WOOD PROPERTIES AND NATURAL DURABILITY OF *Artocarpus altilis* (PARKINSON EX F.A. ZORN) FOSBERG

BY

AREO, Olusola Samuel (172348)
B. Forestry and Wildlife (OOU), M.Sc. Wood and Fibre Science (IB)

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CERTIFICATION

I certify that this research work was carried out by Mr. Areo Olusola Samuel in the Department of Forest Production and Products, University of Ibadan, Ibadan Nigeria

……………………………………………….

SUPERVISOR
A.O. OMOLE
B. Tech (Akure), M.Sc, Ph.D (Ibadan).
Professor, Department of Forest Production and Products,
University of Ibadan. Ibadan, Nigeria.

DEDICATION

This research work is dedicated to God Almighty, the Author and Finisher of my faith for wisdom and knowledge.

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ABSTRACT

Preferred timber species are increasingly becoming unavailable due to overexploitation of natural forests. There is a growing shift in demand to Lesser-Used Species (LUS), like *Artocarpus altilis* as substitutes in Nigeria. Knowledge on wood quality and durability of LUS would enhance efficient utilisation. However, there is limited information on wood properties and natural durability of *Artocarpus altilis*. Therefore, physico-mechanical, anatomical and chemical properties, as well as, natural durability of *Artocarpus altilis* were investigated.

Four trees of *Artocarpus altilis* were purposively selected and felled based on maturity (45.0±0.5 years) at Gambari Forest Reserve, Oyo State, Nigeria. Billets (500 cm) were obtained from base, middle and top of merchantable height of each tree. Each billet was partitioned into corewood, innerwood and outerwood and processed into various dimensions using standard procedures. Physical (density, kg/m^3; shrinkage, %) and mechanical (impact bending, J/m^2; Modulus of Rupture- MOR, N/mm^2; Modulus of Elasticity-MOE, N/mm^2; shear strength, N/mm^2; Maximum Compressive Strength parallel to grain MCS//, N/mm^2) properties were determined using standard methods. Cell morphology (Runkel Ratio, vessel diameter, µm) and chemical properties (cellulose, %; hemicelluloses, %; and ash content, %) were determined following standard procedures. In a factorial arrangement, graveyard experiment and Accelerated Biological Test (ABT) following White Rot (WR) and Brown Rot (BR) fungi biodegradation were used to assess weight loss for 48 and 20 weeks, respectively. Data were analysed using descriptive statistics, Pearson Product Moment Correlation and ANOVA at $\alpha_{0.05}$.

Density decreased significantly from base (602.7±64.5) to top (570.7±56.0) and from outerwood (629.3±54.3) to corewood (590.4±59.4). Shrinkage ranged from 4.9±0.8 (base) to 6.2±0.5 (top) and increased from corewood (5.1±0.8) to outerwood (6.4±0.7). Impact bending increased from base (14.3±3.9) to top (16.5±4.0) and varied from 14.5±3.1 (corewood) to 17.6±4.4 (outerwood). The MOR and MOE were highest at base (42.1±8.8, 3993±1983) and least at top (32.9±5.4, 3145±520.4), but decreased from corewood (37.6±1.9, 3630.1±555.5) to outerwood (36.6±7.2, 2986.0±410.6), respectively. Shear strength and MCS// decreased significantly from base (9.7±1.7, 23±4.1) to top (8.5±0.9, 18±2.7) and from corewood (10.8±1.4, 22.5±2.5) to outerwood (8.5±1.1, 18±3.6), respectively. Runkel Ratio was highest at top (0.7±0.2), least at base (0.5±0.2) but decreased from corewood (0.7±0.2) to outerwood (0.6±0.2). Vessel diameter varied from base (238.0±64.8) to top (238.6±57.8) and increased from corewood (238.7±53.5) to outerwood (249.0±61.8). Cellulose, hemicellulose and ash content were highest at base (47.8±0.7, 27.8±1.2, 0.93±0.4) and least at middle (47.1±0.4, 27.1±0.7, 0.92±0.4), respectively. Weight loss decreased from base (26.5±10.1) to top (24.6±8.6) and increased from outerwood (24.6±5.4) to corewood (27.8±2.4) in graveyard experiment. In ABT, weight loss varied from base (WR: 4.4±2.1, BR: 5.3±2.5) to top (WR: 4.8±1.7, BR: 5.5±2.9). White rot caused the highest weight loss at corewood (4.8±2.9) and least at outerwood (4.6±2.0), while BR caused least weight loss at corewood (5.1±2.2) and highest at outerwood (6.0±6.1). The MOR was positively correlated with MOR (r=0.54) and impact bending (r=0.56).

Artocarpus altilis could be categorised as medium density wood with mechanical properties being superior at the base and corewood. The chemical properties indicated species suitability for light construction and papermaking.

Keywords: *Artocarpus altilis*, Wood properties, Natural forest, Lesser-used tree species, Wood shrinkage

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CHAPTER ONE

INTRODUCTION

1.1 Background information

Growing population, financial and livelihood development are consistently increasing the demand for various forest products particularly timber products (Osabor *et al.,* 2009, Izekor, 2010). Population growth in Nigeria is increasing steadily the request for wood products this has led to enormous pressure and gradual reduction of forests land areas, however the demand for timber in terms of quality is still on the increase vis a vis the regulations imposed by the government as well as restrictions from environmentalist in preserving the world's existing forests; these equally mount pressures on logging activities in many developing countries (Cherdchim *et al.,* 2004).

Although, Nigeria is blessed with over 100 timber species that are being utilised for structural and non-structural construction and furniture making, however, few of the commercial and well known which are usually expensive and highly demanded species are commonly used for a several of purpose and possesses a potential for commercial utilization, hence, attention need to be shifted to the readily available LUS which could also perform as a substitute (Zziwa *et al.,* 2012). Forest areas have been a major and important resource base for wood supply for the Nigerian population (FAO, 2006, Fuwape and Fabiyi, 2003).

However, the commercially accessible forest reserves, which is the major souces for the wood based industry has severely depleted due to the indiscriminate harvesting of choice trees and subsequently aquiredfor other developmental purposes.The developmental programmes includes agriculture, urbanization, and industries (Izekor and Okoro, 2004; Onyekwelu and Akindele, 1995).

The demand for the choice of species and their popularity is based on their desired mechanical properties, natural durability, and aesthetics features properties which have resulted into over-exploitation of available timber,thereby affecting their survival in the

Nigeria landcovers, thereby leaving the forest reserves with immature timbers, and this logs characterised by immature timbers consist of greater portion of sapwood that are not as durable as the matured portion of the trees (Ogunsanwo *et al.*, 2006)

Tropical forest is a major potential resource base for numerous variability and organisms. Approximately 4600 plants in Nigeria's forest areas were recorded by (Burkill, 1997; Jozsa *et al,* 1998; Weitao Xu *et al.* 2020) and more than 560 various timbers were recorded in woodland that attain a top of approximately 12m when fully established and 60cm thickness (Jozsa *et al,* 1994) (Akachuku, 1981). Consequently, forests consist of abundant range of highly desirable timbers. However, these immense tropical rainforest resources are yet to be adequately assessed. It is the responsibility of anyone who manages a forest to advise and usually assess the quantity of them to be harvested from the woodland for industrial wood supply (Jozsa *et al,* 1994; Akachuku, 1981).

The demand for forest products and services in Africa is growing rapidly, as a result of population growth and an expanding economy. UNEP (2015) reported that coming 2030, the domestic requirements for round-wood by wood industries may become twice or even triple from the annual level of 96.2 million m^3. Hence, undue pressure and encroachment of other sectors on forest areas, may contribute to unsustainable levels of exploitation and fast deforestation, culminating to loss of family livelihoods and a diminishing of biodiversity. Moreover, because of the increased request for timber and the inadequate delivery of preferred timber species in many developing countries, encouraging the use of LUS (Bosman, 1997). Hence, the utilisation of potential substitute (LUS) is now been promoted in the various nations to expand the industry's source of materials and lessen the heavy request on choice timber due to the felling of the few timbers currently in demand. Also as prices of highly choice timber begin to go up, likewise the quality and quantity of this timber go down, as a result of this situation, wood products users starts the possibility of using LUS, increasing the use of LUS would contribute to the successful sustainability of the management of forests and the use of tropical forest covers effectively (Bosman, 1997).

As Nigeria's population growth rises, there is a great deal of strain on commercial species that are already over-exploited. The long rotation periods have made the hardwoods very costly on nhe market, combined with tremendous demand and persistent scarcity, which has led to the felling of abandoned timbers such as agricultural fruit trees like *A.altilis* and *invingia* species. Again, the use of LUS timber provided a greater quantity of timber of choice for use and likely reduced the pressure on commercial timber species. In addition to the LUS whose use is increasing, in the supply of industrial wood and fibres, certain 'non-forest' trees cultivated by the agricultural sector slightly than the forestry division are also becoming significant. After several years of exploitation, these tree crops, mostly established for fruit and associated use, often outlive their purpose. They are mostly used in agroforestry systems, which are generally more essential for the supply of fruit and domestic wood fuel to local people than for industrial use (FAO, 2006).

Thus it's expedient to encourage the use of LUS species to possibly replace the threatened recognized wood species. "LUS" term does not imply wood species that are not known but are currently not commonly exploited for utilisation. Walker (2006) describe it as "other" timber species which does not belong to the traditional timbers which are commonly harvested such as *Terminalia ivorensis, Entandrophragma species, Nesorgordonia papaverifera, Milicia excelsa, Afzelia Africana, Triplochiton scleroxylon, Lovoa trichloides* etc.

Utilisation of LUS is one of the key elements in achieving sustainable forestry (Yadav *et al,* 2013). Youngs and Hammett, (2000) reported that only one percentage of harvested timbers were utilised and the unused log was burnt off. Meanwhile, unused wood has been the present focal point in Bolivia's forest division in development and transformation into valuable products (Walker, 2006). Forestry division therefore requires utilising more of the "other" timber species. The pressure placed on the Nigeria forest as a result of the indiscriminate search for these commonly used species will not only amount to the under-utilisation of the Nigeria forest stock but, capable of negatively affecting the Nigeria timber market and trade. According to Wong *et al.,* (2005), the trade pattern for tropical species will change as relatively durable hardwood become less available while lesser-known and secondary species are being introduced into the marketplace as alternative tropical timber resources.

In response to this imminent change, Nigeria timber merchants have embarked on efforts at shifting toward utilisation of substitute species, which have been identified through indigenous knowledge. Therefore, to ensure consistent availability of timber and the sustainable utilisation wood of species, there is urgent need to transfer the emphasis from known commercial timbers to alternative trees, importantly to those that meet the requirements for industrial use. Panshin, (1994) stated that the size of the trees and the quality of the wood are regarded as the main factor determining the appropriateness of timber for various manufacturing product for end-users. Furthermore, wood properties vary extensively and have not been well distinct in relations to utilisation in developing markets for the species. A critical look at the variation in wood properties of lesser-used species is necessary to establish their potential utilisation.

The lesser-used species *A.altilis* (Breadfruit) comes from the family Moraceae and is not a member of the prefered and recognised timbers like *Terminalia ivorensis, Afzelia africana, Triplochiton scleroxylon, Milicia excelsa, Nesorgordonia papaverifera*, e.t.c. *A.altilis* is classified as an agricultural plant but in recent times has gained recognition as good potential construction material. Latest surveys on the timber industry in Nigeria's south-western zone have shown a strong representation of this emerging species and because it grows to an average girth of 25m or more and (82feet) in height, it was therefore selected for evaluation. Knowledge of the wood properties especially those of physical and mechanical are therefore necessary for its utilization to be promoted.

1.2 STATEMENT OF PROBLEMS

The forest products industry is a dynamic, vital, and growing enterprise. There is a great concern for the protection and conservation of natural resources especially, the natural forest and efforts are geared toward more plantation forest to cushion the effects of environmental hazards arising from human activities. The indiscriminate extraction of economic trees, over-exploitation of forest resources, fuelwood gathering, population pressure, decrease of the forest for purposes like urbanisation and industrialisation to satisfy the rising in timber demands for the overflowing population (Saucier, 1990). This has contributed to a significant exhaustion of the resources base to the point that preferred species have become scarce, while others in some ecological zones have become extinct (Fuwape, 2000).

Increasing demand for wood species of choice has led to the scarcity of the favoured wood species. This increasing scarcity has led to calls for in-depth research into the wood properties of LUS to increase the knowledge base and utilisation potentials of this species to meet the demand for wood and wood products. Few of these lesser-known species include tree crops such as wood from mango (*Mangifera indica*), cashew (*Anacardium occidentale*), oil palm (*Elaeis guineensis*), coconut (*Cocos nucifera*), kola nut (*Cola* *acuminata*), *in*vingia *(Invingia gabonensis*), borassus (*Borassus aethiopum*) and breadfruits (*Artocarpus altilis*). Research interest in tree crops as a potential wood resource is as result of the decline in productivity of these trees as they begin to approach senescence since their primary purpose was for the production of fruits for food security. These agricultural trees can then be converted to timber as they become increasingly uneconomical in terms of fruit production.

Whitmore and Sayer (1992) identified a lack of information on the technical properties of wood as a major problem facing wood utilization for wood industries. This was also corroborated by Chowdhury *et al.,* (2005) who recorded that there is an obvious insufficient knowledge on plantation-grown trees' mechanical wood properties, but a dearth of information on on-farm trees. Scarce knowledge towards the utilisation potential of *A. altilis* wood has not improved the usage of this wood in Nigeria and this has led to it being used only as fuelwood in rural communities. The need for information on the wood properties of *A. altilis* is very important as it is strongly linked to its effective utilisation.

1.3 OBJECTIVES OF STUDY

The main objective of this research work is to investigate the properties of *A. altilis* to assessing its wood quality and potential for relevant commercial and industrial utilisation to propose its possible alternative for choice wood species in Nigeria.

The specific objectives are to:

(i) determine the physical properties of the wood such as wood density,specific gravity and percentage shrinkage

(ii) assess the mechanical properties of the wood such as Modulus of Rupture (MOR), Modulus of Elasticity (MOE),Maximum compressive strength (MCS//) parallel to grain, Impacting Bending Test parallel to grain (IM), Shear Test

(iii) evaluate the anatomical characteristics properties of the wood for instance cellwall thickness, fibre diameter, lumen width and fibre length.

(iv) assess the chemical properties and minerals nutrients of the species.

(v) determine its Natural durability through ground contact and resistance to fungi attack in service.

1.4 JUSTIFICATION

The importance of wood in the world economy cannot be overemphasized, increasing market demand of traditional timber species both locally and internationally have rested in their overexploitation, rendering some endangered (Mitchual *et al.,* 2014). Nigeria's demand for wood-based panels is increasing and has virtually exceeded supply, the current concern is whether this future demand can be met sustainably (Emerhi, 1992). Having realized the need to have the sustainable locally sourced raw material for wood and wood products, therefore, it becomes more imperative to beam our search-light on the lesser-known wood trees that are well suited to the climatic provision of Nigeria since the bulk of timber and other wood-based forest products are obtained from forest reserve and free area in the high forest zone of the country (Izekor, 2010).). (Avoka, 1998; Appiah *et al.,* 2011) looked at the importance of the lesser known species from an economic point of view and said that increasing their utilisation will generate more job opportunities, introduce new technology in wood processing, and boost the construction and housing delivery activities. Therefore, adequate diversification of market species could be promoted for the use of lesser-known species that can serve as tools for the sustainably and effective management of Nigeria's tropical forests.

The utilization of LUS will ensure adequate supplies of wood to wood-based industries on a sustainable basis and thus, meet the growing challenge of wood scarcity. The introduction of lesser-known timber species to the market will also expand the resource base and make more raw materials available to the timber industry while it will reduce pressures on the primary species as noted by (Ohagwu *et al.,* 2011 and Anthony, 1998).

Artocarpus altilis which is the focus of this study is commonly grown in semi-deciduous forest and humid low land of Nigeria (Yeboah *et al.,* 2003 and Ojekale *et al.,* 2007). Despite the various benefits derivable from this tree, its wood has not attracted much economic value. Presently, the wood of *A. altilis* is been fell and sold in major planks market for various furniture purposes, thus, scientific information is insufficient to trigger any meaningful decision that will popularize and encourage the development of the species to positively impact the recommendation of the species for construction purposes. Therefore, extensive research on the properties of the species must be done to properly encourage the use of *A.altilis* at regional and global level. The right to use the *A.altilis* wood was not known on a commercial basis until about the last decade but since time immemorial people of the villages have been familiar with the use of wood from fruit trees. Furthermore, the use of wood by *A.altilis* will complement the supply of raw materials for the timber industry and provide low-cost but equally reliable building materials for housing and export programs in these countries. Du-Plessis, (2012) reported that when compared to structural design, wood structures developed without adequate knowledge of the strength characteristics of the wood performed so poorly.

Utilisation potentials of wood are dependent on the physical, mechanical and microstructures attributes of the wood, the roles of wood anatomical structures in the determination of end-use requirements of wood, it is important to stress that anatomical properties of wood ultimately determine the use to which a particular wood is put. Basic wood research uses three patterns for wood characteristics in the standing tree viz: horizontal (radial), vertical (longitudinal), and intra-ring. Several works have been done on variation along and across the bole of other tree specis (Akachuku, 1981; Panshin, 1994; Onilude, 1987; Lim *et al.,* 2016; Ogunsanwo, 2000, Ajala, 2005). Effective wood utilisation strategies must ensure that processing of wood is done with due cognisance of the anatomical qualities so that full potentials of wood could be realised due to the strong relationship between these properties and strength, preservative treatment, rate of drying, woodworking, gluing, sawmilling as well as pulp and paper making. The information on differences in wood characteristics along and across the bole of *A. altilis* wood will help to determine its applications. Therefore, variations of longitudinal and radial planes in physical properties and mechanical properties, and anatomical structure of the wood of *A.altilis* was studied to provide reliable baseline data for assessing the utilization of the species by the wood processing industries and wood users. Therefore, it is very necessary to investigate the physical, mechanical properties, chemical composition, anatomical structure, and natural durability of *A.altilis* wood to ensure its appropriate use.

A very small percentage of the economically viable species are known for their inherent resistance to wood-destroying organisms. With the conditions in the tropics being extremely conducive for wood destroying agents, the natural durability becomes one of the most important factors affecting timber utilisation. Therefore, knowledge of the natural durability of a timber has become the fundamental prerequisites of effective utilization, before one can decide what needs to be done.

However, the species has suffered neglect in terms of research especially in the area of physico-mechanical and anatomical structure of the wood. Hence, this study, therefore, seeks to look into the physical, mechanical properties, chemical composition, morphological structure, and natural durability of the species in the locality where it is most prevalent.

1.5 SCOPE OF THE STUDY

The focus of the study was restricted to *A.altilis* a naturally grown species obtained from Longe village, Busogboro, in Oluyole LGA, Oyo State. Physiognomy characteristics of the trees was observed and noted such as, DBH, Merchantable length, sapwood and heartwood ratio. Both radial and axial variations of the wood on physical, mechanical, anatomical properties, chemical compositions, natural durability and resistance to fungi attack was carried out.The study investigated the characteristic properties of *A. altilis* wood obtained from natural forest location in this ecological zone in Nigeria (Rainforest). Four sampled trees were purposively selected. A tree with straight bole that is devoid of physical defect was used for all the experiment. The trees were sampled destructively.

The properties tested for include: physico-mechanical properties, Anatomical and Chemical properties, Durability and resistance to fungi attack.

CHAPTER TWO

LITERATURE REVIEW

2.2 *Artocarpus altilis*

A.altilis (Parkinson) Fosberg is a genus of *Artocarpus* (Moraceae) (Plate 2.1) and widely distributed in tropical and subtropical regions and has about 50 species, and fruits are a reliable choice of fatty carbohydrates. It can be eaten at all stages of production; the fruit could be boiled, simmered, grilled, roasted and fried. Though breadfruit is rich in dietary fiber, many items are partially substituted by wheat flour, like chips, cakes and sandwiches. In certain part of the world, it is widely consumed. Popular names: breadfruit; arbre pain (French); blofo akate (Ghana); buloy (Senegal); epa oyinbo (French); (Yoruba, Nigeria). Applications: The bark is used to treat skin infections and the leaves are used to treat fall, swelling and oedema. In southern Nigeria, the breadfruit (*A.altilis*) was developed into flours (Achinewu, 1982).

A.altilis tree is a very versatile woody plant in parts of Nigeria, e.g. Ile-ife, because the cultivation almost to be seen in the enclosure of most of the city (Omobuwajo, 2003). Despite the fact that many people in Nigeria have heard of breadfruit, few have eaten it. Perhaps this is due to the crop's insignificant use by many. Breadfruit can be found all over the world, especially in the Caribbeans, as well as in the tropics like Malaysia and Nigeria. Different varieties of these species are being researched into as regards their functional ingredients, particularly starch, proteins and nucleic acids are plentiful (Clement *et al.,* 2009). Breadfruit has been prepared into numerous items for utilization within the nourishment industry such as starches and flours (Loos *et al.,* 1981).

Few reports on this species have shown that, irrespective of the abundance of the tree, its utilisation is limited especially in their properties assessment, and exceptionally small investigation is been carried out on *A. altilis* (Park) Fosberg (Mart) timber. It’s therefore imperatives to explore the wood potentials for different applications to substitute the preffered wood in the Country through its wood quality properties assessment.

Plate 2.1: ***Artocarpus altilis*** **tree**

2.2 Description of *Artocarpus altilis* tree

The *A.altilis* timber is a big, attractive and deciduous in nature, 15-20meter high; it has smooth bark, lightly coloured and the trunk grows up to about1.2meter diameter. The tree can reach a height of 4 meter prior to branching. The tree has a thick, leathery leaves with a dark green face but glossy, the leaves is narrowly obovate in shape to broadly ovate, and of various size and shape. The bulk of the fruit is emanated from each flower's permanent perianth; the perianths are joined together apart from the base, the reflexes stigmas protrude from the center of the disk and sometimes leave a small distinctive scar when blackened and withered; rind typically stained with latex exudates at maturity. Meanwhile, this part vigorously grows as the fruit develops and becomes fleshy as it matures, to a form the edible portion of the fruit.

Fruit size is about 12cm x 12cm, and from globose to oblong shape, it is light green, yellowish-green or yellow when fully matured, and the flesh is creamy white or pale yellow. *A.altilis* seed is a very thin, dark-brown outer skin of 0.5mm thick while the inner is fragile having paper-like membrane that surrounds the fleshy, white edible portion of the seed. The fruit is usually eaten and commonly called breadfruit.

2.3 Distribution and Habitat

A.altilis trees can be regarded as dioecious plant because it has on the same branch; both male and female flowers appear separately. Prior to this, a female flower appears between 10-15 days after the appearance of the male florets, the pollen will then be shed for a period of 4 days. Hence, three days after the appearance of the female florets from the buds, male flowers are receptive and then open in subsequent phases, with the basal flowers emerging next. In comparison to other representatives of its classification, *A. altilis* seems to have a cross-pollinated structure. Indeed, honeybees have been reported to work and collect pollen constantly from the male inflorescence, particularly among productive planted species. But, on the seedless male inflorescence of *A.altilis* other insects such as earwigs were found producing pollen.

2.3.1 Ecology

The tree is an herbaceous perennial that typically grows in the relatively warm grasslands, but also in the uplands. The tree needs reasonably even distribution of sufficient rainfall but is very resilient and can withstand short dry time.

2.4.0 GERMPLASM MANAGEMENT

Seeds exhibit storage activity that is recalcitrant. It should remain wet at 20^0C to avoid drying out or the seed to short-lived. When the seeds grow straight away, it may not be capable of surviving drought, thereby; it will lose capability and can not be stored within a few weeks.

2.4.1 PESTS AND DISEASES

A.altilis trees seems to be a resilient tree and is mostly safe, healthy and free from parasites, but insects of scale, mealy bugs and Cercospora leafspot can be seen on some trees. Problems with pests seem to be geographical. In Hawaii, for instance, the 2-different leaf-hopper has been spotted which usually damage breadfruit trees; while in certain parts of West Africa, Rastrococcus invadens is becoming a pest, and Rosellinina spp. In Trinidad and Grenada, a possible threat was identified. Fruit rot on breadfruit is caused by many causative species such as phytophthora, colletotrichum (anthracnose) and rhizopus (soft rot), although they can easily controlled mostly by early harvesting of mature fruits and the exclusion of infected seeds.

2.5 USES AND PRODUCTS

Staple food: *A.altilis* tree produces abundant nutritious fruits that are typically consumed as a starchy staple when firm and mature. The fruits are high in carbohydrates and a good source of vitamins and minerals. *A.altilis* is canned in brine and sold in the Caribbean and speciality markets in the United States, Europe, and Canada.

Nut/seed: Seeds are high in protein and low in fat and a good source of vitamins and minerals. They are cooked in the fruits and eaten throughout the Pacific islands.

Medicinal: All parts are used medicinally in the Pacific and Caribbean, especially the latex, leaf tips, and inner bark. The latex is massaged into the skin to treat broken bones and sprains and is bandaged on the spine to relieve sciatica. It is commonly used to treat skin ailments and fungus diseases such as “thrush,” which is also treated with crushed leaves. Diluted latex is taken internally to treat diarrhoea, stomach aches, and dysentery. The sap from the crushed stems of leaves is used to treat ear infections or sore eyes. The root is astringent and used as a purgative; when macerated it is used as a poultice for skin ailments. The bark is also used to treat headaches in several islands. In the West

Indies the yellowing leaf is brewed into tea and taken to reduce high blood pressure and relieve asthma. The tea is also thought to control diabetes.

Fuelwood: Breadfruit is used in the Pacific as firewood, but older, less viable trees are typically used.

Wood/tools for craft: The wood is very strong and easy to work with and carve into sculptures, bowls, and other items of quality.

Canoe/boat/raft making: Small one or two-person canoes can be built from light-weight timber.

Fiber/weaving/clothing: The inner bark is used to create bark fabric (tapa).

2.6 WOOD QUALITY OF *A. ALTILIS*

The term defining a particular wood features such as (anatomical, chemical and physical) having a positive impact on particular wood product individually or in combination is refers to as wood quality. Wood quality may be difficult to define since expectations of what constitutes quality vary between forestry categories and wood-based industries, but depend entirely on the targeted end product (Jozsa *et al.,* 1994). Keith (1985) said that many attempts to characterize wood quality have been made. Mitchell (1961) seems to be approved more frequently, “The wood superiority is influenced by the material and element properties of tree or tree components that allow the property needed for various end uses to be fulfilled”.

The principal determinants of wood quality are known to be their density and fiber orientation angles that are primarily measures of load carrying capacity (Deresse *et al.,* 2003). To wood technologists therefore, the density of wood is significant because its importance will increase the strength of wood and the pulp yield for the production of paper (Elliot, 1970). In the paper and pulp mills, long fiber lengths, good runkel ratios and low lignin content are needed as quality wood (Zobel and Van Buijtenen, 1989).

Any wood attribute affecting the supply chain and the use of byproducts could perhaps be considered as wood quality. Johansson *et al.* (1990) reported that, wood quality features can influence the production and product value at virtually every stage in harvesting. A significant loss of product value is represented by drying defects. Some drying defects are closely related to the fundamental characteristics (Passialis *et al.,* 2004).

(Zhang *et al.*, 1998; Zhang *et al.*, 2002) opined that several wood features defect usually reduces timber attributes which require adequate and sustainable woodland management, any improvement to these quality characteristic will enhance the timber quality.

2.6.1 WOOD QUALITY ATTRIBUTES AND LENGTH IN SERVICE

The length of wood planks in use depends primarily on their end uses. Any wood designed for engineering use must have its strength and stiffness, impact resistance and longevity determined before use for users. Features such as machinability, dimensional stability and appearance are very critical for the development of furniture. These important quality conditions are characterized by unique wood attributes, to a different extent, for end-users and producers. Wood stability is influenced by material elements; aesthetic look is measured by microscopic and thermal compositions, whereas impact resistance, strength and ductility are actually dependent on wood's essential properties. In order to reflect buyers and manufacturers, such customer traits must also be kept in mind with regard to other features of wood quality Pande *et al.*, (2004).

Quality characteristics of wood and their effect on wood utilization

The following features are considered to be significant wood quality characteristics for solid wood products:

i. For the sawmilling industry, the important wood crucial parameter is stem dimension. The cost of logging and production decreases with increasing stem diameter, while the recovery of log value and quality output increases substantially (Pande *et al.,* 2004)

ii. Stem formation or anomalies can actually lower timber mass improvement and timber value.

iii. The principal effect of the tree taper is on the quantity of tree with a specific diameter and the wood volume recovery declines dramatically as the stem taper increases. Moreover, broad taper causes in variance of the grain, thus reducing tensile strength.

iv. Maturity influences the development of wood and essential wood features. The quality of inmaturity increases as the timber growing to maturity.

v. Logs are also destroyed during the debarking process, which causes the loss of wood fibre. And contamination of bark can lower the quality and value of chips.

vi. Stem decay makes harvesting and processing trees more expensive. Decay also minimizes product efficiency (Chandrabakty, 2014)

vii. Knottiness decreases the mechanical properties of lumber and is a major factor responsible to timber downgrading. Influence of knots leads to downgrade of appearance and machinability of planks.

viii. There are lower wood properties of reaction wood affecting wood processing.

ix. Grain variance can decrease the strength of lumber and cause warping.

x. Typically, inmatured timber is closely related to small load carrying capacity and stiffness and toughness

xi. Anatomical features: The physico-mechanical attributes of wood are defined by simple wood features. Toughness and water loss of wood are positively linked with the micro fibrillar point. Anatomical wood features are also related to volume and absorption.

xii. The strength and stiffness of wood are specifically correlated with the elemental composition. It influences pulp production and consistency.

xiii. Ring characteristics are commonly correlated with aesthetic features of wood. Machinability impacts them as well.

xiv. Moisture in logs affects many behaviors in the quality collection cycle. Moisture content is also correlated with mould, decay and sapstain formation in logs and boards.

xv. Impact resistance influences structure, the most significant wood quality attribute has long been known to be wood density. In general, high-density lumber is linked to high wood toughness and a high pulp yield associated with it while low-density wood is favored by certain panel manufacturers.

xvi. Construction performance and structural serviceability are determined by dimensional stability but wood warping may cause serious problems inefficiency and structural serviceability.

xvii. For the construction industry, mechanical properties are highly significant characteristics.

xviii. Wood permeation is strongly connected to wood drying temperature and severity. Finishing characteristics can also be affected.

xix. For appearance objects, esthetic features are important.

xx. In wood construction, fire resistance can be a significant attribute.

xxi. For secondary production and housing construction, finishing characteristics are of significance.

xxii. Engineering properties involve clamps adhesive characteristics that are coveted by wood flooring products manufacturers.

