UNIVERSITY OF EDUCATION, WINNEBA
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ASSESSING THE PHYSICO-MECHANICAL PROPERTIES OF PLANTATION GROWN *ALBIZIA LEBBECK* FROM THE SAVANNAH ECOLOGICAL ZONE

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APRIL, 2021

DECLARATION

STUDENT'S DECLARATION

I, ENOCH GBAPENUO TAMPORI, declare that this thesis, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE:…………………………

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SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this dissertation was supervised in accordance with the guidelines and supervision of thesis as laid down by the University of Education, Winneba.

SUPERVISOR: DR. FRANCIS KOFI BIH

SIGNATURE:…………………………..

DATE: …………………………………..

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DEDICATION

To my lovely children, Theodosia Naamwentierimah and Enoch Naamwenkumah JR

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ABSTRACT

The increasing scarcity of major commercial tropical hardwood species has necessitated the utilization of lesser known/used exotic wood species as a possibility of sustaining the wood resource base in Ghana. In order to make lesser known/used exotic wood species as good substitute for the dwindling scarlet species their wood properties must be investigated to expatiate their utilization potentials. This experiment was carried out to assess the physico-mechanical properties of a plantation grown *Albizia lebbeck* from Tamale fuel wood plantation reserve in the Savannah ecological zone. Three matured timber species with diameters (45-50 cm) at breast height (1.3 m) from the ground level were purposively selected and sampled at four stem height levels (0-25%, 26%-50%, 51%-75% and 76%-100% of tree height). The samples were prepared and sawn into the required sizes in accordance to the British standards, BS 373(1957) for testing. The morphology of the heartwood and sapwood proportions were evaluated and the samples further tested for oven-dry density at 12% MC, compression strength parallel to grain, shear strength parallel to grain, hardness, bending strength (MOR) and modulus of elasticity (MOE). Data collected were analysed and presented using descriptive and inferential statistics. The study showed that *Albizia lebbeck* has significant heartwood percentage than sapwood. The study also revealed that, *Albizia lebbeck* is a heavy timber with an overall mean density values of 868.64 kg/m^3, 806.36 kg/m^3, 695.26 kg/m^3 and 564.7 kg/m^3 at 12% MC for tree sections 0 - 25%, 26 - 50%, 51 - 75% and 76 - 100% respectively. In general the wood properties of the plantation grown *Albizia lebbeck* studied exhibited high strength values suggesting that it is endowed with outstanding properties for being an alternative species to supply the wood industry.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Supply of high value timber throughout the world is becoming more limited due to excessive forest exploitation. The proximate causes of this high rate of global forest loss are complex and quite poorly understood (Anon, 2012; Kumi-Wood, 1996; Owoyemi *et al*., 2017). It is generally acknowledged that formulating a good forest police and implementing it effectively are essential for a sustainable forest management (Amoah & Wiafe, 2012; Nsenkyire, 1999). A good forest policy also has the potential for increasing government revenue and improving the livelihoods of poor people in forest communities (Dadzie & Amaoh, 2015; Hawthorne & Gyakari, 2006; Piotto *et al*., 2004). It follows that the total global forests cover as at 2015 increased from 167.5 to 277.9 million hectares of total forest area (Piotto, 2008; Plath *et al*., 2011b). The increase however, was most rapid in the temperate zone, and regionally in Asia, followed by Europe and North America (Montagnini *et al*., 1995; Onyekwelu *et al*., 2011). It is therefore estimated that, the annual increase in forest plantation area by 2022 will hit about 2.28% (Butterfield, 1995; Lin *et al*., 2004).

Apparently, plantation developments have been adopted to reduce the over exploitation of commercial timber species and on the other hand restore degraded areas (Agyeman *et al*., 2010; Foli *et al*., 2019). The establishments of forest plantations have increased worldwide and it accounts for about 35% of the world forest cover (Carnus *et al*., 2006;

FAO, 2001). It is therefore obvious that, afforestation and planting programmes using exotic timber species have gained considerable interest as a means to complement current tropical timber markets and to reduce the overexploitation of the forest and its resources (Bosu *et al*., 2006; Piotto *et al*., 2004). Consequently, Evens and Turnbull (2004) claims that the development of plantation forest through the planting of exotic timber species would bring many benefits including replacing the natural forest in the supply of timber, restore degraded landscapes due to deforestation and also providing environmental service as carbon dioxide sequestration to reduce global warming. The importance of forest plantation in terms of its conservation value, restoration of disturbed areas and reducing logging pressures on the existing forests have been recognized (Gurau *et al*., 2010; Piotto, 2008; Smith, *et al*., 2001).

Simultaneously, the contribution of plantations forest in the production of timber for the wood market is undisputable as it provides about 35% of global round wood (FAO, 2001; Parrotta *et al*., 1997). The plantations forest status in terms of ecological conservation has been positive, especially where natural forest has been converted to plantations. As such, plantations forest are now generally considered as one part of management triad- consisting of ecological reserves, managed natural forests and high-yielding plantations. It follows that, most European countries including the Latin America established their forest plantations in the early eighteenth century. For instance, Japan after the Second World War immediately rolled out a massive plantation programme of about million hectares annually to reforest forest areas denuded in the war (Gibson *et al*., 2017; Liu *et al*., 2014). This is exemplified in some other temperate countries including, New

Zealand, Australia, Spain and Portugal. As such, they currently have substantial plantation areas of exotic timber species.

In like manner, Asia initiated a similar programme at the time and launched out a large scale afforestation programme to increase their forest cover (Choong & Achmadi, 1991). As a result, Korea and China are well endowed with plantation timber species which are made up of the major forest plantations (Sheng-Han & Hui, 2013; Taylor *et al*., 2002). Hence, the development of forest plantations is initiated by planting high quality indigenous species and fast growing exotic species throughout Asia. Moreover, the planting of exotic timber species are among the promising tree species for forest plantations in Malaysia as alternatives to the well-known and preferred timber species (Hartley, 2002; Salehi, 2008). Subsequently, in Indonesia exotic plantations cover over one million hectares and the annual cut is about 8,000 – 10,000 hectares. The social benefits of forest plantations gained strong ground, particularly in tropical Asia as people planted trees outside the forest, in private farms, on community land and other non-forest lands (Barany *et al*., 2003; Rijkaert *et al*., 2001).

Contrarily, many developing tropical African countries increased tree planting after the end of the colonial regimes in the 1950s and 1960s in response to an increased awareness of the need for fuel and industrial wood as a part of overall rural development activities (Appiah-Kubi, 2016; Oduor & Githiomi, 2013). As such, the area of plantations of fast-growing exotic species expanded rapidly in many developed countries than the developing countries (Bao *et al*., 2001; Wagner *et al*., 2008). However, it is imperative to note that the market impetus arising from the shortage of fuelwood, round wood and fodder, external financial support by a large number of donor agencies played a key role in stimulating the establishments of forest plantations in most tropical African countries (Hartley, 2002; Omer *et al*., 2004). It follows that, exotic timber species are planted throughout tropical Africa mainly in agroforestry development programs, for reduction of soil erosion, run-off control to combat desertification and rehabilitation of degraded lands. They also contribute to the production of fuelwood, sawn timber and in some cases for pulp and paper production (Hooper *et al*., 2005).

Evans (1999) therefore reports that the total area of tree plantations in the sub-Saharan region is about 21% of plantations. These plantations forest is mainly exotic species which has been extensively planted in West Africa (Parrotta *et al*., 1997; Smith *et al*., 2001). South Africa have plantation programmes been strongly linked to industrial utilization where about 520,000 hectares of forest are plantations. In Ethiopia, the introduction of forest plantations commenced with exotic timber species (Dupuy, 1995; Omer *et al*., 2004). The government, community and individual small-scale farmers own these plantations which contribute to the production of round wood for sawn timber and to meet wood requirements for local use (Okai, 2002; Oteng-Amoako, 2006). Accordingly, Onyekwelu (2007) reports that in Nigeria about 382,000 hectares have been reforested with indigenous and exotic species representing about 4% of the remaining forest estate of the country. Out of this, the exotic timber species account for about 44% (BirdLife, 2011). The Nigerian governments have tried to re-strategize by involving the local communities as co-managers of the forest estates in order to create mutual dependence and interaction in resource conservation (Jose *et al*., 2006; Kelty, 2006).

It follows that, the interest of forest plantation in Ghana dates back to the 1920s as timber is one of its most readily available resources (Addae-Mensah, 1998; Foli *et al*., 2009; Odoom, 2002; Ofosu, 1997). The general policy at the time was to plant mainly indigenous species in the High Forest Zone (HFZ). The few exotic species that were planted in the HFZ were introduced mainly for fuelwood near large population centres and to fuel boilers for electricity generation or for mining use (Odoom, 2002; Nichols *et al*., 2006). However, in the Savannah Zone (SZ) and Dry Semi-Deciduous Forest Zone (DFSZ) a large number of exotic species were tried from 1951 to supply timber, poles and fuelwood (Amoah & Boateng, 2014; Nichols *et al*., 1999; FAO, 2002). Accordingly, forest plantations in the Northern part of the country in the Savannah Zone are estimated to cover 2,553 hectares and were primarily established for fuelwood production and environmental protection (BirdLife, 2011).

The fact is that, the natural forest is one of the numerous resources that the country is well endowed with (Appiah, 2003; Opuni-Frimpong *et al*., 2004; Oteng-Amoako, 2006). This had given the country unique climate and environmental conditions until of late when the rate of exploitation increased as a result of population increase and the need for development of infrastructure. Subsequently, these indiscriminate exploitation of the forests, large scale destruction of tree habitats, and adverse effects of population, among other factors which causes a number of timber species to disappeared from the forest and many others are awaiting a similar fate (Amoah *et al*., 2015; Hens & Nath, 2003). As such, forestry reports in recent years indicate that the timber species for which Ghana is known in international markets are becoming very scarce (Ntiamoa-Baidu *et al*., 2001; TIDD, 2015).

The over reliance on the most valuable and traditional timber species have led to their extinction in the forest (Appiah-Kubi, 2016; Ofori, 1985). The extinction of these timber species has therefore put pressure on Ghana's forest which is limited in extent. It follows that, the over dependency on the known species in the forest for the past years have not helped in addressing the current challenge. Nevertheless, the increasing market demand for tropical hardwoods both locally and internationally is overwhelming. As such, the maximum volume of timber that sawmills in Ghana can handle is greater than the volume of timber that can be made available to the industry without damaging the forests (Appiah, 2003; Cobbinah *et al*., 2004). It is therefore imperative that the planting and use of plantation grown exotic timber species cannot be an alternative, if the forest resources being used up are to be resupplied and on the other hand reduce the urgent demands on the remaining known species in the forest.

Therefore the current thinking is that, industry players in the wood sector must consider the commercial value of the lesser used exotic species to reduce the pressure on the popular species. This is possible by obtaining a full utilization of the lesser known timber species and possibly substituting them for the limited known tropical hardwoods. In this sense, lesser utilized species should be used as substitutes for the more usual well known species which are gradually becoming extinct.

On the other hand, the overarching strategic reason for promoting forest plantations in the country are to ensure that the country is able to meet demand for forest products for its growing population, mitigate the pressure on the natural forest and contribute to their sustainability (Addae-Mensah, 1998; Appiah, 2003; Oteng-Amoako, 2006). The establishments of plantations through afforestation using exotic species therefore have the potential of replacing the natural forest in meeting the demand for timber (Carle & Holmgren, 2003; Forrester *et al*., 2004). It follows that, forest plantation programmes in Ghana for many years have been skewed towards the planting of exotic monoculture plantations (Opuni-Frimpong *et al*., 2008). Eventually, Odoom (2002) claimed that exotic species plantations dominate most of the existing plantations in tropical countries including Ghana. The preference of exotic timber species is mainly due to their fast growing nature, largely free of pest, disease and fire tolerance characteristics as compared with many indigenous species (Bobby *et al*., 2012; Jayeola *et al*., 2009). Also, Evans and Turnbull (2004) report that the exotic species offer wider range of choices, since their silviculture usually is better understood than the indigenous ones.

In addition to their technical advantages of fast growth, high wood quality and resistance to fire, some of the exotic species offers high commercial opportunities in the international commodity market (Ciesla, 2001; Erskine *et al*., 2006). Hence, the exotic timber species are the preferred planting stock, owing to their rapid growth and immediate economic return (Berger, 2006; Davies *et al*., 2003). It postulates that, the harvesting of abundant but lesser known/used plantation grown exotic timber species needs to be gradually encouraged and increased in the country (Ball *et al*., 1995; Forrester *et al*., 2006a). Accordingly, plantation grown exotic species in Ghana consists of over 45% of the existing plantations (Addae-Mensah, 1998; Nanaag, 2012). As such, Oteng-Amoako *et al*. (2006) reports that, there are over 500 tree species of timber size in the forest of Ghana which have never been used commercially.

In truth, the strength properties of these plantation grown exotic species have not been determined as to how their application in furniture and other structural production can be of great support to the limited tropical timber species. The present lack of reliable information on their properties makes predictions about their structural application hazardous and liable to gross errors. This lack of information is a constraint not only to the development of suitable policies and plantation planning programmes for domestic use and export, but also in evaluating their environmental, social and economic effects.

Obviously, the promotion and utilization of exotic timber species will yield a relief and reduce the demand on the few commercial primary species. The efficient and effective utilization of the abundant exotic timber species will depend largely on an in-depth knowledge of their material properties. When these properties are made known, it will promote their acceptance for local use and for export as well (Blay, 2004; Carnus *et al*., 2006; Feyera *et al*., 2002). Consequently, this research will attempt to discover the hitherto undocumented physico-mechanical properties of plantation grown *Albizia* *lebbeck* from the Savannah ecological zone from the Tamale fuel wood plantation reserve. This will be a sure way to minimize the extinction of the few durable timber species in Ghana's forest due to overexploitation, and on the other hand promote the use of plantation grown exotic timber species which are relatively in abundance in the forest.

1.2 Statement of the Problem

The ever-increasing pressure of an expanding world population and infrastructure has resulted in the exploitation of the forests to disastrous proportions. As such, the increasing demands for timber can no longer be met from the existing natural forests as the rate of extraction of the traditional timber species far exceeds their growth rate (Amoah *et al*., 2012; Oteng-Amoako, 2006). It follows that, large-scale plantation forestry and afforestation of degraded forestlands are the solution to ensure future sufficiency in timber. This led to a significant increase in the establishment of many plantation grown exotic timber species, including *Albizia lebbeck* in the Savannah woodlands of Ghana over the last decade (Odoom, 2002). This brings to the fore the recent forest inventory conducted reported the abundance of their volumes in the Savannah woodlands (Bonsu *et al*., 2006; Odoom, 2002). It appears that this is likely to continue as the indigenous forest resource rapidly dwindles. As such, it is anticipated that to ensure sustainability of our forest timber resources, there is an agent need to substitute the premium and commercial timber species which are limited in supply now with the abundant plantation grown exotic timber species.

However, it is surprising to note that very little is known at present from literature about the physical, mechanical and other technological properties of some of these exotic timber species in order to predict their structural application. Hence their utilization in the wood industry is limited, of which *Albizia lebbeck* is not exceptional. Most of the studies on *Albizia lebbeck* species focus on its medicinal value (Salem *et al*., 2013) and its toxicity against wood destroying agents (Rasib *et al*., 2017). For instance, Ahmed *et al*. (2018) studied the toxicity of heartwood extractives of *Albizia lebbeck* against subterranean termites. Babu *et al*. (2018) investigated the scientific basis of anti-inflammatory activity of different organic solvent extracts of *Albizia lebbeck* against several inflammatory pathologies such as asthma, arthritis and burns.

On the other hand, Iqbal *et al*. (2018) evaluated the different woods against fungus growing termite *odontoterms* and *macrotermitinae* for use in rail stations. *Albizia lebbeck* recorded the least mass losses. Kiaei and Farsi (2016) also investigated the effects of vertical variation of density, flexural strength and stiffness of *Albizia julibrissim.* Seyydnejad *et al*. (2018) studied the antibacterial activity of hydroalcoholic extract of *callistemon citrinus* and *Albizia lebbeck.* Also, Singh and Agrawal (2018) reviewed the general aspect of the *Albizia lebbeck* and concluded that, the exotic species is very valuable from the ethnobtanical point of view as the entire tree extracts are used as homeopathy in Indian as well in the Arabic medicines. On the other hand, Tom-Dery *et al.* (2015) assessed the effect of *Albizia lebbeck* pods used as soil amendment on the growth of solanum aethiopicum (garden eggs). This is evident that, there is no empirical study that has been undertaken to determine the material utilization of *Albizia lebbeck* in the wood industry. To fill this knowledge gap, the aim of this study was to assess the physico-mechanical properties of plantation grown *Albizia lebbeck* from the Savannah ecological zone from the Tamale fuel wood plantation reserve.

