2.2c and d). An important cellular similarity between the softwoods and the hardwoods is that in both kinds of wood, most of the cells are dead at maturity even in the sapwood. The cells that are alive at maturity are known as parenchyma cells, and can be found in both softwoods and hardwoods. Additionally, despite what one might conclude based on the names, not all softwoods have soft, lightweight wood, nor do all hardwoods have hard, heavy wood. The detail identity of softwood and softwood would be discussed based on cell type in the following sections. It is expected that the information gathered from this review will be useful in characterising the cell structure of Iroko wood (the focus of this study) as either hardwood or softwood.

2.5.1 Hardwoods

In this section, the cell structure in hardwood are described in respect of the growth ring pore arrangement, vessel (pore) arrangement, fibers, wood rays, tyloses, parenchyma, colour, odour, and density. In regards to the growth ring pore arrangement; there are three general classifications for this earlywood/latewood transition as depicted in Figure 2.3.In the ring-porous hardwoods (Figure 2.3a) as seen in some groups of species (Oaks and Elms), the earlywood/latewood transition occurs abruptly and is very distinct. Within each growth ring, a band of large earlywood vessels (pores) is clearly visible to the naked eye, after which a band of latewood vessels appears much smaller and requires the use of a hand lens to see. For the semi-ring-porous hardwoods (Figure 2.3b) which occur in Black Walnut, Butternut and Hickory, the pore transition from large to small diameter within a growth ring is gradual.The pores in the earlywood zone have a large diameter that gradually decreases in size as pores enter the latewood zone.

For the diffuse-porous hardwoods (Figure 2.3c), they are characterised by vessels (pores) that are uniform in size across the entire growth ring (yellow poplar, gum and maple). These vessels are usually small, uniform in size and are very difficult to see with the naked eye (a hand lens is needed).



(a) Ring-porous (b) Semi-ring-porous (c) Diffuse-porous

Figure 2.3.Classification of pore transition from earlywood to latewood (Banks and West, 1989)

Considering the vessel (pore) arrangement, vessel elements (pores) can be described by their position relative to each other in a cross section. Different species of hardwood have unique vessel arrangements. Figure 2.4shows some of the more common vessel arrangements. The solitary pores (Figure 2.4a) are single pores that do not touch any other pores – evenly spaced across cross section (maples).In the pore multiples (Figure 2.4b) arrangement two to five pores appear grouped together.Pore multiples usually occur in radial rows (cottonwood), but can occur in both radial and tangential directions (Kentucky coffee tree). The pore chains (Figure 2.4c) arrangement occur when pore multiples appear in radial direction only. The nested pores (Figure 2.4d) occur when larger numbers of pores contact each other both radially and tangentially (cluster). In the wavy bands (Figure 2.4e), pores are arranged in irregular concentric bands. The wavy bands isalso called *ulmiform*because this characteristic is distinctive of all Elms(also hackberry).

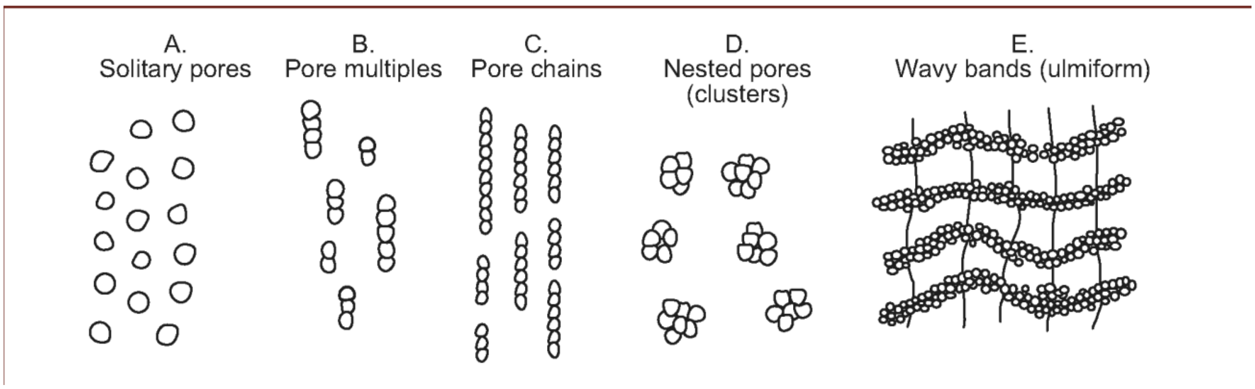


Figure 2.4.Vessel (pore) arrangement (Banks and West, 1989)

Fibers in the hardwoods function solely as support. They are shorter than softwood tracheids (200– 1200 μm) and average about half the width of softwood tracheids, but are usually 2–10 times longer than vessel elements (Figure 2.5).

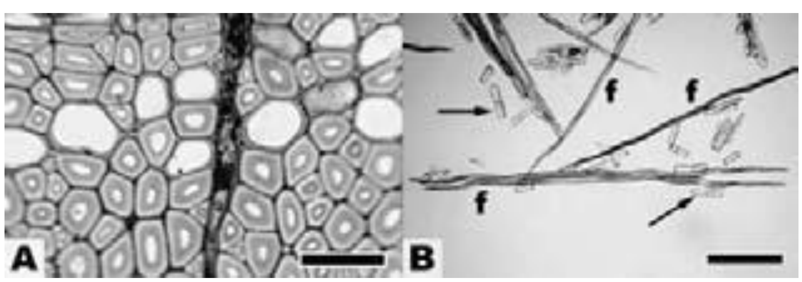


Figure 2.5 Fibers in *Quercusrubra*. (a) Transverse section showing thick-walled, narrow-lumined fibers.

A ray is passing vertically through the photo, and there are nine axial parenchyma cells, the thin-walled, widelumined cells, in the photo. Scale bar = 30 μm. (b) Macerated wood. There are several fibers (f), two of which are marked. Also easily observed are parenchyma cells (arrows) both individually and in small groups (Wiedenhoeft and Miller, 2005*)*

The thickness of the fiber cell wall is the major factor governing the density and the strength of hardwoods. Hardwood species with thin-walled fibers have low density and strength, whereas species with thick-walled fibers have a high density and strength. The air-dry (12% moisture content) density of hardwoods varies from 100–1400 kg/m^3. The air-dry density of typical softwoods varies from 300–800 kg/m^3. The presences of tracheids in hardwoods function in both support and transport (Wiedenhoeft and Miller, 2005).

Wood rays are seen as narrow stripes or lines that extend across the growth rings in the radial direction – from the bark to the center of the tree. Wood rays function to transport food and water horizontally across the diameter of a tree. The size and distribution of wood rays on the cross section are quite unique for many species and groups of species. Species such as Red and White Oaks have very wide rays (many cells wide) that are easily seen without a hand lens. Species such as Yellow-Poplar, Ssh and Maple have numerous and extremely narrow rays (just 1-2 cells wide). The distribution of rays can also be used to separate some species. For example, Beech and Sycamore both have large, conspicuous rays with fine, narrow rays running between them. Another useful characteristic of rays that can be observed on the cross section of some species is the presence of *nodes*, or a swelling of the ray, at the intersection of a new growth ring – where the earlywood zone begins. Ray nodes are seen in Yellow-Poplar, Beech and Sycamore, (Paulo, 2000).

When viewing a piece of wood from either the radial or tangential surface, wood rays can be a key characteristic to help identify the species. Rays vary not only in width, but also in height. The height of a ray is best observed from the tangential surface. Ray height varies between species from imperceptibly small to several inches high. When wood is cut radially, across the plane where rays extend through the diameter of the cross section surface, many rays are split and exposed in patches on the radial surface. In many species – Maple, Sycamore and Beech especially – these patches of split rays contrast in colour from the longitudinal tissue around them and form a freckled pattern on the radial surface called *ray fleck.*

Tyloses are inclusions that form inside the vessels of some hardwoods. Because tyloses are unique to certain hardwood species, they are useful for wood identification. Tyloses are outgrowths of parenchyma cells into the hollow lumens of vessels and they look like bubbles or cellophane-like structures clogging the openings of the vessel elements. Tyloses may be absent or sparse, as in Red Oak; variable, in the case of Chestnut and Ash; or densely packed and abundant, as they appear in White Oak and Locust. Tyloses effectively clog the vessels and subsequently restrict moisture movement.The presence of tyloses is the reason White Oak is used for making whisky barrels.

Parenchyma are small, thin-walled, longitudinal cells that provide food storage. These cells are sparse in softwoods but are often quite significant in hardwoods. Parenchyma are often very small and difficult to see. However, there are many species with visible and unique arrangements of parenchyma cells that offer a clear structural feature for decisive identification.There are two basic types of parenchyma: *paratracheal*and *apotracheal*. The major difference between them is that paratracheal parenchyma make contact with the pores or vessel elements, while apotrachealparenchyma are separated from pores by fibers or rays. Figure 2.6 shows the various types of paratracheal and apotracheal parenchyma.