The behavioural differences often observed between wood and other construction materials, such as steel, concrete and glass are reflection of wood variability. Wood is, therefore, not produced to exact and relatively reproducible specifications. This may create utilisation problems and in some cases may enhance utilisation potentials of species (Pande *et al.*, 2004)

2.6.2 INTERRELATION AMONG WOOD QUALITY ATTRIBUTE

The characteristics of the trunk and wood are related to log circumference, log form, stump taper and tree maturity level; wood structural and molecular traits represent specific wood patterns; broad wood patterns such as immature wood, support and facilitate correspond to materials that vary greatly from the basic wood attributes; others are either visual wood attributes. Subsequently, most attributes of wood quality were mostly intertwined, so it seems rather unreasonable to try to combine them into classes.The traits of wood mass are usually affected by the distinctiveness of the wood trunk, maturity and circumference. For instance, immature wood and heartwood material result in a larger age or diameter. Wood distortion is commonly linked with trunk forms or hardness. The basic wood features of the trunk depend on some degree on the patterns of the stem, because the traits in gross timbers are similar to the patterns in the vascular bundles and this may influence customer desired attributes (Chandrabakty, 2014)

Wood quality studies are not only focused on features of wood but are also projected backwards to relate to the silvicultural treatments embarked upon while the wood was being formed and forward to end uses of wood. It is important to know the extent to which wood features can be silviculturally and genetically controlled. Such information will show how the forest could be managed to produce high quality wood.

2.6.3 WOOD DENSITY

Wood basic density is a measure for characterizing wood. The density is also major important factor that influence the behavior of wood materials, most importantly the mechanical properties and physical properties. Density depends mainly on the fibre length; diameter and cell wall thickness. According to Rowell (2005) opined that having a full knowledge of the densities of timber, this could in a way assist in predicting the mechanical properties because basic density determines the end-use quality of wood. Similarly, Hoadley (2000) reported wood mass is major parameters that affect the mechanical properties.

De Guth, (1980) explaining wood volume of both coniferous trees and evergreens is a valuable wood attribute for solid wood and composite products while Panshin and De Zeeuw (1980) reported that wood volume is an overall total cell predictor and is a great indicator of durability, strength, drying ease, milling, resistance and molecular structure of paper production. Mani, (2012) shared his research observation that volume is a major critical factors affecting the choice of a timber. They stressed that everything influences the engineering output of wood and in fact the toughness and preparation performance of wood products and varnish, and the outputs of wood pulping in paper products. (Jozsa *et al,* 1994; 1998) stated that wood density can be determine as a unit per volume of the cell wall content, providing a very strong overview of the bearing capacity and projected timber pulp outputs. End-use quality attributes including pulping output and reinforced concrete capacity are strongly connected to basic density.

Cown (1992) reported volume could be considered like the main tool to measure the toughness of wood. Evidently, almost all of the difference in wood capacity, either within both species, could be due to variations in wood density, according to Jozsa *et al.,* (1994). Research has shown that trees with greater density tend to have better timber than species with smaller volume (Walker, 2006). Consequently, Eun, *et al,* (2008), also considered that wood density may not have been a simple feature but usually influenced by the thickness of the cell wall, the cell size, the ratio of earlywood to latewood and the wood's chemical components.

2.6.4 SPECIFIC GRAVITY

Specific gravity indicates the quantity of real wood content contained in a unit volume of wood. The specific gravity could be termed as the quantity of wood content per unit volume, otherwise known as the relative density or density index. It has been identified as wood's most valuable physical property and the most useful wood quality descriptor. This is due to its direct relationship with many wood properties (Kellinson, 1984).

The traditional method is to determine the ratio between the dry weights of wood divided by the green volume of the same wood, although there are many techniques used to measure the wood density according to Kellinson (1984). The actual gravity or density of the wood is explained as total matter in the log separated by the total mass, or the wet mass or fresh mass of the lumber by the green mass, or, very rarely, by the dry mass of the green mass of the wood. For both solid wood and fiber goods, wood volume is an essential wood property in softwood and hardwoods and because of its unique association with output and efficiency, as well as its wide variance, it is undoubtedly the single most important attribute in the wood sector (Poku *et al*., 2001).

The output and quality of both fibrous and strong wood products are influenced (Davis, *et al.*, 1987). Mitchell (1963) provided an overview of North American coniferous trees in particular, who estimated that a change in specific gravity of 0.02 would represent a shift in the clear wood rupture of about 1,000 pounds/in^2 (70 kg/cm^2). Similarly, a specific gravity of 0.02 results is a change in dry mass per cord of 100lbs (45.4 kg) or dry processed kraft pulp of 50 lbs (22.7 kg) (1cord= approximately 2 m^3). Elevitch, (2006) reported that the importance of the volume was strongly emphasized, indicating how to establish a particular traits for a possible source of softwood raw materials for pulping and sawn wood, and it would definitely be wood-specific gravity. They describe their relationship with pulping output, paper manufacturing traits, with strength of log and fibres, in summary, hardly any single wood attribute is far more widely studied and reported for a broad applicability in the assessment of wood quality than wood density. According to Chandrabakty, (2014), knots, wood density and longitudinal pattern are mainly due to several conditions in the tropical regions that affect wood quality in rapidly coniferous trees.

Liker, (2003) also stressed the importance of specific gravity knowledge in terms of volume, the conventional way of documenting natural resource development, and tree size is not sufficient. These can be done by recognizing that the measurement of wood density and mass is common in plantation in many regions. Since genetically modified could typically alter wood density very quickly, it is valuable to have data on the degree of product alteration produced by modifications in fibre content.

2.6.5 WOOD PRODUCTS PROPERTIES

Among the many wood types, wood is an exceptionally versatile material with a wide variety of physical and mechanical properties. With an outstanding intensity ratio, it is also a renewable resource. Wood is a suitable building material because wood's energy needs are much smaller than some of competing products, like metal, cement or acrylic, for producing a functional finished product (Jerrold, 1994). Depending on the intended and desired product, lumber characteristics values generally differ, but specific gravity, probably the most important factor measuring the lumber strength because it affects both the performance and productivity of fibre and strong wood (Saranpaa, 2003). For example, wood density in conifers species is closely correlated with pulp output, paper quality, and fracture toughness of the timber (Bhat, *et al.*, 2004). The mass of the wood is a significant stiffness measure for small clear wood samples, whereas density largely determines strength. In determining product performance, the rate of recurrence, dimension and points of the lumber knot, slope plane and load and service-life are all significant.

2.6.6 PULP AND PAPER PROPERTIES

Timber's anatomical and chemical composition stands out among the many indicators that make wood coveted item and valued raw material for the paper manufacruring. Though several study were carried out, the capacity of several wood species for pulp paper and paper manufacturing, no detailed study of the anatomical and chemical characteristics was to serve as the benchmark for the researchers and pulp and paper producers to select any wood material for paper production (Saranpaa, P, 2003). In addition to the micro fibril angle and density, fiber (or tracheid) dimensions are significant for paper products. The evaluation of the characteristics of softwood pulp paper (e.g. *pinus*) and hardwood pulp will indicates the importance of fiber dimensions for the properties of the product (Chandrabakty, 2014)

2.6.7 THE CHEMICAL PULPING

The chemical composition of plant gives an indicator of how viable the plant can be as a raw resource for paper products. The most critical part of the plant is the fibrous portion. The structure and quantity of fibres is expressed in the properties of cell walls since plant fibres consist of cell walls. Lingnocellulose products from wood and non-wood plants are typically composed of cellulose, lignin, hemicellulose, extractive and some inorganic matter. The main constituents of lignocellulosic biomass, polysaccharides and pectin are all necessary to assess the species' suitability for the synthesis of organic compounds pulp and to precursor for synthesis the production of the pulp. Hardwood lignin can be easily extracted during pulping, so trees with higher guaiacyl content are favored in advanced breeding programs. The concentration of cellulose and hemicellulose polymer in hardwoods can indeed be taken into consideration (Chandrabakty, 2014). In determining the techno-commercial suitability, pulping process and paper strength of a specific wood material, information on the chemical composition is relevant (Abdul-Khalil *et al.,* 2010).

2.6.8 MECHANICAL PULPING

Mechanical pulping involves different requirements that are significant including the removal of colour as the fibre pulps bleached partially. The emphasis of the Tree Improvement Program was on increasing height growth and wood specific gravity at the same time (Zobel and Van Buijtenen, 1989, and Zobel, 1984). Notable progress has been made; however, conifers (but still fascinating biological development) have produced a major and all too prevalent quality issue (e.g *A. altilis*). Fast growth in height leads to the development of compression wood in the immature center, presumably because as a result of quick height growth, cambial auxin is increased to hyper-physiological levels (Timell, 1986). Compression wood tends to be structurally unstable in view of its higher density, and fails without warning. In particular, given the escalation of extreme events related to global climate change, it should be emphasized that one thing is not only the ultimate quality of wood serving humans, but also that the physical condition of forest habitats depends on growing trees not experiencing an increase in wood density, achieving a uniform wood density. The issue of uniformity is likely to be solved by silviculture, tree enhancement, genetic modification or any combination, simply because variation in wood density seems to be an inevitable development during the overloading of tree growth in its pre-harvest lifetime Eun and Walker, (1994).

2.6.9 WOOD ANATOMY

Conifers and hardwoods are made of various kinds of cells and have different structures as a result. Softwoods with tracheids that shape the bulk of the wood have a uniform structure in particular. Tracheids are stretched out cells having a pointed ends, the secondary cell-wall are thick, while at maturity, having no living cell material. They are grouped into radial structures that represent the pattern from which they derive the fusiform shifting cells. The words originate from the middle ages timber trade, where cone-bearing forests such as pine trees were seen to be smooth. Consequently, the distinction is based on the tree's botanical taxonomic grouping, and not the true hardness of its wood. Softwoods, including spruces, firs, redwoods, podo-carps and Araucarian pines, originate from plants that are cone-bearing plants or Gymnospermae. Hardwoods, including broad-leaved trees, originate from Angiospermae or flowering plants. Though, low-density and high-density hardwood forests also considered as softwood trees. Meanwhile, wood obatined along-the-grain does have much greater strength while cells in axial resin ducts or axial parenchyma appear in certain softwood, Eun and Walker, (1994).

The fundamental anatomies of conifers are stated very clearly by several research reports (Walker, 2006, and Liker, 2003). The conduction and support functions in hardwood are split into two distinct types of cells: a components joined end-to-end to form long ducts called vessels to conduct or transportation of water while elongated fibers are made to give the tree stability. Inside each growth ring, the arrangement of these two cell types between axial parenchyma in a variety attributes contributes to several immeasurable diversity of timber anatomie. The chemical properties of molecules which shape cell walls (structural components) and within the cell structure are in requisites of composition of the monomeric, the structure of the molecules and intermolecular groupings (extractive components)

2. Distribution (the organization of the cell-walls) of the chemical components in the cell structure and

3. Relative proportions inside the wood cells and tissues of the various chemical components.

The basic characteristics of wood can be directly linked to a combination of variables, and it is therefore important to explicitly relate the use of wood and the quality associated with the finished product to its chemical distinctiveness. Again, in most cases, the difficulty and competitive effects of the structure of microscopic wood, the organization of macroscopic wood, the various traits of individual characheristics for isolation and the combined chemical product in the measuring the traits Panshin and De Zeuuw, (1980).

2.6.10 ANATOMY AND MORPHOLOGY

The chemical components of wood are the major chemical elements that make up the cell wall (cellulose, hemicellulose and lignin) and can be differentiated by the extractive components and their application in the cell wall, whereas the importance of the molecular structure and its effect on end-use and quality factors are related to the characteristics that affect the properties (Ragone, 2006)

2.6.10.1 THE CHEMICAL COMPONENTS OF WOOD

The Element mechanism of wood can be defined as:

(i) Structural components- The construction of the cell walls consists of these components and is responsible for the cell form and the elemental compositions of most timber are macromolecules that are polymerically insoluble. Removing a structural component from the cell wall requires chemical or mechanical techniques to dissociate and solubilize it, at least to some extent Saranpaa, (2003).

(ii) Extractive components – In cell lumina, cellular voids or channels, there are non-structural elements included. Chemical extraneous materials are mostly dissolved and can be separated from lumber without greatly altering the structural biological attributes by using sufficiently polarized additives. (Ragone, 2006)

2.6.10.2 THE MECHANICAL PROPERTIES IMPORTANCES FOR STRUCTURAL APPLICATIONS

The wood comprises a series, slender, porous tubes corresponding to the orientation of the tree stump, which can be considered to be a bundle of tubes aligned in three directions that are mutually perpendicular. The pipes are reasonably solid when pressures are applied comparable to their elongated alignment, but can crack quickly when the load is at right angles. Wood is an extremely anisotropic material and this explains why wood characteristics rely heavily on the direction they are measured, it is evident that the mechanical property values differ by a factor of 20 or even more along the three material axes. Two types are often classified into mechanical properties; Elastic properties are those that represent the rigidity of a material, while strength means the ability to bear loads or to resistance force. In any application, the most important property is defined by the kind of loading needed to withstand the component. For instance, the strength of the long column is partly regulated by the bending resistance, such as the elasticity modulus, on the other side; however, it primarily depends on the tensile strength of the lumber parallel to the grain.

2.7 SHRINKAGE

Shrinkage is a term that is broadly defined as the percentage changes in wood dimension due to moisture loss (Dinwoodie, 1989). According to Desch, (1988), Fibre saturation point (FSP) could be defined as a theoretical condition where wood cavities are void and the cell are saturated with water, meanwhile when wood looses moisture below fibre saturation point, then the wood start shrinking and when it absorb water, it start swelling. Shrinkage occurs during the drying or seasoning process of log. Every timber under goes shrinkages, irrespective of the seasoning types or the methods used. Meanwhile, some timber shrinks more than others.The shrinkage of wood cells sometime does not extend in their length but there is very little shrinkage in the length of a board when it is dried. Again, shrinkage of the medullary rays is little especially in their length, and as they run across the timber.Most shrinkage, therefore takes place in the direction of the growth rings, at right angles to the medullary rays. This is called tangential shrinkage. Tangential shrinkage is always double radial shrinkage and higher than longitudinal shrinkage.

The relationship is expressed as the tangential to radial shrinkage ratio, or simply the T/R ratio, between these two shrinkage values. Ideally, there will be both low volumetric shrinkage and a low T/R ratio of a wood species with good stability. There is almost no shrinkage parallel to a piece of timber's length. Radial shrinkage is perpendicular to the rings of development. The direction towards the center of the tree is shrinkage. The tangential shrinkage is parallel to that in the direction of the growth rings.

2.8 TANGENTIAL SHRINKAGE

Wood is regarded as hygroscopic substance and shrinkage in wood is responsible as a result of the difference in humidity content. Shrinkage is the improvement in the volume of wood when dried to a particular MC from its green state to its condition (normally 12 % MC). Water from cell walls is drained as timber dries, causing them to shrink. For the timber to maintain its dimensional stability, this happens uniformly in the timber. In general, as a result of the moisture content on typical timber species, lower impact on their dimension is visible.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

Chapter three provides an outline of the parameters used in samples selection and methods used to gather data for this investigation. They are discussed under the following headings: facilities, wood species used and sampling procedures, experimental methods and data analysis. The properties investigated in this study were the basic density, tangential and radial shrinkage, fibre morphology and mechanical properties (Modulus of Rupture, Modulus of Elasciticty, Impact Bending, Maximum Compressive Strength, and Shear test parallel to grain) of the species.

3.2 Facilities for Laboratory work

The log conversion and processing were performed at Renewable Natural Resources Faculty (University of Ibadan) and further processing at Department of Forest Production and Products wood workshop. The experiments studies on mechanical property were conducted at the wood workshop, Federal University of Technology, Akure FUTA, while physical properties and other studies was done at Forestry Research Institute of Nigeria (FRIN), at Department of Forest Production Development and Utilisation and Forest Conservation

The tools and equipment used were: A panasonic digital camera was used to snap necessary picture for record purposes, measuring tape was used to determine the log diamenter (girth) and the length to MH. Chain saw (Dolmar CT) was used to fell the selected trees. After haulage the logs to sawmill, WoodMixer machine was used for log conversion into required dimensions while Circular saw (Steton SCE 400), Crosscut saw (Delta HP 5), and Combined Planner and Thicknesser (SICMA RT 520) were used in preparing the samples. Moreover, digital veneer caliper (0-150mm, 0.01mm) was used to determine accurate dimension of test samples while the electronic weighing balance (Sartorious, 0-620g, 0.001g) was used in measuring the weigth of the samples, and thereafter test samples were oven dried in the laboratory Oven (Genlab experimental oven). Computer Control Tensile Testing Machine (WDW-20 Class) was used to determines the strength properties of the wood. The standards used were BS 373 (1957) for wood density and shrinkage measurement as presented in Plate 3.1 (a-g).

3.3 Species used and their origin

Nigeria is situated in the subtropical region with a broad area covered with wood (lat 4^0 and 14^0N, and long 2^0E) Ajewole and Iyanda, (2010). The investigation was carried out in the rainforest zone area of Nigeria; tree species for the study were harvested from Longe Village in Oluyole LGA, Oyo State, South-Western Nigeria, Oluyole Local Government is situated at latitude 30°50''N to 7°10'34''N of the equator. Longe Village, is within latitude 7°10'37''E and 3°50'59'' North while long 3°52'50''East and latitude 70°20''E (Ajewole and Iyanda, 2010) as shown in Figure 3.2. There are many *A.altilis* wood species within cocoa and kola farmland. The River Ona bounded the area on the west and Ijebu-Ode by the east and along the main road to Ibadan, while Odo-Ona and Abanla settlements were located toward the North. Located in the south are Abatan and Mamu settlements in Ogun State. The region experiences both dry and rainy seasons. Three months dry season lasted between every December to February, while average annuall rainfall is 1140 mm and average temperature is around 26.4^0C (800F). The human population is 734,377 people and area land covers is 4000 km^2, this is according to 2006 population census (http://www.oyostate.gov.ng).

Plate 3.1a: Felling operation chain saw machine (Dolmar CT)

Plate 3.1b: Primary conversion process

Plate 3.1c: Converted planks

Plate 3.1d: Secondary conversion circular saw (Steton SCE 400)

Plate 3.1f: **C**onversion Crosscut saw (Delta HP 5)

Plate 3.1e: Prepared samples

Plate 3.1f: Hart-Turner Impact machine

Plate 3.1g: Computer Control Tensile Testing Machine (WDW-20 Class)

Plate 3.1 (a-g): Showing various Machines used during operation process

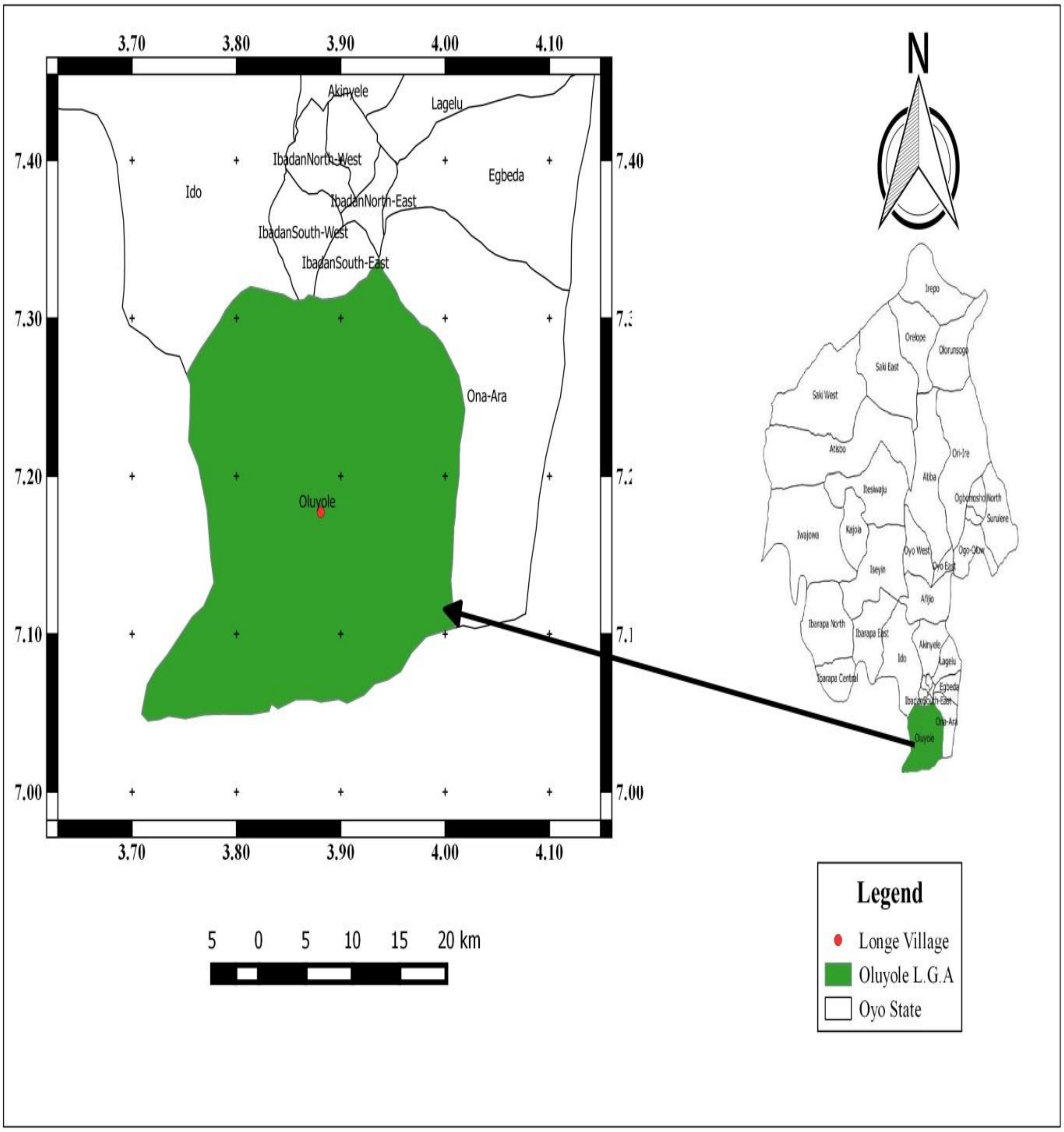

Figure 3.1: Study area map showing sample collection location

3.4 Tree selection and harvesting

Four trees free of any reaction tendencies, natural defects, fairly straight bole, as well as excessive knot were purposively selected and harvested. Meanwhile, age, diameter sizes and growth ring counts were also well thought-out based on details from the farmer. Test samples were obtainedfrom the felled trees across the length of the wood trunk at three different locations (base, middle and top), that is 10 %, 50 % and 90 % of merchantable height, amounting to twelve (12) billets of 500 mm in lenght, for destructive sampling. The billets were then taken for further processing at the Department of Forest Production and Products, Wood Workshop.

3.5 Specimen preparation

Samples were taken at the innermost planks collected in all the billets to provide 12 boards from which test specimen were collected for all the experiments. The main boards were thereafter processed into six (6) equal parts from one-end bark to another end-bark as shown on Figure 3.2 partion 1 and 6 conotes the outerwood parts, 2 and 5 are the innerwood and 3and 4 are the corewood portion.

Wood samples have been dimensioned to determine the various wood properties according to the procedure ASTM143-1983 standards as presented in Table 3.1

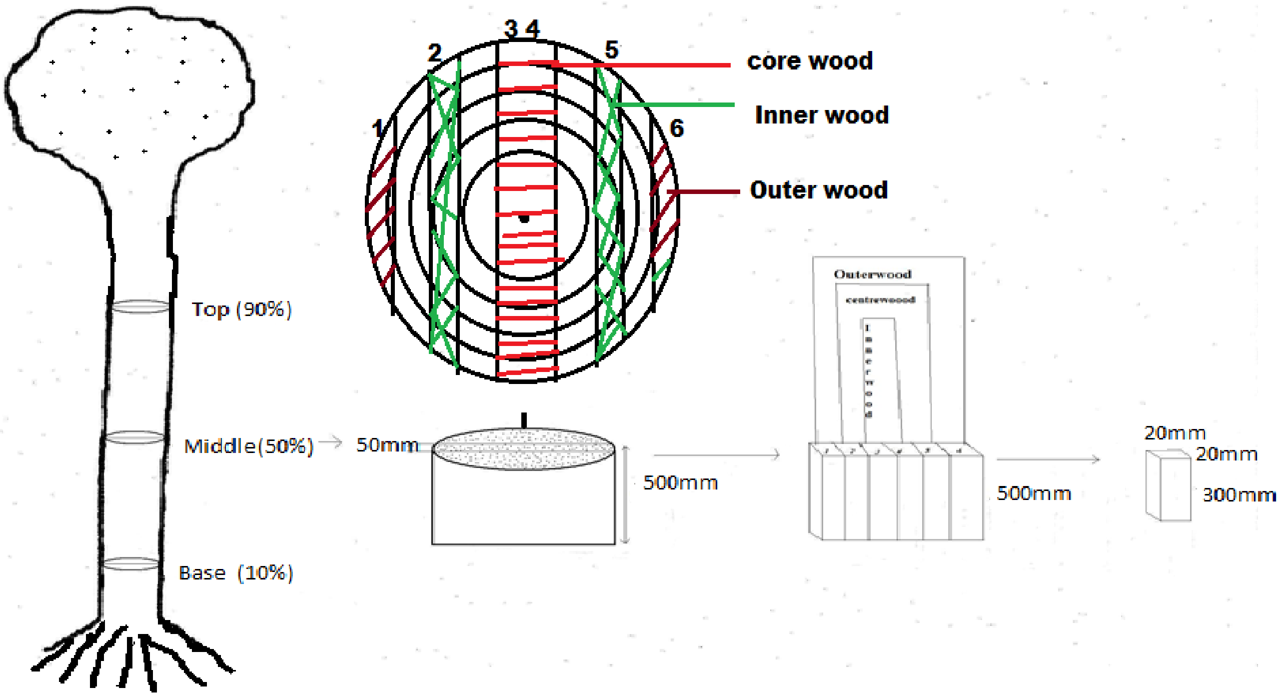

Figure 3.2: Physical and mechanical properties schematic sampling procedure for obtaining test samples.

TABLE 3.1 Wood Test Samples Allocation

Properties	Test	Dimensions (mm^3)	No of Samples
Physical	Density	(20 x 20 x 60)	360
	percentage shrinkage	(20 x 20 x 60)	360
	Volumetric Shrinkage	(20 x 20 x 40)	360
Mechanical	MOR	(20 x 20 x 300)	360
	MOE	(20 x 20 x 300)	360
	Compression strength// to grain	(20 x 20 x 60)	360
	Impact bending	(20 x 20 x 300)	360
	Shear strength	(20 x 20 x 20)	360
Anatomical	Fibre characteristics	Slivers from failed shear test (20 x 20 x 20)	360
Chemical	Cellulose, lignin and Extractive content	Sawdust material	
Natural durability	Ground contact test	(19 x 19 x 457)	360
Fungi Test	White and Brown rot fungi	(19 x 19 x 19)	90

3.6 PHYSICAL PROPERTIES

3.6.1 Determination of Wood Density

For each of the four selected trees, 360 test specimens of dimensions 20x20x60 mm^3 was obtained at the centre planks collected from three levels of the log (that is, the base, center and stem-top). Again, further processing was carried out and specimens were then taken radially from bark to bark from each sampling direction to processed five (5) test specimen from each sampling direction, thus for each replication, 30 test samples were collected given a number of 90 test specimen and, a total number of 360 test specimens from the four timbers felled. The specimens were immersed for 72 hours in distilled water. As recommended by Smith (1954), specimens were dried in the gallemp oven at 103 ± 2^0C and, thereafter re-weighed at intervals until a constant weight was reached on highly receptive weighing machine. The test samples were then weighed after cooling inside a clean jelly desiccator. ASTM D 1413-83 was used to calculate the wood density within the bole.

$$\mathrm{D} = \frac{\mathrm{M}}{\mathrm{V}}\left(\frac{\mathrm{kg}}{\mathrm{m}^3}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where the:

D=density

M = weight of the specimen

V = volume of specimen

3.6.2 Percentage Shrinkage determination

For this test, 360 test samples of 20x20x40 mm^3 were used; for both Tangential and Radial planes, 'T' and 'R' were appropriately labelled and numbered. After that, the test specimens were immersed in sterile liquid for 72 hours to get it damp than the equilibrium moisture point. Test specimens were then taken in sequence and left to drain out surplus water; subsequently, their dimensions were read using sensitive veneer calipers to the nearby millimeter in wet conditions. Following the ovens drying of the samples at 103 ± 2^0C, the percentage of shrinkage was determined in the 2 direction planes

$$\mathrm{S} = \frac{\mathrm{D_s} - \mathrm{Do}}{\mathrm{D_s}} \mathrm{X}\, 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where the:

S = shrinkage percentage

D_S = saturated condition size

D_0 = dried-oven size

$$\text{Volumetric Shrinkage} = S_R + S_T \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.3)$$

Where the:

V_S = the volumetric shrinkage

S_r = the shrinkage at radial plane

S_t = the shrinkage at tangential plane

3.6.3 Determination of Specific gravity

Specific gravity is an index of the amount of wood substance contained in a piece of wood; and specific gravity values reflect the existence of gums, resins and extractives, therefore, as the wood is smooth, straight grain, and no defect, have a significant influence on tensile strength, worthwhile to acknowledge that as greater the values of the wood's specific gravity, the stronger becomes stiffness characteristics, but a change in the specific gravity of the specimen could possibly affect the cell-wall thickness (Green *et al,* 2003).

The test samples for specific gravity were cut into 60mm x 20mm x 20mm squares and subjected to a specific gravity formula established by Smith (1954), wherein the samples were absolutely soaked in distilled liquid for 72 hours. Test samples were then taken from distilled water and cleaned to eliminate surplus moisture from each specimen; specimens then dried in the oven at $103+2^0$C and thereafter weighed at intervals on a sensitive measuring meter till a constant weight was achieved.

$$SG = \frac{1}{\frac{W_{s-W0}}{W_0} + \frac{1}{1.53}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.4)$$

Where the: w_S= saturated weight of specimen

W_O = dried-oven weight of specimen

1.53 is the constant equation as the actual mass of wood substance established by Stamm (1929)

3.6.4 MECHANICAL PROPERTIES

The mechanical property is often referred to as the strength properties of wood because of its capacity to withstand different influences or loads which can alter its shape and size. Modulus of Rupture (MOR), Modulus of Elasticity (MOE), Maximum Compressive Strength parallel to grain (MCS//), Maximum Shear Strength parallel to grain and Impact bending strength were the tests carried out on this study.

3.6.4.1 Determination of Modulus of Rupture (MOR) and Modulus of Elasticity (MOE)

Panshin and DeZeeuw (1980) defined MOR as the amount of force required to cause the collapse of structural loads. The sample dimensions required for this test are clear samples of dimension 20mm × 20mm × 300 mm as described in the ASTM D1037-94 (1994).

$$\mathrm{MOR} = \frac{3\mathrm{PL}}{2\mathrm{bd}^2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (3.5)$$

Where the:

MOR was in N/mm^2

P = load at some point below the proportional limit (N)

L =distance between supports for the beam (mm)

b= beam width (mm)

d = thickness (depth) (mm)

Modulus of Elasticity could be defined as the measure of the resistance to bending, or stiffness of a beam or other wood member. This is the material's capacity to retrieve its initial size or shape when it is under strain (Pansin and Dezeeuw, 1980). (Johnson, 1986) claimed that a wood member's potential to tilt easily and recover normal shape is considered versatility, and toughness is termed the capacity to withstand tilting. This is calculated using the equation according to ASTM D1037-94 (1994).

$$\mathrm{MOE} = \frac{\mathrm{PL}^3}{4\mathrm{bd}^3\ \Delta} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\ (3.6)$$

P = load at some point below the proportional limit (N)

L = distance between supports for the beam (mm)

b = beam width (mm)

d = thickness (depth) of the beam (mm)

Δ = deflection

Delta (Δ) which is the deflection of beam center at proportional limit, was taken directly from the calculation on the Universal Testing machine during MOE test.