1.3 Research Objectives

The purpose of the study is to assess the physico-mechanical properties of plantation grown *Albizi*a *lebbeck* from the Savannah ecological zone.

Specifically, the study seeks to achieve the following objectives;

i. To evaluate the heartwood and sapwood proportions *Albizia lebbeck* species.

ii. To determine some physical properties (oven-dry density and moisture content) of *Albizia lebbeck* species.

iii. To assess the effect of axial variation on the mechanical properties (compression parallel to grain, shear parallel to grain, hardness, MOR and MOE) of *Albizia lebbeck* species.

1.4 Research Questions

The study seeks to address the under-mentioned research questions;

i. What are the heartwood and sapwood proportions of *Albizia lebbeck* species*?*

ii. What are the fundamental physical properties of *Albizia lebbeck* species*?*

iii. What are the axial variations of the structural elements of *Albizia lebbeck* species?

1.5 Significance of the Study

The natural forest has been able to supply Ghana's forest resource needs in the past. However, high population growth and the need for foreign exchange for our country's development have placed great demands on the natural forest. This is to provide export earnings as well fulfill the country's own needs for timber and non-timber resources (Cobbinah *et al.,* 2004). But, there are a good number of exotic timber species in the plantation forests across the Savannah woodlands, but little is known at present about their physical, mechanical and other technological properties in order to predict their suitability for structural applications. As such, the study aims to assess the physico-mechanical properties of plantation grown *Albizia lebbeck* from the Savannah ecological zone and tentatively suggest its potential end uses for effective exploitation and utilization in the wood industry.

The study therefore, would help to critically assess the material properties of the plantation grown *Albizia lebbeck* species for structural applications envisaging the sustainability of the Savannah woodlands. This will not only add value to the existing resources and enhance their utilization, but also assist in reducing deforestation as a result of the over exploitation of the premium and commercially known hardwood species in the forest. As such, Quartey (2009) affirms that lesser utilized plantation grown timber species could be used as substitutes for some of the commercial hardwood species.

Again, the study will establish essential properties for improved processing and utilization of the plantation grown *Albizia lebbeck*. This would also contribute to providing information on the scientific data base of the studied species and extend the knowledge in its use for structural applications. The practical knowledge of wood properties is as important as its application (Barany *et al*., 2003; Menalled & Kelty, 1998; Sayer *et al*., 2004). The study would identify constructional mechanisms to harness the potentials of the exotic timber species in the wood industry. This would be a sure way to help reduce pressure on the natural forest by minimizing the over reliance and usage of the well-known species as they can be substituted with the exotic timber species in the construction industry. As such, Oteng-Amoako (2006) holds that it is time to harvest, promote and use lesser utilized species which are relatively abundant as substitutes for the usual well-known commercial timber species which are gradually becoming extinct.

Moreover, understanding the wood properties and its behaviour in growth is also very important for wood commercialization (Sreevani & Rao, 2014; Taylor *et al*., 2002 Ugalde, 2000). The study would provide empirical justification to improve afforestation and diversify the resources of timber supply in the country, as the plantation grown exotic timber species are more likely to grow faster. This would propel economic growth and the overall socio-economic development of the country. It would explore the link between trees planting and the industrialization process, specifically by determining how the exotic timber species can make positive contribution in developing the country's forest sector for industrial activity. This would thus provide better understanding of variables that influences exotic timber as an engineering material.

The study would provide a comprehensive knowledge of the plantation grown *Albizia lebbeck* with respect to its morphological proportions, density and moisture content which are interrelated and may directly or indirectly influence its utilization. The ability therefore to predict the density and moisture variations in wood is very important in its application as density and moisture induces deformations in timber structures.

Moreover, the determination of the stem height level influence on the physical and mechanical properties will also help to understand the variation in strength properties that may be found among different sections of the same wood species, as to make informed choice in the selection of a section for a particular use. This will help in the establishment of safety values and design functions to be used for structural purposes.

This study would also provide a unique opportunity for researchers in the wood sub-sector, to use it as a point of reference for future studies that would hope to examine the socio-economic impact of exotic timber species in general. This would provide Ghanaians especially, people of the Savannah regions access to reliable, affordable and environmentally sustainable supply of timber of their choice to meet their constructional needs. This would intend help to reduce overexploitation of the traditional known timber species of the forest in order to improve national development.

Recommendations from the study would be of great importance to stakeholders, policy and decision makers, tree farmers, public and private sector plantation managers, various plantation development bodies, research and training institutions such as the Forestry commission of Ghana, CSIR-Forestry Research Institute of Ghana, and nongovernmental organizations about the utilization of the exotic timber species studied. This is more likely to help deal with deforestation, economic downturns, unemployment and slow growth of industrialization of the wood sector in the country.

1.6 Limitations of the Study

The study was limited to only plantation grown exotic timber species (*Albizia lebbeck*) from the Savannah ecological zone in the Tamale fuel wood plantation reserves. As such, the researcher could not increase the sample size above three (3) trees as the Forestry Commission approves only three trees to be harvested from the plantation for research purposes. Due to the inability of the researcher to increase the sample size, in spite of the thousands of exotic species and also harvest samples from all the forest reserves within the Savannah enclave, the resulting sample may be unrepresentative.

Moreover, equipment and tools were not always available when needed due to the fact that FORIG was overwhelmed with a great number of students and researchers carrying out various kinds of test at their facility. Also, the intermittent light outages during the time that the samples were tested contributed greatly to retarding the effort of the hardworking FORIG staff that were determine to help the situation out. These limitations notwithstanding, the study prepares the platform for further empirical investigations of the structural application of plantation grown exotic species in the Savannah ecological zone to be used as substitutes for the extracted tropical hardwoods.

1.7 Organization of the Study

This thesis is organized into six chapters. Chapter one presents the general conceptual approach and broad objectives. It is made up of the introduction, background to the study, statement of the problem, objectives of the study, research questions, significance of the study, the limitations of the study, and the organization of the study. Chapter two presents a summary of related literature reviewed which formed the background to this study. This chapter covers the importance of forest resources and plantations in Ghana, wood as a structural material, variation and causes of variations in wood properties, physical and mechanical properties of wood as well as the description of the selected plantation grown exotic timber species *Albizia lebbeck.* Chapter three describes the research materials and methods use for the study while chapter four comprises of the analysis of the data and presentation of the results. Discussions of the results are presented in chapter five and the summary of the findings, conclusions, recommendations and suggestions for further research forms the conclusion chapter of the study.

CHAPTER TWO

LITERATURE REVIEW

This chapter attempts to give valuable, relevant and usable information about the socio-economic and technical impact that can be derived from using plantation grown exotic timber species. It comprises of brief information on the importance of forest resources and plantations in Ghana, wood as a structural material, variation and causes of variation in wood properties, physical and mechanical properties of wood as well as the description of the selected plantation grown exotic timber species *Albizia lebbeck.* These will help provide important insights into the utilization of plantation exotic timber species as a potential means of Ghana's industrialization.

2.1 Importance of Forest Resources and Plantations in Ghana

Plantations have been the subject of renewed interest in both the developed and developing countries in recent years. It follows that over several decades there have been considerable attempts to define many concepts related to forestry and forest plantation (Carle & Holmgren, 2003). According to FAO (1967), plantation forest is a forest stand raised artificially by afforestation on lands which did not previously have forest before and had been replaced by a new or essentially different crop. Ford-Robertson (1971) claims that, plantation forest is a forest crop or stand raised artificially, either by sowing or planting. Carnevale and Montagnini (2002) also defined plantations as forest stands established the planting or seeding through afforestation or reforestation which are either of exotic or indigenous origin. Hence, Hall and Swaine (1981) proposed plantation forest as a planted forest that have been establish and are intensively managed to produce wood and non-wood forest products for commercial purposes and also to provide environmental service such as erosion control, landslides stabilization and windbreaks.

From these definitions it can be deduced that, reforestation in tropical forest is becoming a major forestry activity in most tropical countries that depend on natural forest for the supply of wood. This is due to the fact that many tropical countries have realized the need to embark on plantation projects to support the supplies from dwindling and unsustainable natural forests (Agyarko, 2001; Onyekwelu *et al*., 2011). The nature of plantations are generally simple mostly, pure stands of the same age which are manage to improve productivity and other benefits which are important to the grower (Appiah-Opoku, 2007; Addo-Danso *et al*., 2012; Blay *et al.,* 2008). Conversely, plantations forest account for more than 50% of all tropical tree plantations (Appiah, 2003; Ball *et al*., 1995; Evans & Turnbull, 2004). Native and exotic tree species are wildly used for plantation establishment in the tropics and sub-tropics, with the exotic one being more common (Bao *et al*., 2001; Dickinson *et al*., 2000; Petit & Montagnini, 2006). The dominance of exotic species is attributed to their superiority in growth performance over their native counterparts, coupled with their ability to control weeds.

In Ghana for instance, plantation establishments begun in the 1950s with the purpose of wood production, wildlife habitat protection and the improvement in the environmental quality (Appiah, 2003; Foli *et al.,* 2009). As such, the Forest Service Division had established over 75000 hectares of plantations as at 1990. Eventually, the National Forest

Plantation Development Programme of Ghana was launched in 2001 with the aim of promoting the development of a sustainable forest resource base that will meet the demands of timber for industrial use and improve the quality of the environment. Exotic timber species however are among the species that are predominant Ghana forests due to their fast growing perform (Bosu *et al.,* 2006; Evans & Turnbull 2004; Nketia, 2002).

The modified Taungya system where farmers who participated in the programme are co-owners of the plantation together with the forestry commission was used. Forest plantation programmes in Ghana for many years have been skewed towards the planting of exotic monoculture plantation (Agyeman *et al*., 2010; Appiah, 2003). According to Odoom (2002), the preference for exotic timber species is mainly due to their fast growth, largely free of pest and diseases and their fire tolerance characteristics as compared with many indigenous species. Nonetheless, forest policies over the years recommend regenerating harvested areas with a mixture of tree species preferably exotic tree species with indigenous ones (Addae-Mensah, 1998; Plath *et al*., 2011b; Yaday *et al*., 2011). The overarching strategic reason for promoting forest plantations, are to ensure that the country is able to meet the demand for forest products for its growing population, mitigate the pressure on the natural forest and contribute to their sustainability (Abu, 2000; Agyarko, 2001).

Consequently, plantation forestry is up to reduce deforestation, protect the natural forest resources base thereby reducing deforestation and ensures the availability of forest products to meet social, environmental and economic objectives (Appiah, 2003; Carnus *et al*., 2006; Sayer *et al.,* 2004). Plantations that have been established in Ghana are estimated to have great impact annually in that they are usually more productive than natural forests (Agyeman, 2004; Foli *et al.,* 2009; Kelty, 2006; Ntiamoa-Baidu *et al.*, 2001). As such when they are managed well they can achieve high growth rates and high wood quality. Plantations therefore have become the obvious option to meet this challenge. The establishment of plantations through afforestation or reforestation therefore cannot be overemphasized.

On the other hand, forests play a major role in the socio-economic development of mankind and are essential sources of harvestable products. The forests are important sources of timber, fuelwood, and other essential harvestable products like food, medicines, oil and resins (Cobbinah *et al.,* 2004; Sayer *et al.*, 2004). Forests therefore play vital roles in maintaining the ecological balance and environmental make up of our worlds as well as meeting the demand of timber and reduction of global warning (Blay *et al.,* 2008; Kelty, 2006). They do not only help maintain biological diversity, but also mitigate climate change, control hydrology, mineral cycling, and soil erosion, improve air quality, create wildlife habitats and alleviate poverty (Odoom, 2002; Ohyama *et al.*, 2001; Sayer *et al*., 2004). As such Marfo (2009) reports that many developing countries virtually depend on forests and their resources to support their socioeconomic and national developments. Hence, Ghana's forests have made significant contributions to the national economy. Timber, which is the major market based forest product is currently the fourth largest contributor to Ghana's foreign exchange earnings aside minerals, cocoa and tourism (Abbot *et al.,* 2001; Twumasi, 2001). According to Marfo

(2009) the timber industry accounts for 11% of foreign exchange earnings and contributes about 6% to Gross Domestic Product and directly employs about 100,000 people. For instance, in the year 2009 Ghana earned an amount of ¢128,226, 984 from export of 426, 221 m^3 wood products, though there was a decrease of 31.29% in value and 21.93% in volume over the same period in 2008 (Appiah-Opoku, 2007; TIDD, 2015). The forests of Ghana also play important socioeconomic roles in the lives of most communities.

2.2 Wood as a Structural Material

Throughout the course of history wood has remained one of the most important natural resources available to man and is found in every area of modern existence. Worbes (1999) reports that wood is a complex biological structure, a composite of many chemistries and cell types acting together to serve the needs of a living plant. The property of wood like the physical, mechanical, chemical, biological, and technological are fundamentally derived from the fact that wood is formed to meet the needs of the living tree. To accomplish any of these functions, wood must have cells that are designed and interconnected in ways sufficient to perform these functions (Amoah *et al.*, 2012; Bergseng & Vatn, 2009; Rijkaert *et al.,* 2001). These functions have influenced the different species of woody plants, each with unique properties, uses, and capabilities, in both plant and human contexts. According to Hoadley (2000), understanding the basic requirements dictated by these functions and identifying the structures in wood that perform them allow insight to the realm of wood as an engineering material.

However, every part of the tree has different mechanical and biological functions (Anderson *et al*., 2002; Dadzie, 2013). The uptake of water and minerals in the roots, the transport of the sap through the stem and the branches and the photosynthesis in the leaf exposed to the sunlight describes briefly the biological function of the different parts (Bamber, 1976; Birkinshaw, 2005; Schroth & Sinclair, 2003). It follows that, the leafs resist the direct exposure to wind and rain whereas the branches and the stem are more resistant to bending to support the crown and transfer the corresponding load effects to the roots where the tree is anchored into the ground. The load however, is transferred through a large and efficient root system. Apparently, a large crown also loses much water by transpiration. The water evaporated must be replaced by sufficient quantities of fresh supplies transported to the shoots by an equivalent root system. It follows that, the available space for the root system is limited, since the ground has to be shared with other plants (Anderson *et al*., 2002; Okai, 2002; Sreemannarayana *et al*., 1994). Wood properties therefore vary from species to species, from one position to another in the tree, from one tree to another grown in the same locality, and between trees grown in one locality and those grown in another. Progress is being made in controlling the quality of wood a tree produced by means of selective tree farming. It is hoped that by such means, straighter and fast growing trees may be produced with more nearly uniform properties than found in trees from the natural forests.

Moreover, wood is a structurally sound material and compares favorably with concrete steel, and stone and a variety of other building materials. Wood in its natural state can be used for many forms of construction (Amoah *et al*., 2012; Jayanetti, 1998; Tewari &

Mariswamy, 2013). As a structural material, wood is strong, light, flexible and easily worked with. In contrast to the other structural materials such as brick, metal, concrete and plastics, wood can be produced and transported with little energy consumed and wood is a renewable material (Bowyer, 2001; Kumi-Woode, 1996). Accordingly, the properties and behaviour of wood are much more complex unlike the other building materials. The fact is that wood is a natural material and man has little control over its properties. For most structural application, wood has several advantages with outweigh its disadvantages. For structural purposes wood is renewable and can be produced and transported with little energy consumed as compared to brick, metal, concrete and plastics (Miranda *et al*., 2011; Wilcox *et al*., 1991). The properties of solid wood for instance and the structural durability of certain species of timber have provided man with a material, which has performed many functions including its use as a building material for shelter (Bhat *et al*., 2001; Ohyama *et al*., 2001; Onyekwelu *et al.,* 2011). As such more wood products are used for construction all over the world.

2.3 Variation and Causes of Variation in Wood Properties

Wood is basically a porous mass of tube-like material held together by amorphous molecules of lignin and depending upon species and types, containing various chemicals, minerals, gum and silica (Brown, 1997; Osafo, 2005). It is extremely a complex substance whose versatility is unparalleled by any other material (Panshin & deZeeuw, 1980). As such the strength properties of wood species are known to varies, as trees grow from seedlings to old age. It follows that the cross-sections of stems show in most cases clearly that the width of growth rings is not uniform from pith to bark but varies.