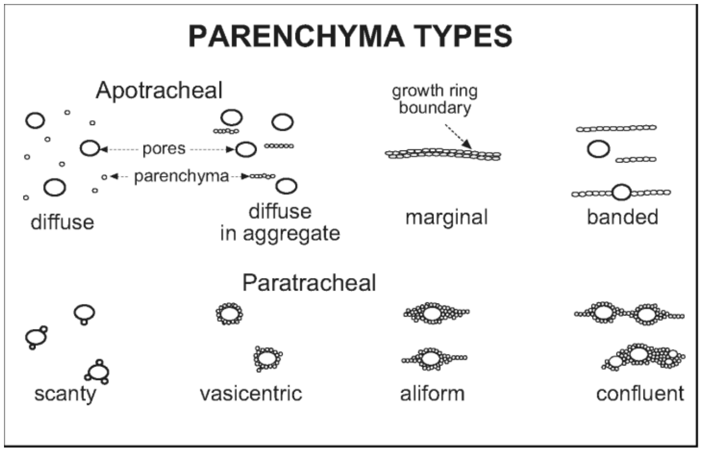


Figure 2.6.Classification of parenchyma arrangements around hardwood pores - cross-section view (Banks and West, 1989)

In most species, apotracheal parenchyma are not useful in identifying wood with just a hand lens. One exception is Yellow-Poplar, which has a fine, clear, bright line of marginal apotracheal parenchyma at the edge of every growth ring.

The colour, odour, and density characteristics are remarkably variable in hardwoods and often provide the first clue to identify a particular wood species. Hardwoods come in a variety of colors and shades that often allow immediate and unmistakable recognition. Consider the lush reddish brown of Black Cherry, the deep chocolate brown of Black Walnut or the creamy white of Hard Maple.Less obvious, but certainly helpful to wood identification are odour characteristics. Many hardwoods have distinctive natural odours. Black Cherry, for example, has an unmistakably fragrant aroma, while Red Oak has more bitter and acidic smelling.

Hardwoods also vary significantly with respect to density. The density of wood is related to its hardness, strength and weight. Typically, a dense species of wood is heavier, harder and stronger than other, less dense species. Hardness is particularly useful when distinguishing between Hard and soft Maple. Soft Maple can be easily dented with fingernail or sliced with a razor blade, while Hard Maple is significantly more difficult to make an impression. Hickory, Black Locust and Osage-Orange are quite heavy compared to most other species.

2.5.2 Softwoods

In this section, the cell structures in softwoods are described in respect of the resin canals, growth ring pore arrangement, colour, odour, and density.

Resin canals are tubular passages in softwood that exude pitch, or resin, to seal off wounds that occur due to insect or mechanical damage. Resin canals most often occur in or near the late wood zone of the growth rings. Softwoods can be separated into two classifications based on the presence or absence of resin canals. Species that have resin canals include Pines, Spruces, Larches and Douglas-fir. The species that do not have resin canals include Firs, Hemlocks, Cedars, Redwood, Baldcypress and Yew. Woods with resin canals are further separated into two groups: (1) those with large resin canals: -Pines, and (2) those with small resin canals: Douglas Fir, Spruce and Larch. Using a sample wood identification set to compare the size and number of resin canals of different species is useful in determining how much they can differ between species. For example, most Pines have quite large and numerous resin canals that can be seen without the aid of a hand lens. Spruce and Larch, on the other hand, have much smaller resin canals that occur less frequently. Douglas-Fir has many small resin canals (Bond and Hamner, 2002)

In softwoods, early wood/latewood characteristics can provide useful information for identification. The features to compare are: (1) the nature of the early wood/latewood transition: abrupt or gradual, and (2) the percentage of latewood occupying the growth ring. When identifying hardwoods, the size and distribution of pores between earlywood and latewood are discriminating factors. Since softwoods have no pores, the difference between the earlywood and latewood zones in the growth ring occurs due to effects that the growing season has on the longitudinal tracheids (the dominant cell type in softwoods). The earlywood zone of a growth ring typically consists of thin-walled, larger-diameter cells, while the latewood zone features thick-walled, smaller-diameter cells. Thus, for many species, the earlywood zone appears lighter, contrasting with the latewood zone, which is often a darker or browner shade. For some species the transition from the lighter-colored earlywood to the darker-colored latewood is distinct and abrupt (Southern Yellow Pine, Douglas Fir, Redwood). For other woods, this transition is extremely gradual and even imperceptible (White Pine, Cedars). Some species have an earlywood and latewood transition that falls between gradual to abrupt (Spruce, Fir, Hemlock).

As with the hardwoods, colour, odour and density are useful characteristics in identifying softwoods. Some species have distinct colour differences, while others do not. Eastern White Pine is consistently Yellowish White, darkening to light brown with age. Eastern Redcedar has a distinctive deep purplish-red colour, and Redwood a deep reddish-brown. Examples of odours include the "piney" fragrance of Pines, the "Cedar Chest" scent of Eastern RedCedar and the relative absence of smell in Spruce, Firs and Hemlocks. Softwoods also vary substantially in density. Because many species are quite dense and strong, softwood lumber is typically used for structural or construction purposes. Southern Yellow Pine, Spruce, Hemlock, Fir and Douglas Fir are all commonly used in the construction industry.

In considering the cited literature in this section so far, it is evident that none of the woods which their cell structure had been described is native to the Nigerian nation. Therefore, it is imperative that this study investigates the cell structure of Iroko wood with a view to providing empirical evidence towards classifying it as a softwood or hardwood. It is also expected that the knowledge gained from this study will be helpful in developing the curriculum for teaching wood technology, and providing guidance for production engineers working in the wood industry towards appropriate application of Iroko wood for suitable technological purposes. In order to further understand the properties of wood, the planes of sectioning woods will be described in the next section.

2.6 Planes of Section

The organization and interrelationship between the axial and radial systems in woods give rise to three main perspectives from which they can be viewed (Figure 2.7). These three perspectives are the transverse plane of section (the cross-section), the radial plane of section, and the tangential plane of section. The latter planes of section are referred to as longitudinal sections, because they extend parallel to the axial system (along the grain).The transverse plane of section is the face that is exposed when a tree is cut down; looking down at the stump one sees the transverse section. Transverse cut through the stem will reveal the growth rings as concentric circles. In structural lumber, partial growth rings are evident at the ends of timber and the surface is known as end grain.

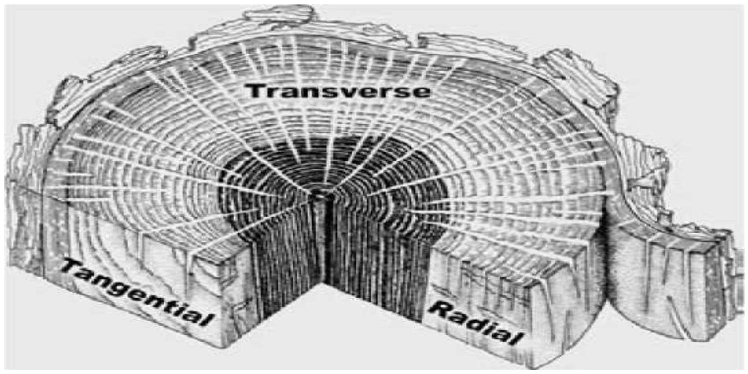


Figure 2.7: Illustration of the three planes of section. Note that for the tangential plane of section, only the right-hand portion of the cut is perpendicular to the rays; due to the curvature of the rings, the left portion of the cut is out of plane (Wiedenhoeft and Miller, 2005)

The radial plane of section runs in a pith-to-bark direction, and it is parallel to the axial system, so it provides information about longitudinal changes in the stem and from the pith to bark along the radial system. To describe it geometrically, it is parallel to the radius of a cylinder, and extending up and down the length of the cylinder. In a practical sense, it is the face or plane that is exposed when a log is split exactly from pith to bark. The tangential plane is at a right angle to the radial plane. Geometrically, it is parallel to any tangent line that would touch the cylinder, and it extends along the length of the cylinder. Growth rings here will appear as a series of wavy lines or cones stacked one above another. The three planes of section are determined by the structure of wood, and the way in which the cells in wood are arrayed. The cells are laid down in these special arrangements by a special part of the trunk. Furthermore, the strength of wood is highly dependent upon grain direction. Tensile strength values in the longitudinal, radial and tangential directions on average are in the ratio of 20:1.5:1(Paulo, 2000). The variation of strength between different directions can be attributed to the fine structure of the wood cells.

Having considered the plane of section, the wood chemistry, a relevant concept of interest to production engineers working in the wood industry will be elucidated briefly in the next section.

2.7 Physical properties of wood

2.7.1 Moisture Contents

According to Wiedenhoeft and Miller (2005), the wood structure is formed in a water-saturated environment in the living tree, thus, the elastic property of the wood as well as its ability to withstand environmental strain such as high wind loads is sustained by the moisture content of the living tree. Moreover, the wood in use is a hygroscopic resource, therefore, its dimensional, mechanical, elastic, and thermal properties are determined by its moisture content. The moisture content of wood is defined as the weight of water in wood given as a percentage of ovendry weight. In equation form, moisture content (MC) is expressed as follows:

$$MC = \frac{W_m - W_d}{W_m} X 100\% \tag{2.1}$$

Where MC is the moisture contents

W_m is the moist weight

W_d is the dry weight (Paulo, 2000)

Water is required for the growth and development of living trees and constitutes a major portion of green wood anatomy. In living trees, moisture content depends on the species and the type of-wood, and may range from approximately 25% to more than 250% (two and a half times the weight of the dry wood material). In most species, the moisture content of sapwood is higher than that of heartwood. Water exists in wood either as bound water (in the cell wall) or free water (in the cell cavity). As bound water, it is bonded (via secondary or hydrogen bonds) within the wood cell walls. As free water, it is simply present in the cell cavities. When wood dries, most free water separates at a faster rate than bound water because of accessibility and the absence of secondary bonding. The moisture content at which the cell walls are still saturated but virtually no water exists in the cell cavities is called the Fiber Saturation Point (FSP). FSP ranges from 20 to 50 percent weight gain depending on the wood species (Feist and Tarkow 1967).