Ninety (90) test samples were obtained per block out of which 5 per wood zone was used for the test MOR and MOE totaling 360 samples. The MOR and MOE were determines using BS Method 373 (1957) procedure. Computer Control Tensile Testing Machine (model WDW-20 Class: 1) was used to determine the MOR and MOE. Modulus of rupture and Modulus of Elasticity weights were registered at their breakdown on the machine and the results from PC variables were computed from the device and recorded. The values obtained were used to calculate the modulus of rupture and modulus of elasticity using the equation stated above.

3.6.4.2 Determination of Maximum Compressive Strength (MCS//) parallel to grain

MCS// can be described as a material's ability to resist a crushing force or stress applied to the specimen. The compressive strength parallel to the grain test were determined with specimen dimension (20mm x20mm x 60mm. Ninety (90) test specimens were obtained per block out of which 5 per wood zone were used for the test MCS// totaling 360 samples. Computer Control Tensile Testing Machine (model WDW-20 Class: 1) was used to determine the MCS//. The MCS// weights was registered at their breakdown on the machine and the results from PC variables were computed from the device and recorded.The values obtained were used to calculate the compressive strength using the equation below, according to ASTM designation D1037-94 (1994).

$$\mathrm{MCS//} = \frac{\mathrm{Pmax}}{\mathrm{A}}\,\mathrm{N/mm^2} \ldots\ldots\ldots (3.7)$$

Where;

Pmax= load to failure (N)

A = area of test specimen section (mm)

3.6.4.3 Determination of Impact bending strength (IM)

Impact bending strength can be defined as the capacity of specimens to withstand unexpectedly applied force and one of the toughness assessment parameters (Johnson, 1986). Impact bending is generally or widely used as an indication of toughness of wood material. The impact bending testing was conducted out at the Department of Forest product development and utilisation, FRIN, Ibadan, on Hatt-Turner Universal Test Device; following British Standard BS 373 (1957)

In this study, Ninety (90) test samples were obtained per block out of which 5 per wood zone were used for the impact bending test totalling 360 samples and standard test specimen (20mm x 20mm x 300mm) over a range of 240 mm, spring limited swing arms are fitted on a radiused 15 mm frame to arrest rebound. This was then exposed at an initial height of 50.8 mm to repeated blow from the weight of 1.5 kg, and then every 25.4 mm, before total failure occurred at which point the height was calculated in meter at the top lever drop height. The maximum distance of hammer drop was read and recorded directly from the impact bending machine in meter using the equation below and according to ASTM D1037-94 (1994).

$$\mathrm{IM} = \frac{\mathrm{w}}{\mathrm{A}} = \frac{\mathrm{F\,x\,D}}{\mathrm{B\,x\,D}} \ldots\ldots\ldots..\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.8)$$

Where the:

IM = Impact work (J/m^2)

W = Work-done

A = area of the samples

F = weight of the hammer

d = distance of hammer drop

b = length of sample

d = depth of sample

3.6.4.4 Determination of Maximum Shear Strength parallel to grain

The measure of ability of wood to resist internal slipping of one part upon another along the grain is what is referred to as Shear strength. This was done parallel to the grain. Three hundred and sixty (360) specimens of 20 x 20 x 20 mm size were derived for each of the four trees centre planks and collected at each sampling position (that is, at the base, center stem and at the top). Five (5) test specimens in each sample point were radially taken from bark to bark from each sampling height. In order to produce 360 test specimens, 90 specimens were collected from the four trees and 30 test samples were therefore obtained for each replication. This was done in compliance with British Standard BS 373 (1957) for the testing of small and clear timber samples. The maximum Shear strength was measured according to the formula below; according to ASTM D1037-94 (1994).

$$\text{Shear Test} = \frac{\mathrm{P}}{\mathrm{bd}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.9)$$

Where:

P is Load in Newton, d is depth (mm^2), b is width (mm^2),

3.6.5 Determination of Natural durability

The natural resilience of timber species is measured on the basis of its resistance to attack in service by wood destroying agents. To evaluate durability of timber, long term out door and ground contact testing are more commonly known as 'grave-yard' testing has been adopted by many researchers including Ling *et al.,* (2003). Test specimen of (19 x 19 x 457) mm in accordance with ASTM D 1758-74 was adopted as the testing protocol. The test samples were buried in graveyard with evidence of infestation by termite in spacing not less than 300 mm between specimens and not less than 600 mm between rows in accordance with ASTM D 1758-78. The initial weight was first determined before taken to field. This treat lasted for 12 months and the weight was measured thereafter, and the weight loss was calculated in accordance with ASTM D 3345-08 by using the following formula. For the test, three hundred and sixty (360) test specimens were used.

$$\mathrm{W} = \frac{\mathrm{W}_1\text{-}\mathrm{W}_2}{\mathrm{W}_1} \text{ X } 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.10)$$

Where the:

W= Weight loss

W_1=Initial weight

W_2=Final weight after attack

3.6.6 Culture medium

White rot fungus (*Xylaria spp*) and brown-rot fungus (*Sclerotium rolfsii*) inoculums were carried out at Forestry Research Institute of Nigeria (Pathology Section). Cultures of the inoculums were grown in Potato Dextrose agar (PDA), in the same laboratory while inoculation of bottles with the test fungi and incubated at (27 ± 2^0C). Hence, the laboratory experiments lasted for 20 weeks.

3.6.6.1 Infection of Test Blocks

The test blocks of (20x 20 x 20) mm^3 were incubated at 27 ± 2^0C for 20 weeks in the bottles. The test samples were separated from the culture bottles at the end of the gestation cycle, cleaned of the adhering mycelia; splinters of wood were carefully separated and re-weighed immediately to assess the absorbed moisture. Then, samples at 103^0C were oven-dried to persistent dry wetness.This is in line with the method employed by Arora, (2006) and Sarker *et al.,* (2006).

3.6.6.2 Determination of Durability after Incubation

The wet weights of the test blocks were determined at the conclusion of the experiment, after which they were dried in the oven for 18 hours at 103^0C and were allowed to cool before final weight was measured. The durability level of the wood samples was determined based on the percentage of weight loss of the specimens indicating increased susceptibility to white and brown rot fungi attacks. The average percentage weight loss was determined using equation below and also used for the analysis of the resistance of the fungi on the samples as indicated by the resistance classes to specific test organism which ranged from resistant to slightly resistant or non-resistant.

$$W = \frac{W_1 - W_2}{W_1} X\,100 \text{ ....} (3.11)$$

Where the:

W= weight loss,

W_1=initial weight before fungi attack and,

W_2=final weight after fungi attack (after oven dried).

3.7.0 Anatomical characteristics

3.7.1 Determination of Fibre dimension

From individual disks, radial strips were obtained from pith to bark based on the relative distance from pith to bark as used by H'ng Paik San *et al.,* (2000) and the strips were split into three zones: corewood, innerwood and outerwood

3.7.2 Maceration of wood test samples

Wood slivers parallel to the grain of about 1mm x 2mm x 2mm, obtained from different positions of the ring blocks were macerated in equal volumes of hydrogen (1:1) of 10% glacial acetic acid and 30% hydrogen peroxide inside an oven at about 100^0C for 2 hours after the method of Franklin (1945). The resulting solution was then agitated thoroughly to separate it into individual fibers and viewed on stage micrometer attached with Light Microscope (Zeiss) at 80 magnifications. The test specimens were obtained axially from the base, the middle, and the tip and across, corewood, innerwood and outerwood of which each of them was replicated 3 times totaling 270 samples. On slides, random samples of macerated fibers were installed and weighed. From each representative sample, twenty (20) fibres were measured. The microscopy was carried out according to the 2007 ASTM D1413-61 protocol.

3.7.3. Fibre measurement

Two (2) macerated fibres were placed on a slide (7.5cm x 2.5cm) by means of a dropper and 25 cells were measured following the process used by (Ogbonnaya *et al.* 1997) and viewed under the Light Microscope (Zeiss). Thickness cell-wall, fiber diameter, lumen width and fiber length parameters using 10× Magnification were measured.

3.7.4 Derived morphological indices

On the basis of the method adopted by Oluwadare and Sotannde (2006) for derived morphological indices were determined using these equations;

$$\text{flexibility power} = \frac{\text{lumen width}}{\text{fibre diameter}} \text{X} \frac{100}{1} \ldots\ldots\ldots..\ldots\ldots.\ldots\ldots\ldots..\ldots (3.12)$$

$$\text{Runkel Ratio} = \frac{\text{cell wall X2}}{\text{lumen width}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots..\ldots\ldots (3.13)$$

$$\text{slenderness} = \frac{\text{fibre length}}{\text{fibre diameter}} \ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots (3.14)$$

$$\text{rigidity} = \frac{\text{cell wall thickness}}{\text{fibre diameter}} \text{ X} \frac{100}{1} \dots\dots\dots\dots\dots\dots\dots\dots.. (3.15)$$

$$\text{Muhlsteph ratio} = \frac{\text{fibre width}^2 - \text{lumen width}^2}{\text{fibre width}^2} \text{X } 100 \dots\dots\dots\dots\dots\dots. (3.16)$$

$$\text{F} - \text{factor} = \frac{\text{fibre length}}{\text{fibre cell wall thickness}} \dots\dots\dots\dots.\dots\dots\dots\dots\dots..\dots\dots.\dots\dots (3.17)$$

3.7.5 Sectioning

The determination of anatomical properties starts with sectioning of the wood materials. Sectioning refers to the cutting of thin slice of the wood material. It was carried out with the use of a microtome. Prior to this, the 20 x 20 x 20 mm sample of wood blocks was treated in preparation for dissection on the basis of the density collected. Specimens were boiled in water until they sank to the base of the beaker to get softened. In order to display the dimensional axes such as, transverse, radial and tangential sections, the wood blocks were oriented. Then, 0.02 mm thick wood in size sections were used.

The measures taken in slide preparation are as follows;

> For 30 minutes, the segment was stained with Safranine O and rinsed in water. The sections were soaked in 50 % and 95 % ethanol to extract the surplus staining on the sections.

> The ethanol solvent was extracted by covering the sectioned for around 5 minutes with several drops of clove oil.

> In xylene, parts were moved. The dehydration and separation process is called the process of immersion in xylene solvent.

>Through the use of Canadian balsam, section were then placed on the slides. The Canadian balsam's function is to facilitate placement of the fibres intact without shrinking or collapsing for a much lengthier amount of time and to stay clearer.

Finally, 90 representative slides of the sample were picked, prepared and microscopic examination to observe the cell differentiation of the wood just at the base, middle and top and core, inner, outer for all the trees. All the dimensional planes were observed and the photomicrographs for vessels were taken, counted and measured. Twenty (20) measurements were recorded (length and diameter) per sample for vessels.

3.8.0 CHEMICAL PROPERTIES

The chemical constituent of wood can be classified into four groups. Cellulose and hemicellulose collectively termed holocelullose, account for 70-75 % of the wood substance. Lignin is present in amount ranging from 25-30 % and extractive which are diverse groups of low molecular weight compounds are found in variable quantities from 3-10 % (Evans, 1991).

3.8.1 Determination of Extractive Content

Sawdust from the billets was collected during the process of samples conversion in accordance with ASTM D1413 (2007). The mill was cleaned after each conversion to ensure that different samples did not mix. The sawdust was dried and sieved in order to give standard size, which passed through No. 60 (250 µm) sieve and retained on a No.80 (180 µm) sieve. 200 g of the sawdust was put into the extraction thimble of the Soxhlet extractor apparatus and extracted with 500 ml of ethanol-toluene and extracted for the duration of 8 hrs. The extracted sawdust was air dried and then weighed. The extractive content was calculated using the formula as follow;

$$\mathrm{Ec} = \frac{\mathrm{W1} - \mathrm{W2}}{\mathrm{W1}} \text{ x } 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.18)$$

Where the:

W_1 = Weight of saw dust before extraction

W_2 = Weight of saw dust after extraction

Ec = % extractive content

3.8.2 Determination of Cellulose Content

The cellulose content using ASTM D1348-94 (2008) was assessed and classified as follows: Five grams of extractive free saw-dust was boiled in 1% sodium hydroxide (NaOH) for around 30 minutes. It was thoroughly washed away with purified water. Chorine gas produces in large amounts when hydrochloric acid (HCl) was pour on boiled dust for 45 minutes, thereafter, potassium permanganate ($KMnO_4$) was introduced to the dust at wet state through a tilted tube. For HCl extraction, the residue was washed with purified water, 2 % sodium sulphide solution (Na_2SO_3) was added. This blend was boiled for 5 minutes and added 0.2 % sodium hydroxide (NaOH) to the mixture. The substance was permitted to continue for another 5 minutes on the gas burner. The process was repeated extensively until the specimens become bleached. This happens at the stage in which any colour alteration is no longer caused by additional chlorination, suggesting that the lignin was completely detached by the addition of chlorine. The processing was done by addition of 0.1 % of sodium hypochlorite to complete the bleaching of the residual while the pulp sheet produces was allowed to solidify and was then oven-dried at 100^0C for 2 hours. The proportion amount of cellulose was determined as;

$$\mathrm{Cc} = \frac{\mathrm{Wp}}{\mathrm{Wd}} \text{ X } 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots. (3.19)$$

Where:

Cc = cellulose content

w_p = weight of oven dry pulp

w_d = weight of extracted dust.

3.8.3 Determination of lignin content

Lignin is a biopolymers component that acts as a thickening agent that binds every individual fiber together. The composition of lignin was assessed based on the TAPPI T222 om-02 (2002). When stirring and mixing, 1g of extractive free sawdust was dried in the oven to determine the weight and digested with 15 cm^3, 72 % sulphuric acid was added slowly. The experiment was permitted to continue with regular stirring at room temperature in water bath for 2 hours. 475 cm^3 of distilled water was subsequently added. By adding hot distilled water, the content was allowed to boil for approximately 4 hours at constant rate. The insoluble lignin formed was allowed to settle overnight, filtered and rinsed inside hot distilled water till it appeared bleached. The sample collected was then dried in the oven at 85^oC until it reaches stable weight. Thereafter, percentage insoluble lignin was calculated using this formula;

$$\%\ \text{lignin} = \frac{\text{weight of lignin}}{\text{oven dried weight of extractive free sawdust}} \times 100 \ldots\ldots (3.20)$$

3.8.4 Determination of Hemicellulose Content

Holocelluloses consists of cellulose and hemicellulose. According to Jane *et al.,* (1970) the composition of cellulose and lignin are closely related where the greater lignin content the lower cellulose in wood. The method developed by Wise *et al.* (1946) had been utilized within the determination of holocellulose substancet. 2g of extractive free sawdust of known dampness substance was soaked in frosty-water and the excess dampness was extracted by suction. The test was chlorinated for five minutes and extracted by including 50 ml of 95 % ethanol and hot ethanol-monoethanolamine solution. During each processing, the residue was meticulously washed with distilled water before being extracted again until the residue turned white. The washing process was repeated several times until the residue was litmus-neutral. The collected residue was oven dried to a consistent weight. Below equation was used to calculate the percentage of holocellulose in a moisture-free extractive-free milled sample.

$$\%\ \text{Holocellulose} = \frac{W0}{W1} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.21)$$

Where the:

w_0 = moisture free and extractive free milled sample weight

w_1 = weight of dried holocellulose residue.

3.8.5 Determination of Percentage Ash Content

Percentage ash content was evaluated based on the TAPPI, T211 cm-02 (2002) method by heating 2g of pulverized wood samples in a muffle furnace at 600ºC for 4 hours and then cooled in desiccators. The crucible and as well as samples were weighed and then put in the oven at 103±2ºC. It was cooled inside desiccators and weighed. This continued until constant weight is obtained. The crucible and its content was placed in the muffle furnace and ignited until the carbon is eliminated. The content was heated slowly at the start to avoid flaming and to avoid mechanical loss of test specimen. The temperature of final ignition will be 580-600ºC. The crucible with its content was removed from the furnace and placed inside desiccators to cool and weighed accurately.

$$\text{Ash Content} = \frac{W2}{W1}\ X100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots (3.22)$$

Where the:

w_1= weight of crucible and ash

w_2 = weight of crucible and oven dried sample.

3.8.6 Determination of silica content and Atomic Absorption Spectrophotometer (AAS)

Percentage silica content using TAPPI T203 cm-02, 2002 method

$$\% \text{ silica} = \frac{w_0 - w1}{w_2} \text{ X} \frac{100}{1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.23)$$

Where:

$w_{1=}$ weight of oven dried sample

w_1= crucible weight

w_2 = weight of crucible and oven dried sample

3.8.7 Determination of Atomic Absorption Spectrophotometer (AAS)

AAS using PERKIN ELMER method model aaatyst 200Mg, for Fe, Zn, Pb, Mg, Cu, Ca, Al, K, Na, P/PO4.

3.9 Statistical Analysis

Analysis of Variance (ANOVA) was used to analyzed the data obtained

3.10 Analysis of Variance

The eassesment of the distinctive causes of variation in all physical properties, mechanical properties, anatomical structure and the natural durability measure, the analysis of variance (ANOVA) was used. The differences in means from treatment at sampling direction (Base, Centre and Top) and radial location, (corewood, innerwood and outer-portion) were the considered factors. Therefore, the Duncan DMRT was used to perform differentiation of treatment approaches in order to determine the discrepancy between the means and to choose from the factors in question the best treatment combination.

3.11 Experimental Design

Randomized Complete Block Design with five replications for the specimen adopted was a split-plot 2 cause on the main-plot and sub-plot for Physical and Mechanical properties. Completely Randomized Design (CRD) experimental design was adopted in 3 X 6 X 2 factorial experiment for fungi experiment, Completely Randomized Design (CRD) experimental design was also adopted in 3x6 factorial experiment for graveyard test and 3x4 factorial experiments was used for Chemical composition and extractives components. The following are the variables;

1. Sampling height: top, middle and base
2. Radial position: outer1, inner1, core1,core 2, inner 2 and outer 2
3. Fungi test: Brown rot and White rot
4. Stand: *A. altilis* stand 1, stand 2, stand 3and stand 4

3.11.1 Model specification: The mathematical model for 2 factor split plot experiment is given as;

$$Y_{ijk}=\underbrace{\mu+R_i+A_j+(RA)_{ij}}_{\text{Main plot component}}+\underbrace{B_k+(AB)_{jk}+\varepsilon_{ijk}}_{\text{Sub-plot component}}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.24)$$

Where:

Y_{ijk}= Individual observation

μ = General mean

R_i = Effect of the block (or replicate)

A_j = Effect of factor A

B_k = Effect of Factor B

RA_{ij} = Effect of interaction RA (Error (A)

$(AB)_{jk}$ = Effect of interaction AB

ε_{ijk} = Sub- plot experimental error (Error (B)

In this design, the main factor is sampling level where the sub-factor is the radial zone which is allotted on the main plot. Each tree wre treated as replicates.

3.11.2: The mathematical model for the Chemical composition and extractive components 3x4 factorial experiments are given as:

$$Y_{ijk}= \mu + A_i +B_j + (AB)_{ij} +E_{ijk}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3.25)$$

Where the;

μ = General mean of individual observation

A_i = Effect of factor A (Sampling Height)

B_j = Effect of factor B (Stand)

$(AB)_{ij}$= Effect of interaction between factor A and B

E_{ijk}= Effect of interaction Error term.

3.11.3 The mathematical model for the Fungi resistance test, 3 X 6 X 2 factorial experiment is given as:

$$Y_{ijk} = \mu + A_i +B_j + C_k+ (AB)_{ij}+ (AC)_{ik}+ (BC)_{ij}+(ABC)_{ijk}+E_{jk}\ldots\ldots...(3.26)$$

Where the:

Y_{ijk}= Individual observation
µ = General mean
A_i = Effect of factor A (Sampling Height)
B_j = Effect of Factor B (Radial position)
C_k=Effect of factor C (Fungi test)
$(AB)_{ij}$= Effect of interaction between factor A and B
$(AC)_{ik}$ = Effect of interaction between factor A and C
$(BC)_{ij}$= Effect of interaction between factor B and C
$(ABC)_{ijk}$ = Effect of interaction between factor A, B and C
E_{ijk} = Effect of interaction Error term.

3.11.4: The mathematical model for the Grave yard test, 3 X 6 factorial experiments is given as:

$$Y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + E_{ijk} \qquad (3.27)$$

Where the:

Y_{ijk}= Individual observation
µ = General mean
A_i = Effect of factor A (Sampling Height)
B_j = Effect of Factor B (Radial position)
$(AB)_{ij}$ = Effect of interaction between factor A and B
E_{ijk}= Effect of interaction Error term.

3.12. Statement of Hypothesis

The factor considered in the hypothesis includes (a) Trees (Replicate), (b) Sampling height; (c) Radial sampling.

Hypothesis stated thus:

1. H_o there is no significant differences in the properties exhibited by individual tree
2. H_o Effect of height level on wood properties studied is not significant
3. H_o Effect of radial position of test samples on the wood properties is not significant

3.13 Regression Analysis

Regression Analysis was use to predict strength properties from wood density in the species.

$Y=b_o + b_1X_1 + \varepsilon$……………………………………………. (3.28)

Where the:

Y = Strength property (MOE, MOR, MCS//, Impact Bending, and Shear test)

b_o = Constant, ε = Error of estimation, X = Wood Density

CHAPTER FOUR

RESULTS

Chapter four provides results of this study from the data obtained from the experiments during the study. Physical properties (density, specific gravity, percentage shrinkage), mechanical properties (MOR, MOE, MCS//, IM and Shear test), anatomical, chemical and durability characteristics for the *A. altilis* are shown according to the sequence of the experiments. Data obtained were analysed and recorded in tables. Plate 4.1 shows the physical appearance of *A.altilis* wood.

4.1: The result of Physical Properties *A.altilis* Wood

4.1.1: Wood Density

Mean density of *A.altilis* wood was 581.48±57 kg/m^3. The density value ranges from 602.74±64 kg/m^3 at the base, 571.00±47 kg/m^3 middle to stem-top 570.70±56 kg/m^3. This depicts that density reduces at base to the stem-top as shown in Table 4.1 Radially, the average mean wood density values ranges from 590.41±59 kg/m^3 to 629.28±54 kg/m^3 corewood to outerwood at the base, 572.67±49 kg/m^3 to 570.79±44 kg/m^3 corewood to outerwood at the middle, and 570.52±86 kg/m^3 to 579.02±54 kg/m^3 corewood toward outerportion wood at the stem-top as shown in Figure 4.1. Hence, highest density was recorded at the base. Table 4.5 shows that wood density of *A.altilis* can be categorised as low density wood.

Analysis of variance presented in Table 4.2 reveals a significant influence of sampling height *(*p=0.047*)* but radial position (p=0.550) has no significant effect on the wood density of *A. altilis* at 0.05 % level. Interaction between sampling height and radial position has no significant influence on the wood density of *A. altilis*. Duncan Test reveals that significant difference exits in wood density at the base between outerwood and corewood, outerwood and innerwood, corewood and innerwood. The density of the corewood, innerwood, and outerwood at the midlle and stem-top of the wood is significantly different along the radial location, as shown in Table 4.1

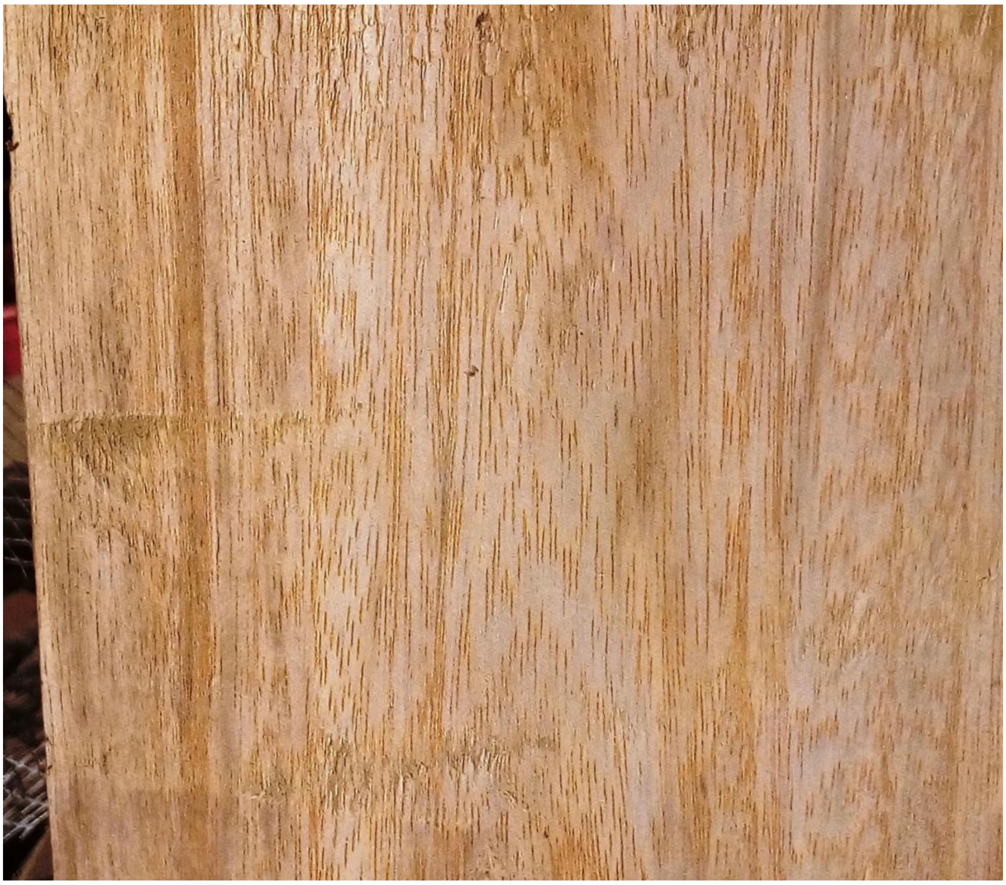

Plate 4.1. Physical appearance of *A.altilis* wood

Table 4.1 The Mean Values for Wood density and specific gravity of *A. altilis* wood

Sampling Position	Radial location	Wood Density Mean ±SD (kg/m^3)	Specific gravity Mean ±SD
Base	Corewood	590.41±59.41$_{b}$	0.59±0.07$_{b}$
	Innerwood	581.28±64.88$_{c}$	0.61± 0.04$_{a}$
	Outerwood	629.28±54.32$_{a}$	0.59± 0.08$_{b}$
Pooled Mean		**602.67±59.47**	**0.60± 0.06**
Middle	Corewood	572.67±49.93$_{a}$	0.59± 0.06$_{ab}$
	Innerwood	569.56±58.57$_{b}$	0.54± 0.05$_{b}$
	Outerwood	570.79±44.02$_{ab}$	0.61± 0.10$_{a}$
Pooled Mean		**571.01±47.36**	**0.58± 0.06**
Top	Corewood	570.52±86.45$_{ab}$	0.57 ± 0.05$_{b}$
	Innerwood	562.56±30.57$_{b}$	0.57 ±0.06$_{ab}$
	Outerwood	579.02±54.33$_{a}$	0.59± 0.04$_{a}$
Pooled Mean		**570.70± 56.02**	**0.57± 0.07**
Mean		581.48±57.61	0.58 ±0.06

Means±Standard mean error for repeated samples of 5 samples. Values in and column of the same alphabet were never significantly different at alpha = 0.05 using the Duncan multiple range test.

4.1.2 Specific gravity

A.altilis wood had specific gravity means 0.58±0.1.The specific gravity was ranged at base 0.57±0.01, at middle 0.58±0.06, and at stem-top mean 0.57±0.06. This reveals the specific gravity reduced at the base to the top as presented in Table 4.1. Radially, specific gravity ranges from 0.60±0.07 to 0.60±0.08 at the corewood to the outerwood along timber trunk just at base, 0.59±0.06 to 0.61±0.10 from the corewood to the outerwood, while center ranges from 0.57±0.05 to 0.59±0.04 corewood to the outerwood at the stem-top, as shown in Table 4.2 and Figure 4.1 respectively.

Analysis of variance presented in Table 4.2 reveals that both sample direction and radial plane variations insignificantly influence the specific gravity at 0.05 % probability level (p=.834 and p=.903). Interaction between sampling and radial position has a significant influence on the specific gravity of *A.altilis*. Duncan Test reveals that significant difference exits in specific gravity at the base between innerwood and corewood, innerwood and outerwood, while at the radial levels; specific gravity is considerably influenced at the midlle and top of the wood at the corewood and innerwood as presented in Table 4.1.

Table 4.2. Analysis of Variance for Wood Density and Specifi gravity of *A.altilis*

Sources of variation	Df	Density	Specific gravity
Tree (Block)	3	0.0006 *	0.0000*
Sampling Height (SH)	2	0.0471*	0.834^{ns}
Major plot Error	6	-	-
Radial Position (RP)	5	0.5504^{ns}	0.9025^{ns}
SH x RP	10	0.855^{ns}	0.0857*
Sub plot Error	45		
Total	71		

ns= not significant (p-values > 0.05)

*⁼ significant (p-values < 0.05)

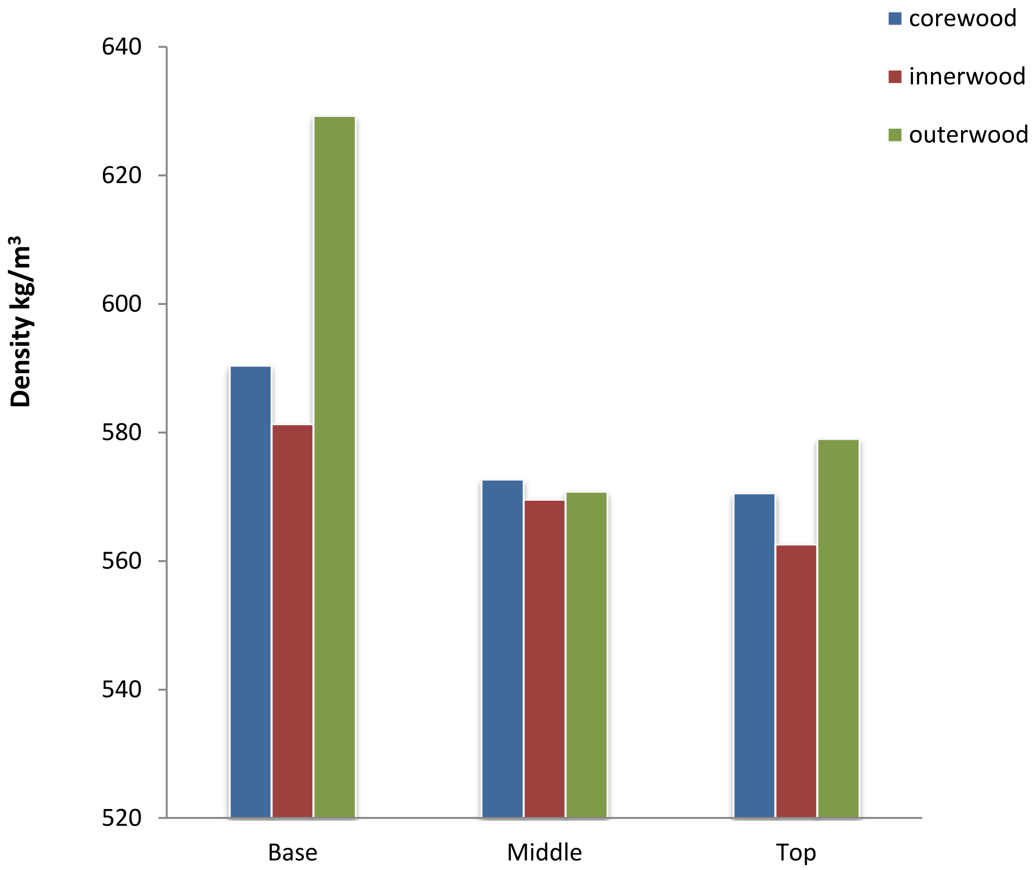

Figure 4.1: Effect of SP and RP on wood density of *A.altilis*

4.1.3: Tangential Shrinkage (TS)

A.altilis' total mean of tangential shrinkage (at 12% mc) was 4.30±0.71 %. The tangential shrinkage ranges at the base 3.69±0.81 %, middle 4.33±0.38 %, 4.74±0.39 % at the stem-top.It reveals that tangential shrinkage increased at base to stem-top as presented in Table 4.3. Radially, tangential shrinkage mean values rise from base to top, varying from 3.90±0.80 % till 3.56±0.99 % corewood to outerwood across the trunk at the base, 4.33±0.54 % to 4.39±0.18 % at corewood to outerwood across the trunk at the center and 4.69 ± 0.38 % to 4.75±0.17 % at corewood to outerwood of the trunk at the top as shown in Figure 4.2. The higest tangential shrinkage was recorded at the stem-top of the wood.