Apparently, the variations are exhibited by growth ring structure, cell morphology, ultrastructure, and chemical composition. These characteristics vary within a tree and between trees of the same species. For instance, within a tree there is a horizontal variation of wood structure, thus from pith to bark and a vertical variation, from base to top. Tsoumis (1991) claims that, the age of the cambium that produces wood, and the stimuli to which the cambium is subjected during tree growth are factors affecting variation within a tree.

Moreover, the natural origin of wood both physical and mechanical properties frequently exhibit unusually wide degree of variability. The variability of wood characteristics within individual trees is fundamentally influenced by changes in the cambium as it ages, the genetic controls that influences the form and growth of the tree as well as the environmental influences such as seasonal, geographical conditions and the nutrient supply. Taylor *et al.* (2002) also report that there is horizontal variation in the wood structure from the pith to the bark and a vertical variation from the base to the crown. At any height level, and from the pith to the bark, there is a general variation in structural characteristics. The parenchyma cells in any zone after some time lose their living protoplasm and the vessels and tracheids cease their conductive function, wood then function as supporting tissue as these changes take place. These may give rise to modifications of the basic patterns for variance of wood. Barnett and Jeronimidis (2003) holds that a comprehensive knowledge of the structure of wood, its physical, mechanical and chemical behavior, as well as the causes of wood variability as they affect its utilization and form the basis of the potential utilization of wood.

Accordingly, the differences in structure and performance occur not only between different species growing in different environment but also between different parts of a single tree (Dinwoodie, 2000; Sheng-Han & Hui, 2013). This is due to the fact that wood is an inherent variable material owing to its origin as a product of metabolism and its properties are subject to wide variations culminating from the physiology of tree or its genetic constitution and environmental influences affecting its growth condition. It is therefore essential to understand the variations that occur in wood, since they have great influence on wood processing and utilization. Some indication of the spread of property value is therefore desirable (Effah *et al*., 2013). Nonetheless, due to the interactive influence of the factors that influences tree growth it is difficult to ascribe the characteristics of wood variability to a single or a combination of factors.

2.4 Physical Properties of Wood

There are a number of physical properties of wood that also affect the strength of timber and can lead to different results being obtained from different specimens of the same species (Burgert, 2006; Dadzie *et al*., 2017; Taylor, 1991). According to Desch and Dinwoodie (1996), density is perhaps the most important single factor influencing the strength and stiffness of timbers, but there are many other variables, some anatomical in origin such as knots, slope of grain and microfibrillar angel, and some environmental such as moisture content and temperature, all of which play a significant role in determining the strength and stiffness of wood.

2.4.1 Density

It has been generally assumed that the quality of wood as a building material depends mainly on its density. Density is the best and simplest index of the strength of a clear wood, with increasing density, strength also increases (Amoah & Fordjour, 2012; Antwi *et al*., 2014). This is because density is a measure of the amount of cell wall materials contained in a given volume of wood. Thus density can be expressed as the mass per unit volume. Therefore, higher density denotes larger amount of cell wall available to resist external forces. This simplest method of determining the density of a piece of wood is to weigh it and then to find its volume. If the sample has regular dimensions without cracks, its length, width, and thickness can be measure to calculate the volume. For samples of irregular shape, an immersion method is more suitable. However, the use of radiation methods has in recent years become prominent for the measurement of material quality. Thus, the application of radiation methods such as the X-rays, beta rays, and gamma radiation have gained in importance for the wood technologist for rapid, accurate, and non-destructive physical measurements of wood properties, such as density and moisture content.

However, since density to a large extent is influenced by the moisture content of the wood, comparisons of density figures is made at the same moisture content between 0 and 12%. The density of a piece of wood therefore is determined not only by the amount of wood substance present, but also by the presence of both extractives and moisture. Bayton *et al.* (2006) therefore claims that, the presence of moisture in wood does not only increases the mass of the timber but also increases its volume. According to Dinwoodie

(2000), increasing density in wood corresponds with increases in all strength properties, except for axial tension. The elasticity and shock resistance properties of wood also correlated less with density. However, high density of wood is associated with thick fibre walls and a higher proportion of fibres. These are the very qualities which contribute to strength and in the absence of any other data about the properties of a particular species. Hence, wood density is used as a guide to its utilization (Antwi-Boasiako & Pitman, 2009; Shrivastava, 1997).

2.4.1.1 Density Variations in Trees and Species

Variations in the density of wood are due to differences in the structure and to the presence of extraneous constituents. The structure is characterized by the proportional amounts of different cell types such as fibres, tracheids, vessels, resin ducts, wood rays, and by their dimensions, especially the thickness of the cell walls. Hereditary tendencies, physiological and mechanical influences as well as factors of environment such as soil, heat, precipitation, and wind affect the structure of wood and thus its density. It follows that, density within a tree varies from pith to the bark and with height in the stem. Wood density also varies from early wood to latewood tissue within each annual ring. The latewood tissue is mostly composed of cells of relatively small radial diameter with a thick wall and a small lumen and as a result has a higher density than the thin walled early wood cells with a larger cell lumen (Effah *et al*., 2013; Ofori *et al*., 2009). Apparently, in some trees the basic density of the latewood is more than twice the early wood, thus increase in the proportion of latewood leads to an increase in basic density

(Antwi-Boasiako & Pitman, 2009). As such, the relative densities of the early wood and latewood within a tree are strongly correlated.

It follows that, the position in the tree-trunk has a considerable effect on the density of the wood. The influence of position in the tree on density and thereby on strength properties is that the butt log contains wood of the greatest density and that the lowest density occurs in the upper portion. Hence there is occasionally correlation between height in the tree and density. It was also observed that the density in the base of trees with a cylindrical stem is greater than in one that is strongly tapered (Appiah-Kubi *et al*., 2012; Dadzie *et al*., 2017). The variations in density throughout a particular cross-section of the stem are less pronounced than are those in height, and are very much affected by the width of the annual rings. Ofori *et al*. (2009) noted that the density of wood near the pith as well as that at some distance from the pith decreases with increasing height above ground. At any particular height, the wood adjacent to the pith is lighter than that nearer to the bark. Climatic conditions may influence the density of wood, but local factors interrupt and even mask this general trend. Therefore variability may be very marked even within the bole of a tree.

In coniferous trees, the wood of lowest specific gravity is always produced near the pith of the tree where wide rings usually are formed (Okai, 2002; Zhang & Zhong, 1992). The average density of these species increases with decreasing elevation of the site. While in broadleaved trees, the density increases outward from the center of the stem and reaches a maximum at a greater age, correlated with an optimum width of the growth rings as well as the formation of less narrow rings. Hartley (2002) concludes that, the highest density is produced near the center in broadleaved trees. Nevertheless, the density of the heartwood is generally higher with darker color. Moreover, wood containing a larger amount of mineral constituents such as calcium oxalate and silicates are heavy and hard. The presence of high resin content and tyloses in the vessels also increases the wood density. The differences in the concentration of these extractives and the chemical composition of the wood cell walls have great influence on density. This is due to the fact that, there is variation in the anatomical structure between species.

2.4.2 Moisture Content

Wood is a hygroscopic material that absorbs and losses moisture from and to the environment. The moisture content of wood is a function of atmospheric environment and depends on the relative humidity and temperature of the surrounding air (Ayarkwa *et al*., 2000; Bruchert *et al*., 2000). The moisture content is either distributed equally in the whole log or significant moisture gradients can exist in radial or longitudinal direction. Besides the moisture differences in a single log, there can also be significant differences of moisture content and distribution in different logs of the same wood species at the growing conditions (Reid, 2009). Boampong *et al*. (2015), described moisture content of wood as the amount of water present in the wood which can be expressed as the percentage of the oven-dry mass of the piece of wood. The moisture content within a certain range influences the strength properties of wood such as, stiffness, hardness, abrasion resistance, machinability, heat value, thermal conductivity, yield and quality of pulp and resistance of wood against decay. Wood, like many other organic materials, shrinks as it loses moisture below the fibre saturation point and swells as it adsorbs moisture. Moisture content is important in drying, impregnation, finishing and bending of wood. The costs of transportation and handling in lumber yards depend on the density of wood which is influenced by its moisture content.

The determination of moisture content and the knowledge of wood liquid relations can therefore not be overemphasized. Water in wood is contained in the cell walls and cavities of the various wood cells. The water in the cavities is called bound water due to the strong bonds caused by chemical and physical binding forces (Appiah-Kubi *et al*., 2012; Berthier *et al*., 2001). At the moisture content between 0 and 6%, water is bounded by chemical-sportive manner, between 6 and 15% the bound is by different types of adsorption forces, and between 15 and 30% the bound is by capillary condensation. The range in which the cell walls of wood fibres are saturated and free water is removed is termed the fibre saturation point. The numerical value of fibre saturation point depends not only on the wood species but also on the wood temperature and can therefore range between 22 to 36%. Blow fibre saturation point, shrinkage or swelling occurs and leading to the increasing or reduction in cohesion and stiffness (Almeras *et al*., 2005; Kollman & Cote, 1984). It follows that the disparities in wood moisture content cannot be stopped entirely but can be minimized by the application of treatments or surface coatings of the wood. In structural application, moisture content of wood undergoes gradual and short-term changes with varying temperature and humidity of the prevailing environment. As water is removed from the cell wall, the long molecules move closer together and thus becomes more tightly bound and increase in strength begins as the moisture level drops slightly below the fibre saturation point usually around 30% moisture content.

The recommended moisture content for any piece of wood in service is intended to reduce changes in moisture content to a minimum, thereby minimizing dimensional movement due to swelling or shrinkage. The moisture content requirement depends upon the use of the lumber or wood products either in the interior of buildings or outdoors and also upon climates. In general, the moisture content averages are less important than the range in moisture content permitted in individual pieces. It is a common commercial practice to dry wood to the lowest moisture content. But during storage, manufacture, and use the moisture content will be increased and the distribution of moisture will be equalized. If lumber for construction purposes is insufficiently seasoned, a severe loss of moisture combined with shrinkage is unavoidable when used for construction. The moisture content of wood can be determined by using the following methods, oven-drying, distillation, titration, use of hygroscopic elements, and measurement of certain electrical properties.

2.5 Mechanical Properties of Wood

Wood as an orthotropic material has unique and independent mechanical properties in the direction of three mutually perpendicular axes (longitudinal, tangential and radial). The mechanical properties of wood and its significance are categorized broadly into elastic properties and strength properties. Hoadley (2000) stated that elastic properties relate the resistance of a material to deformation under an applied stress to the ability of the material to regain its original dimensions when the stress is removed. The elastic properties include modulus of elasticity (MOE), modulus of rigidity, and Poisson's ratio. Whereas the strength properties for design include modulus of rupture in bending, maximum stress in compression parallel to grain, compressive stress perpendicular to grain, and shear strength parallel to grain. Additional measurements are often made to evaluate work to maximum load in bending, impact bending strength, tensile strength perpendicular to grain, and hardness. Strength properties less commonly measured in clear wood include torsion, toughness, rolling shear, and fracture toughness. Other properties involving time under load include creep, creep rupture or duration of load and fatigue (Antwi-Boasiako & Barnett, 2009; Chowdhury *et al*., 2009). The size of the test piece to be used is normally determined by the type of information required.

This implies that, to design with any material the mechanical strength properties estimates need to be determined. For instance, the America Standard for Testing Materials (ASTM) and European standards test methods has procedures that require the determination of mechanical properties via stress-strain relationships. Flexural (bending) properties are important in wood design. Many structural designs recognize either bending strength or some function of bending, such as deflection, as the limiting design criterion. Structural examples in which bending-type stresses are often the limiting consideration are bridges or book shelves. Under service conditions timber often has to withstand the imposed load for many years, since timber does not mostly behave in a truly elastic mode, rather its behavior is time dependent. It follows that, the magnitude of the strain is influenced by a wide range of factors which are property dependent, such as density of the timber, angle of grain relative to direction of load application or the angle of the micro fibrils within the cell wall (Dinwoodis, 2000; Effah *et al*., 2013). Temperature and relative humidity are however environmentally dependent.

In practice, timber is frequently subjected to a combination of stresses (compressive, bending tensile and shearing), although one usually predominates. Farmer (1972), expressly explained that many other factors have to be considered as well in the selection of species for a particular purpose, but in general, there are few instances where the choice does not depend to some degree upon one or more of its mechanical properties. Hence, a basic knowledge of the strength properties of timber is essential, if it is to be used efficiently. The fact is that, strength properties largely determine the fitness of wood for structural building purposes and there is hardly a single use of wood that does not depend at least to some degree on one or more of its strength properties.

2.5.1 Methods of Determining Mechanical Properties

The main methods that are employed in the determination of strength properties of wood include the service test and laboratory experiments. The service test has the advantage of being carried out under the same condition to which the timber is exposed in use (Dinwoodie, 2000). The fact is that, the need to classify wood species by evaluating the physical and mechanical properties of small clear specimens has always existed (ASTM D143-94, 2007). However, due to the great variety of species, variability of the material, continually changing conditions of supply, factors affecting test results, and ease of comparing variables, the need will undoubtedly continue to exist. Desch and Dinwoodie

(1996) therefore claim that this method still remains valid for characterizing new timbers and for the strict academic comparison of wood from different trees or different species.

Moreover, test of small specimens of wood is valid for characterizing new time and for strict academic comparison of wood from different species. The method utilizes in a standardized procedure small, clear, straight-grained species of wood, which represent maximum quality that can be obtained. As such, the test specimens are not representative of time actually being used without the application of a number of reducing factors. However, the method does afford the directional comparison of wood from different species. According to Tsoumis (1991), the small clear specimens present the possibility of wider sampling and the systematic study of the effects of various factors like moisture content, density, growth-ring structure, physical and chemical treatment on mechanical properties, while such effect are difficult to transfer to full size members due to variation of wood structure and the presence of defects.

In addition, when small clear specimens are used, reduction factor must be applied to obtain safe working stresses. Test on timber of structural sizes are more representative of service conditions, but they have the disadvantage of being costly and time consuming since large wood samples are required and they take a longer time to rapture. British Standards B.S 373 stated that timber should be tested both in the green state and in the seasoned condition. As a result, BS 373 indicates that the testing of small clear specimens of timber serve mainly to provide data for the comparison of the strength properties of different species. Nonetheless, the test results may be used to determine the relationship between strength and properties as density and moisture content, and also to assist in the establishment of design functions for structural use.

2.5.1.1 Modulus of Elasticity (MOE)

Forest Products Laboratory, (2010) reported that elasticity implies that deformations produced by low stress are completely recoverable after loads are removed. When loaded to higher stress levels, plastic deformation or failure occurs. Modulus of elasticity relates the stress applied along one axis to the strain occurring on the same axis. Hook's Law state, that the ratio of stress to strain for a given piece of wood within the elastic range is constant. Thus MOE = $L3 \times (P_2 - P_1)/48I(d_2 - d_1)$ where $(P_2 - P_1)$ is the load increment (N) in the linear part of the stress – strain curve, L is the sample length between the two supports (mm), $(d_2 - d_1)$ is the deflection (mm) corresponding to the load increment $(P_2 - P_1)$, I is the moment of inertia (mm). The ratio is called the modulus of elasticity. Sometimes also called Young's Modulus usually abbreviated as MOE or simply E, this ratio equals to the stress divided by the resulting strain.

The three moduli of elasticity for wood are denoted EL, ER, ET, to reflect the longitudinal, radial and tangential directions respectively (Forest Products Laboratory, 2010). Elastic constants vary within and between species and with moisture content and specific gravity. The only constant that has been extensively derived from test data is EL. Other constants may be available from limited test data but are most frequently developed from material relationship or by regression equations that predict behaviour as a function of density (Forest Product Laboratory, 2010; Hoadley, 2000). The modulus of elasticity (MOE) is a property of importance in determining the deflection of a beam under load. This is usually considered in conjunction with bending strength. According to Timings (1991), the strength of a long timber column or strut is a critical property determined by the stiffness (MOE) of the material. As such, Almeras *et al*. (2005) claims that the higher the MOE the less the deflection or the greater the stiffness.

2.5.1.2 Modulus of Rupture (MOR)

Reflects the maximum load-carrying capacity of a member in bending and is proportional to maximum moment borne by the specimen. According to Desch and Dinwoodie (1996), the bending strength of wood usually presented as modulus of rupture (MOR) is the equivalent stress in the extreme fibres of specimen at a point of failure. Bending strength results from a combination of all the three primary strengths (compression, shear and tension) which causes flexure or bending in the wood. As such, modulus of rupture is an accepted measure of strength, although it is not a true stress because the formula by which it is computed is valid only to the elastic limit (Appiah-Kubi *et al*., 2012; Geoffrey & Geoffrey, 1992). Modulus of rupture (MOR) = 3PL/3bd[106] where P is the maximum load (N), L is the length of sample between the two supports (mm), b is the sample width (mm), and d is the sample thickness (mm).