Wood is a hygroscopic material that absorbs moisture in a humid environment and loses moisture in a dry environment. As a result, the moisture content of wood is a function of atmospheric conditions and depends on the relative humidity and temperature of the surrounding air. Under constant conditions of temperature and humidity, wood reaches equilibrium moisture content (EMC) at which it is neither gaining nor losing moisture. The EMC represents a balance point where the wood is in equilibrium with its environment. In structural applications, the moisture content of wood is almost always undergoing some changes as temperature and humidity conditions vary. These changes are usually gradual and short-term fluctuations that influence only the surface of the wood. The time required for wood to reach the EMC depends on the size and permeability of the member, the temperature, and the difference between the moisture content of the member and the EMC potential of that environment. Changes in moisture content cannot be entirely stopped but can be retarded by coatings or thermal treatments applied to the wood.

2.7.1.1 Effects of moisture content on strength properties

Changes in moisture content of the wood cell wall below the FSP have a major effect on the mechanical properties of wood. Mechanical properties change very little at moisture contents above the FSP. Mechanical properties increase with decreasing moisture content with compression parallel to the grain being the most affected (Rowell, 2005)

2.7.2 Density of wood

Density can vary widely across a growth or annual ring. The percentage of growth or early wood and late wood in each growth ring determines the overall density of a wood sample. Density of a sample of wood is usually calculated as the weight density instead of mass:

$$d_W = \frac{W_{wm}}{V_{wm}} \qquad 2.2$$

Where d_w is the weight density

W_{wm} is the weight of wood with moisture

V_{wm} is the volume of wood with moisture (Paulo, 2000)

Weight density and bulk density are sometimes synonymous. To distinguish between the two, the moisture content at which the weight and volume were measured must be indicated in some cases weight and volume are at the same moisture content while in other cases they are at different moisture content.

2.7.3 Shrinkage and swelling

Shrinkage and swelling are the cause of many of the problems that occur in wood during drying and in use. Splitting, warping, and open joints are examples of problems that occur in woods due to uneven shrinkage. When water begins to leave the cell walls at the FSP, the walls begin to shrink. Even after drying is complete, wood will shrink and swell as relative humidity varies and water either leaves or enters the cell walls. Stresses that can cause splitting and warp develop because wood shrinks or swells by different amounts in the radial, tangential and longitudinal directions due to its anisotropic nature and because during any moisture content change, different parts of a piece of wood are at different moisture contents.

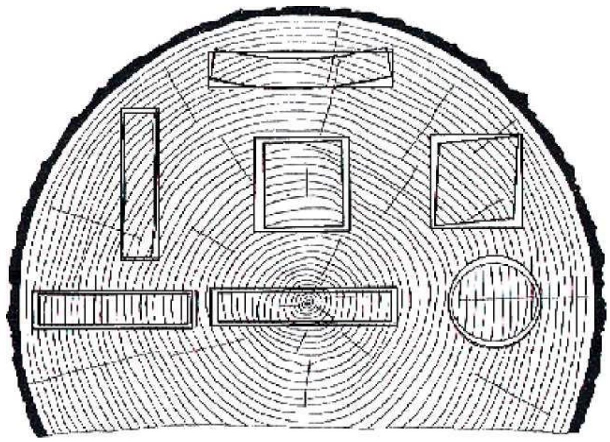


Figure 2.8: Shrinkage and distortion of wood upon drying (Source: Simpson and TenWolde, 1999).

These differences cause internal stresses in parts of the wood that are attempting to shrink or swell without success due to restraint from the surrounding wood.

The following equation 2.4 and 2.5 give the relationship between shrinkage and swelling in percentage and the wood dimension.

$$\text{Shrinkage (\%)} = \left(\frac{D_W - D_d}{D_W}\right) X100 \quad (2.3)$$

$$\text{Swelling (\%)} = \left(\frac{D_W - D_d}{D_d}\right) X100 \quad (2.4)$$

Where D_W is the wet dimension

D_d is the dry dimension (Paulo, 2000)

Woods shrink significantly in the radial and tangential directions than in the longitudinal direction (Paulo, 2000). The shrinkage of iroko wood upon drying depends on several variables, including specific gravity, rate of drying and the size of the piece. The relationship between redial and tangential shrinkage is given below;

$$V_s = SR + ST \tag{2.5}$$

Where Vs = Volumetric shrinkage

SR = Radial shrinkage

ST = Tangential shrinkage

Tangential shrinkage is generally about twice as large as radial shrinkage, and longitudinal shrinkage ranges from approximately one-tenth to one-hundredth of either radial or tangential shrinkage (Pettersen, 1984).

2.8 Mechanical properties

Mechanical properties are the characteristics of a material in response to externally applied forces. They include elastic properties, which characterised resistance to deformation and distortion, and strength properties, which characterise resistance to applied loads. Mechanical property values are given in terms of stress (force per unit area) and strain (deformation resulting from the applied stress). The mechanical properties are influenced by woods dimensional nature which results in markedly different properties in the longitudinal, tangential and radial directions or axes.

The mechanical property values of wood are obtained from laboratory tests of lumber of straight-grained clear wood samples (without natural defects that would reduce strength, such as knots, checks, splits, etc.).

Strength properties are the ultimate resistance of a material to applied loads. With wood, strength varies significantly depending on species, loading condition, load duration, and a number of assorted material and environmental factors. Because wood is anisotropic, mechanical properties also vary in the three principal axes. Property values in the longitudinal axis are generally significantly higher than those in the tangential or radial axes. Strength-related properties in the longitudinal axis are usually referred to as parallel-to-grain properties.

Five strength properties that are commonly measured for design purposes include bending, compression parallel and perpendicular to the grain, tension parallel to the grain, and shear parallel to the grain. In addition, measurements are sometimes required for tensile strength perpendicular to the grain and hardness.

2.8.1 Compression strength

When a compression load is applied parallel to grain, it produces stress that deforms (shortens) wood cells along their longitudinal axis. When wood is stressed in compression parallel to grain, failure initially begins as the microfibrils begin to fold within the cell wall, thereby creating planes of weakness or instability within the cell wall (Winandy, 1994). As stress in compression parallel to grain continues to increase, the wood-cells themselves fold into S shapes forming visible wrinkles on the surface. Large deformations occur from the internal crushing of the complex cellular structure. The average strength of green clear wood specimens of Douglas-fir and loblolly pine in compression parallel to grain is approximately 26.1 and 24.2 MPa, respectively.

When a compression load is applied perpendicular to grain, it produces stress that deforms the wood cells perpendicular to their length. Once the hollow cell cavities are collapsed, wood is quite strong because no void space exists. In practice, compressive strength of wood perpendicular to grain is usually assumed to be exceeded when deformation exceeds 4% of the proportional limit stress. Using this convention, the average strength of green clear wood specimens of Douglas-fir and loblolly pine in compression perpendicular to grain is approximately 4.8 and 4.6 MPa, respectively (Winandy, 1994).

Compression strength of wood is calculated with the following formulae;

$$r = T/A \tag{2.6}$$

Where r = compression strength

T = applied load

A = cross- sectional area of the specimen

Compression applied at an angle to the grain produces stresses that act both parallel and perpendicular to grain. The strength at any intermediate angle is intermediate to values of compression parallel and perpendicular to grain and is determined using Han-kinson's formula which is shown below;

$$\sigma_\alpha = \frac{\sigma_0 \sigma_{90}}{\sigma_0 \sin^2 \alpha + \sigma_{90} \cos^2 \alpha} \tag{2.7}$$

Where σ_0 is the stress parallel to the grain

σ_{90} is the stress perpendicular to the grain

σ_{α} is the off-axis uniaxial stress

α is the direction at an angle to the grain

2.8.2 Tensile strength

Parallel to its grain, wood is very strong in tension. Failure occurs by a complex combination of two modes: cell-to-cell slippage and cell wall failure. Slippage occurs where two adjacent cells slide past one another. Cell wall failure involves rupture within the cell wall with little or no visible deformation prior to complete failure. Tensile strength parallel to grain for clear wood has been historically difficult to obtain, it is often conservatively estimated from bending test values because clear wood normally exhibits initial failure on the face stressed in tension (Winandy, 1994). In contrast to tension parallel to grain, wood is relatively weak when loaded in tension perpendicular to grain. Stresses in this direction act perpendicular to the cell lengths and produce splitting or cleavage along the grain, which can have a significant effect on structural integrity. Deformations are usually low prior to failure because of the geometry and structure of the cell wall cross-section. Strength in tension perpendicular to grain for clear green samples of Douglas-fir and loblolly pine average 2.1 and 1.8 MPa, respectively. However, because of the excessive variability associated with ultimate stress in tension perpendicular to grain design situations that induce this stress should be avoided. Tensile strength in perpendicular and parallel to the grain is calculated with the following equation;

$$UTS = Y/A \tag{2.8}$$

Where UTS is the Ultimate tensile strength

Y =Maximum load

A=cross-sectional area of the specimen ($A = \pi D^2/4$)

2.8.3 Shear strength

When used as a beam, wood is exposed to compression stress on one surface of the beam and tensile stress on the other. This opposition of stress results in a shear action through the section of the beam. This parallel-to-grain shear action is termed horizontal shear. The horizontal shear strength of clear Douglas-fir and loblolly pine averages 6.2 and 5.9 MPa, respectively (Winandy, 1994). Conversely, when stress is applied perpendicular to the cell length in a plane parallel to grain, this action is termed rolling shear. Rolling shear stresses produce a tendency for the wood cells to roll over one another. In general, rolling shear strength values for clear specimens average 18 to 28% of the parallel-to-grain shear values (Winandy, 1994).