Analysis of Variance presented in Table 4.4 shows the sampling position (p=0.000) and radial location (p=.002) had a major effect on *A.altilis* tangential shrinkage at the likelihood level of 0.05%. An interaction between sampling level and radial position has insignificant influence on the tangential shrinkage of *A. altilis*. Duncan test reveals that significant difference exits at the base, between corewood and outerwood, at middle, significant difference exits between outerwood and corewood, outerwood and innerwood, and corewood and innerwood, at top in tangential shrinkage while significant difference also exits between innerwood and outerwood, innerwood and corewood, outerwood and corewood except for interaction between corewood and innerwood, outerwood and innerwood along the radial position as presented in Table 4.3.

4.1.4: Radial Shrinkage (RS)

Means of radial shrinkage (at a mc of 12 %) of *A.altilis* wood had 1.42±0.40%, with the mean at the base 1.31±0.35 %, middle 1.45±0.43 %, and top was 1.49±0.37%. This demonstrates that, radial shrinkage rise at the base to top as presented in Table 4.3, at radial position, mean varies from 1.14±0.09 % to 1.33±0.29 % from corewood to outerwood of the base of trunk, at centre, the values range from 1.33±0.35 % to 1.53±0.47 % corewood to outerwood, and 1.43±0.34 % to 1.64±0.55 % from corewood to outerwood of the trunk at the stem-top as presented in Figure 4.2

Analysis of variance presented in Table 4.4 reveals insignificant effect of sampling position (p=0.132) but radial location (p=0.279) had significant effect on *A.altilis* radial shrinkage at the likelihood level of 0.05%. Then, between sampling levels and radial position interaction exists, likewise, effects of interactions has insignificant influence across the radial shrinkage of wood of *A. altilis*.

The multiple comparison test in Table 4.3 reveals that significant difference at the likelihood level of 0.05% exits in radial shrinkage at the base (innerwood and outerwood, innerwood and corewood,outerwood and innerwood,outerwood and corewood); at middle, significant difference exits between (outerwood and innerwood, outerwood and corewood, innerwood and corewood); at top, significant difference also exits (outerwood and corewood, outerwood and innerwood, corewood and innerwood,corewood and outerwood) along the radial position for radial shrinkage as presented in Table 4.3.

4.1.5: Volumetric Shrinkage (VS) of *A. altilis* Wood

A.altilis had a VS mean of 5.64±0.82 %, with an average mean of 5.64±0.82 %. from 4.94±0.77 % at the base, 5.75±0.56 % middle and at the top was 6.24±0.54 % which showed that axially VS rises from base to the top as presented in Table 4.3. Radially, the means varies along the bole at the base 5.10± .75 % to 4.90±1.01 % corewood to outerwood, across the bole at the middle ranges 5.66±0.76 % to 5.92±0.56 % corewood to outerwood and 6.12±0.48 % to 6.39±0.68 % corewood to outerwood along trunk at the stem-top as shown in Figure 4.2

From Table 4.4, analysis of variance showed that the sampling direction differed significantly from the VS (*p=0.0000*) but no significant difference along the radial position (*p=.798)* at 0.05 %. Between sampling height and radial position interaction, effects of interactions has insignificant influence on the VS of *A. altilis*.

Duncan test result in Table 4.3 showed VS has significant difference at 0.05 level of significance, exist in volumetric shrinkage at the base (corewood and innerwood, but insignificant effect exist (outerwood and corewood, outerwood and innerwood); at middle, significant difference exits between (outerwood and innerwood), but insignificant influence exist (corewood and outerwood, corewood and innerwood); at top, significant difference also exist (outerwood and innerwood, outerwood and corewood, innerwood and outerwood, innerwood and corewood) along the radial position for volumetric shrinkage as presented in Table 4.3.

Table 4.3: Means values for TS, RS, and VS of *A.altilis* wood at SH and RP

Sampling Height	Radial Position	T (%)	R (%)	V (%)
Base	Corewood	$3.93 \pm 0.77_{a}$	$1.14 \pm 0.09_{c}$	$5.08 \pm 0.75_{a}$
	Innerwood	$3.57 \pm 0.81_{ab}$	$1.44 \pm 0.49_{a}$	$4.86 \pm 0.73_{b}$
	Outerwood	$3.56 \pm 0.99_{b}$	$1.33 \pm 0.29_{b}$	$4.89 \pm 1.01_{ab}$
Pooled Mean		**3.69± 0.81**	**1.31± 0.35**	**4.94± 0.77**
Middle	Corewood	$4.33 \pm 0.54_{b}$	$1.33 \pm 0.35_{c}$	$5.66 \pm 0.76_{ab}$
	Innerwood	$4.27 \pm 0.36_{c}$	$1.48 \pm 0.25_{b}$	$5.66 \pm 0.33_{b}$
	Outerwood	$4.39 \pm 0.18_{a}$	$1.53 \pm 0.47_{a}$	$5.92 \pm 0.56_{a}$
Pooled Mean		**4.33± 0.38**	**1.45± 0.43**	**5.75± 0.56**
Top	Corewood	$4.69 \pm 0.38_{c}$	$1.43 \pm 0.34_{b}$	$6.12 \pm 0.48_{c}$
	Innerwood	$4.77 \pm 0.25_{a}$	$1.33 \pm 0.19_{c}$	$6.22 \pm 0.43_{b}$
	Outerwood	$4.75 \pm 0.17_{b}$	$1.64 \pm 0.55_{a}$	$6.39 \pm 0.68_{a}$
Pooled Mean		**4.74± 0.39**	**1.49± 0.37**	**6.24± 0.54**
Mean		**4.3±0.71**	**1.42±0.37**	**5.64±0.82**

Means±Standard mean error for 5 samples repeated. Values in and column of the same alphabet not substantially similar at alpha = 0.05 using the Duncan test

Table 4.4: The Analysis of Variance for TS, RS and VS at SH and RP of *A.altilis* wood

Source of Variation	**Df**	**Tangential (%)**	**Radial (%)**	**Volumetric (%)**
Tree	3	0.0003*	0.0000*	0.015*
Sampling height	2	0.000*	0.1319 ^{ns}	0.000*
Major Plot Error	6			
Radial position	5	0.0021*	0.279 *	0.796 ^{ns}
SH* RP	10	0.8424^{ns}	0.653 ^{ns}	0.978 ^{ns}
Error	45			

ns= not significant (p-values > 0.05)

*= significant (p-values < 0.05)

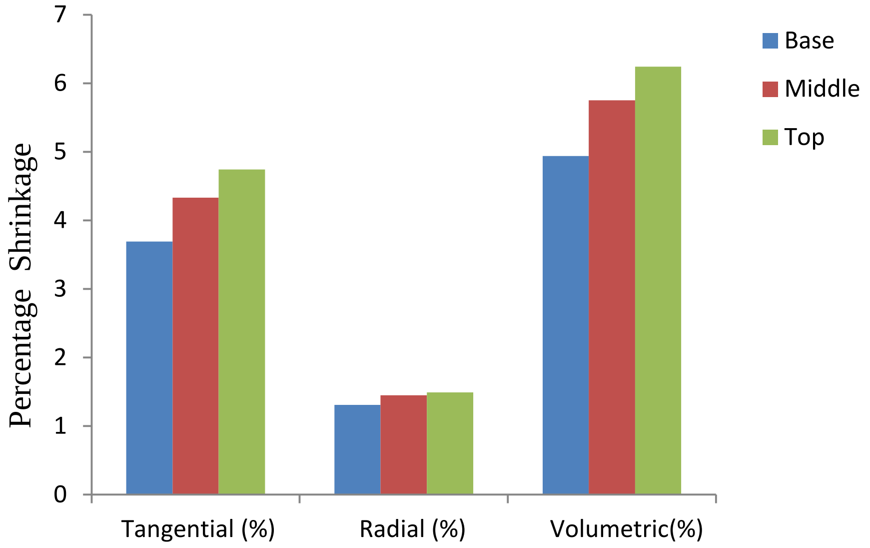

Figure 4.2: Percentage Shrinkage for TS, RS and VS at SH and RP of *A.altilis* wood

4.2: MECHANICAL PROPERTIES

The results of the mechanical properties of Breadfruit (*A.altilis*) wood such as Modulus of Rupture (MOR), Modulus of Elasticity (MOE), Maximum Compressive Strength (MCS//) parallel to grain, Impact and Shear Strength test are presented in Table 4.6. The result of the ANOVA is presented in Table 4.7

4.2.1: Modulus of Rupture (MOR)

Total mean values for MOR (with a moisture content of 12%) of *A. altilis* accounted for 36.05±8.32 N/mm^2, and average means ranged between 42.07±8.79 N/mm^2 at the base, 33.11±7.12 N/mm^2 at the center and 32.99±5.39 N/mm^2 at the top, this indicates that modulus of rupture rises at the wood base to the stem-top as presented in Table 4.6. Radially, means varies from 37.64±1.98 N/mm^2 to 46.81± 4.04 N/mm^2 at the base, 28.54±74.4 N/mm^2 to 39.10±4.04 N/mm^2 at the middle, 30.41±2.75 N/mm^2 to 36.99±5.39 N/mm^2 at the top as shown in Table 4.6. Highest modulus of rupture was recorded at the base.

Analysis of variance in Table 4.7 indicates that the sample height and the radial location have an important effect on the modulus of rupture *(p=0.0001)* and *(p=0.0001)* at a likelihood level of 0.05 %. Interaction between sampling height and radial position shows insignificant influence on modulus of rupture of *A. altilis*.

Duncan test result in Table 4.6 shows modulus of rupture has significant difference at 0.05 level of significant; significant difference exists in modulus of rupture at the base, middle and top (outerwood and innerwood, outerwood and corewood, innerwood and corewood) across the radial position for modulus of rupture.

4.2.2: Modulus of Elasticity (MOE)

Overall mean of modulus of elasticity (at 12% moisture content) of *A. altilis* 3354±1286 N/mm^2. The modulus of rupture mean values ranged from 3993±1983 N/mm^2 at the base, 2924±493 N/mm^2 at the center, and 3145±520 N/mm^2 at the top. This indicates that the modulus of elasticity decreasing from the base to the center and increases after the center to the top as shown in Table 4.6. Radially, means value ranged from 3526.61±604.28 N/mm^2 to 3630.06±555.49 N/mm^2 at the base, 2707.50±407.01 N/mm^2 to 3140.24±308.39 N/mm^2 at the middle, 3344.18±637.01 N/mm^2 to 2986.02 N/mm^2 at the top as shown in Table 4.6. Highest modulus of elasticity was recorded at the base.

Analysis of variance in Table 4.7 shows that the sampling height had a significant influence on the modulus of elasticity *(p=0.0001)* but had no significant influence at a probability level of 0.05 % along the radial position *(p=0.9011).* Interaction between sampling height and radial position shows insignificant influence on modulus of elasticity of *A. altilis*. Duncan test result in Table 4.6 showed modulus of elasticity has significant effect at 0.05 level of significance, exist in modulus of elasticity at the base, (innerwood and outerwood, innerwood and corewood, outerwood and corewood), at middle (outerwood and corewood, but insignificant effect exist between (innerwood and outerwood, innerwood and corewood), at top (corewood and innerwood, corewood and outerwood, innerwood and corewood, innerwood and outerwood,outerwood and corewood, outerwood andinnerwood) across the radial position for modulus of elasticity.

4.2.3: The maximum compressive strength test (MCS//)

The total mean MCS// (12% moisture content) of *A. altilis* 20±3.7 N/mm^2. The MCS// mean values ranged from 23±4.1 N/mm^2 at the base, 20±2.7 N/mm^2 at the middle, 18± 2.7 N/mm^2 at the top. This indicates that the compressive strength decreases from base to stem-top as presented in Table 4.6. Radially, means ranges from 22.5±2.5 N/mm^2 to 22.5±3.3 N/mm^2 at the base, 18.5±3.1 N/mm^2 to 21±2.7 N/mm^2 at the center, 18±3.6 N/mm^2 to 19±1.7N/mm^2 at the tip. Highest maximum compressive strength test (MCS//) was recorded at the base.

Analysis of variance in Table 4.7 reveals that the sampling height had a substantial effect on the maximum compressive force *(p=0.0001)* but had no significant influence on the compressive intensity of *A. altilis* along the radial position *(p=0.7742).* Then, between sampling height and radial position interaction shows insignificant influence of maximum compressive strength test (MCS//) on *A. altilis*.

The multiple comparism test in Table 4.6 shows insignificant difference at 0.05 level of significance, exist in maximum compressive strength test (MCS//) at the base, at middle, significant difference exist between (outerwood and innerwood, outerwood and corewood, innerwood and corewood, corewood and outerwood), at top (outerwood and innerwood, outerwood and corewood, corewood and outerwood) across the radial position for maximum compressive strength test (MCS//).

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Table 4.5 Timber categorisation for MOE, Density and MOR

Categorisation	MOR (N/mm^2)	MOE (N/mm^2)	ñ (kgm^3)
Heavy structure	> 133	>14,700	>720
Medium construction	89-1329	900-14,700	480-720
Light construction	39- 88	6860-9800	400 – 480
Very low density[very light construction]	< 39	< 6860	< 400
Artocarpus heterophyllus	119	6378	458
Artocarpus altilis	**36***	**3354***	**581***

Source: Kityo and Plumptre (1997)

*Values for present study

Table 4.6: The mean values for MOR, MOE, MCS//, Impact and Shear test of *A. altilis* at SP and RP.

Sampling Height	Radial Position	MOR (N/mm^2)	MOE (N/mm^2)	MCS// (N/mm^2)	IMPACT (J/m^2)	SHEAR (N/mm^2)
	Corewood	37.64±1.98$_c$	3526.61±604.28$_c$	22.5±2.5$_a$	12.92±4.55$_c$	9.1± 0.8$_b$
Base	Innerwood	41.76±7.68$_b$	4822.25±376.95$_a$	22.5±5.3$_a$	15.50±2.37$_a$	9.3±1.8$_b$
	Outerwood	46.81± 4.04$_a$	3630.06±555.49$_b$	22.5±3.3$_a$	14.52±3.06$_{ab}$	10.8±1.4$_a$
Pooled Mean		**42.07±8.79**	**3992.97±1983.22**	**23±3.7**	**14.31± 3.92**	**9.7± 1.7**
	Corewood	28.54±7.14$_c$	2707.50±407.01$_b$	18.5±3.1$_c$	13.89±1.83$_{ab}$	8.0±1.6$_c$
Middle	Innerwood	31.69±6.50$_b$	2923.96±692.67$_{ab}$	19±1.9$_b$	18.61±4.12$_a$	9.0±2.1$_b$
	Outerwood	39.10±2.92$_a$	3140.24±308.39$_a$	21±2.7$_a$	14.63±4.60$_b$	9.3±2.1$_a$
Pooled Mean		**33.11± 7.12**	**2923.89±493.25**	**20± 2.7**	**15.70± 4.39**	**8.7± 2.1**
	Corewood	30.41± 2.75$_c$	3344.18±637.01$_a$	18±3.6$_b$	15.86±3.04$_c$	8.4±0.7$_b$
Top	Innerwood	31.98± 3.98$_b$	3105.32±549.52$_b$	18± 2.9$_b$	16.10±3.99$_{ab}$	8.7±1.2$_a$
	Outerwood	36.58± 7.23$_a$	2986.02±410.64$_c$	19±1.7$_a$	17.64±4.42$_a$	8.5±1.1$_b$
Pooled Mean		**32.99± 5.39**	**3145.17±520.37**	**18± 2.7**	**16.53± 4.04**	**8.5± 0.9**
Mean		36.05±8.32	3354± 1286	20±3.7	15.51± 4.17	8.9± 1.7

Means±Standard mean error for 5 samples repeated. Values in and column of the same alphabet not substantially similar at alpha = 0.05 using the Duncan test

Table 4.7: The ANOVA for MOR, MOE, MCS//, Shear and Impact of *A.altilis* wood for SP and RP

Source of variation	**Df**	**MOR**	**MOE**	**MCS//**	**SHEAR**	**IM**
Tree	3	0.0005*	0.0011*	0.0000*	0.7856^{ns}	0.000*
Sampling Height	2	0.0001*	0.0001*	0.0001*	0.0021*	0.081^{ns}
Major Plot Error	6					
Radial position	5	0.0001*	0.9011^{ns}	0.7742^{ns}	0.1305^{ns}	0.003*
SH* RP	10	0.9467^{ns}	0.927^{ns}	0.7182^{ns}	0.3405^{ns}	0.6811^{ns}
Sub-Plot Error	45					
Total	71					

ns= not significant (p-values > 0.05)

*= significant (p-values < 0.05)

4.2.4: Shear Strength Test Parallel to Grain

The average mean shear strength (with a moisture content of 12 %) of *A. altilis* 8.9±1.7 N/mm^2, The shear strength mean ranged from 9.7±1.7 N/mm^2 at the base, 8.7±2.1 N/mm^2 at the center and 8.5± 0.9 N/mm^2 at the top. This indicates a reduction in shear strength from base to top as shown in Table 4.6. Radially, means ranges from 9.1±0.8 N/mm^2 to 10.8±1.4 N/mm^2 at the base, 8.0±1.6 N/mm^2 to 9.3±2.1 N/mm^2 at the middle, 8.4±0.7 N/mm^2 to 8.5±1.1 N/mm^2 at the top. Highest shear strength was recorded at the base.

Analysis of variance in Table 4.7 indicates that the sampling direction *(p=0.1305)* had a substantial effect on *A.altilis* but along the radial position *(p=0.341)* at a 0.05 % likelihood level is insignificant. Between sampling height and radial position interaction shows insignificant influence of shear strength on *A. altilis*. Duncan test result in Table 4.6 shows shear strength has significant difference at 0.05 level of significance, exist in shear strength at the base (outerwood and innerwood, outerwood and corewood but insignificant effect exist (innerwood and corewood); at middle, significant difference exits between (outerwood and innerwood), but insignificant influence exist (outerwood and innerwood, outerwood and corewood); at top, significant difference also exist (innerwood and corewood, innerwood and outerwood) along the radial position for shear strength on *A. altilis*.

4.2.5: Impact Bending Strength Test (IM) Parallel to the Grain

A cumulative mean impact bending test (with moisture content of 12 %) of *A. altilis* wood was 15.51±4.17 J/m^2, with mean range value at the base 14.31±3.92 J/m^2, middle 15.31±4.39 J/m^2, top 1653±404 J/m^2. This indicates that the strength of the impact bending rises from base to top as presented in Table 4.6. Radially, mean ranged from 12.92±4.55 J/m^2 to 14.52±3.06 J/m^2 at the base, 13.89±1.83 J/m^2 to 14.63±4.60 J/m^2, bole at the middle, and 15.86±3.04 J/m^2 to 17.64±4.42 J/m^2 to the top. Highest impact bending result was recorded at the top as shown in Table 4.6

Analysis of variance as presented in Table 4.7 indicates a sampling direction has significant effect on the impact bending strength *(p=0.081)* but has no significant influence on radial position (p=0.003) at a likelihood level of 0.05 % on the *A.altilis* wood. Duncan test presented in Table 4.6 shows impact bending has significant difference at 0.05 level of significance, exist in impact bending at the base (innerwood and corewood) but insignificant effect exist (innerwood and outerwood, corewood and outerwood); at middle, significant difference exits between (innerwood and outerwood), but insignificant influence exist (innerwood and corewood, outerwood and corewood); at top, significant difference also exist (innerwood and corewood, outerwood and corewood) along the radial position for impact bending on *A. altilis*

4.3. Anatomical Characteristics of *A. altilis* wood

The results of the Anatomical characteristics of *A.altilis* such as; Cellwall thickness, Lumen width, Fibre diameter, and Fibre length are presented in Table 4.8 and the ANOVA is presented in Table 4.9

4.3.1 Fibre Length

A.altilis' total mean fibre length is 1.52±0.28 mm. The fibre length means ranged from 1.58±0.28 mm at the base, 1.49±0.35 mm at the center and 1.48±0.19 mm at the top, this suggests that fiber length reduces from base to top as presented in Table 4.8.Radially, means ranged from 1.53±0.23 mm to 1.58±0.32 mm at the base, 1.33±0.23 mm to 1.52±0.36 mm at the center and 1.37±0.18 mm to 1.58±0.20 mm at the top as presented in Table 4.8, and also shown in Figure 4.4a.

From Table 4.9, analysis of variance indicates that sampling height *(p=0.2506)* had a major effect on fibre length of *A. altilis* wood, but radial location *(p=0.1510)* on the fiber length of *A. altilis* does not have a major impact at a likelihood level of 0.05 %. Sampling height and radial position interaction effect has insignificant influence on the fibre length of *A. altilis*. Duncan test in Table 4.3 reveals that has significant difference exist in fibre length at the base between (innerwood and corewood, but insignificant effect exist (outerwood and innerwood, outerwood and corewood); at middle, significant difference exist between (innerwood and outerwood, innerwood and corewood, corewood and outerwood), at top, significant difference exist between (innerwood and outerwood, innerwood and corewood, corewood and outerwood) along the radial position for fibre length as presented in Table 4.8

Table 4.8: The mean values for FL, FD, LW and CWT of *A.altilis* wood at RP and SP

Sampling Height	Radial Position	FL (mm)	FD (µm)	LW (µm)	CWT (µm)
Base	Corewood	1.53±0.23^{b}	44.77±10.3^{a}	27.12±10.84^{a}	6.52±0.17^{a}
	Innerwood	1.63±0.34^{a}	34.76±4.67^{ab}	21.54±8.24^{b}	6.12±0.49^{b}
	Outerwood	1.58±0.32^{ab}	31,57±7.02^{b}	18.80±4.96^{c}	6.05±0.33^{c}
Pooled Mean		**1.58±0.28**	**37.03±9.22**	**22.49±8.54**	**6.23±0.75**
Middle	Corewood	1.33±0.23$_{c}$	36.23±5.34$_{a}$	25.34±3.85$_{a}$	6.07±0.67$_{c}$
	Innerwood	1.63±0.41$_{a}$	32.60±4.58$_{b}$	20.16±5.74$_{c}$	6.27±0.56$_{b}$
	Outerwood	1.52±0.36$_{b}$	31.84±4.61$_{b}$	23.55±10.55$_{b}$	6.37±0.68$_{a}$
Pooled Mean		**1.49±0.35**	**33.55±5.09**	**23.01±7.89**	**6.23±0.71**
Top	Corewood	1.37±0.18$_{c}$	37.16±3.48$_{a}$	27.22±8.23$_{a}$	5.72±0.68$_{b}$
	Innerwood	1.49±0.13$_{b}$	32.13±5.86$_{c}$	22.67±4.67$_{b}$	5.87±0.43$_{b}$
	Outerwood	1.58±0.20$_{a}$	34.84±8.94$_{b}$	20.18±6.28$_{c}$	6.08±0.26$_{a}$
Pooled Mean		**1.48±0.19**	**34.70±7.67**	**23.36±7.53**	**5.88±0.53**
Mean		**1.52±0.28**	**35.09±7.56**	**22.95±7.89**	**6.11± 0.68**

Means±Standard mean error for 5 samples repeated. Values in and column of the same alphabet not substantially similar at alpha = 0.05 using the Duncan test

fl = fibre length, fd = fibre diameter, lw= lumen width, cwt = cell-wall thickness

Table 4.9: The ANOVA for FL, FD, LW and CWT at SP and RP of *A. altilis* Wood

Variation Sources	**Df**	**fibre length (mm)**	**fibre diameter (µm)**	**lumen width (µm)**	**cell-wall thickness (µm)**
Tree	3	0.0000*	0.0003*	0.0003*	0.0273*
Sampling Height	2	0.2506*	0.191^{ns}	0.912^{ns}	0.143^{ns}
Major Plot Error	6				
Radial position	5	0.1510^{ns}	0.0159*	0.066^{ns}	0.983^{ns}
SH* RP	10	0.942^{ns}	0.332^{ns}	0.6027^{ns}	0.418^{ns}
Sub-Plot Error	45				
Total	71				

fl = fibre length, fd = fibre diameter, lw= lumen width, cwt = cell-wall thickness.

ns= not significant (p-values > 0.05)

$*^{=}$ significant (p-values < 0.05)

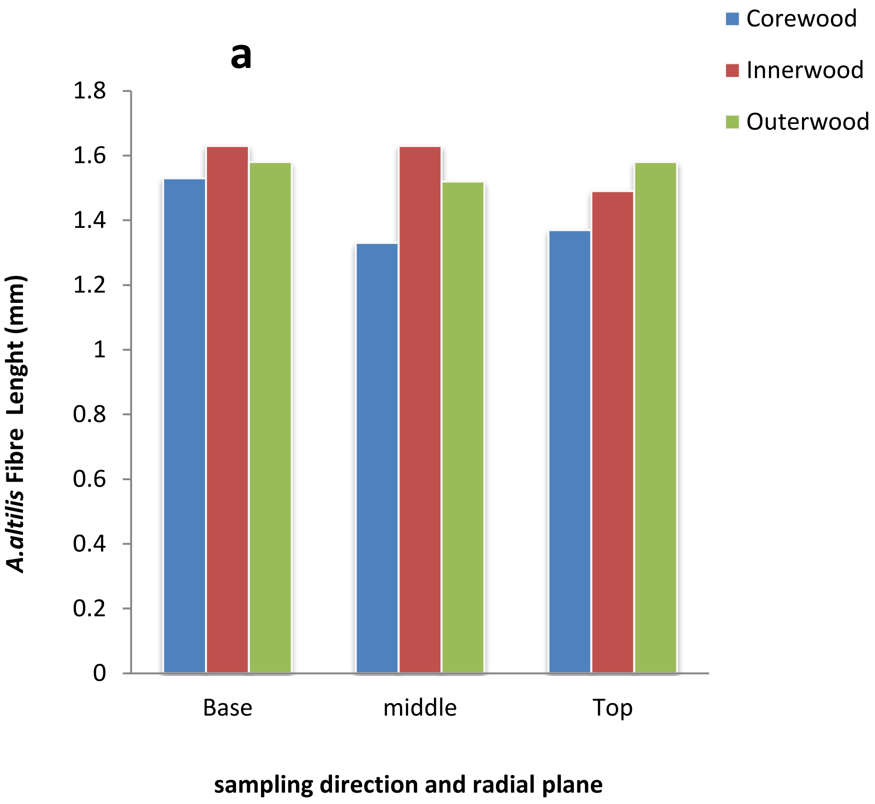

Figure 4.4a: Effect of SP and RP on FL of *A.altilis* wood

4.3.2 Fibre Diameter

The average mean diameter of the fiber of *A.altilis* is 35.09±7.56 µm.The fiber diameter ranged from 37.03±9.22 µm at the base, 33.55±5.09 µm at the center and 34.70±7.67 µm at the top. This depicts that fiber diameter reduces from base to stem-top as presented in Table 4.8. Radially, average mean fiber diameter values ranges from 44.77±10.29 µm to 31.57 7.02 µm at base, 36.23±5.34 µm to 31.84±4.61 µm at the middle, 37.16 ±3.48 µm to 34.84±8.94 µm at top. This shows that a specific trends of variation across the sampling direction and radial location did not reveals fiber diameter, although reductions from foundation to center and negligible rise to the top, rise to the wood-inner at the corewood and decrease to the wood outer portion as shown in Figure 4.4b. Highest fiber diameter was recorded at the base.

The analysis of variance presented in Table 4.9 indicates insignificant impact of the sampling position *(p=0.191)* on the fiber diameter of *A. altilis* while a significant influence was observed in the radial plane *(p=0.0159)* at the likelihood level of 0.05%. Sampling height and radial position interactions effects has insignificant influence on the fiber diameter of *A. altilis*. Duncan test in Table 4.9 shows that significant difference exist in fibre length at the base between (corewood and outerwood, but insignificant effect exist (innerwood and corewood, innerwood and outerwood); at middle, significant difference exist between (corewood and innerwood), but insignificant effect exist between (innerwood and outerwood), at top, significant difference exist between (corewood and outerwood, corewood and innerwood, outerwood and corewood) across the radial position for fibre diameter.

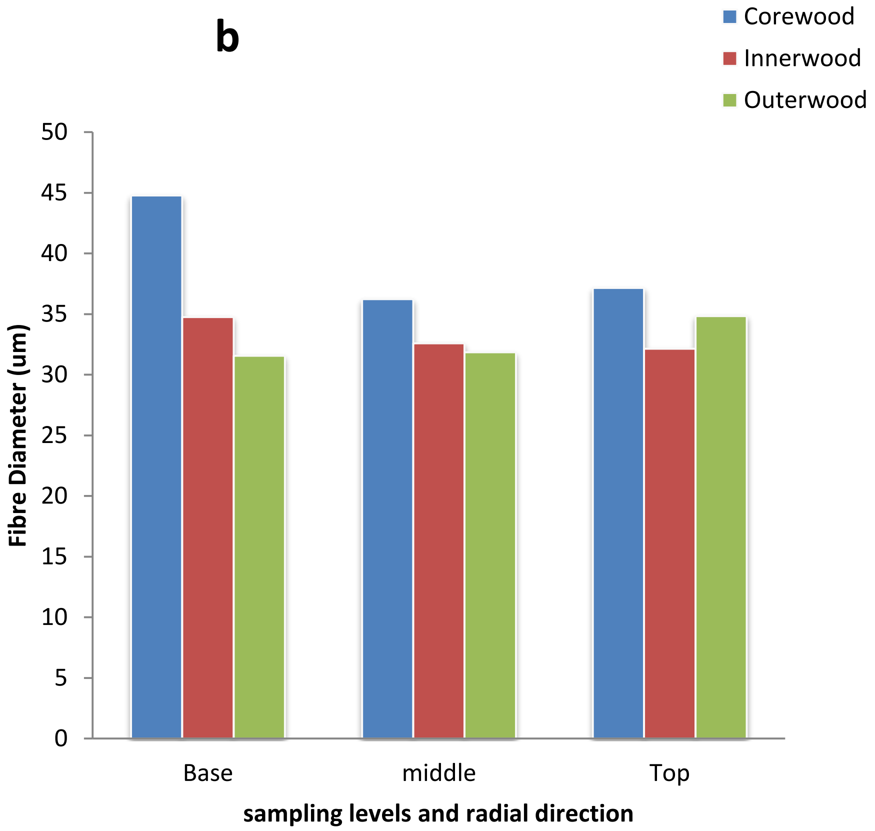

Figure 4.4b: Effect of SP and RP on FD of *A.altilis* wood

4.3.3 Lumen Width (µm)

The average mean width of a lumen of *A. altilis* is 22.95±7.8 µm, with an average mean value ranged from 22.49±8.54 µm at the base, 23.01±7.89 µm at the middle, and 23.36±7.53 µm at the top. This suggests that lumen width rises from base to top as presente in Table 4.9. Radially, ranged from 27.12±10.84 µm to 18.80±4.96 µm at the base; 25.34±3.85 µm to 23.55±10.55 µm at the center, 27.22±8.23 µm to 20.18±6.28 µm at the top as shown in Figure 4.4c. The top-stem had the highest lumen width.