2.5.1.3 Compressive Stress

This is the maximum stress sustained by a specimen from a test with compression forces applied parallel or perpendicular to the surface. Tests are made with the long dimension of the specimen cut both parallel and perpendicular to the long dimension of the board to determine the material's resistance to crushing in each of the primary panel directions. The specimen is packed with oscillating loading progressively up to the failure. Timings (1991) holds that, compressive strength parallel to the grain or maximum crushing strength is the property that measures the ability of timber to withstand loads when applied on the end grain. When wood is stressed in compression parallel to the grain, failure initially begins as the micro fibrils begin to fold within the cell wall. As stress in compression parallel to the grain increases, 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, high strength in longitudinal compression is required of timber used as columns, props and chair legs.

On the other hand, compressive strength perpendicular to the grain which is the resistance to crushing is an important property in a few selected end uses such as railway sleepers, rollers, wedges, bearing blocks and bolted timbers. Those timbers which are high in density have high compression strength across the grain (Desch & Dinwoodie, 1996; Miranda *et al*., 2011). The resistance of wood against perpendicular-to grain compression is practically important for much building constructions and for railway ties. But it is very important to ensure that crushing strength across the grain does not exist. The wood only will be densified under the influence of compressive force acting perpendicular to the grain.

According to Forest Products Laboratory, (2010) compressive stress perpendicular to the grain is reported as stress at proportional limit and added that there is no clearly defined ultimate stress for this property. Compression perpendicular to the grain strength is often not carried out but is computed from the side hardness of the timber since there is a very high correlation between the two properties (Brunner *et al*., 2007; Lavers, 1983). Bosu *et al*. (2004) therefore claims that the stress which causes 1% deformation is reliable. According to ASTMD 143 – 52 the samples undergoing test should be clear and should measure 20mm × 20mm × 60mm. the force is applied to the tangential face through a centrally located rectangular steel plate.

2.5.1.4 Shearing Stresses

Shear strength is the measure of the ability of wood to resist forces that tend to cause one part of the material to slide or slip on another part adjacent to it (Shrivastava, 1997). Shearing stresses may be parallel, or perpendicular to the grain. However, shearing stress sets up an equal stress at right angle to it, and since wood is much stronger in shear across the grain than it is along the grain, it is extremely difficult to obtain the true shear strength perpendicular to the grain, as failure always occurs by shear parallel to the grain. The ultimate shearing strength parallel to grain is related to the torsional properties but the shear test is problematic due to superposed, mostly bending, stresses. Compressive stresses, stress concentrations and internal checks are others which mask a clear picture of the shear phenomenon. As a result, the ultimate shearing strength is always remarkably lower than the torsional strength. For solid wood members, the allowable ultimate torsional shear stress may be taken as the shear stress.

On the other hand, there is a shearing force that tends to move the fibres of a beam past each other in a longitudinal direction. This shear, called horizontal shear, results from the slipping of the fibres over one another as several boards are placed longitudinal on each other, tend to bend. According to Hoadley (2000) these forces are considered in designing structural forms of wood that may be subjected to bending while in service. Tsuomis (1991) added that the strength of wood in axial shear has the greatest practical importance; under the influence of shearing loads, wood usually fails in this manner.

2.5.1.5 Hardness

Hardness refers mainly to the resistance of the surface of the wood to bruising, marring and indentation. The hardness test is a measure of the load required to force a small steel ball into the wood to half its diameter. The load is gradually applied as the force required by static loading to embed a steel hemisphere 0.444 inch in diameter, corresponding to 1 cm^2 of hemisphere surface, completely into the wood is determined. It is also important to note the, the procedure of dropping the steel-ball on a wood surface is easy, but the sources of error are greater. Nevertheless, the hardness test as a non-destructive or a hardly destructive test, especially for finished wood parts, remained attractive. The test block is about 60 mm in length and 20 mm in cross section. There is also a strong correlation between dynamic end-hardness and crushing strength along the grain. But there is no distinction between side hardness on a radial or a tangential face, but only between side and end hardness.

Subsequently, many hard timbers have good wearing properties, thus resisting abrasion or wearing away. It is therefore obvious that, hard timbers are usually dense, having relatively thick-walled cell, and are often difficult to saw, plane or nail. According to Amoah and Boateng (2014) hardness determines the material that can be used for flooring, paving blocks and bearing block. For the anisotropic, heterogeneous, hygroscopic wood, the hardness value is more than doubtful.

2.6 Description of *Albizia lebbeck*

Albizia lebbeck, commonly known as *lebbeck* is a deciduous timber species that belongs in the Fabaceae family. Other common names are siris tree (India), *Albizia indiana* (Italy), Borhan (Bangladesh), kokko (Myanmar), rain tree (Australia), chreh (Cambodia), mother-in-law's tongue (Caribbean) and in Europe (India walnut). The species is also known in Hawaii and the Philippians as women's tongue because the pods remain on the tree for three to five months and make a chattering noise in the wind. *Albizia lebbeck* is generally distributed throughout Asia, India, Bangladesh, Pakistan, Venezuela, Australia, Cambodia, Malaysia, Indonesia, Vietnam, Thailand, Sri Lanka, and topical Africa (Elzaki *et* al., 2012; Salehi, 2008; Sesoltani & Paulsen, 2011). According to Zia-Ul-Haq *et al.* (2013) *Albizia lebbeck* is widely naturalized within sub-humid, semi-arid tropics and subtropical areas where there is a marked dry season and reliable rainy season. Apparently *Albizia lebbeck* has naturalized and become invasive at riverbanks, forests as well as Savannah's hence there are about half dozen of varieties in tropical Africa (Cossalter & Pye-Smith, 2003; Saha & Ahmed, 2009).

It follows that *Albizia lebbeck* is a deciduous stemmed tree which can attain a height of 20 – 30m and a stem diameter of 1m (Bobby *et al.,* 2012). It can also produce multi-stemmed variety when grown in the open, with large spreading crown of feathery foliage and grey fissured corky bark, somewhat flaky. The compound leaves are glabrous and slightly hairy on the axis with about 2 – 11 pairs of obliquely oblong to elliptic-oblong leaflets shortly stalked, initially bright green and maturing to a duller glabrous green and folding at night (Hassan *et al*., 2007; Prinsen, 1988; Sasmal *et al*., 2013). The glabrous glands are raised, elliptic to circular, on the upper side of the stalk, close to the base and between most pairs of leaflets. *Albizia lebbeck* shows its growth seasonally, with no growth in the early part of the dry season. Leaf loss occurs with the period 3 months, and the tree will remains leafless for 2 months until the end of dry season when growth resumes and flowering begins (Bobby *et al*., 2012). *Albizia lebbeck* plant species produce an incessant rattle in the wind hence the name 'women's tongue' and 'rattle pod' derive from the noise of pods shaking in the wind.

Nehdi (2011) reports that, *lebbeck* in florescence consists of large clusters of about 5-7.5 cm wide of fragrant globular flower heads, on stalks of about 5-10 cm long. The corolla is about 5.5-9 mm long, globrous, cream, white or green, with numerous pale green stamens on filaments of about 15-30 mm long. The entire inflorescence is fluffy in appearance, 60 mm in diameter, yellow-green with a pleasant fragrance. The pods are pale straw to light brown at maturity, narrow-oblong, papery leathery swollen over the seeds and not constricted between them, indehiscent and born in large numbers (Yaday *et al.,* 2011). According to Uma *et al.* (2009) the seeds are brown, flat, orbicular or elliptic, and transversely placed with 3-12 in each pod. The seed viability is usually high and seen can be stored for up to 5 years without serious decline in viability.

Moreover, *lebbeck* grows in a wide range of climates, covering an annual rainfall range of 600-2500 mm, and can be grown successfully in areas with an annual rainfall as low as 400mm. It can tolerate lower and more irregular rainfall conditions (Motamedi *et al.,* 2009). The species shows high adaptation to a wide range of soil types and grows well in shallow and well drained loamy soils, acid alkaline and saline soils. It has naturalized and become invasive in a number of locations including riverbanks, forest, bushy areas as well as Savannah, hence there are about half dozen of varieties in tropical Africa, widely cultivated mainly as shade tree and as a roadside tree (Carvers *et al*., 2004: Chaddha *et al*., 2011). Its shade is a of great benefit in animal production in the dry tropics, as such the species is commonly grown as a shade tree in the north.

Purendra and Teena (2018) hold that, *Albizia lebbeck* is actively promoted particularly in relation to agroforestry where it is regarded as having potential for use in silvopastoral systems in semi-arid regions. This interest stems from its apparent ability to improve pasture production and quality, as well as providing food supplement in the form of the leaves, flowers, and pods (Chulet *et al.,* 2010). This on the other hand enhances pasture production, probably due to shading and related improved soil moisture status and fertility from litter breakdown. Accordingly *Albizia lebbeck* is a good soil binder and is recommended for soil conservation and erosion control (Sreemannarayana *et al*., 1994). Saha and Ahmed (2009) also claim that its nitrogen rich leaves are valuable as mulch and green manure. In all, it serves as fuelwood, charcoal, round wood, fodder, forage, invertebrate food for lac/wax insects, agroforestry, boundary, windbreaks, shelterbelts, mulch, erosion control or dune stabilization, revegetation, shelter, soil improvement and conservation, ornamental, honey flora, dye/tanning or gum/resin materials as well as medicinal purposes (E1-Hawary *et al.,* 2011).

CHAPTER THREE

MATERIALS AND METHODS

This chapter comprises of the methodology used for the research. It considers the study area, selection and collection of research materials, preparation of test specimen, experimental parameters and procedures and the data analysis tool. The properties investigated in this study includes the heartwood and sapwood proportions, density, moisture content, compression parallel to grain, shear parallel to grain, modulus of elasticity, modulus of rupture, and hardness of the selected plantation grown exotic timber species (*Albizia lebbeck*) obtained from the Savannah ecological zone.

3.1 Study Area

The study was carried out in the Tamale fuel wood plantation, one of the twenty-four (24) plantation reserves of the Savannah ecological zone. It is rich in biodiversity and well protected evergreen plantation situated within the Tamale Metropolis (Nsenkyire, 1999). The Metropolis is one of the 26 Districts in the Northern Region. It is located in the central part of the Region which shares boundaries with the Sagnarigu District to the West and North, Mion District to the East, East Gonja to the South and Central Gonja to the South-West (Figure 3.1). The Metropolis has a total estimated land size of 646.90 square kilometers (GSS, 2010). Geographically, the Metropolis lies between latitude 9º 16 and 9º 34 North and longitudes 0º 36 and 0º 57 West. The land generally is undulating with a few isolated hills and is about 180 meters above sea level.

Source: Town and Country Planning Department, TaMA, 2014

Figure 3.1: Map of Tamale Metropolitan Assembly

3.1.1 Climate and Temperature

The climate of the Metropolis is the tropical continental type with a single rainfall season in the year starting from May to October (GSS, 2010). The highest rainfall season occurs from July to September with an average rainfall of about 200 mm and 300 mm per year. The period between November and April is the dry season which is mostly characterized by the harmattan winds. In terms of temperature, the coldest nights within the year are experienced from the months of December to February. During this period the air becomes dry and the atmosphere becomes hazy and cold. Mean annual temperatures in the Metropolis are low around 25^{o}C in August and high around 40^{o}C in March. High temperatures are experienced between the months of March to May, but mean temperature begins to fall when the rain start.

3.1.2 Soil and Vegetation

The Metropolis lies within the Savannah ecological zone in the country and poorly endowed with water bodies. The only natural water systems are a few seasonal streams which have water during the rainy season but dry up during the dry season. The main soil types in the Metropolis are sandstone, gravel, mudstone and shale that have weathered into different soil grades. The soil is generally very fertile for agricultural cultivation. But due to seasonal erosion, soil types emanating from this phenomenon are sand, clay and laterite ochrosol. However, the availability of these soil types have facilitated real estate development in the area as estate developers have resorted to using these materials in the building industry.

It follows that, the vegetation is mainly Guinea Savannah wood land with spread of trees which are short scattered wood lots in nature. As such the flora and fauna is diverse and composed of different species of both economic and ornamental tree species with varying heights. The trees shed their leaves during the dry season. Major tree types in the natural vegetation of the Metropolis include dawadawa, nim, acacia, mahogany, baobab, shea, cashew, kapok and mango. The economic trees are the shea and cashew trees which has gained international recognition. Besides, the Metropolis is endowed with naturally grown tall grasses during the rainy season which are used to make the local mats popularly called "zanamat". However, due to the interference by man and animals through cultivation, grazing and exploitation for fire wood. In the dry season, the grasses in most part of the Metropolis are periodically burnt down to either clear the land for crops cultivation or hunting of animals (Abu, 2000). These activities have deprived the land of much vegetation cover and nutrients over the years. Apparently, there has been a drastic change in the rain pattern and food productions in the Metropolis.

3.2 Wood Sample Collection

Three (3) mature plantation grown exotic timber species, *Albizia lebbeck* were sampled to determine their physico-mechanical properties. By the help of field assistants from the Tamale regional forestry department, the trees were identified and marked. Purposeful sampling technique was adopted based on, the diameter at the breast height (dbh) greater than 45cm, the overall straightness of the trunk and defect free. In order to minimize tree-to-tree variation, the sampling approach by Bao *et al*., (2001) was adopted. Trees of similar diameters at breast height were selected for harvesting. The height of each tree above ground level was also measured using graduated poles and the trees were felled by a chain-saw at 1.3m at breast height from the ground level. The merchantable lengths of the clear bole between where the first branch begins and the terminal point of buttresses of each species were measured and recorded (Figure 3.2).

Figure 3.2: Identification of Trees (**A**) and merchantable lengths divisions (**B** and **C**)

The average diameters of the trees harvested at 1.3 meter above ground level (dbh) and the height from the stump level to the beginning of the crown of the trees were 48cm and 5.24m respectively. The total merchantable height of the lumber (bole) was divided into four (4) equal billets to determine the within and among tree variation (Figure 3.3). A stem sectional disc approximately 7.5cm in thickness was cut at each end of the divided sections (0-25%, 26-50%, 51-75% and 76-100%) for the determination of the density and moisture content. These divisions were used to reflect the whole length of each tree. The billet of each selected portion was then divided into four parts (North, South, East and West) and sawn into three planks (1-3), from the pit portion of the billet to the bark portion of the tree to represent heart and sapwood part of the tree (Figure 3.4). The radial variation was studied by sampling in each wood disc while the heartwood and sapwood proportions were measured and recorded by the use of a microscope and calipers.