Shear strength is expressed as;

$$S = Z/A \qquad (2.9)$$

Where S = shear strength (N/mm^2)

Z = maximum load (N)

A = cross- sectional area of the wood specimen (mm^2) (Adeleke, 2008)

2.8.4 Hardness

Hardness represents the resistance of wood to indentation and marring. Hardness is measured as resistance to indentation using a modified Janka hardness test, measured by the load required to embed an 11.3-mm (0.444-in.) diameter ball to one-half its diameter into the wood.

$$\text{BHN} = \frac{2P}{\pi D(D - \sqrt{(D^2 - d^2)})} \tag{2.10}$$

where:

BHN = Brinell Hardness Number

P = applied force (kg)

D = diameter of indenter (mm)

d = diameter of indentation (mm). (Adeleke, 2008)

2.8.5 Impact strength

In the impact test, a hammer of given weight is dropped upon a beam from successively increased heights until rupture occurs or the beam deflects 152 mm or more. The height of the maximum drop, or the drop that causes failure, is a comparative value that represents the ability of wood to absorb shocks that causes stress beyond the proportional limit.

2.8.6 Modulus of rupture (MOR)

Modulus of rupture reflects the maximum load-carrying capacity of a member in bending and is proportional to maximum moment bear by the specimen. MOR is also referred to as the bending strength of wood which is the equivalent fibre stress in the extreme fibres of the specimen at the point of failure. Modulus of rupture is an accepted measure of strength, although it is not a true stress because the formula (equation 2.11) by which it is computed is valid only to the elastic limit (Mitchell, 1988).

$$MOR = \frac{3UH}{2xy^2} \tag{2.11}$$

Where MOR is the Modulus of Rigidity, measure in N/mm^2

U = Maximum load at failure (N)

H = Span of the material between the supports (mm)

x = Width of the Material (mm)

y = Thickness of the Material (mm)

2.9 Factors affecting Properties of Wood

To understand the properties of various wood (discussed in the previous section) products, industrial and production engineers working in the wood industry must appreciate the impacts of several anatomical and processing-related factors. They must also appreciate the interactive nature of environmental factors. This section will attempt to briefly relate the importance of many of these factors independently and as a whole.

2.9.1 Anatomical factors

The mechanical properties of wood vary between species, they are often compared via species averages. However, because mechanical properties vary within a species, it is incorrect to think that all material of species A is stronger than material of Species B if, for example, average values are 10 to 15% different.

2.9.2 Specific Gravity and Density

The property values of wood increase with increasing specific gravity (SG). While the density is a measure of weight per unit volume often reported in kilograms per cubic meter, SG is a dimensionless ratio of the density of wood at a specified moisture content to the density of water. Because changes in moisture contents result in dimensional changes, SG and density should be compared at the same moisture content. Specific gravity is an index of mechanical property values of wood free from defects; the higher the SG, the higher the appropriate property value. However, SG and density values for lumber are also affected by the presence of gums, resins, and extratives, which contribute little to mechanical properties.

2.9.3 Knots

A knot is that portion of a branch that has become incorporated in the bole of the tree. The influence of a knot on mechanical properties of a wood member is due to the interruption of continuity and change in direction of wood fibers associated with a knot. The influence of a knot depends on its size, its location, its shape, its soundness, and the type of stress measured. Most mechanical property values are lower at sections containing knots. Knots generally have a greater effect on tensile strength than on compressive strength. For this reason, knots have their greatest influence in the tension zone when exposed to bending stress.

2.9.4 Slope of Grain

Mechanical properties of wood are quite sensitive to fiber and ring orientation. For example, parallel-to-grain tensile or compressive strength property values are generally 10 to 20 times greater than those perpendiculars to grain. Deviations from straight grain in a typical board are termed slope of grain or cross-grain. The terms relate the fiber direction to the edges of the piece. Any form of cross-grain can have detrimental effects on mechanical properties.

2.9.5 Juvenile Wood

During the first 5 to 20 years of growth, the immature cambial tissue produces wood cells with distinct variations in microfibril orientation throughout the important layer of the cell wall. This wood is referred to as juvenile wood. Juvenile wood exhibits excessive warpage because of anatomical differences within this layer of the cell wall. It also exhibits lower strength properties and becomes a problem within the wood industry because of the trend toward processing younger, smaller diameter trees as the larger diameter, old-growth stock becomes more difficult to obtain.

2.9.6 Creep

Wood is a viscoelastic material. Initially, it will act elastically, experiencing nearly full recovery of load-induced deformation upon stress removal. However, wood will experience non-recoverable deformation upon extended loading. This deformation is known as creep. For example, the magnitude of additional creep-related deformation after a 10-year loading will roughly equal the initial deformation caused by that load. The rate of creep increases with increasing temperature and moisture content.

2.9.7 Moisture Content

Mechanical property values of wood increase as wood dries from the fiber saturation point (FSP) between 10 to 15% moisture content. For clear wood, mechanical property values continue to increase as wood dries below 10 to 15% moisture content. For lumber, studies have shown that mechanical property values reach a maximum at about 10 to 15% moisture content, then begin to decrease with decreasing moisture content below 10 to 15%. For either product, the effects of moisture content are considered to be reversible in the absence of decay (Alex and Regis, 2005)

2.9.8 Temperature

Strength and stiffness decrease when wood is heated and increase when cooled. The temperature effect is immediate and, for the most part, reversible for short heating durations. However, if wood is exposed to elevated temperatures for an extended time, strength is permanently reduced because of wood substance degradation and a corresponding loss in weight. The magnitude of these permanent effects depends on moisture content, heating medium, temperature, exposure period, and to a lesser extent, species and specimen size. As a general rule, wood should not be exposed to temperatures above 65^{O}C. The immediate effect of temperature interacts with the effect of moisture content so that neither effect can be completely understood without consideration of the other (Alex and Regis, 2005).

2.9.9 Decay and insect damage

Wood is susceptible to decay and insect damage in moist and warm conditions. Decay within a wood structure cannot be tolerated because strength rapidly reduced in even the early stages of decay. It has been estimated that a 5% weight loss from decay can result in strength losses as high as 50% (Hon and Shiraishi, 1991). If the warm or moist condition required for decay cannot be controlled, then the use of naturally decay resistant wood species or chemical treatments are required to impede decay. Insects such as termites and certain types of beetles, can be damaging to mechanical performance of wood. Insect infestation can be controlled via mechanical barriers, naturally durable species, or chemical treatments of woods.

2.10 Review of previous literatures

In the past few years, several studies have been conducted on the effect of MC on the compression strength perpendicular and parallel to the grain of nominal 38-mm- (2-in.-) thick commercial lumber

(Green and Evans 1989; Barrett and Lau 1991). This work established that compression strength perpendicular and parallel to the grain increase with decreasing MC. For example, compression strength parallel-to-grain, at most percentile levels, first increases with decreasing MC below the fiber saturation point and then decreases as MC falls below about 10% to 15% (Green, Pellertn, Evans, and Kretschmann, 1990).

The number of researchers who have data on properties of clear wood at less than 6% MC is much more limited than those with data greater than 6% MC. From the studies reported (Green and Kretschmann 1994), it appears that modulus of elasticity (MOE) in bending and compressive strength parallel- and perpendicular- to-grain increases linearly with drying below the fiber saturation point. Some data indicate that the MOE parallel- and perpendicular- to-grain MC curves flatten for levels less than about 6% MC. Tensile strength parallel and perpendicular-to-grain, shear strength parallel-to-grain, and Mode I and II fracture toughness also increase with decreasing MC from green to about 12% to 15%. Several studies have indicated that a significant decrease in these clear wood property values may occur with additional drying (Green and Kretschmann 1994). These property-value decreases could explain the loss in the UTS of lumber at MC levels less than 12%.

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Preparation of Specimen

Two trees with a diameter at breast height diameter (dbh 1.3 m above ground) of 70 – 100cm were obtained from Ala forest reserve, Akure, Ondo state. In this forest iroko wood grows in abundance. This forest reserve also contains several species of useful soft and hard wood. For this reason, most saw millers operating in Akure and its neighboring community acquire their lumber from the forest reserve.