The analysis of variance presented in Table 4.9 reveals that the sampling position (p=0.912) and the radial location (p=0.066) has no major influence on the lumen width of *A. altilis* at a likelihood level of 0.05 %. Sampling height and radial position interactions effects has insignificant influence on the lumen width of *A. altilis*.

The multiple comparism test in Table 4.8 indicated that significant difference exist in lumen width at the base between (corewood and innerwood, corewood and outerwood, innerwood and corewood, innerwood and outerwood, outerwood and innerwood, outerwood and corewood); at middle, significant difference exist between (corewood and innerwood, corewood and outerwood, innerwood and corewood, innerwood and outerwood, outerwood and innerwood, outerwood and corewood) at top, significant difference exist between (corewood and innerwood, corewood and outerwood, innerwood and corewood, innerwood and outerwood, outerwood and innerwood, outerwood and corewood) across the radial position for lumen width of *A. altilis*.

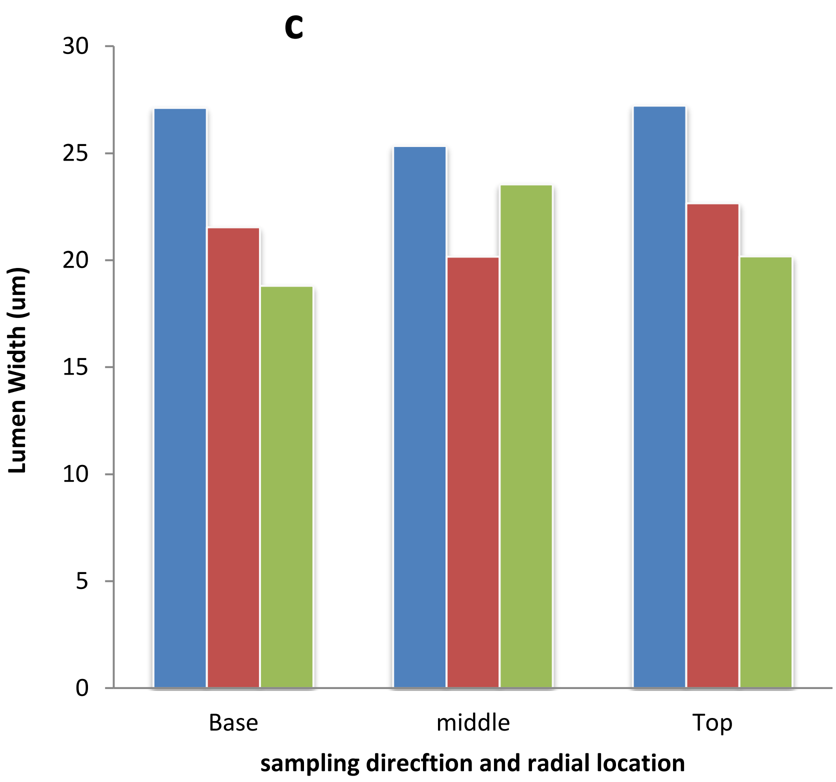

Figure 4.4c: Effect of SP and RP on LW of *A.altilis* wood

4.3.4 Cell wall thickness (CWT)

The gross median thickness of the cell wall of *A. altilis* is 6.11±0.68 µm, and average mean ranged at the base of 6.23±0.75 µm, 6.23±0.71 µm at the center and 5.88±0.53 µm at the top. This indicates that the thickness of the cell-wall reduces from base to center and top as shown in Table 4.8, although radially, mean value of CWT ranged from 6.52±0.17 µm to 6.05±0.33µm at the base, 6.07±0.67 µm to 6.37±0.68 µm at the center and 5.72±0.68 µm to 6.08±0.26µm at the top as presented in Figure 4.4d.

The analysis of variance presented in Table 4.9 reveals insignificant difference between sampling position (p=.143) and radial plane *(p=0.983)* on the cellwall thickness of *A. altilis* at the likelihood level of 0.05 %. Sampling height and radial position interactions effects has insignificant influence on the cellwall thickness of *A. altilis*.

The multiple comparism test in Table 4.8 shows significant difference in cellwall thickness at the base between (corewood and innerwood, corewood and outerwood, innerwood and corewood, innerwood and outerwood, outerwood and corewood, outerwood and innerwood); at middle, significant difference exist between (outerwood and innerwood, outerwood and corewood, innerwood and outerwood, innerwood and corewood, corewood and outerwood, corewood and outerwood); at top, significant difference exist between (outerwood and innerwood, outerwood and corewood, innerwood and outerwood) across the radial position for cellwall thickness of *A. altilis*.

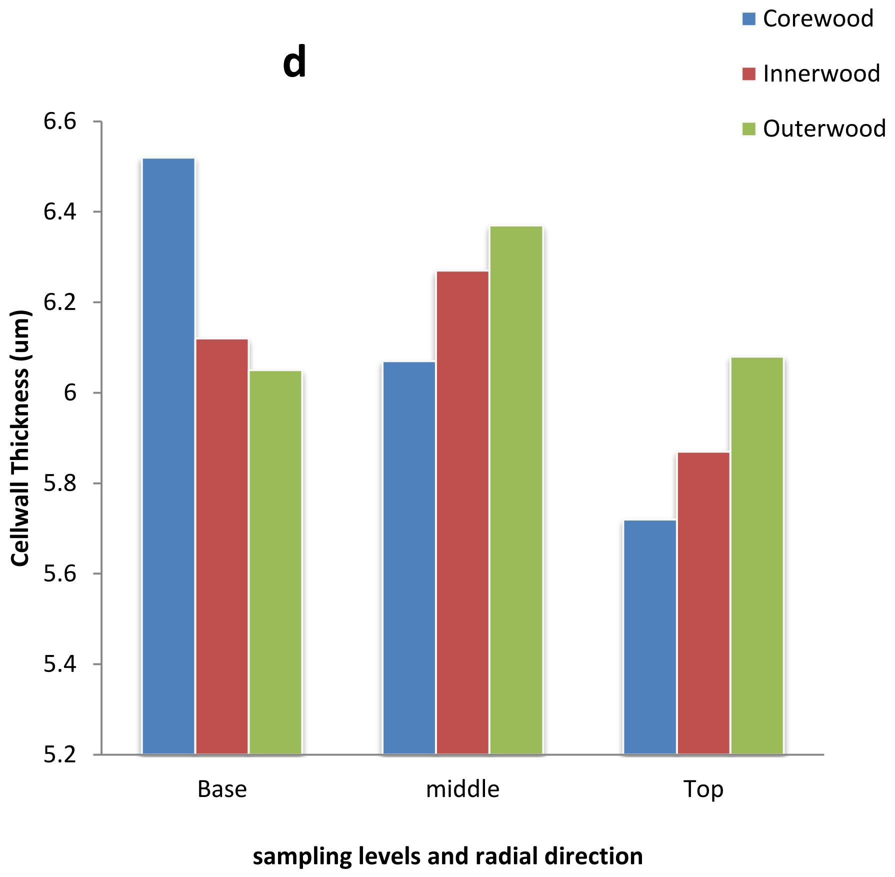

Figure 4.4d: Effect of SP and RP on CWT of *A.altilis* wood

Table 4.10 The mean values for 1, 2, 3, 4, 5 and 6 of morphological Indice at SP and RP

SH	**RP**	**Slenderness (1)**	**Flexibility (%) (2)**	**Runkel Ratio (3)**	**Rigidity (%) (4)**	**F-factor (5)**	**Ratio of muhls (%) (6)**
Base	Corewood	35.13±6.91$_{c}$	69.44±9.32$_{a}$	0.46±0.22$_{c}$	0.15±0.05$_{b}$	240.28±55.12$_{c}$	51.11±12.53$_{c}$
	Wood-inner	47.25±8.91$_{ab}$	64.34±4.24$_{b}$	0.56±0.10$_{b}$	0.18±0.02$_{ab}$	264.58±37.32$_{a}$	58.41±5.46$_{b}$
	Outerwood	51.18±10.54$_{a}$	59.96±10.2$_{c}$	0.71±0.29$_{a}$	0.20±0.05$_{a}$	261.95±50.94$_{b}$	63.25±12.46$_{a}$
Pooled Mean		**44.52± 10.94**	**64.57± 8.62**	**0.58± 0.22**	**0.18± 0.04**	**255.60± 46.59**	**57.60± 11.04**
	Corewood	37.09±7.29$_{c}$	65.73±7.35$_{a}$	0.55±0.2$_{b}$	0.18±0.04$_{b}$	220.73±46.20$_{c}$	56.25±9.06$_{b}$
Middle	Innerwood	50.86±12.30$_{a}$	60.29±8.62$_{b}$	0.69±0.3$_{ab}$	0.19±0.05$_{b}$	262.97±76.22$_{a}$	63.09±10.2$_{ab}$
	Outerwood	48.30±12.84$_{b}$	59.21±8.65$_{b}$	0.72±0.27$_{a}$	0.22±0.05$_{a}$	243.61±92.75$_{b}$	64.37±10.05$_{a}$
Pooled Mean		**45.41± 12.64**	**61.74± 8.20**	**0.65± 0.24**	**0.19± 0.04**	**242.43c 63.96**	**61.23± 9.76**
	Corewood	37.11±6.02$_{b}$	68.67±6.25$_{a}$	0.47±0.13$_{c}$	0.16±0.04$_{b}$	246.84±60.74$_{b}$	52.47±8.75$_{b}$
Top	Innerwood	47.41±9.16$_{ab}$	62.40±7.96$_{b}$	0.63±0.2$_{ab}$	0.19±0.04$_{ab}$	255.76±34.16$_{b}$	60.56±9.91$_{a}$
	Outerwood	48.76±13.61$_{a}$	62.30±9.82$_{b}$	0.65±0.27$_{a}$	0.19±0.05$_{a}$	259.87±36.22$_{a}$	60.21±12.1$_{ab}$
Pooled Mean		**44.43± 11.31**	**64.46± 8.62**	**0.72± 0.24**	**0.18±0.04**	**254.15± 48.79**	**57.70± 11.05**
Mean		**44.79±11.49**	**63.59±8.46**	**0.60±0.23**	**0.18±0.04**	**250.73± 53.25**	**58.86±10.62**

Means±Standard mean error for 5 samples repeated. Values in and column of the same alphabet not substantially similar at alpha = 0.05 using the Duncan test

Table 4.11 The Analysis of Variance for 1, 2, 3, 4, 5, and 6 of *A. altilis* wood morphology at SP and RP

Source of variation	**Df**	**Slenderness (1)**	**Flexibility (%) (2)**	**Runkel Ratio (3)**	**Rigidity-Coefficient (%) (4)**	**F -Factor (5)**	**Muhlsteph Proportion (%) (6)**
Tree (Block)	3	0.6277^{ns}	0.0000*	0.0005*	0.0000*	0.00021*	0.0000*
Sampling Height	2	0.941^{ns}	0.283^{ns}	0.3062^{ns}	0.1887^{ns}	0.533^{ns}	0.269^{ns}
Major Plot Error	6						
Radial Position	5	0.0049*	0.0612^{ns}	0.0872^{ns}	0.0378^{ns}	0.3523^{ns}	0.0533^{ns}
(SH*RP)	10	0.950^{ns}	0.869^{ns}	0.9212^{ns}	0.9125^{ns}	0.948^{ns}	0.8319^{ns}
Sub-Plot Error	45						
Total	71						

ns = not significant (p-values > 0.05)

*$^{=}$ significant (p-values < 0.05)

4.3.5 SLENDERNESS RATIO (SR)

A.altilis' total mean slenderness ratio is 44.79±11.49. The slenderness ratio value ranged from 44.52±10.94 at the base, 45.41±12.64 at the center and 44.43±11.3 at the top. This indicates a pattern of increases from base to center and a slight decrease to top as shown in Table 4.10, although radially, slenderness ratio ranged from 35.13±6.91 to 51.18±10.54 corewood to outerwood at the base, 37.09±7.29 to 48.30±12.84 from corewood to outerwood at the middle, 37.11±6.02 to 48.76±13.61 corewood to outerwood along the trunk towards stem-top of the wood as presented in Figure 4.5a.

The analysis of variance presented in Table 4.11 indicates insignificant effects of the sampling position at (p=0.941) but that variation along the radial location (p=0.0049) has a significant impact on the slenderness ratio at 0.05 % likelihood level of *A.altilis* wood.
Interaction between the sampling location and radial planes has insignificant influence on the slenderness ratio of *A.altilis* wood. Duncan test in Table 4.11 shows that significant difference exist in slenderness ratio at the base between (outerwood and corewood, but insignificant effect exist (outerwood and innerwood, corewood and innerwood); at middle, significant difference exist between (innerwood and outerwood, innerwood and corewood, outerwood and corewood, corewood and innerwood, corewood and outerwood), at top, significant difference exist between (outerwood and corewood, corewood and outerwood), but insignificant effect exist between (innerwood and outerwood, innerwood and outerwood) across the radial position for slenderness ratio of *A.altilis* wood.

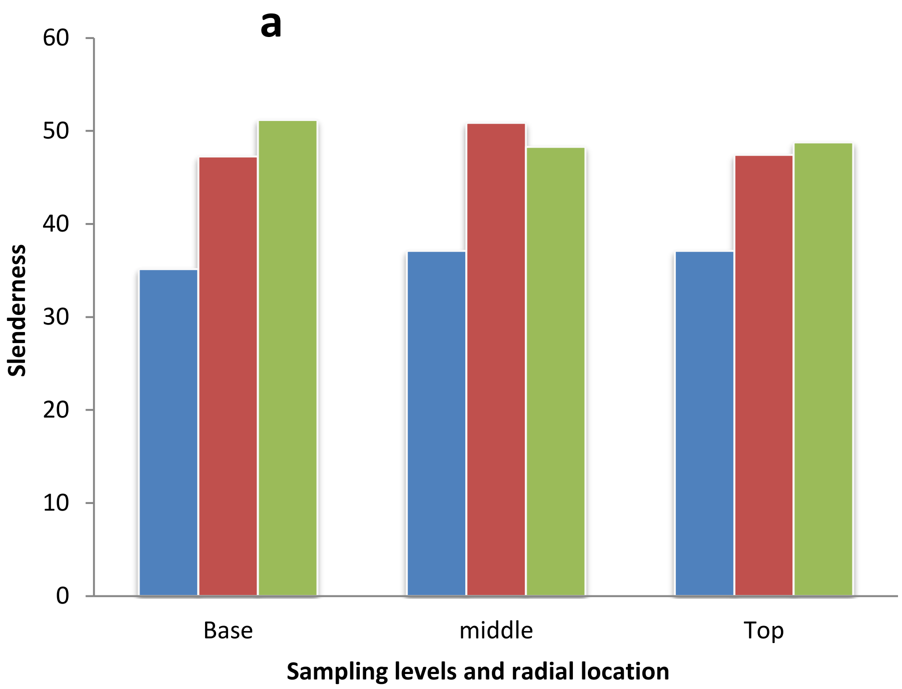

Figure 4.5a: Effect of SP and RP on Slenderness of *A.altilis* wood

4.3.6 FLEXIBILITY

The total average versatility of *A. altilis* is 63.59±8.46 %. The flexibility values ranged from 64.57± 8.62 % at the base, 61.74± 8.20 % at the middle and 64.46± 8.62 % at the top. This demonstrates that flexibility reduces at base to middle and again rises to the stem-top as presented in Table 4.10, Radially, flexibility ranged from 69.44±9.32 % to 59.96±10.25 % corewood to outerwood at the base, 65.73±7.35 % to 59.21±8.65 % corewood to outerwood at the middle and 68.67±6.25 % to 62.30±9.82 % at corewood to outerwood at the stem-top been presented in Figure 4.5b.

The analysis of variance presented in Table 4.11 reveals that insignificant difference exist in the sampling height *(p=0283)* and radial location *(p=0.0612)* on the flexibility of *A.altilis*. Interaction likewise between sampling levels *(p=0283)* and radial location on the flexibility of *A.altilis* is insignificant difference.

The multiple comparism test in Table 4.10 indicates significant ($p \leq 0.05$) difference in flexibility at the base (corewood and innerwood, corewood and outerwood, innerwood and corewood, innerwood and outerwood, outerwood and corewood, outerwood and innerwood), at middle, significant difference exist (outerwood and corewood, corewood and outerwood, but insignificant effect exist (innerwood and outerwood, innerwood and corewood); at top, significant difference exist (corewood and innerwood, but insignificant effect exist between (innerwood and coewood, innerwood and outerwood) across the radial position for flexibility of *A.altilis* wood.

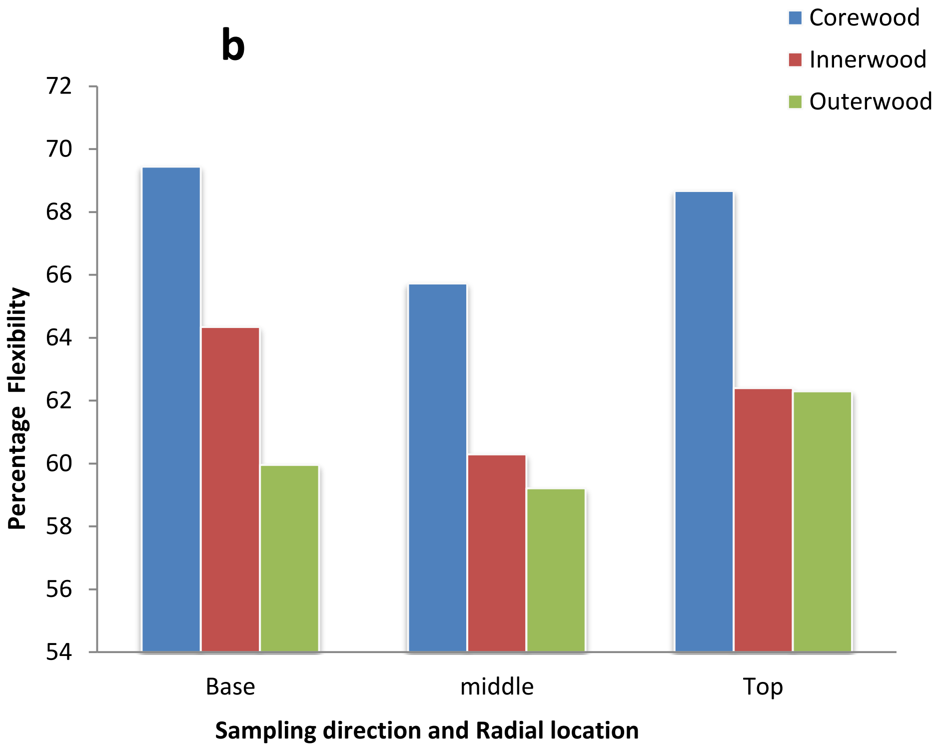

Figure 4.5b: Effect of SP and RP on Flexibility of *A.altilis* wood

4.3.7 RUNKEL RATIO (RR)

The average mean ratio of Runkel Ratio of *A.altilis* is 0.60±0.23. The Runkel Ratio mean values ranged from 0.58±0.22 at the base, 0.65±0.24 at the center and 0.72±0.24 at the top. This suggests that the Runkel Ratio rises from base to top of the stem as presented in Table 4.10. Radially, the values ranged from 0.46±0.22 to 0.71±0.29 at the base, 0.55±0.20 to 0.72±0.27 at the middle, and 0.47±0.13 to 0.65±0.27 the top. This indicates radial position trend in Runkel Ratio of the fibres was consistent; it decreased from corewood to the outerwood as shown in Figure 4.5c.

The analysis of variance in Table 4.11 indicates that the sampling position ($p=0.306$) and radial location ($p=0.087$) do not have a major impact on the Runkel Ratio of *A.altilis* wood at a probability level of 0.05 %. Interaction likewise between sampling levels and radial location for the runkel ratio of *A.altilis* wood is insignificant different.

The multiple comparism test in Table 4.10 indicates significant ($p\leq0.05$) difference in runkel ratio at the base (outerwood and innerwood, outerwood and corewood, outerwood and corewood, outerwood and corewood) at middle, significant difference exist (outerwood and corewood, corewood and outerwood, but insignificant effect exist (innerwood and outerwood, innerwood and corewood); at top, significant difference exist (outerwood and innerwood, but insignificant effect exist between (innerwood and outerwood, innerwood and corewood) across the radial position for runkel ratio of *A.altilis* wood.

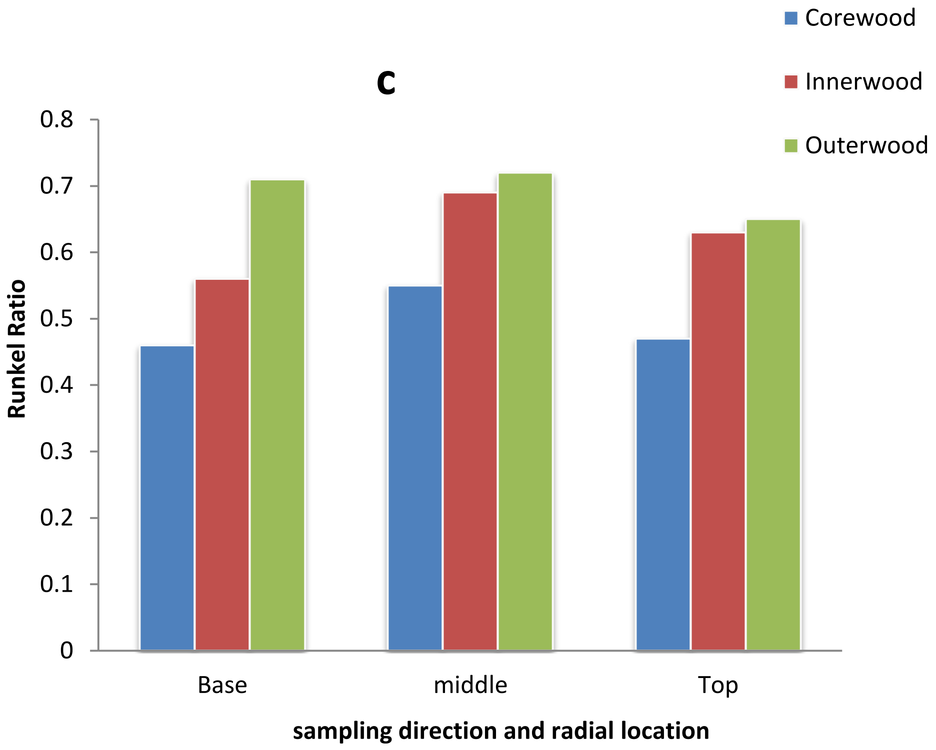

Figure 4.5c: Effect of SP and RP on Runkel ratio of *A.altilis* wood

4.3.8 RIGIDITY COEFFICIENT

The gross mean coefficient of rigidity is 0.18±0.04 %. The coefficient of rigidity mean values ranged at the base 0.18±0.04 %, 0.19±0.04 % at the middle, and 0.18±0.04 % at the top.This depict that coefficient of rigidity increase from base to stem-top as presented in Table 4.10. Radially, the average mean coefficient of rigidity ranges from 0.15±0.05 % to 0.20±0.05 % through the bole at the base, corewood to outerwood, 0.18±0.04 % to 0.22±0.05 % from corewood to outerwood in the center of the bole and 0.0±0.05 % at corewood to outerwood in the base of the bole. This shows that the trend in the rigidity coefficient of the fibers was not consistent in the sampling and radial direction; it increased from base to middle and then decreased to the top, rose from corewood to wood-inner and then decreased to the outerwood as shown in Figure 4.5d.

The result of the analysis of variance in Table 4.11 shows insignificant difference exist in the sampling height *(p=0.1887)* and radial location *(p=0.0378)* on the rigidity coefficient of *A.altilis* wood. Likewise, the interaction between sampling levels and radial location upon rigidity coefficient of this wood is insignificant different.

The multiple comparism test in Table 4.10 reveals significant ($p \leq 0.05$) difference in rigidity coefficient at the base (outerwood and corewood) but insignificant influence exist (innerwood and outerwood, innerwood and corewood); at middle, significant difference exist (outerwood and innerwood, outerwood and corewood, but insignificant effect exist (innerwood and corewood); at top, significant difference exist (outerwood and corewood) but insignificant influence exist (innerwood and outerwood, innerwood and corewood) across the radial position for rigidity coefficient of *A.altilis* wood.

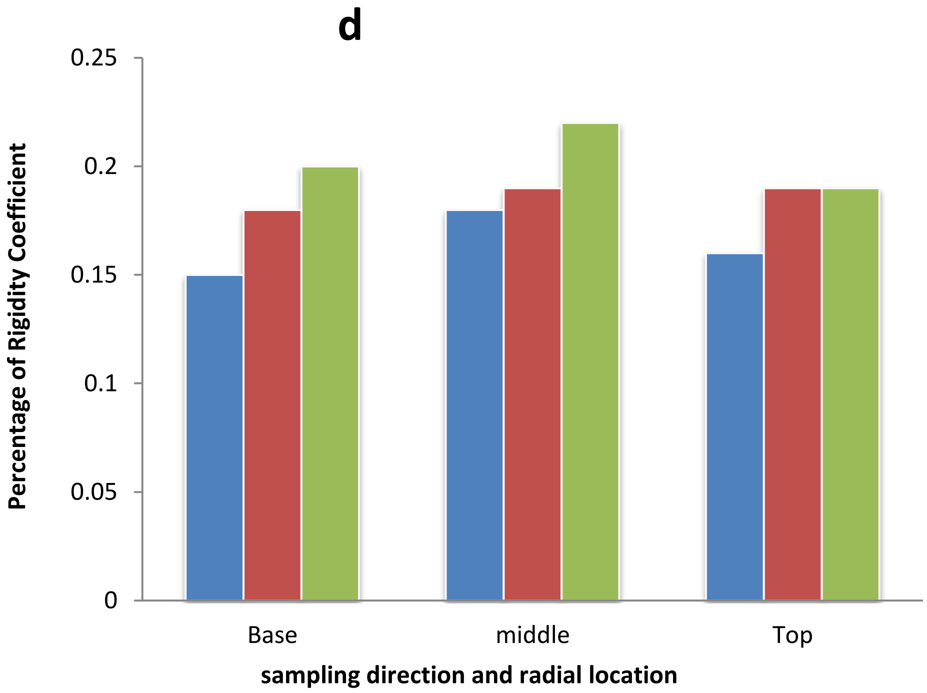

Figure 4.5d: Effect of SP and RP on Rigidity Coefficient of *A.altilis* wood

4.3.9 FORM FACTOR (FF)

The average total F-factor of *A.altilis* is 250.73±53.25. The F-factor mean value ranges at the base 255.60±46.59, 242.43±63.96 at the middle, at the top 254.15±48.79. This indicates that it decreases from base to center and marginally rises from middle to top as presented in table 4.10. Radially, F-factor mean values range at the base 240.28±55.12 to 261.95±50.94 at corewood to outerwood, 220.73±46.20 to 243.61±92.75 at the center, corewood to outerwood across the bole and 246.84±60.74 to 259.87±36.22 at corewood to outerwood at the top across the bole. The fiber F-Factor pattern was not consistent; it decreased from corewood to inner-portion in the radial position and then increased towards outer-portion as shown in Figure 4.5e

Analysis of variance presented in Table 4.11 shows insignificant difference exist in the sampling height *(p=0.533)* and radial location *(p=0.352)* on the F-Factor of *A.altilis* wood. Similarly, the interaction between sampling levels and radial location on the F-Factor of *A.altilis* wood is insignificant different.

The multiple comparism test in Table 4.10 indicates significant *($p\leq 0.05$)* difference in F-Factor at the base (innerwood and outerwood, innerwood and corewood, outerwood and innerwood, outerwood and corewood, corewood and innerwood, corewood and outerwood); at middle, significant difference exist (innerwood and outerwood, innerwood and corewood, outerwood and innerwood, outerwood and corewood, corewood and innerwood, corewood and outerwood) at top, significant difference exist (outerwood and innerwood, outerwood and corewood) but insignificant influence exist (innerwood and outerwood, innerwood and corewood) across the radial position for F-Factor of *A.altilis* wood.

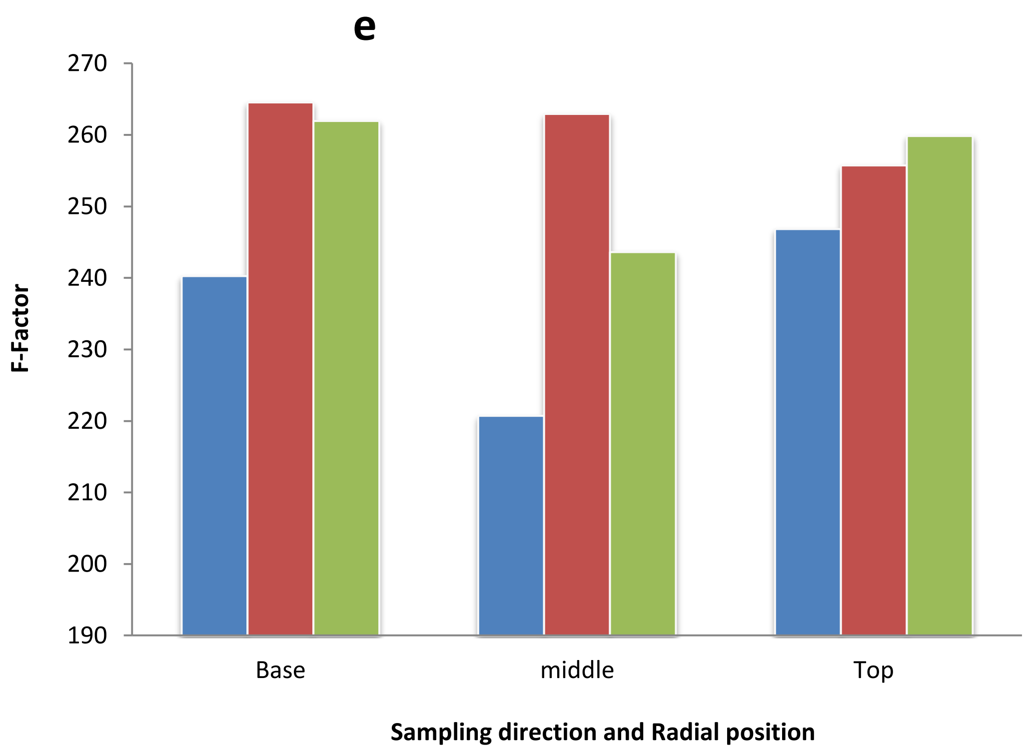

Figure 4.5e: Effect of SP and RP on Form-Factor of *A.altilis* wood

4.3.10 MUHLSTEPH'S RATIO (MR)

Total average Muhlsteph ratio had mean 58.86±10.62 %. The Muhlsteph ratio mean values ranged at base 57.60±11.04 %, middle 61.23±9.76 % and top 57.74±11.05 %. This indicates that the ratio of Muhlsteph increased just at base to center and reduced slightly to the top as shown in Table 4.10, while radially, the Muhlsteph ratio ranged from 51.11±12.53% to 63.25±12.46% at the base, 56.25±9.06 % to 64.37±10.05 % at the middle, 52.47±8.75 % to 60.21±12.10 % at the top of the bole. The pattern observed for the fiber ratio of the Muhlsteph was not consistent; it increased from core-portion to internal-wood in the radial position and then decreased towards the outer-portion as shown in Figure 4.5f.