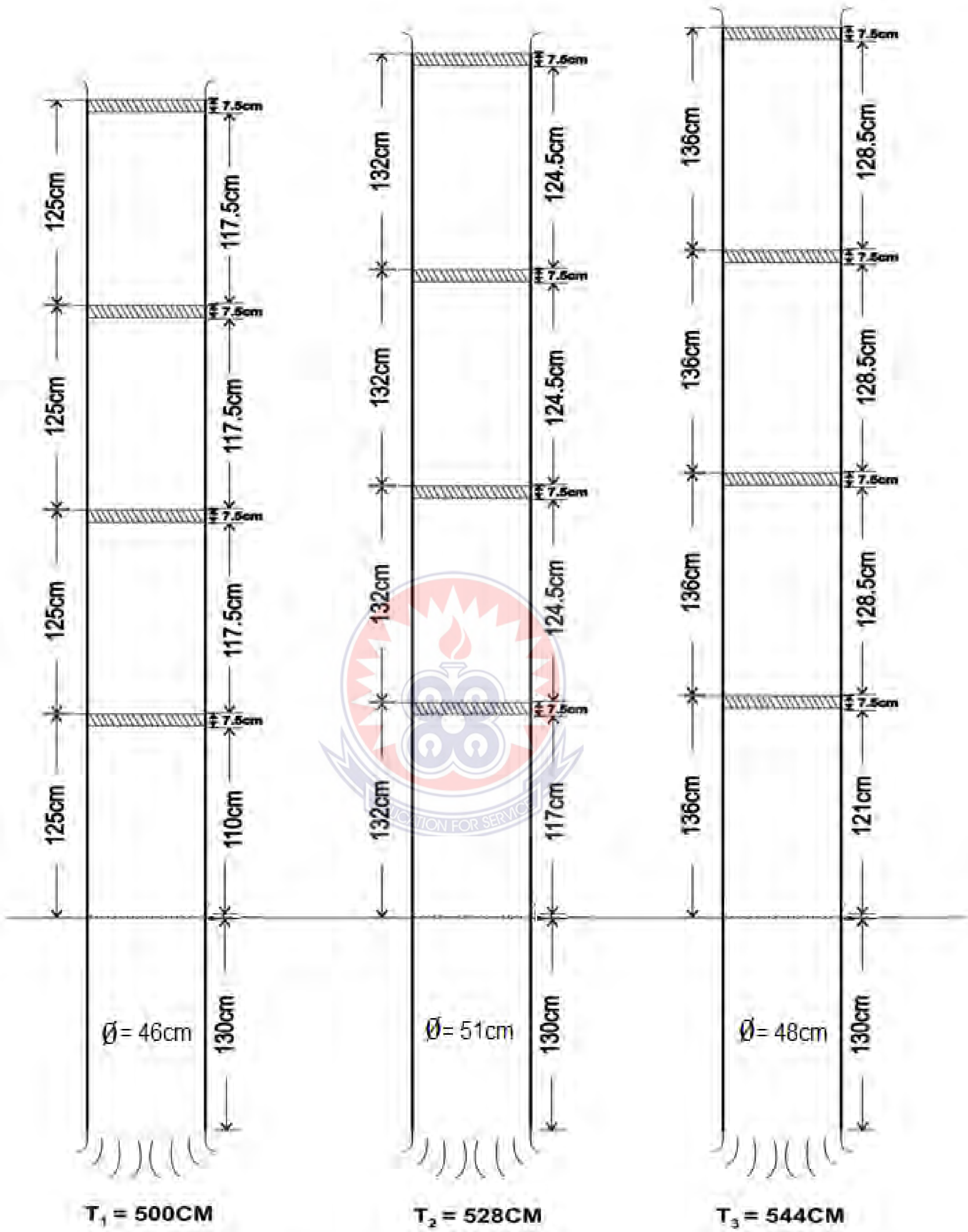

Figure 3.3: Sample Tree Heights and Divisions Showing Points Where Test Samples Were Collected

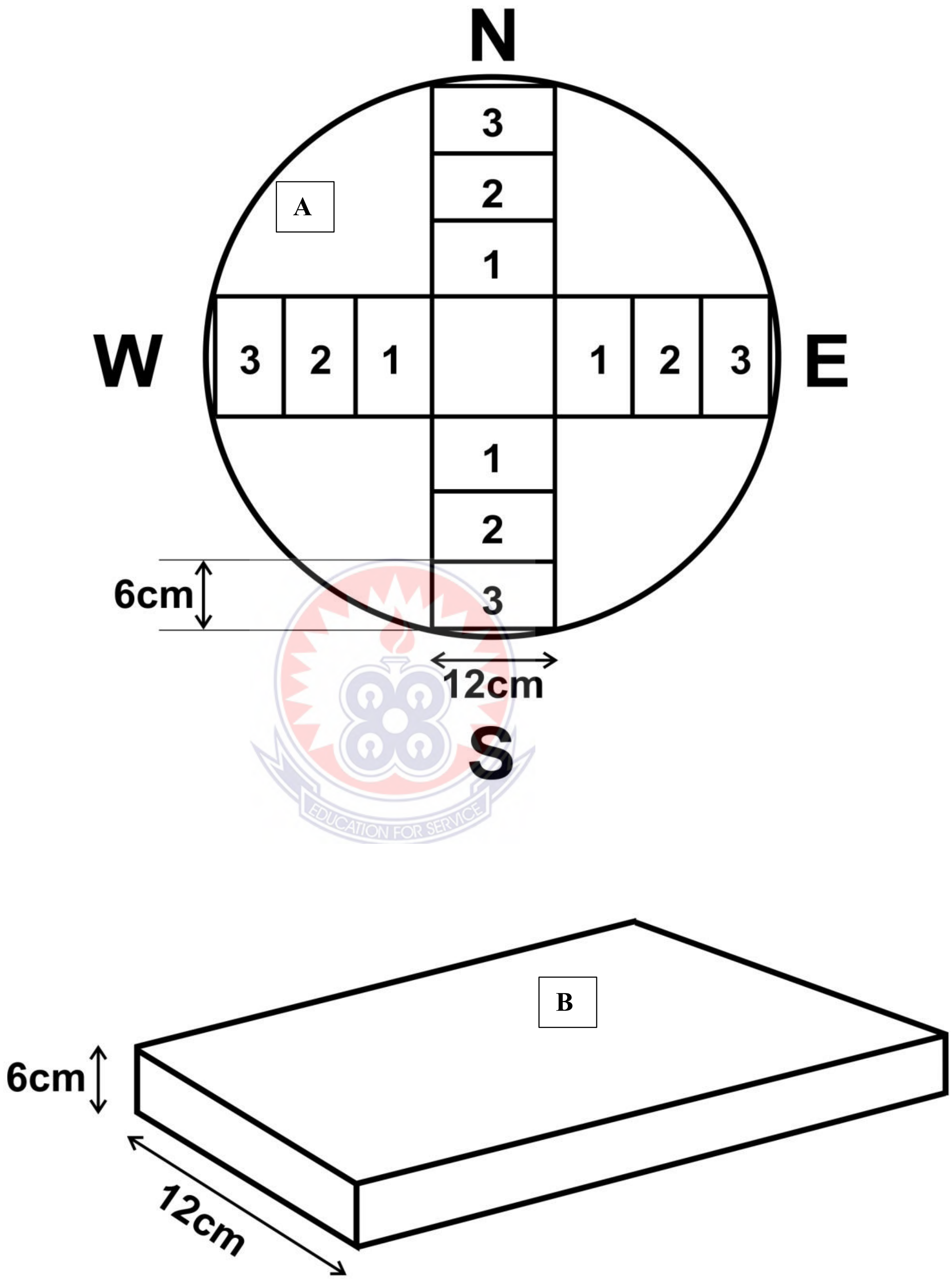

Figure 3.4: Schematic Illustrations of the Convention of the Billets (A) into Planks (B)

3.3 Preparation of Test Specimen

The samples were prepared based on British Standards BS 373 of testing small clear specimen of timber for moisture content, oven-dry density, compression parallel to grain, modulus of rupture, modules of elasticity, shear parallel to grain, hardness and static bending perpendicular to grain. This standard utilizes small, clear, straight-grained pieces of wood, which represent maximum quality that can be obtained. Marking and sawing were carefully done to ensure that the heartwood and sapwood portion of each billet was obtained. Since, in most application the heartwood is considered to have superior properties to sapwood.

In preparing the samples, the sawn planks were further carefully selected free from defects such as knots, sloping grain and other deterioration caused by insects and fire as these factors reduces the strength properties of wood. After sawing, the boards were further planed and carefully examined for any visible defect. Each wood samples was further ripped into the various sizes for the tests (Figure 3.5). The samples were immediately packaged and carried to the laboratory where an experimental study was employed to test all the various properties.

Figure 3.5: Sawn Planks (**A**) Ripped to the Recommended Sizes (**B**) and Packaged (**C**) for Transportation to the Laboratory

Tools and machinery used in preparing and processing the specimen include the following; Chain Saw (Dolmar), Circular Saw, Band Saw, Crosscut Saw, Surface Planer, Thicknesser, Electronic Balance, Digital Caliper, Electric Oven, Climate Chamber and the Intron Testing Machine. The wood samples were prepared at the Tamale Technical University Wood Technology Workshop. Moisture content and oven-dry density determination were done at the Construction and Wood Laboratory, University of Education, Winneba – Kumasi campus whiles all the other tests were carried out at the Timber Mechanics and Engineering Laboratory, Forestry Research Institute of Ghana (FORIG) of Council for Scientific and Industrial Research (CSIR).

3.4 Evaluation of the Heartwood and Sapwood Proportions

Before the sampled trees were cut down, their trunks were marked at east and north directions. After felling, stem discs with a thickness of approximately 7.5cm were obtained at sections 0-25%, 26-50%, 51-75% and 76-100%. Thus four discs each were obtained from each tree. Every disc was numbered and marked with the north direction. Each disc diameters (heartwood and sapwood) were identified and measured (±0.001mm) with a microscope, digital caliper and a tape measure in order to determine the heartwood and sapwood proportions. The heartwood and sapwood proportions were calculated separately as the mean of the observed values in eight directions (South, South- East, East, North- East, North, North- West, West and South-West) as shown in Figure 3.6.

Since Area of a circle is expressed as πr^2

Heartwood Surface Area = πr^2

$$\text{Where; } r = \frac{r1 + r2 + r3 + r4 + r5 + r6 + r7 + r8}{8} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(3.1)}$$

Sapwood Surface Area = πR^2

$$\text{Where; } R = \frac{R1 + R2 + R3 + R4 + R5 + R6 + R7 + R8}{8} \quad \ldots\ldots\ldots\ldots \text{(3.2)}$$

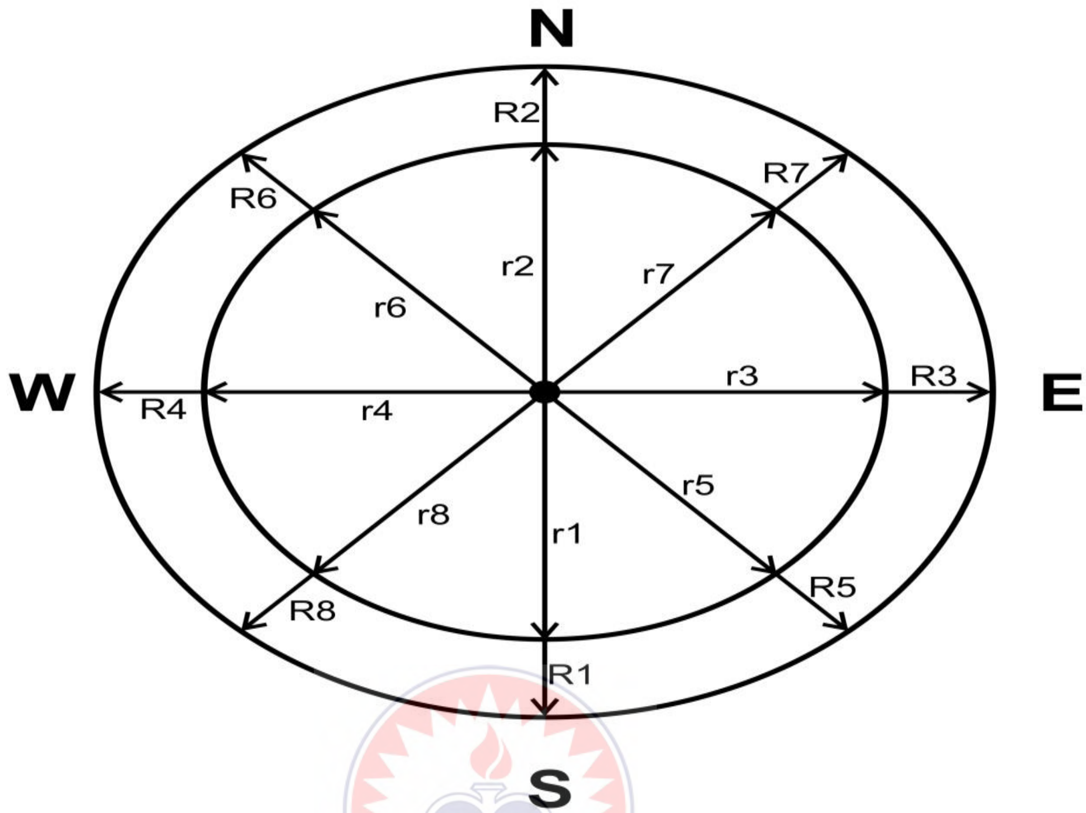

Figure 3.6: Measurement of the Heartwood (r_1-r_8) and Sapwood (R_1-R_8) Radius in Each Disc (N: North; S: South; E: East; W: West)

3.5 Determination of Some Physical Properties (Moisture Content and Oven-Dry Density at 12% MC)

The 75mm stem sectional discs (0-25%, 26-50%, 51-75% and 76-100%) were sawn into sizes of 20mm x 20mm x 20mm in accordance with the British Standards, BS 373 (1957). In all four hundred and sixty-three (463) cubes were obtained from the twelve (12) discs extracted from the three trees for the moisture content and oven-dry density determination.

3.5.1 Moisture Content of Wood Samples

Moisture content (MC) was determined by the oven-dry method were green samples collected from the entire merchantable sections (0-25%, 26-50%, 51-75% and 76-100%) were sawn into sizes of 20mm x 20mm x 20mm. after the preparation of the test specimen, they were immediately weighed by an electronic balance (Figure 3.7). The specimens were then oven dried at 103±2 ^{0}c, cooled in desiccators and reweighed on the electronic balance. The procedure was repeated until constant weight was obtained. According to Panshin *et al*. (1980), moisture content of wood can be expressed as the percentage of the over dry weight of the wood. The initial weights (W_1) and the oven-dry weight (W_2) were substituted in the MC equation for the moisture content determination.

Thus, MC = $\frac{W1-W2}{W2}$ $x\ 100$ ……………………..(3.3)

Where;

W_1 = initial weight of sample in grams (g)

W_2 = oven-dry weight of samples in grams

Figure 3.7: Discs Extracted From the Three Trees (**A**) and Sawn into Sizes (**B**)

3.5.2 Oven-Dry Density of Wood Samples

The same test specimens of moisture content were used for the density test. The mass of the samples were taken immediately after preparation using an ELE International digital electronic balance with precision 0.001g to obtain the initial mass (Fig. 3.8). The wood samples were then air-dried in order to reach an appreciable percentage of moisture content before they were oven-dried at 103 ± 2 ^{0}C with intermittent weighing until a constant oven-dry mass (W_0) was obtained. The specimens were then conditioned to 20°C at 65% relative humidity for 120 days in order to reach a moisture content of approximately 12%. Masses and dimensions of the specimens at 12% MC were used to calculate the oven-dry density values.

Mathematically, it is expressed as $D = \frac{m}{v}$ …………………………...   (3.4)

Where;

D = Oven-dry density (kg/m^3)

m = oven-dry mass (kg)

v = volume of wood sample at 12% MC (m^3)

Fig. 3.8: Weight and Volume of Cubes taking at the Construction and Wood Laboratory, University of Education, Winneba – Kumasi (A and B)

3.6 Determination of Mechanical Properties

The strength properties of the plantation grown *Albizia lebbeck* were determined immediately after preparation of the test specimens (Figure 3.9). The strength properties that were determined include the bending strength (MOE and MOR), Compression parallel to the grain, Shear parallel to grain, and Janka Hardness (Tangential and Radial directions). Four hundred (400) samples of heartwood and sapwood portions of each tree were prepared making a grand total of one thousand and two-hundred (1200) samples for all mechanical tests (Table 3.1). The test specimens were cut to the sizes and orientations required by the British Standard, BS 373. Samples were obtained from the tree sections (0-25%, 26-50%, 51-75% and 76-100%) for each of the three (3) trees. Having air-dried the specimens to an appreciable amount of moisture content they were conditioned to 12% moisture content and were kept in a climate chamber pending the tests. The actual moisture content of the specimens was determined by electrical moisture meter before testing.

Figure 3.9: Specimens Set For Testing

Table 3.1: Samples Taken From Billets of Each Tree for Mechanical Test

Buttress	Compression		MOR		MOE		Shear		Hardness	
	H	S	H	S	H	S	H	S	H	S
T_1										
0 - 25%	10	10	10	10	10	10	10	10	10	10
26 - 50%	10	10	10	10	10	10	10	10	10	10
51 - 75%	10	10	10	10	10	10	10	10	10	10
76 - 100%	10	10	10	10	10	10	10	10	10	10
T_2										
0 - 25%	10	10	10	10	10	10	10	10	10	10
26 - 50%	10	10	10	10	10	10	10	10	10	10
51 - 75%	10	10	10	10	10	10	10	10	10	10
76 - 100%	10	10	10	10	10	10	10	10	10	10
T_3										
0 - 25%	10	10	10	10	10	10	10	10	10	10
26 - 50%	10	10	10	10	10	10	10	10	10	10
56 - 75%	10	10	10	10	10	10	10	10	10	10
76 - 100%	10	10	10	10	10	10	10	10	10	10
Total	120	120	120	120	120	120	120	120	120	120

T = Tree, H = Heartwood, S = Sapwood

3.6.1 Determination of Bending Strength (MOE and MOR)

The modulus of elasticity is an index of the stiffness of a piece of wood. The static bending (modulus of rupture and modulus of elasticity) tests were carried out using the 3-point loading (central loading) system on an Instron Universal Testing Machine at the Timber Mechanics and Engineering laboratory at FORIG. Using this method, the ends of the 20mm x 20mm 300mm samples were supported and a load placed on the centre of the sample. The test pieces were supported at the ends in such a way that they were quite free to allow the bending action and were not restrained by friction which have resisted the bending and tended to introduce longitudinal stresses (Figure 3.10). The loading was applied automatically by the machine at a rate of 0.26 in/min (6.5 mm/min). The applied load and corresponding deflection were recorded by the machine at an interval of every 0.1N. The test piece was loaded at this speed until failure occurred. The maximum load at failure as well as the maximum load at the limit of proportionality was recorded by the computer component of the Instron Universal Testing Machine with reference to the outer points of loading. The duration of the test was 90 ± 30 seconds.