Before making a choice, samples from the forest were presented to saw – millers from five different sawmill which were visited. These saw mills include: Omiru sawmill, Illesa, Osun state; Imo sawmill, Illesa, Osun state; Agba sawmill, esa – oke, Osun state; Ayo bami sawmill, Akure, Ondo state; and Aiyedire sawmill, Ikire, Oyo state.

These saw millers provide professional advice and helpful suggestions which includes the log identification, method of taken the best sample etc.

The area from which the trees were taken was at an elevation of 1530 m and a slop of 36%.

A total of seven planks (defect free) were obtained from the middle log of 2 meters in girth. The lumbers from these logs were prepared at Agba sawmill, Esa – Oke, Osun state. The type of machie used for various tests were the determinant factor of the shape and dimension of the experimental samples.

The iroko wood lumber were finished by a small pen wood lathe machine (Plate 1) with a feed speed of 1m/s. the bias angle of the cutting tool was 45^{o} for the lumber. If the wood piece is sawn so that the annual rings are at least in 45^{o} angle to the surface, the deformations will be smaller, the hardness of the surface will be stronger and the general looks after heat treatment will be better.

Plate I: Small pen wood lathe

A total of eighteen pieces for each experiments (density, moisture contents etc). Three piece for each condition (untreated, 80 ^{o} C, 100 ^{o} C etc) of small clear samples were obtained each for density (20 x 20 x 60) mm, moisture contents, radial and tangential shrinkage, mechanical property – compression strength. The wood samples were prepared in set and each set were labeled A, B and C for easy identification. Label A is used for the samples obtained from the major centre of the wood, B is for samples obtained closer to the major centre while C is for the sample obtained closer to the circumference of the log of the tree. Two sample for microstructure observation with dimension (50 x 50 x 50) mm were also obtained.

The samples were immediately sealed in a pre – weighed air tight containers as soon as it was collected until further treatment is administered.

The microstructure of the samples was taken using an Optical Microscope (Wild M50 Metallurgical Microscope Serial No 500253).

Plate II: Optical Microscope (Wild M50 Metallurgical Microscope Serial No 500253)

The microscope used is a liez aristomet with a variophot and a DC (Direct Current) 300 (Charged Coupled Device) CCD camera connected to a PC with image manager IM50 V.120 software. The samples were prepared by machine polishing with abrasive paper in five steps from 320 to 4000 grains. After polishing debris were removed from the sample surface with compressed air before the observation.

The physical properties experiment were performed at the Metallurgical and Materials Laboratory, Obafemi Awolowo University (OAU), Ile – Ife Osun state. This is because, the laboratory is well equipped to carry out material related experiments. However, the mechanical test – compression strength parallel and perpendicular to grain was done at Forestry Research Institute of Nigeria (FRIN), Ibadan, Oyo state, which is more equipped to carryout mechanical related tests. The change in places is in search of advance testing equipment which is necessary for error free results.

3.2 Physical Properties Measurement

The dimensions of the untreated test samples in three planes were measured using digital vernier calliper with of accuracy to 0.01mm while weighing using a metric digital balance – BP163 with 0.01gm

Plate III: (Metter Digital Balance, PB 163) **Plate IV: (digital Vernier Caliper)**

sensitivity. The samples for the treated tests were then subjected to the treatment temperature (80^0C, 100^0C, 120^0C 140^0C and 160^0) with a Gallenhamp drying oven which is used for all the treatment and each of the above measurement (volume and weight) were taken after six hours of treatment. The sample density for all the conditions were calculated and recorded (Appendix I)

Plate V: Gallenhamp Drying Oven

The moisture content of the wood samples were obtained by measuring the initial weight (W_1) of each of the specimen with a meter digital balance. Initially the samples were left for two weeks before the final weight for the untreated was taken. The samples for the treated tests were subjected to the treatment temperature (80^0C, 100^0C, 120^0C 140^0Cand 160^0) for six hours. The final weight (W_2) of the entire specimen was then measured after cooling down to room temperature from their treatment temperature. The moisture content (MC) was calculated with equation 2.1 and recorded in Appendix I.

The radial, tangential, and volumetric shrinkage of the samples were measured using methods described in American Society for Testing and Materials (ASTM) D143 – standard Method of Testing Small Clear Specimens of Timber (ASTM 1997). Three standard test specimen of dimensions (20x20x60) mm (untreated), oven dried for six hours at 80ºC, 100^0C, 120^0C, 140^0C, and 160^0C were used for this test. The transverse sections of the wood samples were observed with the aid of an hand lens to determine the directions of the wood rays. Perpendicular cuts on the rays give the tangential directions, while parallel cuts on the rays give the radial directions. These samples were properly aligned and denoted ‘T’ and ‘R’ for Tangential and Radial planes respectively. They were then soaked in water for 48 hours in order to get them conditioned to moisture above fibre saturation point (FSP), after which they were removed one after the other. Each of their dimensions in wet condition was taken to the nearest millimetre using a digital vernier calliper (Plate V). Percentage shrinkages along the two planes were calculated using equation 2.3 while the volumetric shrinkage of the wood samples were calculated using equation 2.5.

3.2 Mechanical Property (Compression Strength Parallel and Perpendicular to Grain)

The compression test was carried out on Hounsfield tensometer using compression attachment with a predetermined load of 2000 kg. the load was applied centrally in between two dies.

Plate VI: Hounsfield Tensometer (Monsanto Tensometer, type W, Serial No 10055)

Standard rectangular wood specimens (20 x 20 x 60) mm were used. The tests were carried out in line with British standard B. S. 373:1957. B.S. 373:1957 which prescribe that the loading plates should approach each other at a constant rate of 0.01mm/sec. A group of 3 specimens were used for each condition. For the untreated sample the test was done on the specimen after two weeks of exposure to the atmospheric conditions. Treated samples were exposed to various degree of treatment temperature for six hours and allowing it to cool to atmospheric temperature before subjecting to compression test.

After each test, the maximum compression strength parallel and perpendicular to grain was read directly from the recorded chart. The testing machine automatically divided the load sustained during the test with the cross sectional area of the specimen, before recording it as a stress value on the chart. The experiments were repeated accordingly and the compression strength was recorded in MPa.

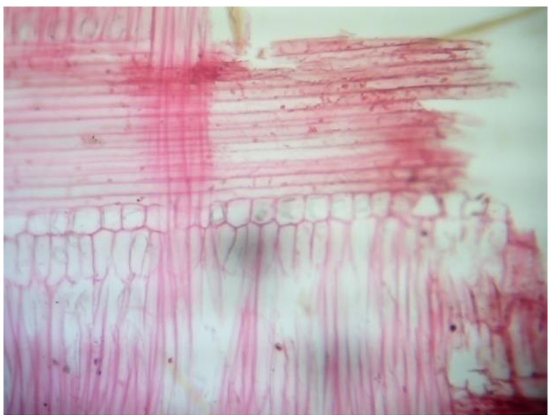
CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

The experimental results and discussion as well as interpretation of results obtained from this research work were presented.

4.1 Microstructure of the Iroko (Miliciaexcelsa) Wood.

The sample has clear year rings reflecting the season based variation in cell wall thickness. Resin channels and radial cells (rays) are also seen. Plate VII and VIII shows the radial and tangential



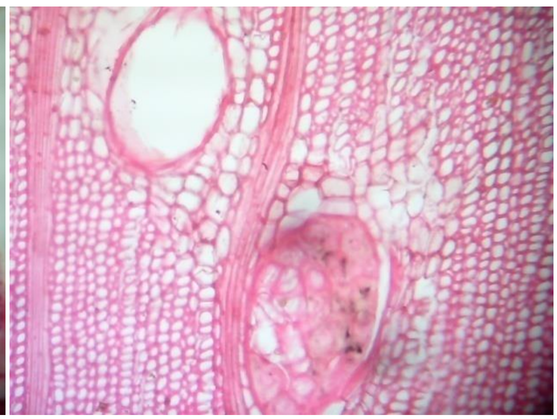


Plate VII: Miliciaexcelsa Radial section Plate VIII: Miliciaexcelsa Tangential section

section of the microscopic observation of the wood sample at a magnification of 20X1. Various microstructure parameter of the iroko wood were measured with the micrographs. The average thickness of the cell wall of iroko was 96µm. The ratio of the longitudinal fibers (or cell wall) with respect to total area occupied by the cell is about 2.69%.