Analysis of variance presented in Table 4.11 shows insignificant difference exist in the sampling levels *($p=0.269$)* and radial location *($p=0.0533$)* on the ratio of Muhlsteph of *A.altilis* wood. Similarly, the interaction between sampling levels and radial location on the ratio of Muhlsteph of *A.altilis* wood is insignificant different.

Duncan test indicates that significant *($p\leq 0.05$)* difference exists in ratio of Muhlsteph at the base (outerwood and innerwood, outerwood and corewood, innerwood and outerwood, innerwood and corewood, corewood and outerwood, corewood and innerwood); at middle, significant difference exist (outerwood and corewood, corewood and outerwood, but insignificant influence exist (innerwood and outerwood, innerwood and corewood); at top, significant difference exist (innerwood and corewood, corewood and innerwood) but insignificant influence exist (outerwood and innerwood, outerwood and corewood) across the radial position for ratio of Muhlsteph of *A.altilis* wood as presented in Table 4.10

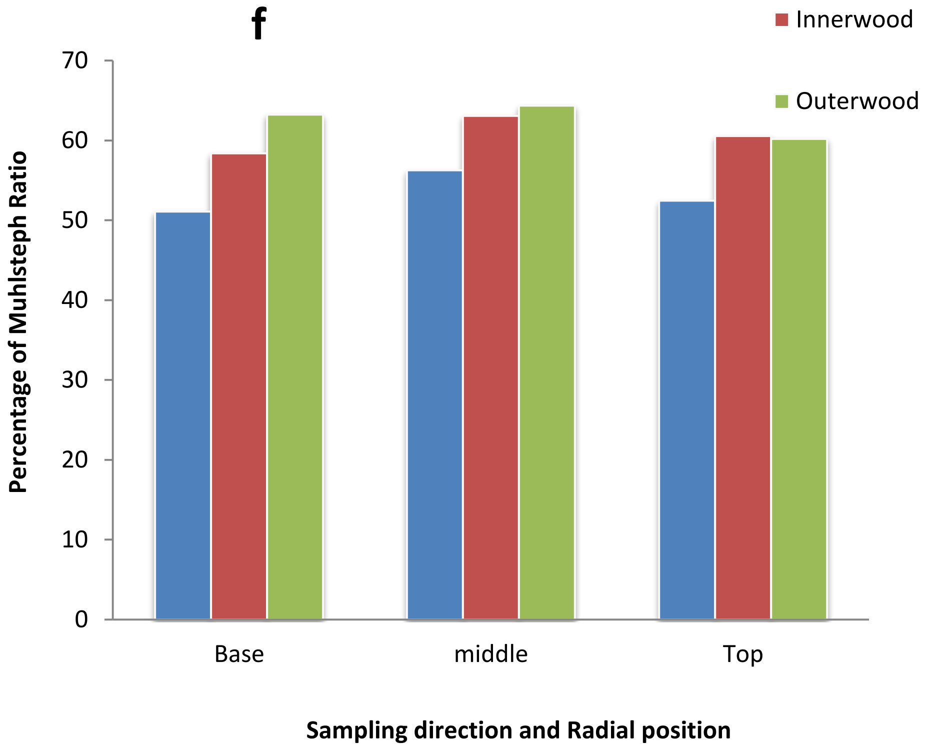

Figure 4.5f: **Effect of SP and RP on Mulsteph's ratio of *A.altilis* wood**

4.4.0 Micrographic Analysis (Sectioning) of *A. altilis* Wood

4.4.1 Vessel length (µm)

Average overall vessel length of *A. altilis* is 252.46±66.99 µm. The vessel length means values range at the base, 240.04±69.00 µm, 264.64±49.06 µm at the center and 25270±7979 µm at the top. This indicates a pattern of increases from base to the middle and a slight rises to the stem-top along sampling plane as shown in Table 4.12. Radially, vessel length ranged from 248.93±89.47 µm to 261.61±72.43 µm at corewood to outerwood across the base bole, 239.01±83.62 µm to 238.08±50.96 µm at core-portion to outer-portion across the middle bole and 247.23±18.77 µm to 263.81±64.77 µm at corewood to outerwood as presented in Figure 4.6a.

Analysis of variance presented in Table 4.13 reveals that insignificant difference exist in the sampling levels *(p=0.518)* and radial location *(p=0.968)* on the vessel length of *A.altilis* wood. Likewise, the interaction between sampling levels and radial location on the vessel length of *A.altilis* wood is insignificant different.

The multiple comparison test in table 4.12 indicates that significant *($p \leq 0.05$)* difference exists in vessel length at the base (outerwood and innerwood, outerwood and corewood), but insignificant effect exists (innerwood and outerwood, innerwood and corewood); corewood and outerwood, corewood and innerwood); at middle, significant influence exists (innerwood and outerwood, innerwood and corewood, but insignificant influence exist (outerwood and innerwood, outerwood and corewood); at top, significant difference exist (innerwood and outerwood, innerwood and corewood, outerwood and innerwood, outerwood and corewood, corewood and innerwood, corewood and outerwood) across the radial position for vessel length of *A.altilis* wood.

Table 4.12: The mean value for VL, VD and VF of *A. altilis* wood

SH	RP	Vessel Length (µm)	Vessel Diameter (µm)	Vessel Frequency (mm^2)
	Corewood	248.93±89.47$_b$	225.68± 90.0$_b$	2.51±0.79$_b$
Base	Innerwood	247.53±50.49$_b$	249.86±56.04$_a$	2.59±0.45$_a$
	Outerwood	261.61±72.43$_a$	238.70±53.55$_{ab}$	2.52± 0.38$_b$
Pooled Mean		**252.70±79.79**	**238.08± 64.89**	**2.54±0.61**
	Corewood	239.01±83.62$_b$	189.26±60.81$_c$	2.34±0.48$_c$
Middle	Innerwood	251.41±79.01$_a$	226.77±60.94$_b$	2.45±0.48$_b$
	Outerwood	238.08±50.96$_b$	229.40±47.44$_a$	2.83±0.87$_a$
Pooled Mean		**240.04± 69.01**	**215.14±54.53**	**2.54± 0.65**
	Corewood	247.23±18.77$_c$	210.65±41.35$_c$	2.36±0.50$_a$
Top	Innerwood	282.88±57.53$_a$	256.22±72.43$_a$	2.29±0.39$_{ab}$
	Outerwood	263.81±64.77$_b$	249.09± 61.81$_b$	2.27±0.35$_b$
Pooled Mean		**264.64± 49.06**	**238.65±57.88**	**2.31± 0.44**
Mean		**252.46± 66.99**	**230.62± 59.45**	**2.46 ±0.58**

Means±Standard mean error for 5 samples repeated. Values in and column of the same alphabet not substantially similar at alpha = 0.05 using the Duncan test

Table 4.13. Analysis of Variance for VL,VD and VF of *A.altilis* wood

Source of Variation	Df	Vessel Length (µm)	Vessel Diameter (µm)	Vessel Frequency (mm^2)
Tree	3	0.0000*	0.0000*	0.386^{ns}
Sampling Height	2	0.518^{ns}	0.034*	0.285^{ns}
Major Plot Error	6			
Radial position	5	0.968^{ns}	0.439^{ns}	0.322^{ns}
SH* RP	10	0.993^{ns}	0.919^{ns}	0.759^{ns}
Error	45			
Total	71			

ns= not significant (p-values > 0.05)

*= significant (p-values < 0.05)

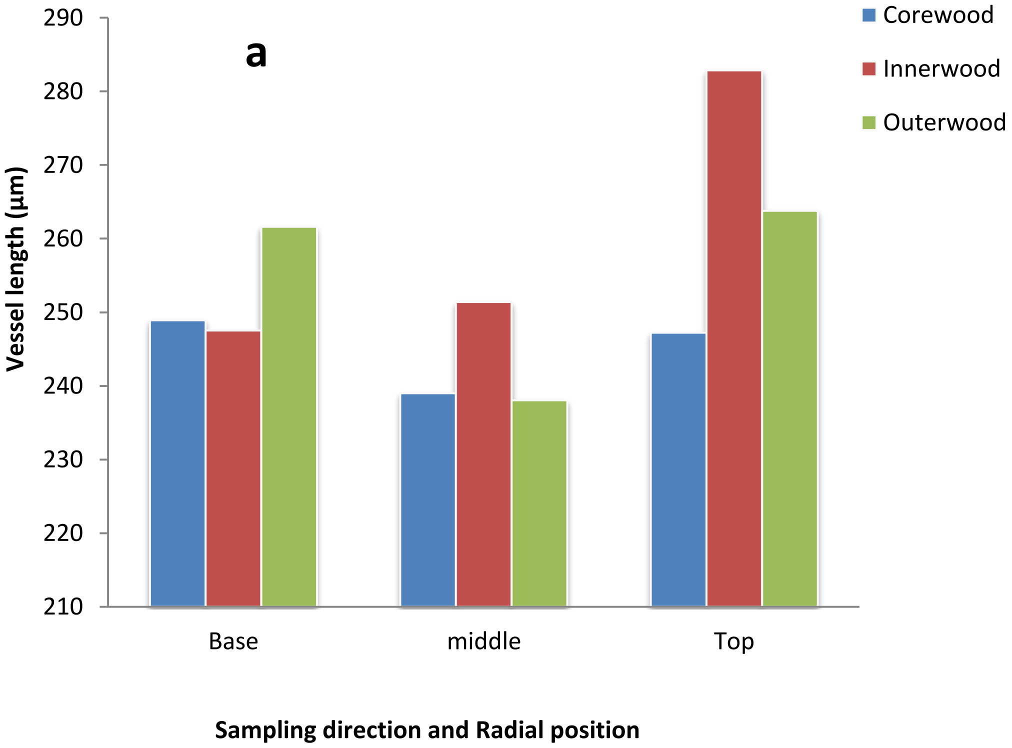

Figure 4.6a: Effect of SP and RP on Vessel diameter of *A.altilis* wood

4.4.2 Vessel diameter (µm)

A.altilis' total mean vessel diameter is 230.62±59.45 µm. The vessel diameter ranges 238.08±64.89 µm at the base, 215.14±54.53 µm at the center and 238.65±57.88 µm at the top. A pattern of reduction from base to middle and a slight rise to the top is indicated by vessel diameter along the sampling location as shown in Table 4.12. Radially, vessel diameter ranged from 225.68±90.0 µm to 238.70±53.55 µm at corewood to outerwood at the base across the bole, 189.26±60.81 µm to 229.40±47.44 µm at corewood to outerwood at the middle across the bole and 210.65±41.35 µm to 249.09± 61.81 µm at corewood to outerwood at the stem-top been presented in Figure 4.6b.

The result of the analysis of variance presented in Table 4.13 indicated significant difference existed at the sampling levels *($p=0.034$)* but insignificant difference exists in radial location *($p=0.439$)* on the vessel diameter of *A.altilis* wood. The interaction between sampling levels and radial location on the vessel length of *A.altilis* wood is insignificant different.

The multiple comparison test in Table 4.12 reveals that significant *($p\leq 0.05$)* difference exists in vessel diameter at the base (innerwood and corewood), but insignificant effect exists (outerwood and innerwood, outerwood and corewood); at middle, significant difference exists (outerwood and innerwood, outerwood and corewood, innerwood and innerwood, outerwood and corewood); at top, significant difference exist (innerwood and outerwood, innerwood and corewood, corewood and outerwood, corewood and innerwood), across the radial position for vessel diameter of *A.altilis* wood.

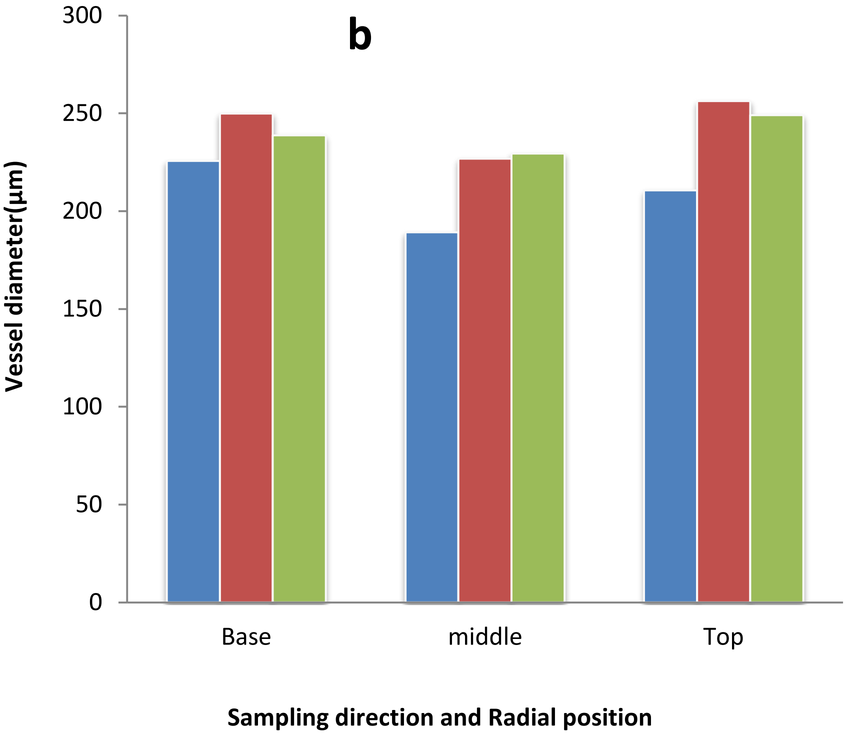

Figure 4.6b: Effect of SP and RP on Vessel diameter of *A.altilis* wood

4.4.3 Vessel frequency (mm^2)

The total mean frequency of the *A.altilis* vessel is 2.46±0.58 mm^2. The vessel frequency mean values ranges 2.54±0.61 mm^2 at the base, 2.54±0.65 mm^2 at the center and top 2.30±0.44 mm^2.This depicts vessel frequency patterns decreases from base to the stem-top been presented in Table 4.12. Radially, vessel frequency ranged from 2.51±0.79 mm^2 to 2.52±0.38 mm^2 at corewood to outerwood along the base bole, 2.34±0.48 mm^2 to 2.83±0.87 mm^2 at corewood to outerwood along the trunk at the middle and 2.36±0.50 mm^2 to 2.27±0.35 mm^2 at corewood to outerwood through the trunk at the stem-top as presented in Figure 4.6c.

In Table 4.13, analysis of variance result shows that significant difference exist in the sampling levels *($p=0.285$)* and in radial location *($p=0.759$)* on the vessel frequency of *A.altilis* wood. The interaction between sampling levels and radial location on the vessel frequency of *A.altilis* wood is insignificant different. Duncan test reveals that significant *($p\leq 0.05$)* difference exists in vessel frequency at the base (innerwood and corewood, innerwood and outerwood), but insignificant effect exists (outerwood and innerwood, outerwood and corewood, corewood and outerwood); at middle, significant effect exists (outerwood and innerwood, outerwood and corewood, innerwood and outerwood, innerwood and corewood); at top, significant difference exist (corewood and outerwood), but insignificant effect exists (innerwood and outerwood, innerwood and corewood), across the radial position for vessel frequency of *A.altilis* wood as presented in Table 4.12

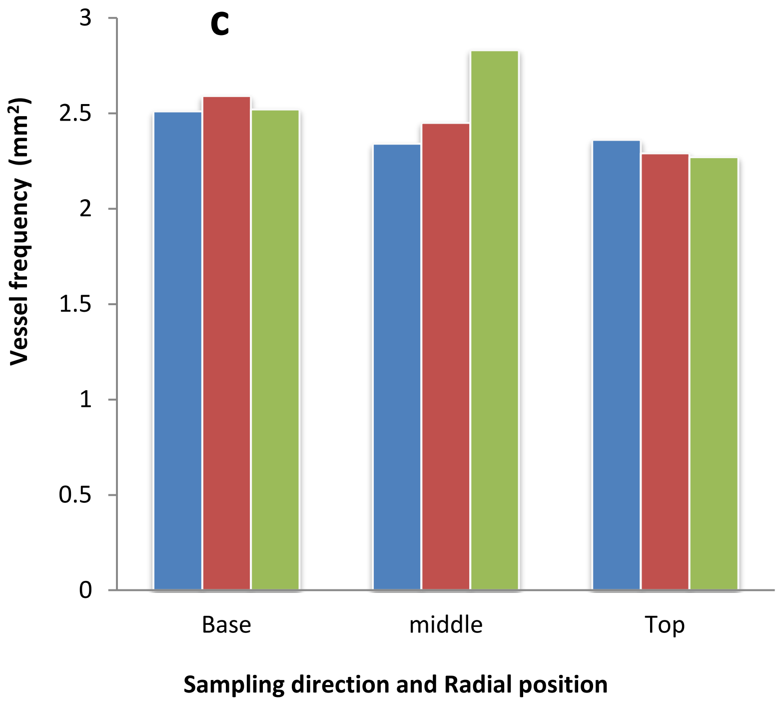

Figure 4.6c: **Effect of SP and RP on Vessel frequency of *A.altilis* Wood**

4.5 Anatomical Properties (Microscopy)

4. 5 .1 Photo Micrographic Description of the *A. altilis* wood

The observed features of *A.altilis* micrographic description wood cells reveals that, the vessels are predominantly solitary, radial multiples present, Vessels are obliquely arranged, and tyloses are present.Wood cells are radially arranged, axial parenchyma cells are both paratracheal and apotracheal. Paratracheal are vasicentric and Apotracheal cells are diffuse. The rays are mostly multiseriate, 5-6 cell wide and heterocellular, rays appeared to vessel pit vestured, Intervascular pits vestured. The fibres are medium-walled and presence of traumatic cell observed, deposits of gum present and intercellular canals observed.

Transverse Sections of *A. altilis*

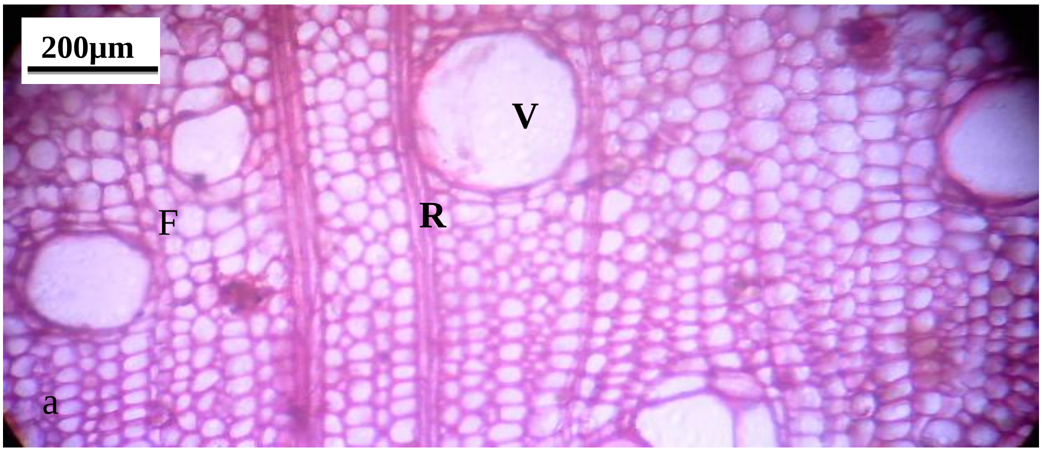

Plate 4.2a Shows F=Fibre, V=Vessel, and R=Ray

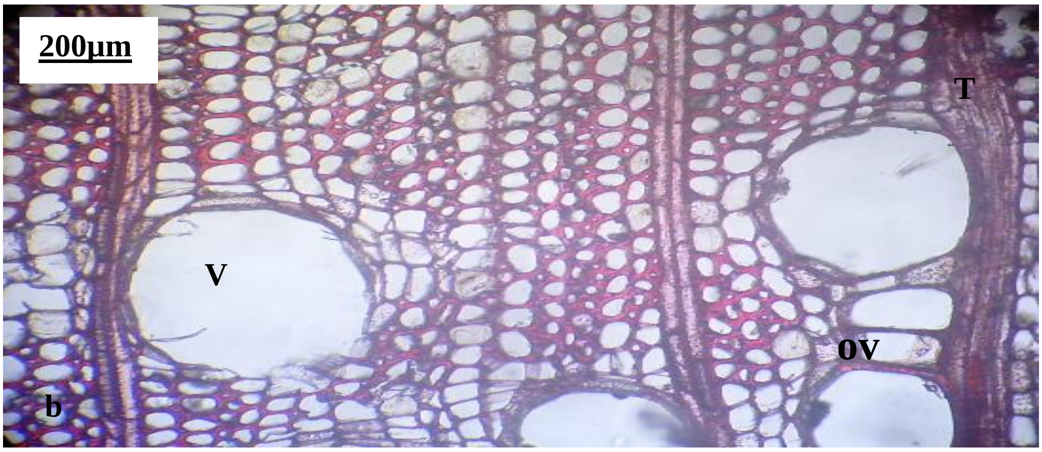

Plate 4.2b. Shows T=Tyloses. Ov=Oblique vessels

Plate 4.2c Showing V = vessel, Ap= Axial Parenchyma

Plate 4.2(a-c): Micrographic description of wood anatomy of *A. altilis* in Transverse sections

Tangential Sections of *A. altilis*

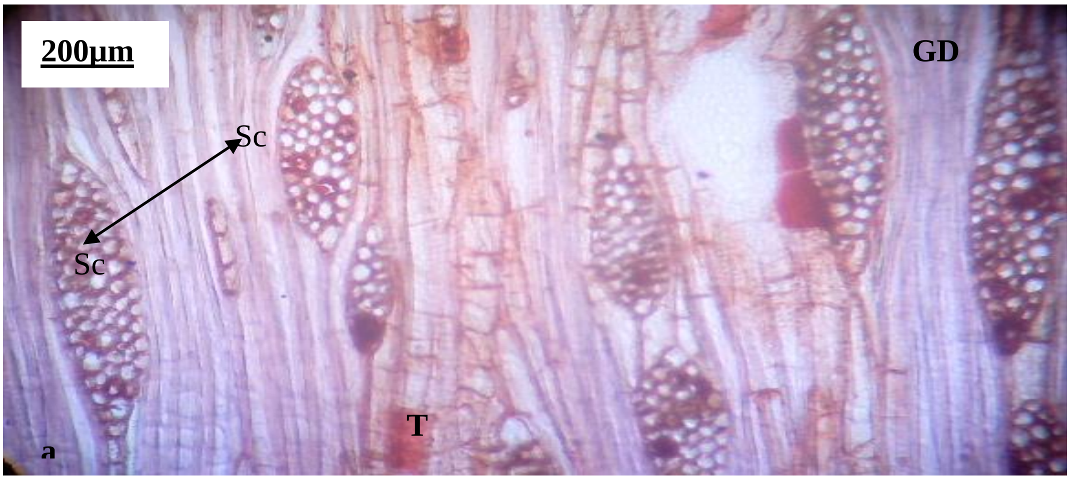

Plate 4.3a: Shows Sc=Shearth cells, Gd= Gum deposits, T= Tyloses

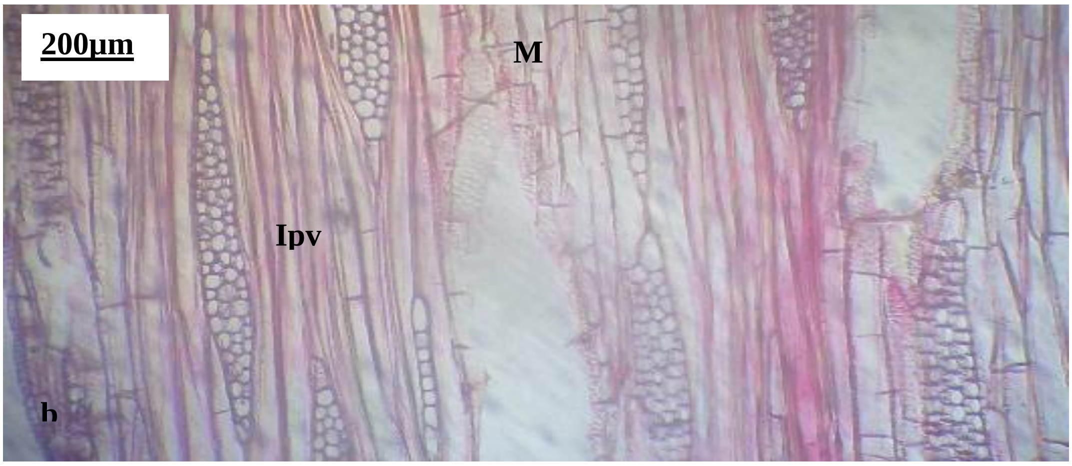

Plate 4.3b: Shows T= Tyloses, Ipv= Intervascular pits to vestured and M=Multiserate rays

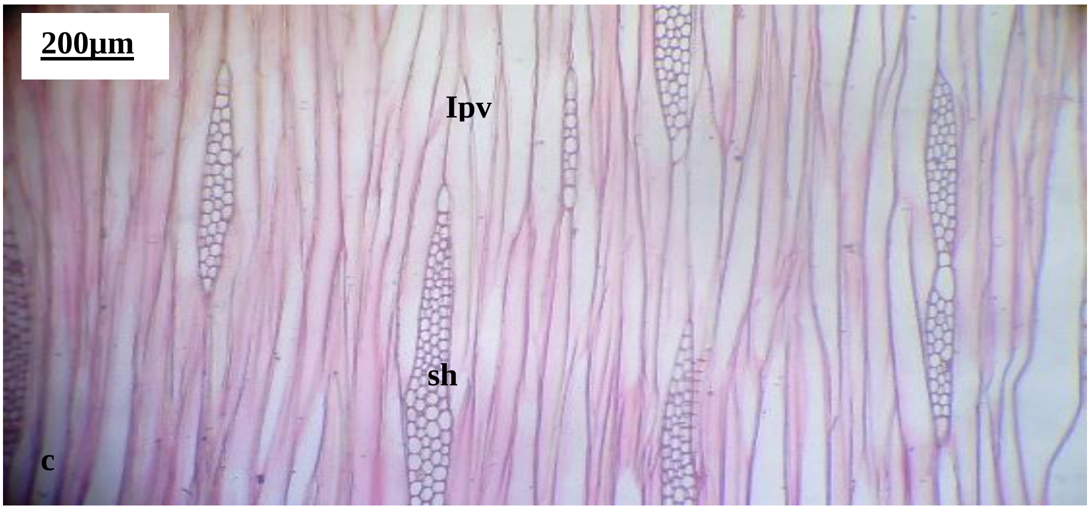

Plate 4.3c: Shows Ipv= Intervascular pits to vestured, sh= shealth cell

Plate 4-3 (a-c): Micrographic description of wood anatomy of *A. altilis* Tangential sections

Radial Sections of *A. altilis*

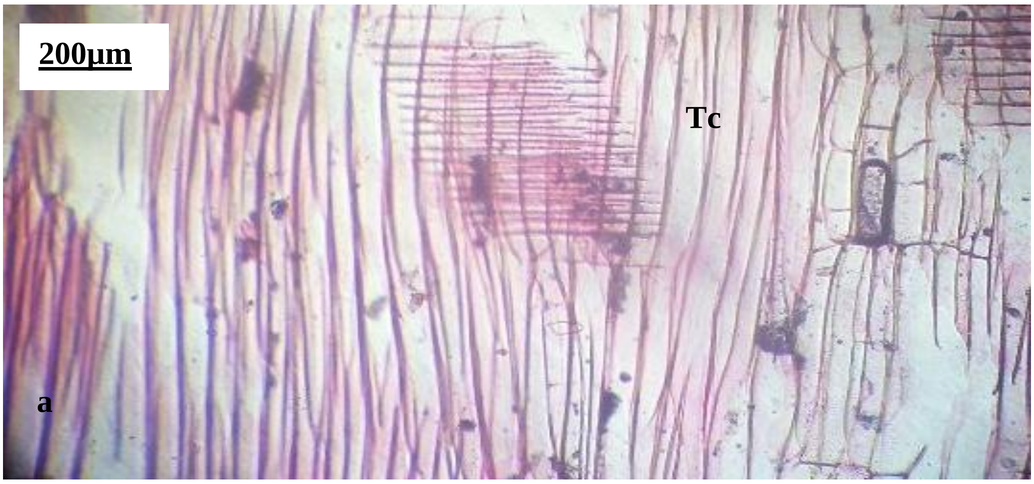

Plate 4.4a.Shows Bs=black streaks among fibre, Tc= Traumatic cells

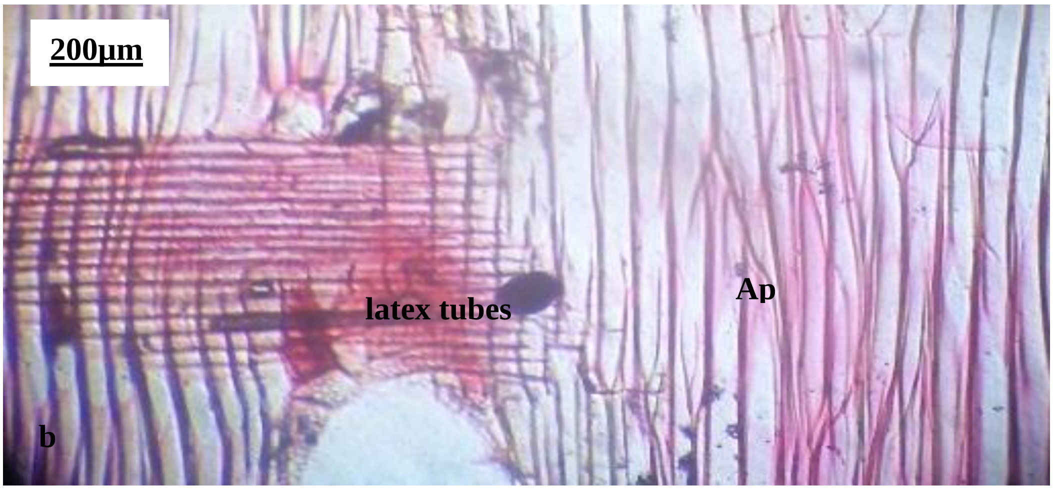

Plate 4.4b: Shows AP=Axial Parenchyma, Latex tube= Intercellular canal present

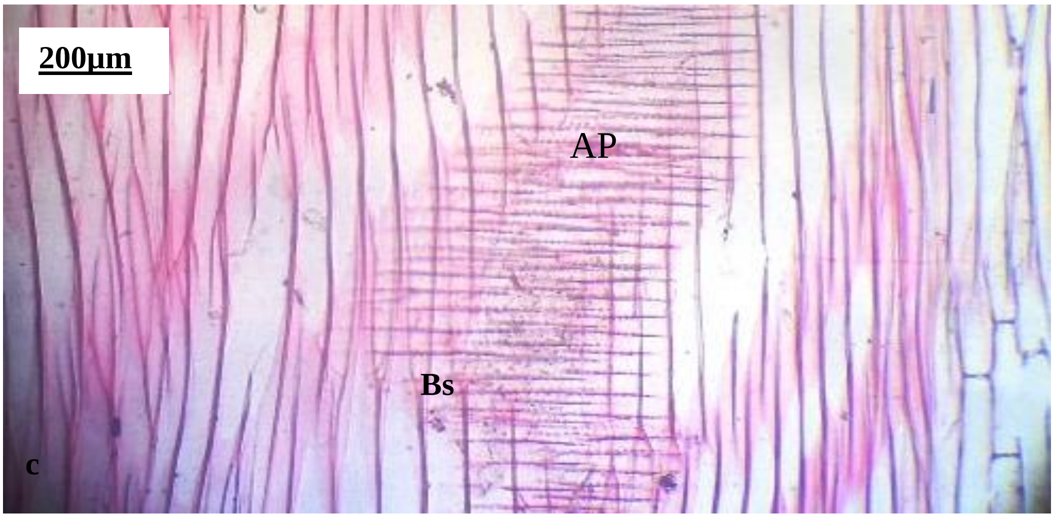

Plate 4.4c; Showing Bs=black streaks fibre, AP=Axial Parenchyma

Plate 4.4 (a-c): Micrographic description of wood anatomy of *A. altilis* radial section

Macerated fibres of *A. altilis*

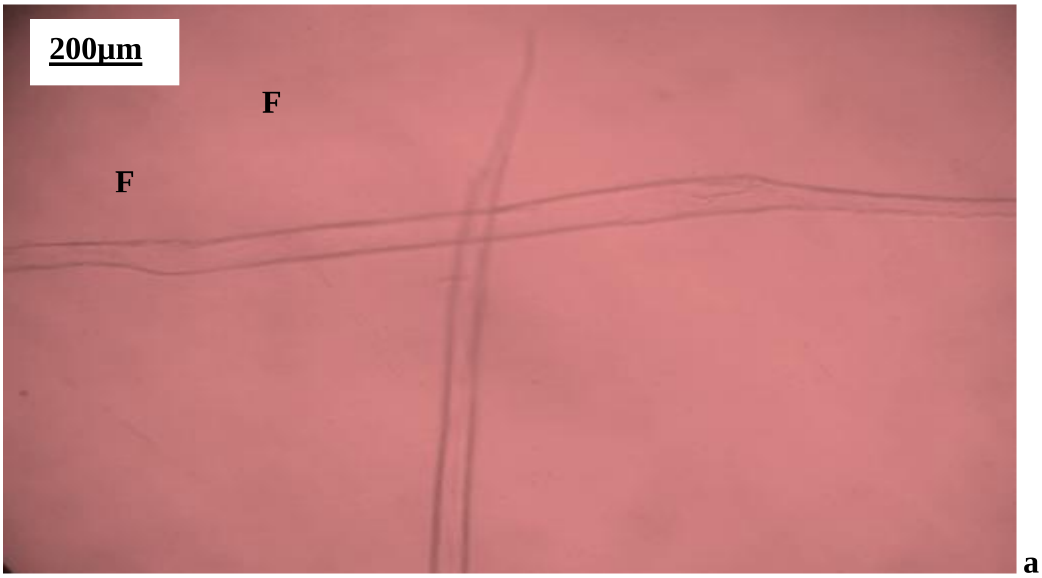

Plate 4.5 Showing the macerated fibres of *A. altilis* (a) F: fiber,

4. 6.0: Chemical Composition and Extractives Components.