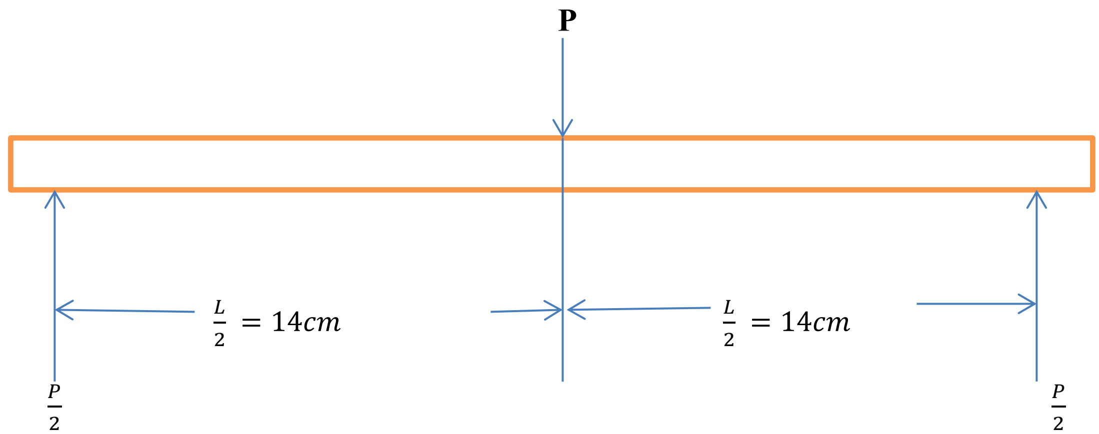

Figure 3.10: Test set up for central loading

The modulus of elasticity, E, is computed by the equation:

$$E = \frac{P^1 L^2}{4\Delta^\prime A^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

Where;

E = Young's modulus of elasticity (N/mm^2)

P^1 = maximum load applied at the limit of proportionality (N)

A = area of cross-section of beam normal to direction of load (mm^2)

Δ^1 = deflection at mid-length a limit of proportionality (mm)

L = span of beam (mm).

The modulus of rupture is the maximum load a wood sample can sustain prior to rupture. The MOR was determined using a similar test procedure as outline for MOR.

Modulus of rupture, R, is computed by the equation:

$$R = \frac{3PL}{2bd^2} \quad \text{---} \quad (3.6)$$

Where;

R = modulus of rupture (N/mm^2)

P = maximum load applied at the midpoint of the sample (N)

L = span of beam (mm)

b = breadth of test piece (mm)

d = depth of the test piece (mm).

3.6.2 Determination of Compression Parallel to Grain

The resistance to compression was determined by using parallel to the longitudinal grain method according to BS: 373 (1957). The sample sizes were cut according to the 2cm standard (2cm x 2cm x 6cm). All specimens were checked to ensure that the rectangular test piece was smooth and parallel and normal to the axis and that the testing machine was of such construction. The plates between which the test piece was placed were parallel to each other and remained so during the whole period of test. These checks were done to make sure accurate results were obtained. A total of two hundred and forty (240) samples were carried out on the Instron Universal Testing Machine. The test was conducted in accordance with the BS 373. The load was applied to the test piece in such a way that the loading plates approached each other at a rate of 3.1 x 10^{-6} mm/min. The test piece was loaded to failure at the specified rate and the maximum load at failure is recorded automatically by the Instron machine. The test duration was 90 ± 30 seconds.

The compressive stress at maximum load is computed as follows:

$$C = \frac{p}{A} - - - - - - - - - - - - - - (3.7)$$

Where;

C = Compressive stress at maximum load (N/mm^2)

P = maximum load in Newton (N)

A = Cross sectional area of sample (mm^2)

3.6.3 Shear Strength Parallel to Grain

The test was conducted in accordance with BS 373. The sample sizes according to the standard were 5cm x 5cm x 5cm. A total of two hundred and forty (240) samples of both sapwood and heartwood of each billet were tested on the Instron Universal Testing Machine with load cell capacity of 100KN. The load was applied at a constant rate of crosshead movement of 0.635mm/min. The direction of shearing was parallel to the longitudinal direction of the grain. The load was applied to the piece until failure occurred. The load at which failure occurred was recorded automatically by the Instron Universal Testing Machine. The test duration was 90 ± 30 seconds.

Shear parallel to the grain (V) is calculated as follows:

$$V = \frac{p}{A} - - - - - - - - - - - - - - (3.8)$$

Where;

V = Shear in N/mm^2

P = Maximum load in Newton (N)

A = Area in shear in mm^2

3.6.4 Hardness (Janka Indention Test)

The test was conducted in accordance with the BS 373. The specimen dimension for the hardness test was 5cm x 5cm x 15cm and was cut radially and tangentially. A total of two hundred and forty (240) samples of both sapwood and heartwood were tested on the Instron Universal Testing Machine with the hardness test fixture. The fixture is made up of a steel bar with a steel ball at one end, measuring 11.3 ± 2.5 mm in diameter. When a load is applied, the hemispherical end of the steel bar (steel ball) penetrates into the test piece. The load necessary to force into the test piece, to a depth of 5.6 mm, by the hemispherical end of the steel ball is recorded automatically by the Instron machine as the failure load. A diagrammatical representation of the fixture used, which incorporates a depth indicating device, as shown in Figure 3.12. Determination was made only on the radial and the tangential surfaces. The radial and tangential surfaces chosen for the test were those which most closely approached the true radial and tangential directions of the grain.

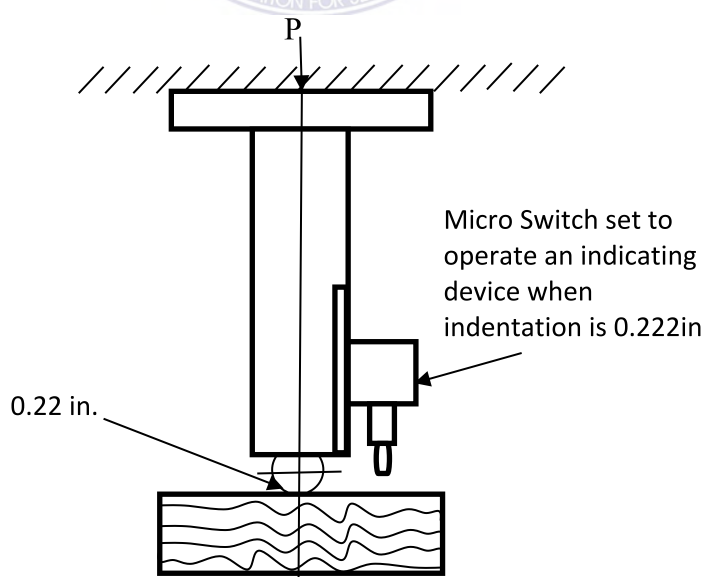

Figure 3.11: Janka Hardness Test Setup

The small clear specimens were scaled to allowable stress values for lumber (ASTM, 2011a; Madsen, 1992). The small clears were adjusted to full-sized lumber according to

$F_b = (\bar{X}\text{-}1.645S) \times F_{time} \times F_{depth} \times F_{grade} \times \frac{1}{F_{safety}}$ …………………………..(3.9)

Where;

F_b = allowable bending stress in bending

$\bar{X}$ = mean MOR_{sc} of the small clear specimens

S = standard deviation of the small clear specimens

F_{time} = adjustment factor for duration of load from minutes to 10 year (0.62)

F_{depth} = depth adjustment for each size

F_{grade} = stated strength ratio for each grade

F_{safety} = safety factor adjustment (1.3)

F_{depth} is calculated as

$$F_{depth} = \frac{SCdepth^{d}}{Ldepth}$$

3.7 Statistical Analysis

The variations in the tested physical and mechanical properties of the plantation grown exotic timber species (*Albizia lebbeck*) were conducted for three trees. Hence data was analyzed statistically to assess the significant difference within each axial division of the merchantable sections (0-25%, 26-50%, 51-75% and 76-100%) of each tree and the variability between their strength properties. Data were imported into the statistical software Origin (Version 9.1 Pro. software) for statistical analysis. Descriptive statistics was used to summarize the data numerically and graphically. The tools used in displaying the results of the various properties determined include the mean, median, standard deviation and line of fit and R square (coefficient of determination) to know the relationship between the stem height and wood properties. Analysis of Variance (ANOVA) was used to determine the significant variation in properties within each bole (all variations were tested at 99% $p = 0.05$). Turkey Multiple Comparison Test was used to test the statistical significance of each pair of means and the variation in the quantitative mechanical properties.

CHAPTER FOUR

PRESENTATION OF RESULTS

This chapter presents results of the study as obtained from laboratory works and analysis of data from wood samples. Summaries of the results are presented in tables and charts.

4.1 Axial Proportions of Heartwood and Sapwood of Plantation Grown *Albizia lebbeck* Trees.

Table 4.1 reports the axial percentages (%) of the heartwood and sapwood proportions of plantation grown *Albizia lebbeck* trees. Tree 1 recorded heartwood and sapwood percentages of 75.72 and 24.28, 74.83 and 25.17, 73.58 and 26.42, 70.21 and 29.79 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively. In tree 2, the heartwood and sapwood percentages obtained are 78.04 and 21.96, 76.34 and 23.66, 72.26 and 27.74, 71.51 and 28.49 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively. The following were the records for tree 3 heartwood and sapwood percentages, 79.70 and 20.3, 75.68 and 24.32, 72.95 and 27.05, 67.67 and 32.33 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively.

This suggests that, the heartwood portion of the stem decreases from the bottom section of the tree to the top section whereas the sapwood portion of the stem increases from the bottom section to the top section. It follows that, the average percentages of heartwood and sapwood for tree 1 recorded 73.58 and 26.42 respectively as tree 2 recorded 74.54

and 25.46, tree 3 obtained 74.00 and 26.00 (Fig. 4.1). The heartwood volume decreases with increasing tree height whilst sapwood volume increases with increasing tree height.

Table 4.1: Axial Percentages (%) of Heartwood and Sapwood Proportions of *Albizia lebbeck*

Trees	Tree Sections							
	0 - 25%		26 - 50%		51 - 75%		76 - 100%	
	r	R	r	R	r	R	r	R
Tree 1	75.72%	24.28%	74.83%	25.17%	73.58%	26.42%	70.21%	29.79%
Tree 2	78.04%	21.96%	76.34%	23.66%	72.26%	27.74%	71.51%	28.49%
Tree 3	79.70%	20.3%	75.68%	24.32%	72.95%	27.05%	67.67%	32.33%

r = Heartwood, R = Sapwood

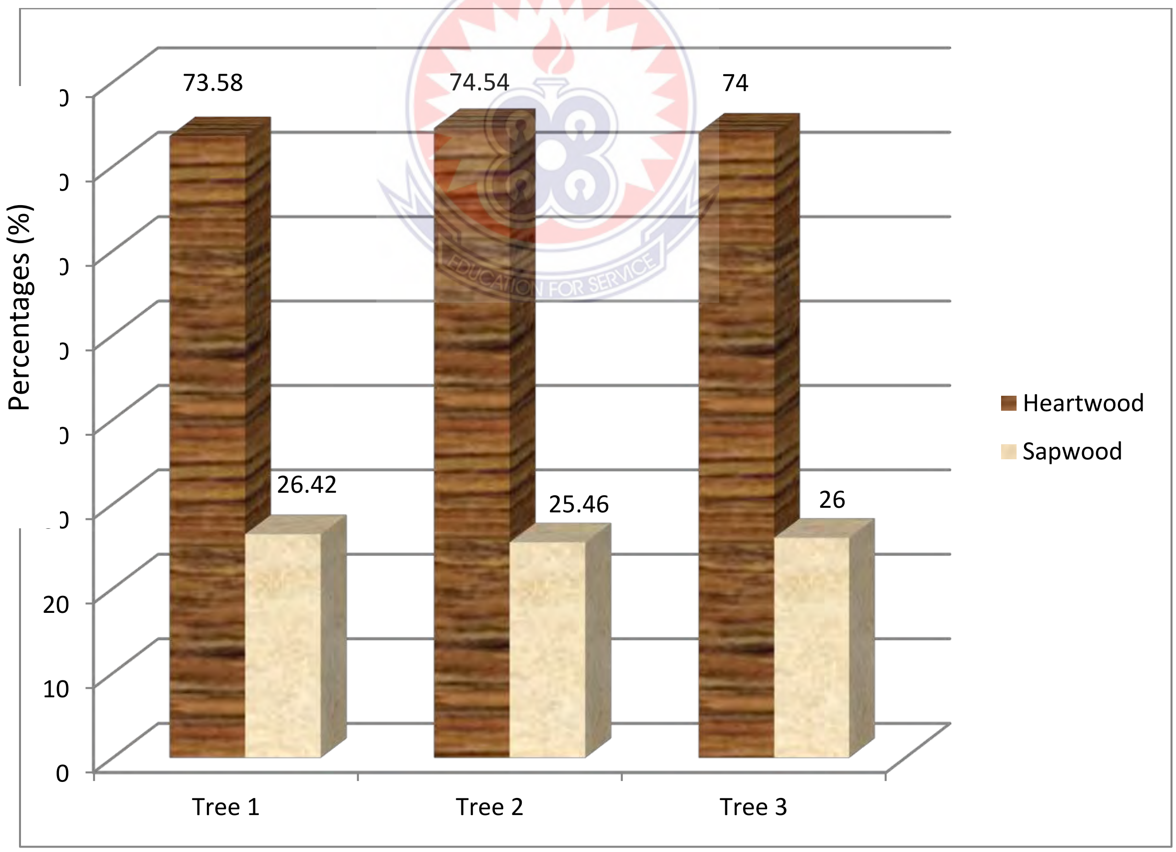

Figure 4.1: Average Percentages (%) of Heartwood and Sapwood Proportions

4.2 Axial Density Variation of Plantation Grown *Albizia lebbeck*

Table 4.2 shows the axial density variation at 12% MC of plantation grown *Albizia lebbeck*. Tree 1 recorded an average of 842.11, 790.02, 659.59 and 573.59 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively. The average axial density variation of tree 2 recorded 871.41, 788.08, 699.85 and 562.40 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively. While tree 3 recorded average density of 892.42, 841, 726.34 and 561.11 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively. This is an indication that, density of the plantation grown *Albizia lebbeck* decreases from the bottom portion of the trees to the top portion.

Table 4.2: Axial Density Variation at 12% MC (kg/m^3) of Plantation Grown *Albizia lebbeck*

Tree Section	Tree 1	Tree 2	Tree 3
0 - 25%	842.11(±81.26)	871.41(±77.66)	892.42 (±100.63)
26 - 50%	790.02 (±67.36)	788.08 (±64.00)	841.00 (±77.33)
51 - 75%	659.59 (±69.28)	699.85 (±63.57)	726.34 (±73.71)
76 - 100%	573.59 (±67.58)	562.40 (±54.64)	561.11 (±51.46)

Average Value and Standard Deviation in Parentheses

4.3 Sectional Comparison of Compression of Individual Trees

Table 4.3 reports the sectional comparison of compression of individual trees. One way ANOVA conducted between the heartwood sections BA, CA, CB, DA, DB and DC for tree 2 and tree 3 respectively recorded p-values ≥ 0.05. This is an indication that the mean difference between the heartwood of tree 2 and tree 3 in terms of their sectional compression strength was insignificant. However, all tree 1 sections recorded p-values ≥ 0.05, except DA which recorded a p-value of 0.016. This suggests that, in terms of heartwood comparison of sections 76-100% and 0-25% the mean difference was statistically significant.