4.2 Variation of Physical Properties with Temperature and Time of Heat Treatment

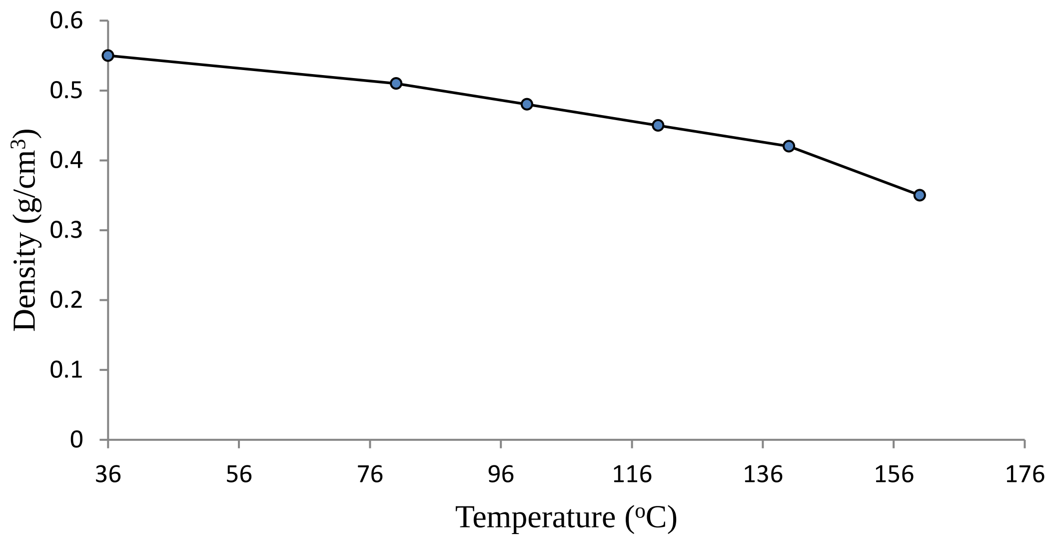


Figure 4.1: Variation of the density with temperature of the wood samples (processing duration of 6 hours).

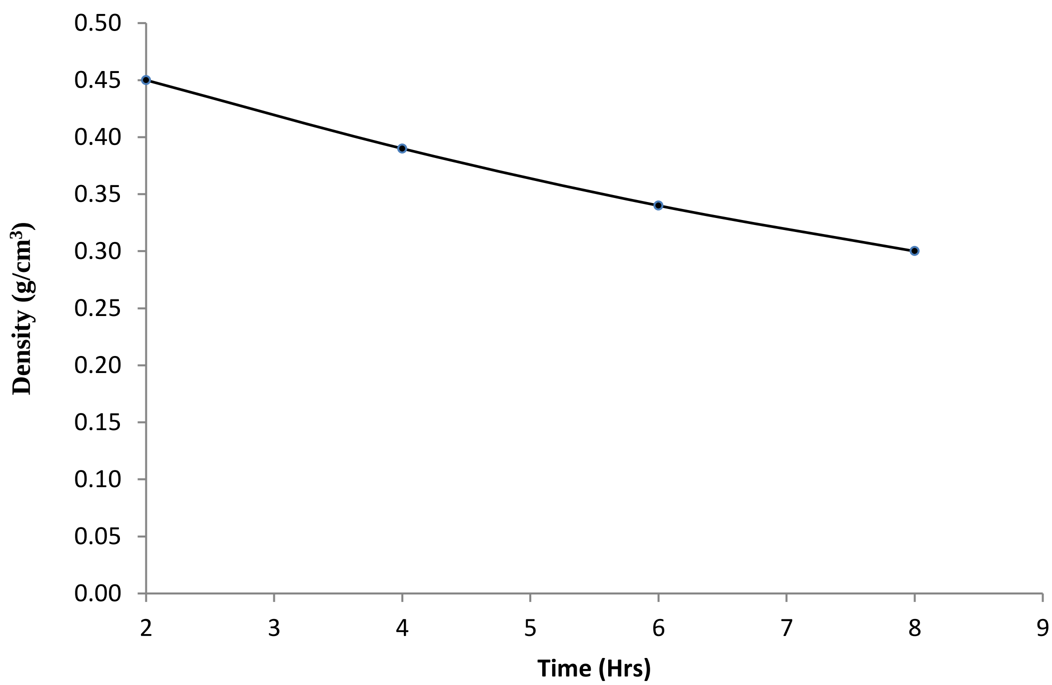


Figure 4.2: Variation of density with temperature duration the wood samples (processing temperature of 120 ^{o}C).

Figure 4.1 shows the graph of density of iroko wood from the untreated at atmospheric temperature to 160^oC heat treatment for 6hrs duration. Figure 4.2 shows the density of the samples when the temperature of heat treatment is maintained at 120^oC and the treatment time is varied from 2hrs to 8hrs at an interval of 2hrs. It is evident in figure 4.1 and 4.2 that the density measured decreased with increasing temperature and duration. Minimum decrease of 5.8% was observed between the temperature of 80^oC and 100^oC for the constant time of 6hrs and 12.3% between the duration of 4hrs and 6hrs at constant treatment temperature of 120^oC. Maximum decrease of 16.7% was also observed between the temperature of 140^oC and 160^oC for the constant time of 6hrs and 13.7% between the duration of 6hrs and 8hrs at constant treatment temperature of 120^oC.

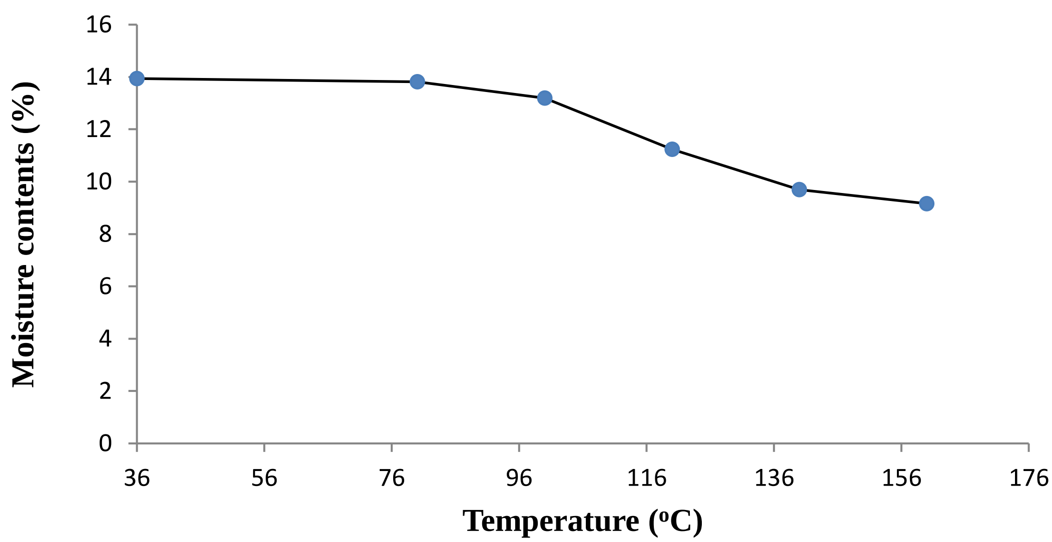


Figure 4.3: Variation of the moisture content with temperature of the wood samples (processing duration of 6 hours).

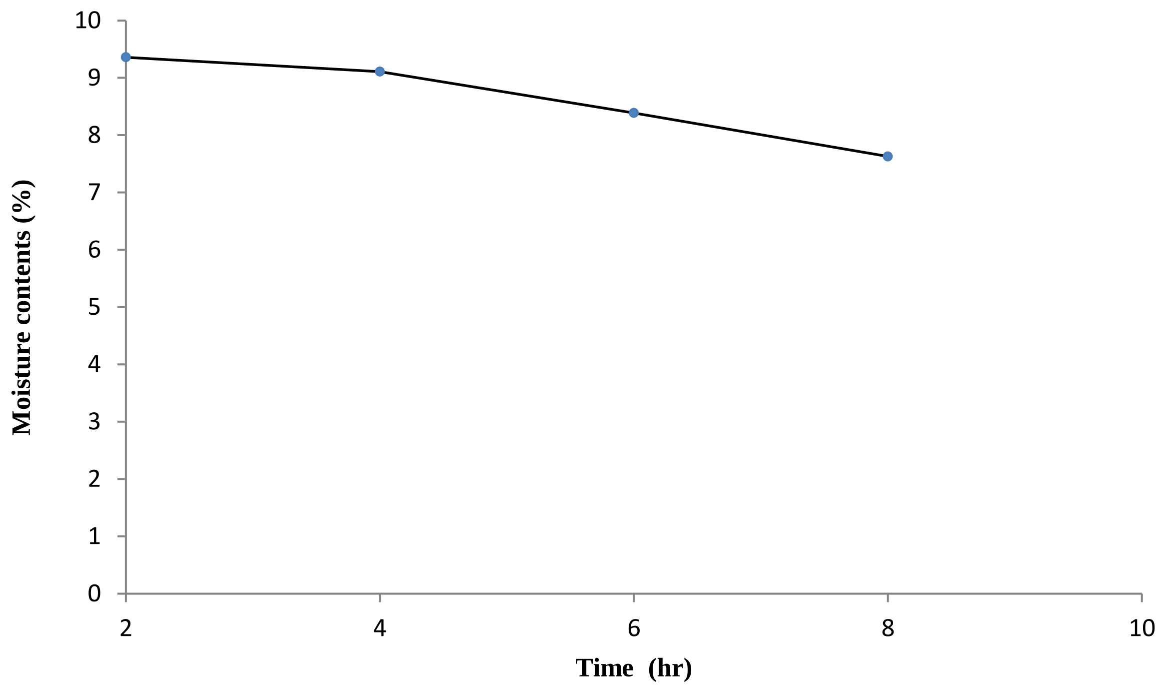


Figure 4.4: Variation of moisture content with time of thermal treatment duration of the wood samples (processing temperature of 120 ^{o}C).