4. 6.1: Chemical Analysis

Results of chemical analysis of cellulose, hemicellulose, lignin and ash contents for the *A. altilis* sawdust materials examined are presented in Table 4.14 and ANOVA presented in Table 4.15

4.6.2: Cellulose Content (%)

The mean cellulose content in *A. altilis* wood sawdust (WSD) was 47.44 %. The cellulose means values range at the base 47.83±0.74 %, 47.13±0.47 % at the middle, 47.37±0.49 % to the stem-top. This reveals cellulose reduced along the sampling levels from base to the stem-top been presented in Table 4.14. Cellulose was highest at the stem-base and lowest at the stem-middle with recorded values of 47.83 % and 47.13 % respectively, as shown in Figure 4.7.

Analysis of variance presented in Table 4.15 reveals significant difference exist between sampling position *(p=0.000)* and trees *(p=0.000)* at the likelihood level of 0.05 % on the cellulose of *A. altilis*. Interaction between sampling height and trees, effects of interactions has significant effect on the cellulose of *A. altilis*.

Duncan test in Table 4.14 shows that significant difference exist in cellulose at the base between (base to top, base to middle, top to base, top to middle, middle to base, middle to top) along the sampling position for cellulose of *A. altilis*.

4.6.3: Hemicellulose Content (%)

The mean hemicellulose in *A. altilis* wood sawdust (WSD) was 27.44±0.91 %.The hemicellulose means values range at the base 27.83±0.74 %, 27.18±0.47 % at the middle, 27.29±0.62 % to the stem-top. This reveals hemicellulose reduces down the sampling hlevels at the base to the stem-top of the timber as presented in Table 4.14. Hemicellulose had the highest value at the stem-base and lowest at the stem-middle with recorded values of 27.44±0.91 % and 27.18±0.47 % respectively, as shown in Figure 4.7.

Analysis of variance presented in Table 4.15 shows significant difference exist between sampling position *(p=0.002)* and trees *(p=0.000)* at the likelihood level of 0.05 % on the hemicellulose of *A. altilis*. Interaction between sampling height and trees, effects of interactions has significant influence on the hemicellulose of *A. altilis*.

The multiple comparison test in Table 4.14 shows significant $(p \leq 0.005)$ difference exist in hemicellulose at the base between (base to top, base to middle, top to base, top to middle, middle to base, middle to top) along the sampling position for hemicellulose of *A. altilis*.

4.6.4: Lignin Content (%)

As shown in Table 4.14, the mean lignin content in *A. altilis* wood sawdust (WSD) was 15.88±0.56 %. The hemicellulose means values range at the base 16.13±0.44 %, 15.68 ±0.46 % at the middle, and 15.83±0.47 % at the top. This shows that lignin content decreases long the sampling height from base to the top. The Lignin had high values at the base and had the low value at the stem-middle with recorded values of 16.13±0.44 % and 15.68±0.65 % respectively, as presented in Figure 4.7.

Analysis of variance presented in Table 4.15 reveals significant difference exist between sampling position *(p=0.002)* and trees *(p=0.000)* at the likelihood level of 0.05 % on the lignin content of *A. altilis*. Interaction between sampling height and trees, effects of interactions has significant influence on the lignin content of *A. altilis*.

The multiple comparison test in Table 4.14 indicates significant $(p \leq 0.005)$ difference exist in lignin content at the base between (base to top, base to middle, top to base, top to middle, middle to base, middle to top) along the sampling position for lignin content of *A. altilis*.

4.6.5: Ash Content (%)

As shown in Table 4.14, the mean ash content in *A. altilis* wood sawdust (WSD) was 0.923 ±0.56 %. The ash content means values range at the base 0.934±0.41 %, 0.916±0.46 % at the centre, and 0.918±0.47 % at the stem-top. This depicts ash content decreases from the sampling levels at the base consistently toward the stem-top. Ash content had highest values at the stem-base and lowest at the stem-middle with recorded values of 0.934±0.91 % and 0.916±0.47 % respectively, as presented in Figure 4.7.

The result of the analysis of variance in Table 4.15 show significant difference exist between sampling position *(p=0.0184)* and trees *(p=0.000)* at the likelihood level of 0.05% on the ash content of *A. altilis*. Interaction between sampling height and trees, effects of interactions has significant difference on the ash content of *A. altilis*.

The multiple comparison test in Table 4.14 indicates significant $(p \leq 0.005)$ difference exist in ash content at the base between (base to top, base to middle, top to base, top to middle, middle to base, middle to top) along the sampling position for lignin content of *A. altilis*.

Table 4.14 The mean values of C, H, L and Ash Content of wood of *A. altilis* at SH

Chemical Composition				
Sawdust	Cellulose (%)	Hemicelluloses (%)	Lignin (%)	Ash (%)
Base	$47.83 \pm 0.74_{a}$	$27.83 \pm 1.19_{a}$	$16.13 \pm 0.44_{a}$	$0.934 \pm 0.41_{a}$
Middle	$47.13 \pm 0.47_{c}$	$27.18 \pm 0.74_{c}$	$15.68 \pm 0.65_{c}$	$0.916 \pm 0.46_{c}$
Top	$47.37 \pm 0.49_{b}$	$27.29 \pm 0.62_{b}$	$15.83 \pm 0.49_{b}$	$0.918 \pm 0.47_{b}$
Mean	**47.44±0.63**	**27.44±0.91**	**15.88±0.56**	**0.923±0.44**

Means±Standard mean error for 5 samples repeated. Values in and column of the same alphabet not substantially similar at alpha = 0.05 using the Duncan test

Table 4.15 Analysis of Variance for C, H, L and Ash Content of *A.altilis* wood

Sources Variation	**Df**	**Cellulose (%)**	**Hemicellulose (%)**	**Lignin (%)**	**Ash Content (%)**
Sampling Height (SH)	2	0.0000*	0.0002*	0.0000*	0.0184*
Tree	2	0.0000*	0.0000*	0.0000*	0.0000*
T*SH	6	0.0000*	0.0254*	0.0059*	0.0041*
Error	24				
Total	35				

ns= not significant (p-values > 0.05)

*= significant (p-values < 0.05)

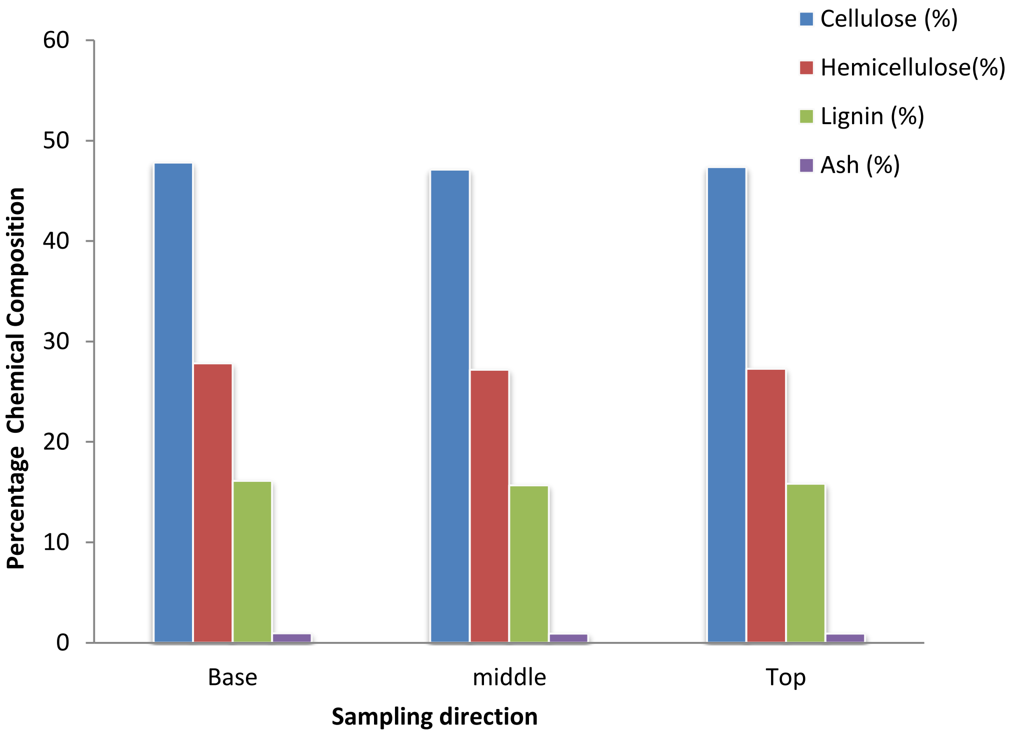

Figure 4.7: Shows the variation in C, H, L, and Ash Content in *A. altilis* at SH

4.7: Mineral Content

4.7.1 Atomic Adsorption Spectrophotometer (AAS)

Wood species for pulp and paper production are usually evaluated for mineral elements as a prerequisite for its suitability. The mineral elements shown in Table 4.16 were; Potassum (K), Phosphorus (P/PO4) Magnesium (Mg), Cupper (Cu), Calcium (Ca), Iron (Fe), Aluminium (Al), Zinc (Zn) , Na, and Lead (Pb).

The mean values of each of the elements; base, middle and stem-top are presented in table 4.16.

The analysis of variance results presented in Table 4.17 show the mean values for Na ranges between 208.75±5.69 mg/100g at the base to 207.08±4.98 mg/100g at the top. Calcium followed wth average mean 121.58 mg/100g, and ranges at base 124.58±8.64 mg/100g to 120.83±7.64 mg/100g at the top. P/PO$_4$ had means 76.53 mg/100g, and mean values range at base 79.17±5.57 mg/100g to 75.42±6.56 mg/100g at the top.

Magnesium had means 45.28 mg/100g, and mean values range at base 47.50±5.00 mg/100g to 44.58±5.42 mg/100g at the top. Potassium had means 31.33mg/100g, and mean values range at base 32.0±3.34 mg/100g to 32.92±2.43 mg/100g at the top. Iron (Fe) had means 3.71 mg/100g, and mean values range at base 3.73±0.25 mg/100g to 3.70±0.25 mg/100g at the top. Aluminum had means 0.67 mg/100g, and mean values range at base 0.66±0.07 mg/100g to 0.63±0.09 mg/100g at the top. Copper had means 0.48 mg/100g, and mean values range at base 0.51±0.08 mg/100g to 0.47±0.07 mg/100g at the top.

Zinc had means 0.55mg/100g, and mean values range at base 0.60±0.09 mg/100g to 0.54±0.08 mg/100g at the top. Pb had means 0.05mg/100g, and mean values range at base 0.05±0.01 mg/100g to 0.05±0.01 mg/100g at the top as also shown in Figure 4.8. There were significant variation in the elemental compositions, likewise interaction difference exist in all the elementa composition evaluated.

Hence, the results presented in Table 4.17 shows that the mineral elements in the wood sawdust samples significantly influenced the mineral contents along the sampling height ($p<0.001$). Duncan test reveals that significant difference exists at the sampling height of the elements Na, Ca, P, Mg, Al, Pb, and Zn but insignificant difference exist K and Cu as presented in Table 4.17.

4.7.2. Silica Content (%)

Sampling position had no significant influence on silica content variations in WSD of *A. altilis* ($p=0.00021$) as showed in Table 4.16. Silica content observed in wood sawdust did not follow specific variation patterns along the sampling direction; it was highest at the stem-base with 0.58 % and lowest at the mid-stem with 0.47 %, the silica content had a mean of 0.53 % as shown in Figure 4.8

Table 4.16: The mean values of each of element at the Base, Middle and Top at SH of *A. altilis*

Mineral Elements	Base	Middle	Top	Pooled Mean
Na^+ (mg/100g)	208.75±5.69	202.92±3.34	207.08±4.98	**206.25±5.26**
Ca^{++} (mg/100g)	124.58±8.64	119.17±8.75	120.83±7.64	**121.53±8.44**
P as PO_4^{---}(mg/100g)	79.17±5.57	75.00±7.07	75.42±6.56	**76.53±6.53**
Mg^{++} (mg/100g)	47.50±5.000	43.75±5.69	44.58±5.42	**45.28±5.47**
K^+ (mg/100g)	32.08±3.34	30.00±4.26	32.92±2.43	**31.33±3.46**
Fe^{++} (mg/100g)	3.73±0.249	3.70±0.39	3.70±0.25	**3.71±0.29**
Al^{+++} (mg/100g)	0.66± 0.07	0.59±0.09	0.63±0.09	**0.67±0.09**
Cu^{++} (mg/100g)	0.51±0.08	0.45±0.08	0.47±0.07	**0.48±0.08**
Zn^{++} (mg/100g)	0.60±0.09	0.50±0.07	0.54±0.08	**0.55±0.09**
Pb^{++} (mg/100g)	0.052±0.007	0.042±0.009	0.047 ±0.009	**0.05±0.01**
Silica %	0.5833±0.072	0.4667± 0.048	0.5333± 0.05	**0.53± 0.07**

Means±Standard mean error for 5 samples repeated. Values in and column of the same alphabet not substantially similar at alpha = 0.05 using the Duncan test

Table 4.17: Analysis of Variance for Minerals Composition in *A.altilis* wood at SH

Sources	**Df**	**Ca**	**P**	**Mg**	**K**	**Fe**
WSD						
Sampling (SH)	2	0.0256*	0.0211*	0.0275*	0.22019^{ns}	0.68727^{ns}
Trees	3	<0.000000	<0.00000	<0.000001	<0.023622	<0.00000
SH* Trees	6	0.8589	0.9029^{ns}	0.84644^{ns}	0.733935^{ns}	0.063009
Errors	24					
Totals	35					

		Al	**Cu**	**Pb**	**Zn**	**Na**	**Si**
Sampling (SH)	2	0.0556*	0.1225^{ns}	0.00555*	0.00743*	0.0569*	0.00021*
Trees	3	<0.00009	<0.014654	<0.0015*	<0.0072*	<0.0092*	0.40984^{ns}
SH* Trees	6	0.4219^{ns}	0.8638^{ns}	0.80204^{ns}	0.85435^{ns}	0.8094^{ns}	0.44805^{ns}
Error	24						
Total	35						

ns= not significant (p-values > 0.05)

*= significant (p-values < 0.05)

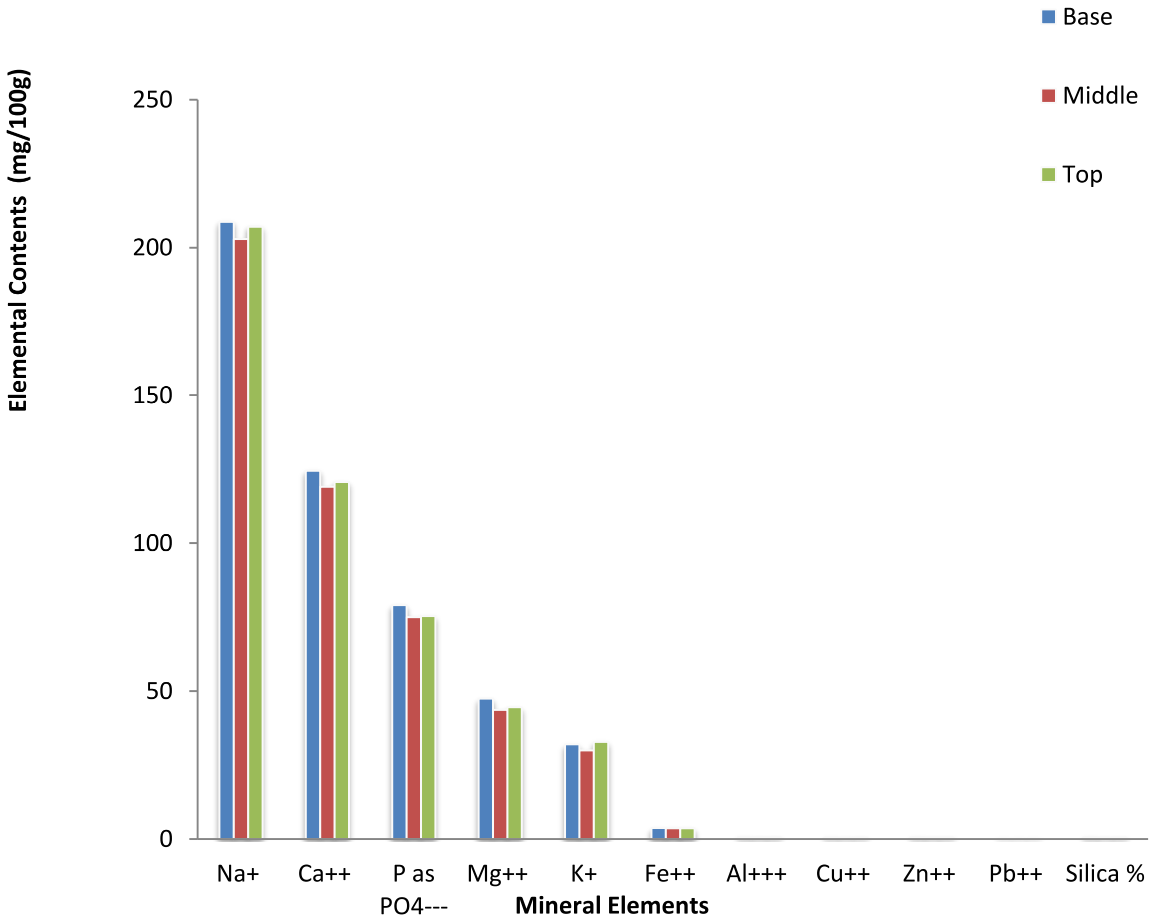

Figure 4.8: Mineral content and silica variations in SH in the WSD of *A. altilis*

4.8.0 DURABILITY TEST

4.8.1 Grave Yard Test (Ground Contact)

The mean result shows the % weight loss of *A. altilis* was 24.50±9.24 %, with the average range value between 26.57±10.05 % at the base, 22.28±8.82 % at the middle and top 24.65±8.66 %. This indicates that weight loss reduces at the base consistently toward the centre and slightly rises toward the stem-top as shown in Table 4.18. Radially, weight loss mean values ranges from 27.42±20.38 % to 27.81±2.40 % at the base, 23.99±7.46 % to 21.78±9.68 % at the middle, 22.32±7.07 % to 24.62±5.46 % at the top. Durability test trend of *A. altilis* was not consistent; in radial position; it decreased from corewood to wood-inner and then increased toward the outerwood as presented in Figure 4.9.

Analysis of variance in Table 4.18 shows insignificant difference exists in the sampling position *(p=0.1325)* while insignificant difference exists in the radial plane *(p=0.0353)* on the % weight loss of *A. altilis* at the likelihood level of 0.05%. Interaction between sampling height and radial position, effects of interactions has significant influence on the % weight loss of *A. altilis*.

The multiple comparison test in Table 4.19 shows significant $(p \leq 0.05)$ difference exist in % weight loss at the base between (outerwood and innerwood, but insignificant effect exist (corewood and outerwood, corewood and innerwood); at middle, significant difference exist between (corewood and innerwood, corewood and outerwood, innerwood and outerwood), but insignificant effect exist between (innerwood and outerwood), at top, significant difference exist between (innerwood and outerwood, innerwood and corewood, outerwood and innerwood, outerwood and corewood, corewood and innerwood, corewood and outerwood) across the radial position for percentage weight loss of *A. altilis*.

Table 4.18 Analysis of Variance for percentage weight loss of termite on *A.altilis* Wood

Sampling Height	Radial Position	% Weight loss after 12 months
Base	Corewood	$27.42\pm20.38_{ab}$
	Innerwood	$24.48\pm 6.14_{b}$
	Outerwood	$27.81\pm 2.40_{a}$
Pooled Mean		**26.57±10.05**
Middle	Corewood	$23.99\pm7.46_{a}$
	Innerwood	$21.07\pm7.37_{b}$
	Outerwood	$21.78\pm9.68_{b}$
Pooled Mean		**22.28±8.82**
Top	Corewood	$22.32\pm7.07_{c}$
	Innerwood	$27.00\pm4.39_{a}$
	Outerwood	$24.62\pm5.46_{b}$
Pooled Mean		**24.65±8.66**
Mean		**24.50±9.24**

Means±Standard mean error for 5 samples repeated. Values in and column of the same alphabet not substantially similar at alpha = 0.05 using the Duncan test

Table 4.19 Analysis of Variance for percentage weight loss of termite in *A.altilis* Wood

Source of Variation	Df	Sum of squares	Mean of square	f-cal	p-values
Sampling Height(SH)	2	221.96	110.98	2.0989	0.1325^{ns}
Radial position (RP)	5	687.34	137.47	2.5999	0.0353*
Interaction (SH*RP)	10	2296.93	229.69	4.3442	0.0002*
Error 45	45	2855.19	52.87		
Total	71	6061.42			

ns= not significant (p-values > 0.05)

*= significant (p-values < 0.05)

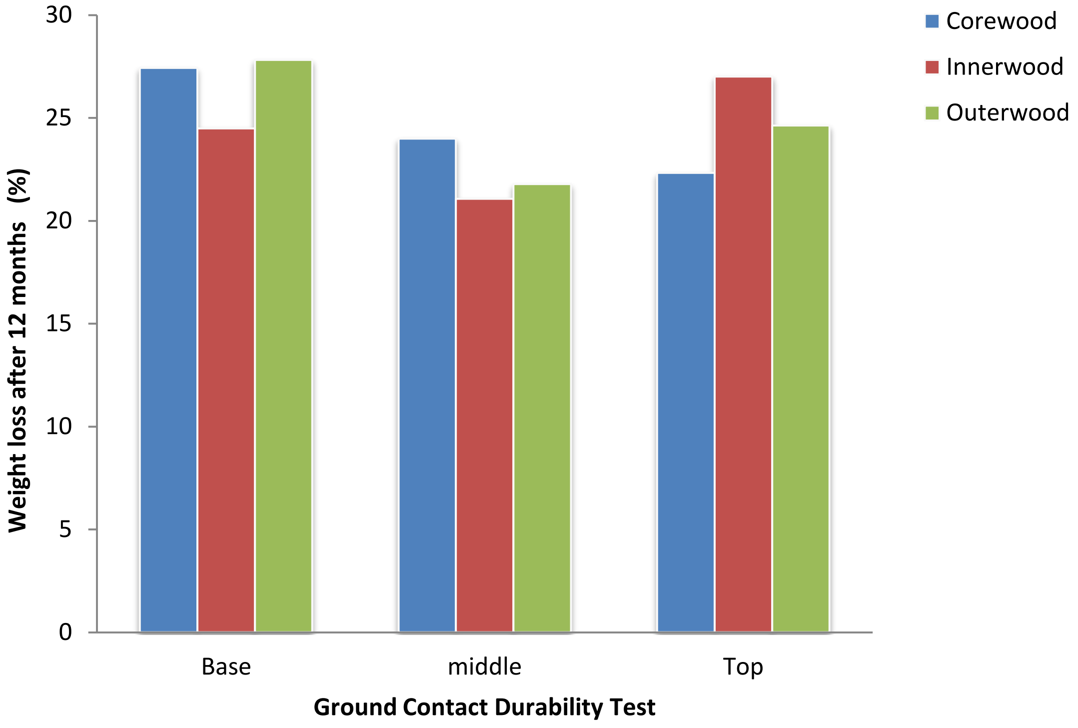

Figure 4.9: Percentage weight loss for termite in *A. altilis* wood

Plate 4.6: Test samples buried at the Timber Graveyard at 25% of sample height and at 1m x 1m interval on the field.

4. 8.2: Rating of the Wood of *A. altilis*

Weight loss was studied and visual rating was also conducted based on AWPA Standard E 21-06 (2009) visual termite bioassay rating of field test samples as presented in Table 4.20

4.8.3 FUNGI RESISTANCE TEST

A.altilis wood had means value ranges 4.70±2.12 % for white rot. White rot mean range from 4.49±2.12 % at the base, 4.76±2.48 % at the center and 4.85±1.79 % at the top.This depict white rot increased from base to the stem-top as presented in Table 4.22. Radially, white rot mean value range at base 4.84±2.92 % to 4.29±1.33 %, 5.59±3.57 % to 4.57±1.56 % at the middle, 4.68±2.07 % to 5.58±1.86 %. The outcome demonstrates that *A.altilis*' proportion losing weight is resistant to fungal attack as shown in Figure.4.10a.

Brown rot means value ranges 5.47±2.89 %. Brown rot mean range from 5.31±2.53 % at the base, 5.58±2.90 % at the center and 5.51±2.04 % at the top.This depict brown rot increased from base to the stem-top been presented in Table 4.22. Radially, brown rot means value range at base 5.12±2.25 % to 4.23±2.01 %, 6.01±6.15 % to 4.62±1.79 % at the middle, 5.70±1.81 % to 5.97±1.64 % as presented in Figure 4.10b

Analysis of variance presented in Table 4.23 shows insignificant impact of the sampling position *($p=0.813$)*, radial plane *($p=0.854$)*, and fungi *($p=0.061$)* on the white rot and brown rot of *A. altilis* wood. Interaction between sampling height, radial position and fungi effects of interactions has insignificant influence on the white rot and brown rot of *A. altilis*.
The multiple comparison test in Table 4.22 shows significant *($p \leq 0.05$)* difference exist in white rot and brown rot at the base (corewood and innerwood, corewood and outerwood, innerwood and corewood, innerwood and outerwood); at middle, significant difference exist between (corewood and outerwood, corewood and innerwood, outerwood and corewood, innerwood and corewood, innerwood and outerwood), at top, significant difference exist between (outerwood and corewood, outerwood and innerwood, corewood and outerwood, corewood and innerwood, innerwood and outerwood, innerwood and corewood) across the radial position for white rot and brown rot of *A. altilis*.