It follows that the sapwood sections, CB, DB and DC recorded p-values ≥ 0.05 whereas BA, CA and DA recorded p-values < 0.05. This indicates that there was significant mean difference among sections BA, CA and DA respectively of tree 1 (Table 4.4). With tree 2, all the sections recorded p-values ≥ 0.05 except DA. Also, tree 3 sections recorded p-values ≥ 0.05, except CA and DA which recorded p-values of 0.031 and 0.014 respectively. This indicates that sapwood comparison of sections 0-25%, 51-75% as well as 76-100% varies significantly.

Table 4.3: Sectional Comparison of Compression of Individual Trees Heartwood

Tree Sections	Tree 1		Tree 2		Tree 3	
	Mean Diff.	P-Value	Mean Diff.	P-Value	Mean Diff.	P-Value
B A	6.1	0.187	6.1	0.261	1.2	0.993
C A	2.7	0.793	6.3	0.241	3.1	0.895
C B	-3.3	0.671	0.1	0.999	1.9	0.971
D A	9.4	0.016	1.4	0.970	2.9	0.914
D B	3.2	0.690	-4.7	0.494	1.7	0.980
D C	6.6	0.132	-4.8	0.467	-0.2	0.999

Sig. equals 1.00 indicates that the difference of the means is significant at the 0.05 level.
Sig. equals 0.00 indicates that the difference of the means is insignificant at the 0.05 level
(A=0-25%, B=26-50%, C=51-75%, D=76-100%)

Table 4.4: Sectional Comparison of Compression of Individual Trees Sapwood

Tree Sections	Tree 1		Tree 2		Tree 3	
	Mean Diff.	P-Value	Mean Diff.	P-Value	Mean Diff.	P-Value
B A	-17.3	7.897×10^{6}	-2.0	0.856	-4.9	0.148
C A	-19.0	1.340×10^{6}	-3.1	0.612	-6.5	0.031
C B	-1.7	0.937	-1.1	0.972	-1.6	0.889
D A	-20.5	2.829×10^{7}	-8.7	0.007	-7.3	0.014
D B	-3.2	0.702	-6.7	0.053	-2.3	0.728
D C	-1.5	0.957	-5.6	0.133	-0.7	0.988

Sig. equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig. equals 0 indicates that the difference of the means is insignificant at the 0.05 level
(A=0-25%, B=26-50%, C=51-75%, D=76-100%)

4.4 Sectional Comparison of Shear Strength of Individual Trees

Table 4.5 shows sectional comparison of shear strength of wood of the individual trees. One way ANOVA conducted among BA, CA, CB, DA, DB and DC for tree 1, tree 2 and tree 3 respectively recorded p-values ≥ 0.05 for heartwood. Similarly for sapwood (Table 4.6), tree sections BA, CA, CB, DA, DB and DC of tree 1, tree 2 and tree 3 respectively recorded p-values ≥ 0.05. This strongly suggests that the differences between the trees studied were not significant in terms of their shear property.

Table 4.5: Sectional Comparison of Shear Strength of Individual Trees Heartwood

Tree Sections	Tree 1		Tree 2		Tree 3	
	Mean Diff.	P-Value	Mean Diff.	P-Value	Mean Diff.	P-Value
B A	3.4	0.195	1.5	0.881	1.3	0.851
C A	3.8	0.121	0.4	0.995	-1.7	0.710
C B	0.4	0.994	-1.0	0.958	-3.1	0.257
D A	-0.4	0.993	1.6	0.860	-0.7	0.969
D B	-3.8	0.117	0.1	0.999	-2.1	0.596
D C	-4.2	0.069	1.1	0.946	1.	0.925

Sig. equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig. equals 0 indicates that the difference of the means is insignificant at the 0.05 level
(A=0-25%, B=26-50%, C=51-75%, D=76-100%)

Table 4.6: Sectional Comparison of Shear Strength of Individual Trees Sapwood

Tree Sections	Tree 1		Tree 2		Tree 3	
	Mean Diff.	P-Value	Mean Diff.	P-Value	Mean Diff.	P-Value
B A	-1.4	0.936	-0.9	0.948	-0.5	0.990
C A	-2.6	0.699	-0.9	0.943	-1.3	0.857
C B	-1.2	0.957	-0.0	1	-0.8	0.960
D A	-6.2	0.068	-1.5	0.815	-4.4	0.071
D B	-4.8	0.218	-0.5	0.986	-3.9	0.133
D C	-3.6	0.469	-0.5	0.988	-3.1	0.316

Sig. equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig. equals 0 indicates that the difference of the means is insignificant at the 0.05 level
(A=0-25%, B=26-50%, C=51-75%, D=76-100%)

4.5 Sectional Comparison of Hardness of Individual Trees

Table 4.7 reports the sectional comparison of hardness of individual trees. One way ANOVA conducted among BA, CA, CB, DA, DB and DC for tree 1 recorded p-values ≥ 0.05. In like manner, among BA, CA, CB, DA, DB and DC for both tree 2 and tree 3 recorded p-values ≥ 0.05. This is an indication that, there was no significant difference between the heartwood of the 3 trees in terms of their hardness property. Considering the sapwood (Table 4.8), the one way ANOVA conducted among BA, CA, CB, DA, DB and DC for all the 3 trees recorded p-values ≥ 0.05. Only DA of tree 3 recorded a significant difference with p-value of 0.025. This suggests that, there was no significant difference between all the trees in relation to their hardness property except that at section 0-25% differs from that of section 76-100% of tree 3.

Table 4.7: Sectional Comparison of Hardness of Individual Trees Heartwood

Tree Sections	Tree 1		Tree 2		Tree 3	
	Mean Diff.	P-Value	Mean Diff.	P-Value	Mean Diff.	P-Value
B A	-0.3	0.995	-1.030	0.939	-0.262	0.997
C A	2.4	0.377	-2.182	0.624	-1.174	0.815
C B	2.8	0.263	-1.151	0.918	-0.912	0.902
D A	0.8	0.946	-3.474	0.234	-3.335	0.077
D B	1.1	0.862	-2.443	0.534	-3.073	0.117
D C	-1.6	0.704	-1.291	0.889	-2.160	0.382

Sig. equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig. equals 0 indicates that the difference of the means is insignificant at the 0.05 level
(A=0-25%, B=26-50%, C=51-75%, D=76-100%)

Table 4.8: Sectional Comparison of Hardness of Individual Trees Sapwood

Tree Sections	Tree 1		Tree 2		Tree 3	
	Mean Diff.	P-Value	Mean Diff.	P-Value	Mean Diff.	P-Value
B A	-0.2	0.999	-0.02	1	-0.3	0.988
C A	-2.9	0.594	-2.5	0.302	-0.7	0.887
C B	-2.7	0.652	-2.5	0.308	-0.3	0.977
D A	-5.4	0.112	-3.6	0.078	-2.9	0.025
D B	-5.2	0.135	-3.5	0.080	-2.6	0.054
D C	-2.4	0.715	-1.04	0.889	-2.2	0.127

Sig. equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig. equals 0 indicates that the difference of the means is insignificant at the 0.05 level
(A=0-25%, B=26-50%, C=51-75%, D=76-100%)

4.6 Sectional Comparison of Modulus of Rupture of Individual Trees

Presented in Table 4.9 is the sectional comparison of heartwood modulus of rupture (MOR) of individual trees. One way ANOVA conducted on tree 1 among BA, CA, CB, DB and DC recorded p-values ≥ 0.05 whereas only DA recorded a p-value of 0.045. With respect to tree 2, BA, CA, CB, DA, DB and DC recorded p-values ≥ 0.05. Among BA, CB, DA and DB of tree 3 also recorded p-values ≥ 0.05 whilst CA and DC recorded p-values of 0.041 and 0.036 respectively. This indicates that, there was no significant difference in tree 2 in terms of sectional comparison of heartwood modulus of rupture. However tree 1, section DA suggests that MOR at 76-100% and 0-25% have significant differences. Tree 2 sections CA and DC equally indicate that there was a significant difference among the sections.

It follows that, between sections BA, CA, CB, DA, DB and DC of tree 3 sapwood recorded p-values ≥ 0.05. This indicates that the mean difference between tree 3 sapwood sections for MOR was insignificant (Table 4.10). However, tree 1 and 2 sections BA, CA, CB, DB and DC recorded p-values ≥ 0.05 respectively, except section DA which recorded p-value of 0.011 in tree 1 and 0.044 in tree 2. This suggests that, section 76-100% and 0-25% of both tree 1 and tree 2 differ in terms of the sapwood sections MOR comparisons.

Table 4.9: Sectional Comparison of Modulus of Rupture of Individual Trees Heartwood

Tree Sections	Tree 1		Tree 2		Tree 3	
	Mean Diff.	P-Value	Mean Diff.	P-Value	Mean Diff.	P-Value
B A	22.6	0.163	20.2	0.225	-7.2	0.931
C A	5.5	0.953	-2.1	0.996	-33.3	0.041
C B	-17.1	0.388	-22.4	0.154	-26.1	0.150
D A	29.1	0.045	10.6	0.737	0.7	0.999
D B	6.5	0.928	-9.6	0.790	7.9	0.911
D C	23.6	0.138	12.8	0.610	34.1	0.036

Sig. equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig. equals 0 indicates that the difference of the means is insignificant at the 0.05 level
(A=0-25%, B=26-50%, C=51-75%, D=76-100%)

Table 4.10: Sectional Comparison of Modulus of Rupture of Individual Trees Sapwood

Tree Sections	Tree 1		Tree 2		Tree 3	
	Mean Diff.	P-Value	Mean Diff.	P-Value	Mean Diff.	P-Value
B A	-19.7	0.156	-14.7	0.217	-8.2	0.910
C A	-20.2	0.141	-16.8	0.125	-14.2	0.670
C B	-0.4	0.999	-2.1	0.990	-5.9	0.964
D A	-30.3	0.011	-20.4	0.044	-33.2	0.054
D B	-10.5	0.660	-5.7	0.865	-24.9	0.210
D C	-10.1	0.692	-3.5	0.962	-18.9	0.438

Sig. equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig. equals 0 indicates that the difference of the means is insignificant at the 0.05 level
(A=0-25%, B=26-50%, C=51-75%, D=76-100%)

4.7 Sectional Comparison of Modulus of Elasticity of Individual Trees

Table 4.11 presents the sectional comparison of modulus of elasticity (MOE) of individual trees. One way ANOVA conducted among BA, CA, DA, DB and DC of tree 1 heartwood recorded p-values ≥ 0.05, whereas only CB recorded p-value of 0.049. This indicates that there was no significant difference between all the various heartwood sections of tree 1 MOE, except CB (51-75% and 26-50%) which recorded a significant difference. It follows that, sections BA, CA, CB, DA, DB and DC among tree 2 and tree 3 recorded p-values ≥ 0.05. This is an indication that, there was no significant difference between tree 2 and tree 3 in terms of the heartwood sectional comparison of the MOE of the individual tress.

However, tree sections BA, CB and DC for tree 1 sapwood recorded p-values ≥ 0.05 whereas CA, DA and DB recorded p-values ≤ 0.05 (Table 4.12). It follows that, among sapwood sections BA, CA, CB, DA, DB and DC of tree 2 and tree 3 respectively recorded p-values ≥ 0.05. This is an indication that there was no significant difference among the sapwood sectional comparison of MOEs of tree 2 and tree 3. Only CA, DA and DB of tree 1 recorded p-values of 0.016, 0.055 and 0.023 respectively suggesting that, there was significant difference.

Table 4.11: Sectional Comparison of Modulus of Elasticity of Individual Trees Heartwood

Tree Sections	Tree 1		Tree 2		Tree 3	
	Mean Diff.	P-Value	Mean Diff.	P-Value	Mean Diff.	P-Value
B A	-429.6	0.947	-183	0.993	123.7	0.999
C A	1700	0.156	940	0.517	-804.2	0.916
C B	2129.6	0.049	1123	0.363	-927.9	0.878
D A	1643	0.179	563.1	0.840	-290.3	0.995
D B	2072.6	0.058	746.1	0.693	-414	0.987
D C	-57	0.999	-376.9	0.944	513.9	0.976

Sig. equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig. equals 0 indicates that the difference of the means is insignificant at the 0.05 level
(A=0-25%, B=26-50%, C=51-75%, D=76-100%)

Table 4.12: Sectional Comparison of Modulus of Elasticity of Individual Trees Sapwood

Tree Sections	Tree 1		Tree 2		Tree 3	
	Mean Diff.	P-Value	Mean Diff.	P-Value	Mean Diff.	P-Value
B A	-398.9	0.956	-341	0.952	-114.2	0.999
C A	-2475.9	0.016	-420	0.916	-204.9	0.998
C B	-2077	0.055	-79	0.999	-90.7	0.999
D A	-2755.8	0.006	-1064.5	0.371	-2145.1	0.372
D B	2356.9	0.023	-723.5	0.684	-2030.9	0.420
D C	-279.9	0.984	-644.5	0.755	-1940.2	0.460

Sig. equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig. equals 0 indicates that the difference of the means is insignificant at the 0.05 level
(A=0-25%, B=26-50%, C=51-75%, D=76-100%)

4.8 Means of Mechanical Properties

Table 4.13 represents the average strength properties of tree 1. The MOE recorded an average of 14688 N/mm^2, 14289 N/mm^2, 12212 N/mm^2, and 11932 N/mm^2 for tree sections 0-25%, 26-50%, 51-75% and 76-100% respectively. The MOR had an average of 128.65 N/mm^2, 108.90 N/mm^2, 108.43 N/mm^2 and 98.35 N/mm^2 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively. The average strength in compression parallel to grain recorded 66.63 N/mm^2, 49.33 N/mm^2, 47.60 N/mm^2 and 46.09 N/mm^2 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively. Shear parallel to grain recorded an average of 21.45 N/mm^2, 20.02 N/mm^2, 18.78 N/mm^2 and 15.18 N/mm^2 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively. The following average hardness properties was obtained 12.53 KN, 12.31 KN, 9.57 KN and 7.07 KN for sections 0-25%, 26-50%, 51-75% and 76-100% respectively. Axial variation in the parameters strongly suggests that, all the mechanical properties of tree 1 reduce from the bottom portion of the tree to the top portion.

Table 4.13: Means of Mechanical Properties of Tree 1

Mechanical Properties	Tree Sections			
	0-25%	26-50%	51-75%	76-100%
MOE (N/mm^2)	14688 (±1950.12)	14289 (±1885.69)	12212 (±1257.56)	11932 (±1465.17)
MOR (N/mm^2)	128.65 (±12.62)	108.90 (±27.23)	108.43 (±16.68)	98.35 (±18.27)
Compression // to grain (N/mm^2)	66.63 (±9.66)	49.33 (±4.60)	47.60 (±5.55)	46.09 (±3.95)
Shear // to grain (N/mm^2)	21.45 (±3.64)	20.02 (±7.24)	18.78 (±5.26)	15.18 (±3.91)
Hardness (KN)	12.53 (±4.00)	12.31 (±8.30)	9.57 (±3.23)	7.07 (±2.01)

Average Value and Standard Deviation in Parentheses

Table 4.14 shows means of mechanical properties of stem position of tree 2. The average MOE was 15087 N/mm^2, 14746 N/mm^2, 14667 N/mm^2 and 14022 N/mm^2 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively. The average MOR recorded 135.77 N/mm^2, 121.06 N/mm^2, 118.87 N/mm^2 and 115.28 N/mm^2 for sections 0-25%, 25-50%, 50-75% and 75-100% respectively. With respect to compression parallel to grain, the average strength recorded 54.70 N/mm^2, 52.69 N/mm^2, 51.59 N/mm^2 and 45.94 N/mm^2 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively. Also, shear parallel to grain recorded an average of 21.45 N/mm^2, 20.52 N/mm^2, 20.49 N/mm^2 and 19.94

N/mm^2 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively. In terms of hardness, the average recorded 8.70 KN, 8.68 KN, 6.12 KN and 5.08 KN for sections 0-25%, 26-50%, 51-75% and 76-100% respectively. This suggests that, MOE, MOR, compression, shear and hardness property of tree 2 reduces from the bottom portion of the tree to the top.