Figure 4.3 shows the graph of moisture content of iroko wood from the untreated at atmospheric temperature upto 160^{o}C heat treatment for 6hrs duration. Figure 4.4 shows the moisture content of the samples when the temperature of heat treatment is maintained at 120^{o}C and the treatment time is varied from 2hrs to 8hrs at an interval of 2hrs. It is evident in Figures 4.3 and 4.4 that the density measured decreased with increasing temperature and duration. Minimum decrease of 0.9% was observed for untreated and 80^{o}C at a constant time of 6hrs and 2.6% recorded for duration of 2hrs and 4hrs at constant treatment temperature of 120^{o}C. Maximum decrease of 14.78% was also observed between the temperature of 100^{o}C and 120^{o}C for the constant time of 6hrs and 9% between the duration of 6hrs and 8hrs at constant treatment temperature of 120^{o}C.

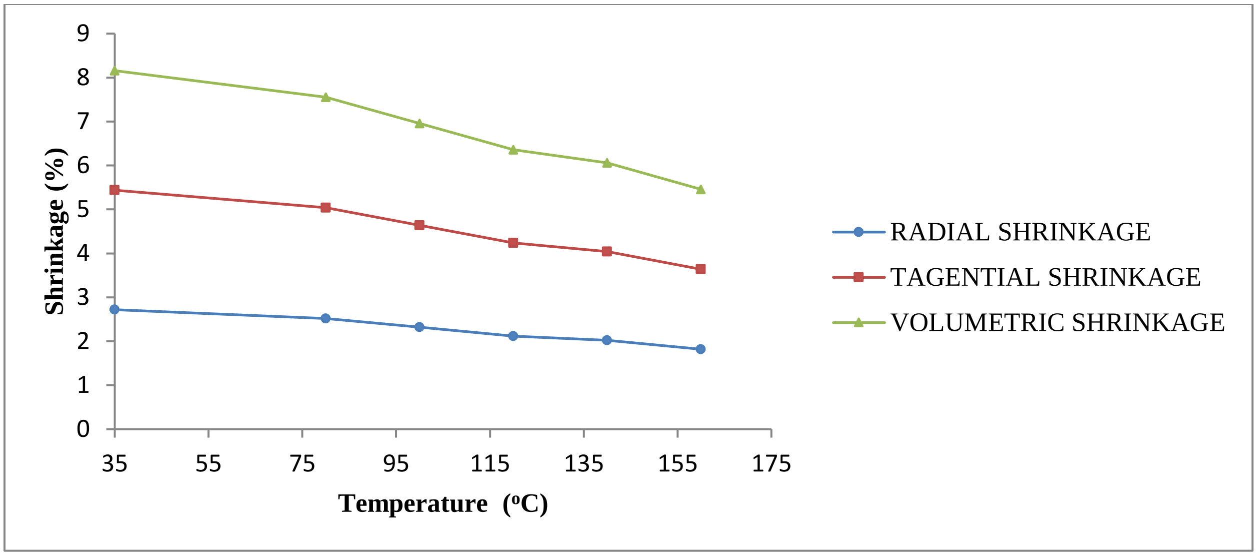


Figure 4.5: Variation of the shrinkage with temperature of the wood samples (processing duration of 6 hours).

Figure 4.5 shows the graph of shrinkage of Iroko wood from the untreated at atmospheric temperature to 160ºC heat treatment for 6hrs duration. In Figure 4.5 the shrinkages are represented as radial, tangential and volumetric shrinkage accordingly. The overall percentage radial, tangential and volumetric shrinkage are 33.1%, 48.6% and 39.7% respectively for the untreated treatment range upto 160ºC and 6hrs treatment duration.

A decrease in shrinkage result in an increase in dimensional stability, which is required for several use of wood.

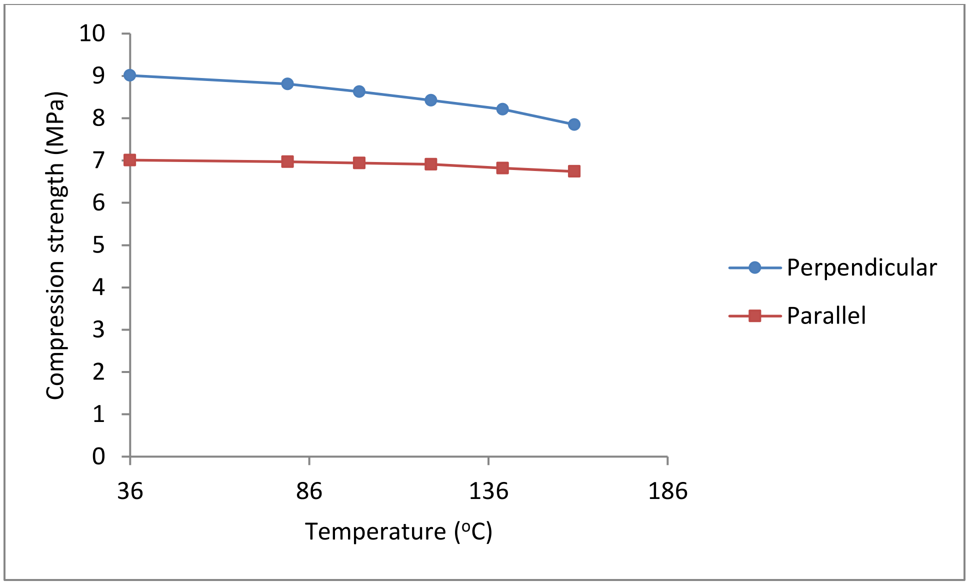


Figure 4.6: Variation of compression strength parallel and perpendicular to the grain with temperature of the wood samples (processing duration of 6 hours).

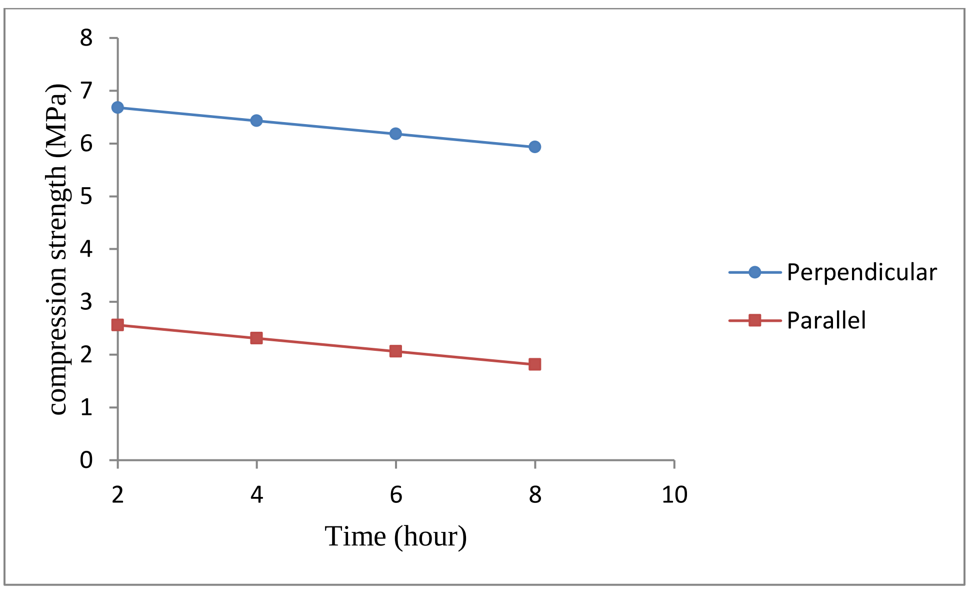


Figure 4.7: Variation of compression strength parallel and perpendicular to the grain with temperature duration of the wood samples (processing temperature of 120 °C).

Figure 4.6 shows plot of compression strength parallel and perpendicular to grain of iroko wood from the untreated at atmospheric temperature to 160^{o}C heat treatment for 6hrs duration. Figure 4.7 shows the compression strength parallel and perpendicular to grain of the samples when the temperature of heat treatment is maintained at 120^{o}C and the treatment time is varied from 2hrs to 8hrs at an interval of 2hrs. It is evident in Figure 4.6 and 4.7 that the compression strength parallel and perpendicular to grain measured decreased with increasing temperature and duration. Minimum decrease of 0.43% and 2% was observed between the temperature of 80^{o}C and 100^{o}C for the constant time of 6hrs and 9.8%, 3.7% between the duration of 2hrs and 4hrs at constant treatment temperature of 120^{o}C. Maximum decrease of 1.3%, 4.4% was also observed between the temperature of 140^{o}C, 160^{o}C and 120^{o}C, 140^{o}C respectively for the constant treatment time of 6hrs, and 12%, 4% between the duration of 6hrs and 8hrs at constant treatment temperature of 120^{o}C.