Table 4.14: Means of Mechanical Properties of Tree 2

Mechanical Properties	Tree Sections			
	0-25%	26-50%	51-75%	76-100%
MOE (N/mm^2)	15087	14746	14667	14022
	(±1230.09)	(±1321.94)	(±1285.54)	(±1644.44)
MOR (N/mm^2)	135.77	121.06	118.87	115.28
	(±15.54)	(±14.38)	(±14.00)	(±18.87)
Compression // to grain (N/mm^2)	54.70	52.69	51.59	45.94
	(±6.43)	(±5.66)	(±4.48)	(±4.65)
Shear // to grain (N/mm^2)	21.45	20.52	20.49	19.94
	(±2.59)	(±3.98)	(±2.76)	(±4.77)
Hardness (KN)	8.70	8.68	6.12	5.08
	(±2.15)	(±4.47)	(±1.96)	(±3.05)

Average Value and Standard Deviation in Parentheses

Table 4.15 reports the means of mechanical properties of tree 3. The MOE had an average of 13292 N/mm^2, 13178 N/mm^2, 13087 N/mm^2 and 11147 N/mm^2 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively. MOR recorded an average of 122.70 N/mm^2, 114.41 N/mm^2, 108.46 N/mm^2 and 89.46 N/mm^2 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively. Considering the compression parallel to grain, an average of 54.23 N/mm^2, 49.2 N/mm^2 47.65 N/mm^2 and 46.92 N/mm^2 for sections 0-

25%, 26-50%, 51-75% and 76-100% was recorded respectively. Average shear parallel to grain recorded 21.33 N/mm^2, 20.80 N/mm^2, 19.88 N/mm^2 and 16.88 N/mm^2 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively suggesting that there was a marginal reduction of shear value as the tree height increases along the sections. In terms of hardness, there was an average of 11.15 KN, 10.83 KN, 10.43 KN and 8.18 KN for 0-25%, 26-50%, 51-75% and 76-100% tree sections respectively. This suggests that, all the mechanical properties reduces from the bottom portion of the tree to the top portion.

Table 4.15: Means of Mechanical Properties of Tree 3

Mechanical Properties	Tree Sections			
	0-25%	26-50%	51-75%	76-100%
MOE (N/mm^2)	13292	13178	13087	11147
	(±2160.50)	(±2529.27)	(±1939.03)	(±4024.22)
MOR (N/mm^2)	122.70	114.41	108.46	89.46
	(±24.44)	(±23.71)	(±21.04)	(±34.97)
Compression // to grain (N/mm^2)	54.23	49.28	47.65	46.92
	(±5.43)	(±3.95)	(±2.25)	(±6.53)
Shear // to grain (N/mm^2)	21.33	20.80	19.88	16.88
	(±3.40)	(±2.42)	(±2.90)	(±3.88)
Hardness (KN)	11.15	10.83	10.43	8.18
	(±2.40)	(±2.42)	(±2.27)	(±1.00)

Average Value and Standard Deviation in Parentheses

CHAPTER FIVE

DISCUSSIONS

This chapter discusses the findings of the study. The discussions cover the heartwood and sapwood proportions, some physical properties investigated (oven-dry density and moisture content) and the effect of axial variation on the mechanical properties (compression parallel to grain, shear parallel to grain, hardness, MOR and MOE) of plantation grown *Albizia lebbeck* from the Savannah ecological zone.

5.1 Axial Proportions of Heartwood and Sapwood of Plantation Grown *Albizia lebbeck* Trees

In general, heartwood is more durable than sapwood and less subject to attack by insects, stain and mold producing fungi (Bobby *et al*., 2012; Elzaki *et al*., 2012). The heartwood portion is usually coloured and therefore considered more ornamental than the white sapwood, except in a few cases (Hassan *et al*., 2007; Zia-Ul-Haq et *al*., 2013). The results indicated that the heartwood and sapwood portions of the plantation grown *Albizia lebbeck* showed significant differences in axial and radial direction among all the tree sections (Table 4.1). The heartwood portion in the stem decreases from the bottom portion of the tree to the top portion whereas the sapwood portion of the stem increases from the bottom to the top portion. This is consistent with previous assertion by Qadri and Mahmood (2005) that as tree grows in height the bottom portion matures more into heartwood property than the top portion. Trees stem section was observed to be a significant source of variation.

It follows that, axial variation of the heartwood percentages tend to decrease from the bottom portion of the trees to the top portion whereas a reverse trend was observed for the sapwood percentages. The bottom sections represented the lowest sapwood percentages, increasing in the middle sections across to the trees top portion. Apparently, the amount of sapwood observed was relatively small at the butt as compared to the top most part of each tree (Fig. 4.1). As such, there was a significant exponential relationship between heartwood volume and tree height. The proportion of heartwood increases while sapwood proportion was in the reverse with increasing tree height.

5.2 Some Physical Properties (Oven-dry Density and Moisture Content) of *Albizia lebbeck*

Density at 12% moisture content (MC) of the plantation grown *Albizia lebbeck* decreases along the tree height from the bottom portion to the top portion. Regarding the axial variation of the plantation grown *Albizia lebbeck* obtained from the Savannah ecological zone, it was generally observed that the bottom portion recorded higher density values than the top portion (Table 4.3). But, statistically the mean difference between all the sections was insignificant, suggesting that the wood is relatively stable in terms of its material strength and therefore will not pose any engineering or utilization problem. This trend was also reported by Moya and Ledezma (2003) as supported by the findings of Forest Products Laboratory (2010).

For radial variation, the heartwood displayed the highest oven-dry density than its sapwood portion. There was significant difference in density between the heartwood and sapwood in all the trees studied. According to Searle and Owen (2005), wood generally increases in density during wood transformation from sapwood to heartwood. The change in weight is generally due to deposition of extractives such as phenols and quinnines which enhances durability of wood. Factors that might have had influence on the density values include the growth rate, plantation site, climate and geographical location (Sasmal *et al.*, 2013; Wanneng *et al.*, 2014). The average density of *Albizia lebbeck* at 12% MC ranged between 565.7 kg/m^3 and 908.94 kg/m^3 (Table 4.2). This can favourably be compared to the most well-known timber species that are in short supply in the timber markets.

5.3 Axial Variation on Mechanical Properties (Compression Parallel to Grain, Shear Parallel to Grain, Hardness, MOR and MOE) of *Albizia lebbeck*

5.3.1 Compression Parallel to Grain

Largely, there was no significant difference among the studied trees in terms of their sectional comparison (Table 4.3). But there was significant difference among sections DA of tree 1. The variability may arise either from genetic reasons or due to the position of the stem in the stand. It follows that the bottom portion recorded higher mechanical values than the top portion, but statistically the difference was not significant at 5% level of probability ($P<0.05$). Average compressive strength results obtained for *Albizia lebbeck* 51.05 N/mm^2 (Table 4.13, Table 4.14 and Table 4.15) for tree 1, 2 and 3 respectively compares favourably with values of most timber species used for heavy construction. Some of these include odum (*Milicia exelsa*) with compressive strength of 52 MPa, ofram (*Terminalia superba*) with compressive strength of 33.80 MPa, iroko

(*Chlorophora spp*) with compressive strength of 32.62 MPa, emeri (*Terminalia ivorensis*) 35.00 MPa and dahoma (*Piptadeniastrum africanum*) 23.00 MPa (Lavers, 1983; Brunner *et al*., 2007; Forest Products Laboratory, 2010; Appiah-Kubi *et al*., 2012). The compressive strength parallel to the grain have been classified according to Farmer (1972) as very low, low, medium, high and very high when the strength values are under 20 MPa, 20-35 MPa, 35-55 MPa, 55-85 MPa and above 85 MPa respectively. This classification consequently rates *Albizia lebbeck* compressive strength as medium.

5.3.2 Shear Strength Parallel to Grain

Shear strength comparison indicated significant mean difference between the heartwood and sapwood (Table 4.5). This suggests that, radial variation strength of heartwood is stronger to resist failure than the sapwood. Though the axial shear strength properties marginally reduces from the bottom portion to the top portion of the tree as depicted in Table 4.13, Table 4.14 and Table 4.15 for tree 1, 2 and 3 respectively. This trend confirms earlier assertion by Hassan *et al*. (2007); Sasmal *et al*. (2013). Strength values obtained for plantation grown *Albizia lebbeck* trees (19.72 N/mm^2) compare favourably to most heavy construction species including denya (*Cyclidiscus gabunensis*) 11.10 MPa, dahoma (*Piptadeniastrum africanum*) 9.60 MPa, asanfena (*Aningeria altissima*) 9.50 MPa, (Lavers, 1983; Antwi *et al*., 2014).

5.3.3 Janka Hardness (Radial and Tangential)

The average hardness of the axial positions (0-25%, 26-50%, 51-75% and 76-100%) varied significantly along the bole (Table 4.7). The strength decreases from the bottom portion through to the top portion of each tree studied. Evidently, these results demonstrate the ability of the various parts of all the trees to resist indentation (Table 4.13). The resistance of *Albizia lebbeck* to indentation was relatively high (9.22KN) for all the trees and can be classified as class IV hardwood hence it can be used for high class furniture production.

5.3.4 Modulus of Rupture

Sectional comparison heartwood and sapwood portions for modulus of rupture (MOR) of *Albizia lebbeck* was comparable as depicted in Table 4.9 and Table 4.10 respectively. For axial variation, the bending strength values of the species generally reduces along the tree height from the base to the top portion. Marginal reduction in MOR from the bottom portion of the tree to the top portion was observed. This confirms previous assertions that, strength properties increase with decreasing moisture content (Addae-Mensah, 1998; Ayarkwa *et al*., 2000; Uma et *al*., 2009). The mean difference was however insignificant among the trees in terms of sectional comparison of modulus of rupture of the heartwood. But tree 1 and tree 2 sapwood sections differ in terms of MOR comparisons. It was inferred from this observation that, high frequency of fibres and aggregates of vessels may be a contribution factor. Modulus of rupture mean values obtained for *Albizia lebbeck* (111.08 N/mm^2, 122.74 N/mm^2 and 108.75 N/mm^2) for tree 1, 2 and 3 respectively compare favourably to most heavy construction species such as essa (104 MPa), dahoma (109 MPa) (Addae-Mensah, 1998; Ayarkwa *et al.*, 2000). Based on Bolza and Keating (1972) classification, *Albizia lebbeck* is a class S3 wood.

5.3.5 Modulus of Elasticity

Modulus of elasticity measures the stiffness of a wood, and is indispensable in the determination of the deflection of a beam under load. There was no significant mean difference between all the various sections of heartwood sectional comparison of the MOE of the individual tress (Table 4.11). Similar observation was recorded for the sapwood, except tree 1 which indicated a significant difference in terms of the sectional comparison of MOEs (Table 4.12). Axial variation of the plantation grown *Albizia lebbeck* strongly suggests that, MOE values reduces from the bottom portion of the tree to the top portion with an average strength of 13280 N/mm^2 (Table 4.13), 14630 N/mm^2 (Table 4.14) and 12676 N/mm^2 (Table 4.15) for tree 1, 2 and 3 respectively. However, the difference between the means was insignificant. This result confirms the assertions that, the axial variation of some timber species decrease significantly along the bole height from the bottom portion to the top (Shrivastava, 1997; Chulet *et al*., 2010).

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

This chapter presents summary of the major findings from the study with conclusions drawn from the results and recommendations for future work. The study covered the heartwood and sapwood proportions, some physical properties (oven-dry density and moisture content) and the effect of axial variation on the mechanical properties (compression parallel to grain, shear parallel to grain, hardness, MOR and MOE) of plantation grown *Albizia lebbeck* sampled from the Savannah ecological zone.

6.1 Summary of Findings

6.1.1 Evaluation of the axial proportions of heartwood and sapwood of plantation grown *Albizia lebbeck* trees

i. The overall percentages of heartwood and sapwood proportions were 73.58% (26.42%), 74.54% (25.46%) and 74% (26%) for tree 1, 2 and 3 respectively. The bottom portion of each tree recorded a greater percentage of heartwood portions whereas the sapwood portion of the stem increases from the bottom to the top portion.

6.1.2 Some physical properties (oven-dry density and moisture content) of *Albizia lebbeck* species.

i. The average density values at 12% MC for tree 1 recorded 842.11 kg/m^3, 790.02 kg/m^3, 659.59 kg/m^3 and 573.59 kg/m^3 for sections 0 - 25%, 26 - 50%, 51 - 75% and 76 - 100% respectively.

ii. The average density values at 12% MC for tree 2 recorded 871.41 kg/m^3, 788.08 kg/m^3, 699.85 kg/m^3 and 562.40 kg/m^3 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively.

iii. The average density values at 12% MC for tree 3 recorded 892.42 kg/m^3 , 841.00 kg/m^3, 726.34 kg/m^3 and 561.11 kg/m^{3}for sections 0-25%, 26-50%, 51-75% and 76-100% respectively.

These imply that, the density values of the plantation grown *Albizia lebbeck* decreases from the bottom portion of each of the trees to the top portion, but statistically the mean difference was insignificant.

6.1.3 Assessing the effect of axial variation on the mechanical properties (compression parallel to grain, shear parallel to grain, hardness, MOR and MOE) of *Albizia lebbeck* species.

i. The mean compressive strength values were 58.52 N/mm^2, 50.43 N/mm^2, 48.94 N/mm^2 and 46.31 N/mm^2 for tree sections 0-25%, 26-50%, 51-75% and 76-100% respectively.

ii. The shear strength mean values were 21.41 N/mm^2, 20.44 N/mm^2, 19.71 N/mm^2 and 17.33 N/mm^2 for tree sections 0-25%, 26-50%, 51-75% and 76-100% respectively.

iii. The mean hardness recorded 10.79 KN, 10.60 KN, 8.70 KN and 6.77 KN for tree sections 0-25%, 26-50%, 51-75% and 76-100% respectively.

iv. The mean bending strength (MOR) of 129.04 N/mm^2, 114.79 N/mm^2, 111.92 N/mm^2 and 101.03 N/mm^2 was recorded for tree sections 0-25%, 26-50%, 51-75% and 76-100% respectively.

v. The mean Modulus of Elasticity (MOE) values were 14355 N/mm^2, 14071 N/mm^2, 13322 N/mm^2 and 12367 N/mm^2 for tree sections 0-25%, 26-50%, 51-75% and 76-100% respectively.

In terms of the axial variation on the mechanical properties (compression parallel to grain, shear parallel to grain, hardness, MOR and MOE), the plantation grown *Albizia lebbeck* species recorded high values at the bottom portion of each tree but the mean difference was insignificant. This suggests that, the entire *Albizia lebbeck* wood is more likely to be stable in terms of its strength properties with no regard to the section it is obtained.

6.2 Conclusions

From the findings of the study, the following conclusions were drawn;

i. The heartwood and sapwood proportions of the studied species suggest a significant heartwood percentage than the sapwood, hence can produce more boards during conversion.

ii. The heartwood of the plantation grown *Albizia lebbeck* species is dark brown, streaked with dark and white shades thereby gives the heartwood a good figure for interior works and furniture.

iii. At 12% MC all the trees exhibited high values of density. Though the density values vary from the bottom portion of the tree to the top portion, the mean difference was insignificant.

iv. All the means of the mechanical properties (compressive // to grain, shear // to grain, hardness, MOR and MOE) generally decreases along the tree height from the bottom to the top portion, but the mean difference was insignificant.

v. The compressive strength and resistance to shear values where similar to reported values of most heavy construction timber species such as denya (*Cyclidiscus gabunensis*), dahoma (*Piptadeniastrum africanum*), asanfena (*Aningeria altissima*) and can be used for construction and furniture production.

vi. The resistance of *Albizia lebbeck* to indentation was relatively high, as well as the modulus of elasticity and modulus rupture mean values for all the trees. Timber of *Albizia lebbeck* can be used for furniture and other interior constructions.

6.3 Recommendations

The study recommends that;

i. The heartwood and sapwood percentages are generally within the limits for utilizable hardwoods and could be utilized for various wood products including furniture.

ii. The *Albizia lebbeck* wood may be suitable for various applications in the wood industry by the local furniture producers and carpenters, since the studied timber species exhibited high density and strength properties comparable to other commercial available hard woods.

iii. The wood physical and mechanical properties showed significant strength values among the trees studied, but within each tree the mean difference was insignificant. As such, the success of *Albizia lebbeck* as raw material in timber industries may lie on its wood characteristics and the highest strength to weight ratios as compare to other commercial available woods.

iv. Diversification of timber species should be encouraged to accommodate lesser known/used exotic wood species including *Albizia lebbeck* to improve upon the sustainable management of the tropical forestry areas in the country. However, it is worthy to note that proper processing and manufacturing procedures are applied to allow the products meet international quality requirements, standards and specifications.

6.4 Suggestions for Future Study

i. The timber species were extracted from a plantation forest in the Savannah ecological zone for the study. It is therefore suggested that some physical and mechanical properties of *Albizia lebbeck* at different geographical areas within the ecological zone should be carried out in order to get more information on the exotic species characteristics.

ii. Further research should be carried out using laboratory and field tests to evaluate the anatomical characteristics and natural durability of the studied species for outdoor applications.

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