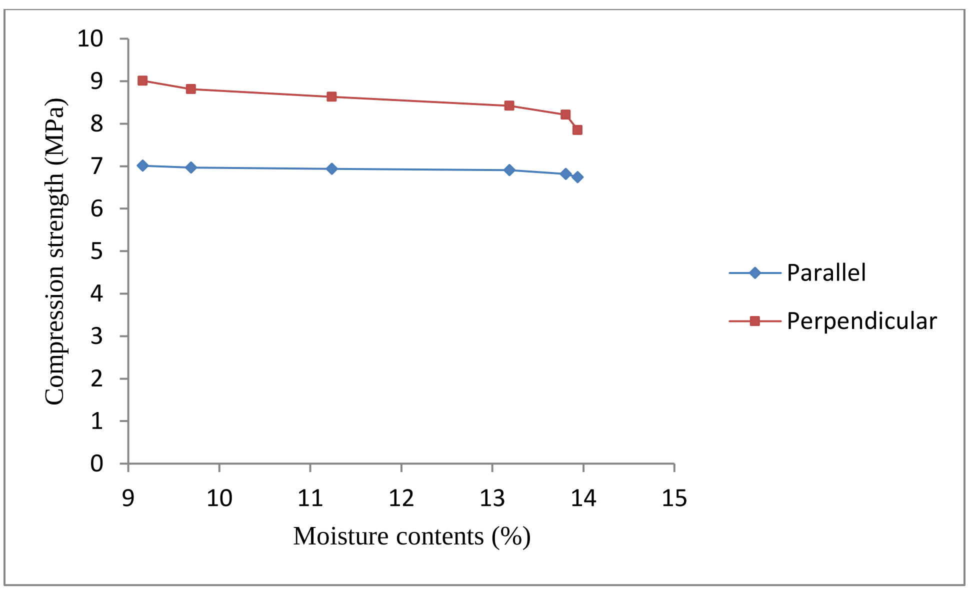


Figure 4.8: Variation of compression strength parallel and perpendicular to the grain with moisture contents of the wood samples

Figure 4.8 shows plot of compression strength perpendicular and parallel to grain of iroko wood with moisture contents from the unprocessed through the processes. As evidence from the graph the moisture contents decrease from 13.94 % to 9.16 % while the compression strength perpendicular and parallel to grain increase from 7.85 to 9.01 MPa and 6.74 to 7.01 MPa respectively. There was a drastic increase in compression strength perpendicular and parallel to grain as the moisture contents reduces from 13.94 % to 13.81 %. However, compression strength perpendicular to grain is higher than compression strength parallel to grain.

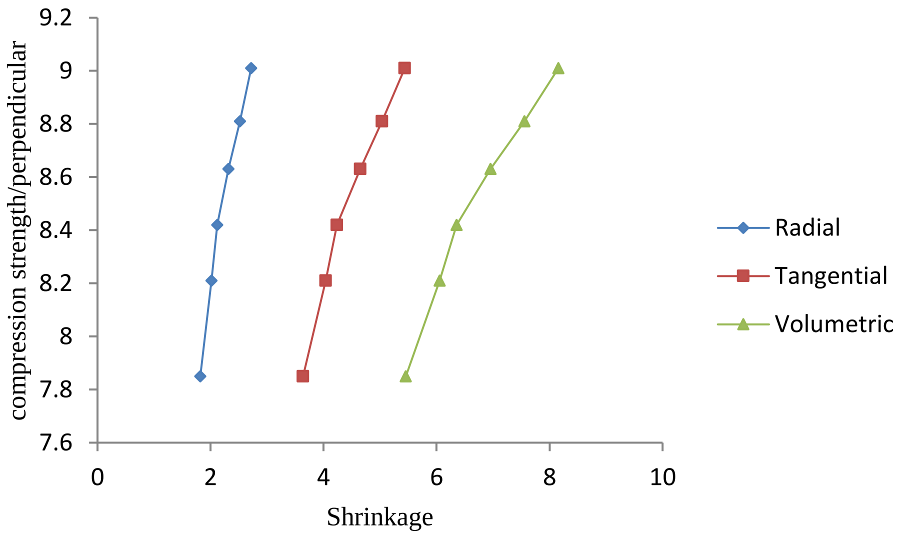


Figure 4.9 Variation of compression strength perpendicular to the grain with shrinkages of the wood samples

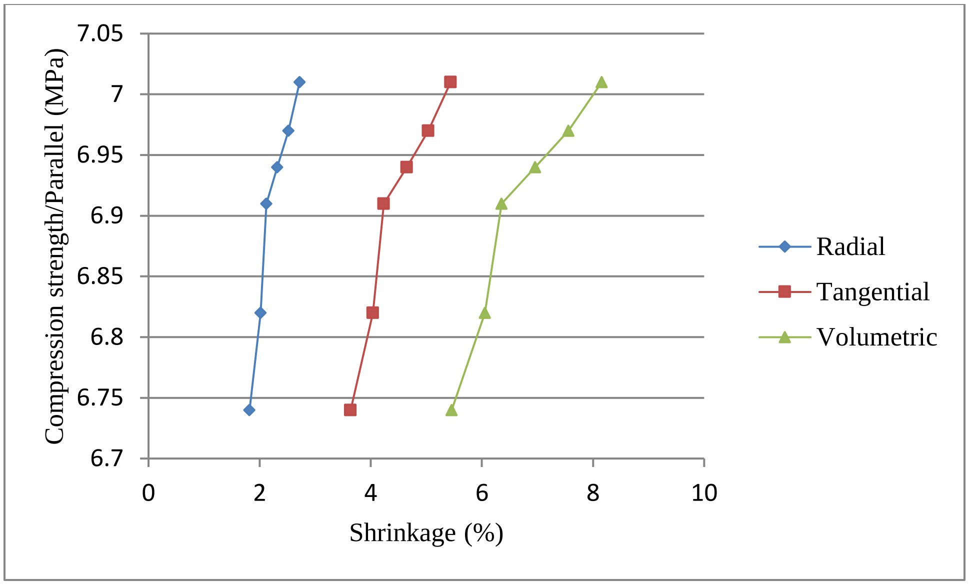


Figure 4.10 Variation of compression strength perpendicular to the grain with shrinkages of the wood samples

Figure 4.9 shows the graph of compression strength perpendicular to grain with radial, tangential and volumetric shrinkages. While Figure 4.10 shows the compression strength parallel to grain with the measured shrinkages.

As indicated in figure 4.9 compression strength perpendicular to grain reduces from 9.01 MPa to 7.85 MPa, radial shrinkage reduces from 2.719% to 1.819%, tangential shrinkage decreases from 5.438% to 3.638% and volumetric shrinkage decrease from 8.157% to 5.457%.

Figure 4.10 reveals that compression strength parallel to grain reduces from 7.01 MPa to 6.74 MPa, radial shrinkage reduces from 2.719% to 1.819%, tangential shrinkage decreases from 5.438% to 3.638% and volumetric shrinkage decrease from 8.157% to 5.457% respectively.

Figure 4.9 and 4.10 shows that smaller shrinkage produce equivalent smaller compression strength perpendicular and parallel to grain.

In general the effects of heat treatment on the physical and mechanical properties of iroko wood are compatible with findings of other authors on the effect of heat treatment on different species of hard wood. In a study on the effect of heat treatment, with pine sapwood heated at 110, 130, 150 and 180ºC it was found that compression strength decreased by 5% (Fengel, 1973). Similarly another study showed that for Eucalyptus (Eucalyptus saligna) wood, compression strength parallel to grain decreased at 110–155ºC for 10–160h treatments (Suleyman, Samil, Derya and Tugba, 2008). Suleyman, Samil, Derya, Tugba (2008) concluded from a series of experiment that at longer treatment time and higher temperature, the density of hard wood decreased

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the study on the effect of thermal treatment on the physical and mechanical properties of Iroko (*Milicia excels*) wood, it can be concluded that all the characteristics measured (moisture contents, density, shrinkages, compression strength perpendicular to the grain, compression strength parallel to the grain) of the iroko (*Milicia excels*) wood, decreased with increasing treatment temperature and treatment duration.

The smallest decrease was recorded at the heat treatment of 120 ^{o}C for 2hrs. In this research, physical properties and mechanical property (compression strength parallel and perpendicular to grain) all decreased with increasing time and temperature of treatments.

The improved characteristics in shrinkages and temperature of heat treated timber have to be balanced against the decrease in strength values when evaluating the effectiveness of using this treatment. The most important property, when compared to untreated wood, is that the equilibrium moisture content of the heat – treated wood reduced and as such shrinkage of the wood also reduced. Iroko (Milicia excels) can be utilized using proper heat treatment techniques without any losses in strength values in areas where wood working and stability are important.

The work elucidate the physical, mechanical and microstructural relationship of iroko (*Milicia excels*) wood which is required for the proper design of the material.

It is worth noting that iroko (*Milicia excels*) wood has been suggested as a substitute for teak (*Tectonagrandis*). Its durability makes it suitable for boat building piles, other marine work and rail road crossties. Iroko wood is also found suitable in many and most carpentry and joinery, flooring, furniture, veneer and cabinet works.

5.2 Recommendations

After performing the experiments on the physical and mechanical properties of iroko (*Milicia excels*) wood, the following recommendation could be made;

1. Proper treatment applied to iroko (*Milicia excels*) wood could make it one of the best substitutes to Teak for industrial applications.
2. Iroko (*Milicia excels*) wood could be a source of non oil export, if proper treatment is administered which is good for the economy of the nation.