Table 4.20: Visual Termite bioassay rating of field test samples (AWPA Standard E 21-06, 2009)

Natural durability class	Weight loss (%)	Class of Resistance
I	< 3.52	Very resistant
II	3.52 – 7.50	Resistant
III	7.50 – 10.96	Moderate
IV	10.96 – 18.94	Poor
V	18.94 – 31.89	Very poor

Plate 4.7: Visual observation of moderately attacked wood samples of *A. altilis*

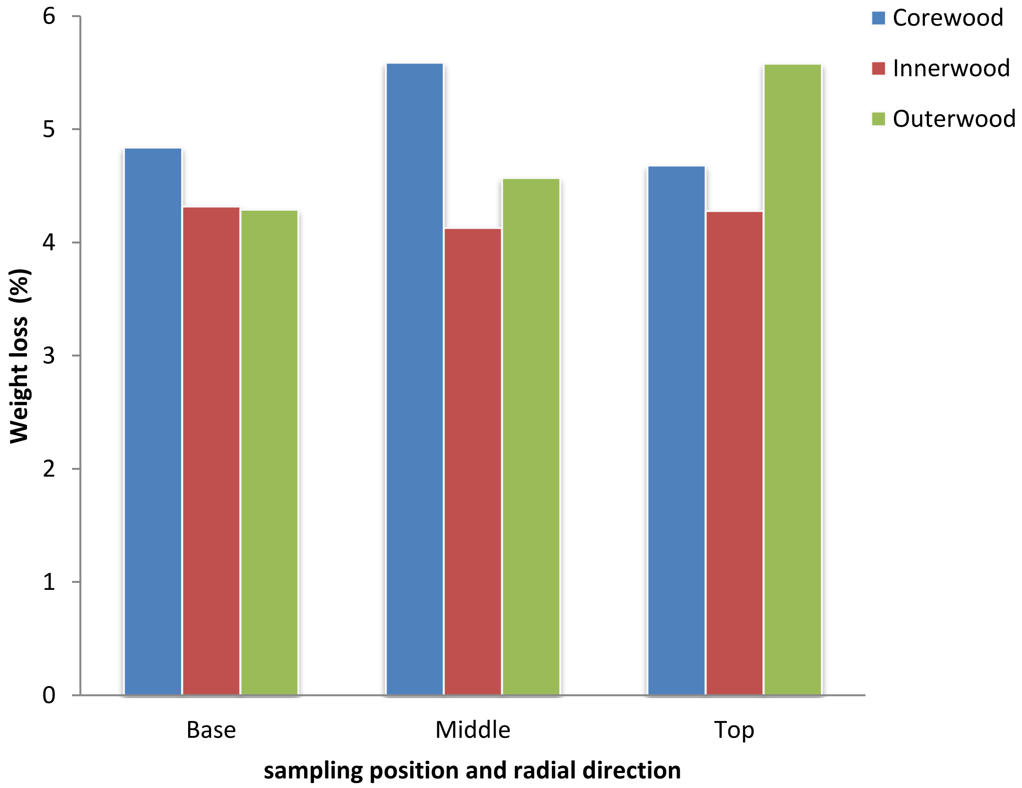

Figure 4.10a: Effect of SH and RP on weight loss of White rot fungi

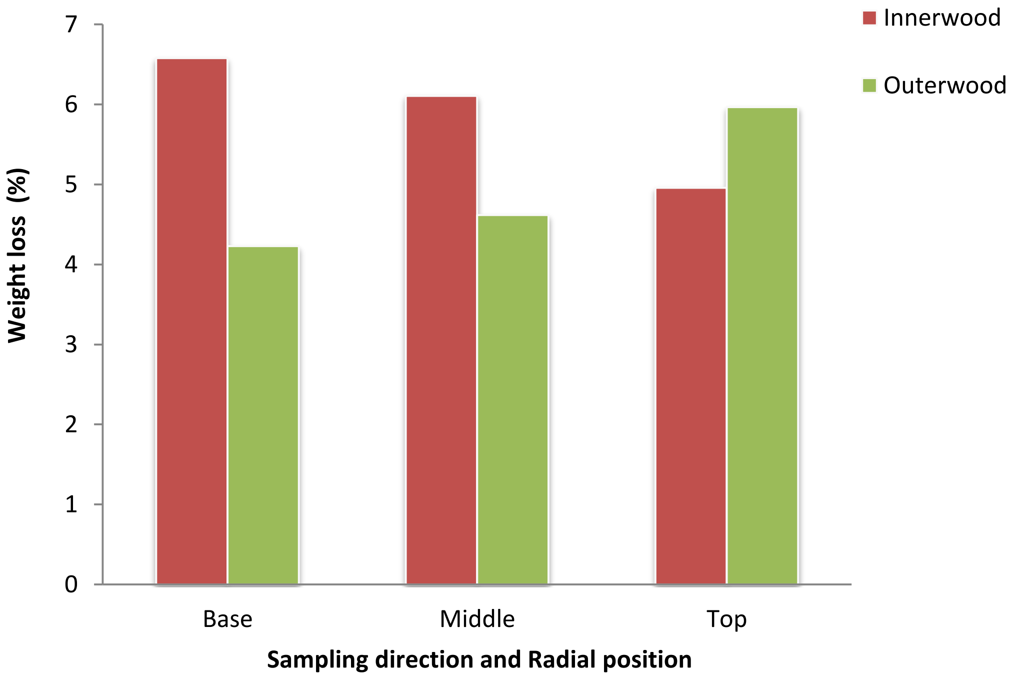

Figure 4.10b: Effect of SH and RP on weight loss of Brown rot fungi

Table 4.21: Classification of Resistance to Termite attack based on SNI 01.7202.2006 Rating

Average Weight Loss (%)	Average Residual Weight (%)	Indicated Class of Resistance
0 to 10	90 to 100	Highly resistant
11 to 24	76 to 89	Resistant
25 to 44	56 to 75	Moderately resistant
45 or above	55 or less	Slightly resistant or non-resistant

Table 4.22 Mean values of percentage weight loss of fungi attack of *A. altilis* wood at SH and RP

Sampling direction	Radial Position	Fungi attack after 20 weeks White Rot	Severity of attack	Fungi attack after 20 weeks Brown Rot	Severity of attack
Base	Corewood	$4.84\pm2.92_{a}$		$5.12\pm2.25_{b}$	
	Innerwood	$4.32\pm1.76_{b}$		$6.58\pm2.97_{a}$	
	Outerwood	$4.29\pm1.33_{c}$		$4.23\pm2.01_{c}$	
Pooled Mean		**4.49±2.12**	**Highly resistant, 0-10%**	**5.31±2.53**	**Highly resistant, 0-10%**
Middle	Corewood	$5.59\pm3.57_{a}$		$6.01\pm6.15_{c}$	
	Innerwood	$4.13\pm1.71_{c}$		$6.11\pm3.96_{b}$	
	Outerwood	$4.57\pm1.56_{b}$		$4.62\pm1.79_{a}$	
Pooled Mean		**4.76±2.48**	**Highly resistant, 0-10%**	**5.58±2.90**	**Highly resistant, 0-10%**
Top	Corewood	$4.68\pm2.07_{b}$		$5.70\pm1.81_{ab}$	
	Innerwood	$4.28\pm1.47_{c}$		$4.96\pm1.87_{b}$	
	Outerwood	$5.58\pm1.86_{a}$		$5.97\pm1.64_{a}$	
Pooled Mean		**4.85±1.79**	**Highly resistant, 0-10%**	**5.51±2.04**	**Highly resistant, 0-10%**
Mean		**4.70±2.12**		**5.47±2.89**	

Means±Standard mean error for 5 samples repeated. Values in and column of the similar alphabet at α = 0.05 are not significaantly different

Table 4.23: Analysis of Variance for resistance to fungi attack of *A.altilis*

SV	Df	SS	MS	F-cal	P-value
SH	2	2.473	1.237	0.2078	0.8127^{ns}
RP	5	11.627	2.325	0.3908	0.8542 ^{ns}
Fungi	1	21.311	21.311	3.5820	0.0611^{ns}
SH*RP	10	40.668	4.067	0.6835	0.7377 ^{ns}
SH*Fungi	2	0.182	0.091	0.0153	0.9849 ^{ns}
RP*Fungi	5	37.807	7.561	1.2709	0.2818 ^{ns}
SH*RP*Fungi	10	23.782	2.378	0.3997	0.9442 ^{ns}
Error	108	642.553	5.950		
Total	143	780.402			

ns = not significant at (p value >0.05)

4.8.4: Mechanical Properties and Density Interaction of *A.altilis* wood

Research has shown that wood density affect strength properties and a good predictor of some wood mechanical properties on various hardwood species such as *Nauclea diderichii* (Fuwape and Fabiyi, 2003); *Eucalyptus nitens* and *Eucalyptus regnans* (Yang and Evans 2003); *Celtis spp* (Ocloo and Laing, 2003) and *Celtis mildbraedii* and *Maesopsis eminii* (Zziwa *et al.* 2006b). The linear relationship amongst density and elastic modulus, such as Ductility (MOR), Flexural Strength (MOE) and Maximum Flexural Toughness (CS), parallel to grain, Impact bending test (IM) and Shear strength parallel to grain using regression analysis was considered in this study.

In this present study, regression analysis was used to develop a mathematical model using wood density as a predictor for MCS//, MOR, MOE, Shear test and Impact bending, the equation with good fit using the various assessment procedures are presented in Tables 4.24 and 4.25. The correlation coefficients determination (R^2) as shown in Table 4.24 for the regression model logarithms of wood density to mechanical properties such as IM (0.54), Shear (0.80), MOR (0.60), MOE (0.82) and MSC// (0.18).

The correlation coefficients in Table 4.25 reveal the level of linear relationships between the wood density and Mechanical properties assessed. Wood density positively correlated with MOR (r = 0.54) and impact bending (r = 0.56). Meanwhile, wood density had weak correlation with all the wood properties with MOE having the highest correlation (r = 0.82). Among the six mechanical properties predicted, MOE was more correlated with wood density (r = 0.82) and Shear (r = 0.80), while the least was MCS// (r = 0.18). The linear relationships between wood density and other indices measured could be used as their predictive indicator.

Table 4.24 Regression Equations relationship between Wood Density and Mechanical Properties of *A.altilis* wood

Model Number	Logarithms of Density		Equation	R	R^2	F- Ratio	Standard Error
1	InIM	=	6.46+0.079InD	0.23	0.54	3.97	0.095
2	InSHEAR	=	6.26+0.046InD	0.92	0.80	0.595	0.097
3	InMOR	=	6.003+0.1InD	0.25	0.60	4.50	0.094
4	InMOE	=	5.73+0.078InD	0.212	0.82	3.29	0.096
5	InMCS//	=	5.653+0.237InD	0.42	0.18	15.26	0.88

Table 4.25. Correlation coefficients indicating linear relationships between Wood density and Mechanical properties of *A.altilis* wood

		lnDensity	InIM	lnShear	lnMOR	lnMOE
In Density	Pearson Correlation	1	.232	.092	.246*	.212
	Sig. (2-tailed)		.050	.443	.037	.074
	N	72	72	72	72	72
lnIMB	Pearson Correlation	.232	1	.172	.557**	.336*
	Sig. (2-tailed)	.050		.149	.000	.004
	N	72	72	72	72	72
lnShear	Pearson Correlation	.092	.172	1	.255*	.047
	Sig. (2-tailed)	.443	.149		.031	.693
	N	72	72	72	72	72
lnMOR	Pearson Correlation	.246*	.557**	.255*	1	.538*
	Sig. (2-tailed)	.037	.000	.031		.000
	N	72	72	72	72	72
lnMOE	Pearson Correlation	.212	.336**	.047	.538**	1
	Sig. (2-tailed)	.074	.004	.693	.000	
	N	72	72	72	72	72
lnMCS//	Pearson Correlation	.071	0.003	.241	.002	
	Sig. (2-tailed)	.021	.0056	.005	.943	1
	N	72	72	72	72	72

* Correlation is significant at the level of .05 (2-tailed)
** Correlation is significant at the level of .05 (2-tailed)

CHAPTER FIVE

DISCUSSION

5.1 Introduction

This chapter discusses results of the study from the data gathered during the research. The results are discussed according to outcome of the experiments and how the results were displayed.

5.2: Physical Properties of *A. altilis* (Breadfruit)

5.2.1: Wood Density

Wood density is known as a main factor that influence the material characteristic particularly the physical and mechanical properties which usually depend on the fibre diameter, fibre lenght and thickness of the cell wall. From this study, it was observed that *A.altilis* wood density values reduces at the base to the stem-top consistently and significantly down the sampling height. *A.altilis* had average wood density of 581.48±57.61 kg/m^3 and the outcome obtained in this study followed the results of the research report by Ragone, (2011) Anthony, (2009) and Clement *et al,* (2009) recorded 505-645kg/m^3 at 15% mc for this specie. Richter and Dallwitz (2000) also reported density ranges of 350-620kg/m^3, for *Artocarpus* species. Nelson-Quartey, (2007) observed that as the amount of water absorbed in wood increases, the weight also increases which in turn led to the wood weight decrease in the axial direction at the base to the stem-top of the timber. The heartwood formation often leads to a higher density at the base of a tree. Due to the occurrence of inmature wood in vertical variation roughly the pith, the density is always lower at the top of the tree (Ogunsanwo, 2001). This means that the water absorption has a direct effect on the properties of every sawn timber resulting in the main reason why all the experiments were performed at specified moisture content.It was observed that larger density from the base of a timber could be as a result of the development of heartwood when the ratio of heartwood is higher than the amout of the sapwood. Then, it could be

observed also that wood at the upper part of the timber is lower in densitywhich could be as a result of the juvenile wood influence within the pith in erect variation.
The decrease in wood density values from the trunk to the stem-top of the tree may be due to improvements in wood arrangement, while the rise in size distribution and anatomical improvement of the log can be attributed to wood exponential in yearly growth rings as well as the expansion of more wood arrangement of modern cells as the timber grows in body size. Akachuku (1981) opined that wood density of *Gmelina arborea* grown in Nigeria has variations in trees mass occur due to cell multiplication and the increment in cambium in to maturity. Fuwape and Fabiyi (2003) also opined that there is a general reduction in wood density at the outerpart to the pith in plantation grown *Nauclea diderichiiiI*

In this study, it was observed that the density of *A. altilis* wood decreases generally from base to tip-stem as shown in Table 3. The research finding agrees with the study by (Zziwa *et al.,* 2012) on *Artocarpus heterophyllus*, who documented a comparable trend in the wood variation. Again, Izekor, (2010); Jozsa and Middleton, (1995) and Rupert *et al.,* (2000) reported a trend of variations along the axial plane in wood density from their studies.

Panshin and DeZeeuw (1980) reported that intra species differences in wood density could be due to growing conditions resulting from a situation such as competition within a stand. These conditions can cause major differences in magnitude and pattern of variability in wood density, in homogenous stand. In such a situation, the trees which are dominant may show one pattern of variability in wood density while the trees that are suppressed may be due to differences in fibre morphology as observed in this study. Hughes (1973) and Akachuku (1981) working on *Gmelina arborea* trees found significant differences between the mean density of trees within the same plot. Variations in density may also be affected by such factors including site growth, age, climatic condition of the area, and the portion along the tree bole from which the wood samples were collected.

5.2.2: SPECIFIC GRAVITY

Specific gravity of a wood could be defined as the quantity of dry matter present in the solid wood. Mean of *A.altilis* wood was 0.58. Obtained mean values compared favourably with *Dipterocarpus indicus* as recorded by Nageeb and Devi, (2010) in the range of 0.45-0.59. This is in line with 0.58 obtained for *Khaya ivorensis* (Jamala *et al.,* 2013), but greater than 0.46 for *A.heterophyllus*, (Ali *et al.,* 2012), *Ficus exasperata* 0.50 (Anguruwa, 2018), and Ogunkunle *et al.,* (2008) reported 0.46 for *F. thonningiiii* wood. The specific gravity decreased from the base to the centre, and toward the stem-top, are 0.60, 0.58 and 0.57 respectively. From this study, there is a decrease in the radial direction from corewood to outerwood (bark-bark), ranges from 0.60±.10 to 0.60±0.08 corewood to outerwood at base of the trunk, at corewood to outerwood of the middle 0.60±0.06 to 0.61±0.10, while at the top of the trunk 0.57±0.05 to 0.60±0.04 at corewood to outerwood

This observed pattern of variation in this study corroborated Ogunsanwo and Adedeji, (2018); Ogunsanwo and Onilude (2000); Josue (2004) and Veenin *et al.,* (2005) on other wood species. Hence, from this, studies, inconsistency pattern was observed radially from pith to the outerwood of *A. altilis,* and this could be deduced from the pith eccentricity as a result of bending influence which varies considerably over the life of the tree. The eccentricity of pith was strongest at the center and top of the *A.altilis* merchantable bole of the entire length of the timber. Interaction variations effects between sampling height and radially position are significantly different. The obtained result is in line with type I pattern of variation reported by Panshin and deZeeuw (1980) who observed that specific gravity increases from the inner portion of the wood to the bark.

Specific gravity is also related to wood characteristics, such as crushing forces required for machining, dimensional stability, mechanical strength, sheet properties, deformation, protectant treatment, fuel quality, and acoustical, thermal and electrical insulating properties (Chundoff, 1984). One or more physiological changes are correlated with the rise in wood specific gravity, average increase in fiber wall thickness, a reduction in fiber lumen diameter, and an increase in fiber frequency. As a result of increasing linearly with radial size, this is one of the most critical factors for the resourceful utilisation of timber, at any given height. Roa *et al.,* (1998) noted that with a rise in the distance from the pith to the outside, there is a significant increase in specific gravity and thus attributed such patterns to the increment wall thickness, decrease in fibre content and circumference of fiber lumen. The low specific gravity found in this study demonstrates that the timber can be split conveniently without wearing down the chipper knives, but that the rate for delignification will be high, but that the amount of liquor consumed during pulping will be small.

5.2.3: Tangential Shrinkage

In current research, *A.altilis*' mean shrinkage at tangential level is 4.3 %, The *A.altilis* mean values at the base from 3.70 %, middle 4.33 % and the top 4.74 %. This indicates that tangential shrinkage increases with a significant difference in sampling direction at base to tip. Radially, the mean value is from 4.00±0.77% to 3.56±0.99% at corewood to outerwood around the trunk at the base, 4.33±0.54% at the base. These differences in tangential shrinkage may be attributed to changes caused by the rise in cell size and early wood percentage. The observed differences may also be due to the presence of more mature-wood resulting from the increasing age of the cambium. Tangential shrinkages decreased along the tree bole at the base-stem to the stem-top.

This variance pattern is comparable, but slightly higher than the results of the study 4.3 % for *A.altilis* wood to reported values by Ananias, (1989), for *A.elasticus*, was (2.9%), *A. Scortechinii*, *Parartocarpus venenosus* was (3.9%) and Izekor (2010) for *Parartocarpus venenosus* was (4.4 %). Radially, Shukla *et al.,* (2003) observed a rise in shrinkage tangential from the pith-eccentricity to the wood bark hybrid poplar clones species. Poku, *et al.,* (2001) reported a decreasing tangential shrinkage with height, corroborated this by showing an inconsistent trend of variance along the sampling direction for all types of wood in shrinkage tangential level. Meanwhile, the extractive material's masking effect reduces predictability of wood shrinkage from the thickness of the cell-wall. The gradual rise in dimensional wood shrinkage from pith to bark, as determined by age, could be associated with the degree of growth of the cell wall, so the mean percentage shrinkage achieved in the tangential direction almost doubles that in the radial direction.

5.2.4: Radial Shrinkage (RS)

Radial shrinkage average mean of *A. altilis* was 1.42 %, and the average mean at the base 1.31 %, at middle 1.45 % and top had 1.49 % as presented in Table 4.3. This indicates that shrinkage radial level rises at base to top, and radially, it ranging between 1.14±0.09% to 1.33±0.29% at corewood to outerwood along the base-bole, 1.33±0.35 % to 1.53±0.47% at corewood to outer-portion and 1.33±0.35 % to 1.53± 0.47% as shown in Table 4.2

This pattern of variance is identical to the study findings by Ananias, (1989) who recorded (1.5%) in *A. elasticus,* (1.6%) in *A. scortechinii* and (2%) in *parartocarpus venenosus* wood species. Meanwhile, Ogunsanwo and Onilude (2000) also reported that *Triplochiton scleroxylon's* radial shrinkage dramatically decreased at the base to the top. Increasing percentage causes reduction in variation patterns as observed from the pith to the bark (bark to bark).

This observed pattern is close to the research report on variations observed by Ananias, (1989), it was concluded that the internal wood shrinks in normal and circumferential dimensions less for the outerwood and obstruction influence of the rays at the radial level, this condition might become responsible for the higher quantity of elements and could influence the rise in bulk density from the internal portion to the external portion. According to MacTop *et al.*, (1990) stated that due to the restriction influence of the rays on the radial plane, degree of lignifications between the radial and tangential walls, the differences in microfibrillar angle between the two walls and the increased thickness of the middle lamella in the tangential direction in relation with that in the radial direction could have shrinkage in timber. The radial shrinkage is reasonably high in shrinkage, as shown by the consistent trend observed.

5.2.5: The Volumetric shrinkage (VS) of *A.altilis* wood

The percentage VS mean value of *A. altilis* was 5.64%. The *A. altilis* mean 4.95% at the base, middle 5.75% and 6.24% at the top as shown in Table 4.2, Radially, mean ranges from 5.08±0.75% to 4.89±1.01% from corewood to outerwood along the base-trunk, 5.70±.76% to 5.92± .56% from corewood to outerwood across the middle and 6.12±0.48% to 6.39±0.68% from corewood to outerwood across the stem-top as presented in Table 4.2

From current study, as observed in volume shrinkage, the value rises at the tree base to the stem-top of the wood species and similarly at the mid-level to the outer-portion (bark-bark). Similar findings have been observed by Quintanar *et al.,* 1997) and this report is in line with Izekor (2010) and Shukla *et al.,* (2003). The accumulation of greater quantities of extractives in the inward wood can be by adding appropriate to the amorphous space in the material of the cell-wall, preventing normal shrinkage. Therefore, the innerwood has less volumetric shrinkage than the outerwood and this implies that the wood is light as it has a low propensity for contraction and therefore can be used for both structural and non-structural use.

5.3: Mechanical Properties of *A. altilis* Wood

5.3.1: Modulus of Rupture

In current studies, the mean modulus of rupture values at *A. altilis* was 36.05±8.32 N/mm^2, and average mean ranged of 42.07±8.79 N/mm^2 at the base, 33.11±7.13 N/mm^2 at the center and 32.99±5.39 N/mm^2 at the tip, respectively as shown in Table 4.6. It varies from 37.64±1.98 N/mm^2 to 46.81± 4.04 N/mm^2 at corewood to outerwood at the base of the bole, 28.54±7.14 N/mm^2 to 39.10±2.92 N/mm^2 corewood at the center of the bole and 30.41±2.75 N/mm^2 to 36.58±7.23 N/mm^2 corewood to outerwood wood at the top of the bole as presented in Table 4.6

Modulus of rupture values generally reduce from base to the top. The modulus of rupture values observed decreased in modulus of rupture from base to top agrees with the report of Ogunsanwo (2000) and Jamala *et al.* (2013) for *Triplochiton scleroxylon*, Fuwape and Fabiyi (2003) on Modulus of rupture values for *Nauclea diderichii*. Modulus of rupture reduced from base to the top, and this observed decrease agrees with the FPR (1987) which reported a mean modulus of rupture values of 39.9 N/mm^2 for *Antiaris africana*, Jamala *et al.,* (2013) reported mean value 30.87 N/mm^2 for *Triplochiton scleroxylon*, while, Zziwa *et al.,* (2012) reported mean value 119 N/mm^2 for *Artocarpus heterophyllus.*

The pattern of variation of Modulus of rupture values from base to top could be attributed to the normal and consistent stem of *A. altilis* tree. Ogunsanwo (2000), Haygreen and Bowyer,(1989) reported that the increasing trend of MOR values from corewood to outerwood could be associated to variations in some morphological factors such as fibre length, fibre diameter, lumen width and cell wall thickness as observed in this study on the anatomical characteristics of *A. altilis* wood.

This was corroborated by Ogunsanwo (2000) who observed a rise in modulus of rupture from inner to bark in *Triplochiton scleroxylon* wood. Kibblewhite and Bawden, (1991) opine that the morphology of wood fibers, particularly the proportions of tracheid wall thickness and lumen diameter, affects the surface strength of wood, thus affecting the processing and properties of wood products.

The modulus of rupture of *A. altilis* value obtained compared favourably with some timbers such as *Triplochiton scleroxylon, Antiaris toxicaria* and *Alstonia boonei* for light construction works as common timber been used for furniture production in Nigeria. According to modulus of rupture 36.05±8.32 N/mm^2 of *A. altilis* mean, wood is in the low-density category as shown in Table 4.5. Therefore, this shows that the wood may be ideal for the furniture maker.

5.3.2: Modulus of Elasticity

The mean modulus of elasticity of *A. altilis* was 3354±1286 N/mm^2. The modulus of elasticity and mean ranges 3993±1983 N/mm^2 at the base, 2924±493 N/mm^2 at the middle, and 3145±520 N/mm^2 at the top. Radially, modulus of elasticity ranged between

3526.61±604.28 N/mm^2 to 3630.06±555.49 N/mm^2 at corewood to outerwood along the bole at the base, 2707.50±407.01 N/mm^2 to 3140.24±308.39 N/mm^2 corewood to outerwood along the bole at the middle and 3344.18±637.01 N/mm^2 to 2986.02 N/mm^2 at corewood to outer-portion at the stem-top of the timber as shown in Table 4.6

The modulus of elasticity values obtained in this research reduces from base to the middle and slightly increased at middle to the top. The modulus of elasticity varied non-uniformly along the sampling height with a maximum value of 3993 N/mm^2 recorded at 10% merchantable height, the pattern of variation in the modulus of elasticity seemed to be inconsistent. Generally the trend in variations of modulus of elasticity across the radial position showed a decrease from corewood to the wood-inner, and slightly increased to the outerwood (bark to bark). The observed non-uniformly trend in modulus of elasticity is likely due to the variations in anatomical characteristics of the *A. altilis.* Similar trend in modulus of elasticity was recorded in *A. heterophyllus* (Zziwa *et al.,* 2012), *A. heterophyllus,* (Ali *et al.,* 2012), Blackwood (Machado *et al.,* 2014), *Nauclea diderichii* (Fuwape and Fabiyi, 2003), *Triplochiton scleroxylon* (Ogunsanwo, 2000) and Slash Pine (Mactop *et al.,* 1990).

The modulus of elasticity variation observed in this study is consistent with Ishengoma and Nagoda (1991) who stated that variations along the tree bole decreasing uniformly, which could be attributed to the reduction within the lesser bole and rising in the high bole, and increase from base to top in a consistent manner. The pattern, however, reveals a contrary trend and which could due to the effect of other strength factors such as microfibrillar angle, cellulose proportion and the amount of cellulose crystallinity. From this present study, modulus of elasticity across the radial plane, it was observed that, there was an inconsistent change in modulus of elasticity from corewood to outerwood believed to have been influenced by the amount of cell wall development. Meanwhile, all tested parameters in this study varied inconsistently, which further confirms anisotropic nature of this species.

Modulus of elasticity and modulus of rupture are the most important elastic properties in wood utilisation, therefore, as presented in Table 4.5, modulus of elasticity is in the category of low to medium density. Hence, *A. altilis* timber is categorised for a light structure based on the obtained values. This shows that the wood is suitable for use in the wood-based industry and production of furniture items.

5.3.3: Maximum Compressive Strength Test (MCS//) Parallel to the Grain

This current study, mean compressive strength test of *A.altilis* was 20±3.7 N/mm^2. The compressive strength mean values range 23±4.1 N/mm^2 at the base, 20± 2.7 N/mm^2 at the middle and 18±2.7 N/mm^2 at the top.Radially, values ranged between 22.5±2.5 N/mm^2 to 22.5±3.3 N/mm^2 at corewood to outerwood at the base, 18.5±3.1 N/mm^2 to 21±2.7 N/mm^2 corewood to outerwood at the centre and 18±3.6 N/mm^2 to 19±1.7 N/mm^2 at corewood to outerwood at the stem-top as shown in Table 4.6

Compressive strength parallel to grain reduces from the wood base to the top-stem. A related pattern was recorded by Ogunsanwo (2000) in *Triplochiton scleroxylon* and Beaudom *et al*., (1989) in *Tamarach spp* by FPR (1987) observed 16.94 N/mm^2 for *H. barteri*, 30.5 N/mm^2 for *A.africana* and 34.4 N/mm^2 for *Daniellia oliveri*. The trend may be as a result tree age and sampling height of *A. altilis*. Lausberg, *et al.,* (1995) also reported that genetic factors and growing condition may cause different variation. Rulliaty and America (1995) and Panshin and deZeeuw (1980), reported that cell wall thickness of *Sweetennia macrophylla* decreases from base to top, since cellwall thickness controls mechanical properties and, the influence of felling stress on the properties of wood at the 90% merchantable height of the tree could be parallel to grain values, which could be responsible for the poor compressive strength values recorded at the 90% merchantable height of the tree bole.

Across the bole, compressive strength parallel to grain values generally improved at pith to bark. Similar pattern was observed by Ogunsanwo (2000) in *Triplochyton species*, that wood having between 80-90% from pith are homogenous and, this increase in compressive strength parallel to grain from pith to bark may be due to the cell wall development and, Panshin and Dezeeuw (1980) also corroborated that compressive strength parallel to grain has control on mechanical properties of wood.

5.3.4: Shear Strength Test Parallel to Grain

The shear test measures the maximal shear stress of a material sliding along a direction parallel to the forces applied before failure occurs. In this present study, the mean value of the shear strength of *A. altilis* was 8.9±1.7 N/mm^2. The shear strength mean value ranges from 9.7±1.7 N/mm^2 at the base, 8.7±2.1 N/mm^2 at the middle and 8.5± 0.9 N/mm^2 at the top, this reveals that shear strength rises from base to the top as shown in Table 4.6 Radially, the means value ranges 9.1± 0.8 N/mm^2 to 10.8±1.4 N/mm^2 at corewood to outerwood along the base, 8.0±1.6 N/mm^2 to 9.3±2.1 N/mm^2 corewood to outerwood at the centre and 8.4±0.7 N/mm^2 to 8.5±1.1 N/mm^2 at corewood to outerwood at the stem-top as presented in Table 4.6

From this study, shear strength along the radial position was uniformly increased from corewood to the outerwood of the *A. altilis* wood. This is similar to Sulaiman and Lim, (1989); Mahmud *et al., (*2017) observed for *Gmelina arborea* wood.

5.3.5: Impact Bending Strength Test (IM) parallel to the grain

The mean value impact bending strength test of *A.altilis* 15.51±4.17 J/m^2, with the value range 14.31±3.92 J/m^2 at the base 15.31±4.39 J/m^2 at the middle and 16.53±4.04 J/m^2 at the top, while radially ranges from 12.92±4.55 J/m^2 to 14.52±3.06 J/m^2 at corewood to outerwood along the bole base, 13.89±1.83 J/m^2 to 14.63±4.60 J/m^2 corewood to outerwood along the centre,15.86±3.04 J/m^2 to 17.64±4.42 J/m^2 at corewood to outerwood along the stem-top as shown in Table 4.6

This indicates that impact bending strength rises consistently from base to the top. This is similar to the previous research findings on *Ficus Mucuso* (Adejoba *et al.,* 2009), *Anningeria robusta,* (Ajala, 2005) and *Triplochiton scleroxylon,* (Ogunsanwo, 2000). It was observed that the impact bending trend is the same at any sampling position of the wood. Along the radial position, impact bending increased uniformly from corewood to outerwood, this behaviour of individual wood type shows that both corewood and outerwood varied consistently along the radial position bark to bark, these results corroborate the report of Moreira *et al.,* (2017); Ogunsanwo (2000).

Again, Green *et al.,* (2003) observed that the variance can be owing to the belief that wood is a renewable material and the tree is subject to frequent changes in the characteristics of the wood. Emily *et al.,* (2018) asserted that impact strength in bending understanding is important in structures that will be exposed to narrow impact loads.

5.4. Anatomical Characteristics of Breadfruit (*Artocarpus altilis*) wood

Table 4.11 to 4.12 presents the results of the Anatomical Characteristics of Breadfruit (*A. altilis)*, for instance length of fibre, diameter of fibre, width lumen and CWT.

5.4.1 Fibre Length

The fibre length of *A.altilis* in this present study was 1.52±0.28 mm, and average means ranged at base 1.58±0.28 mm, middle 1.49±0.35 mm and the top 1.48±0.19 mm. Radially, the mean values ranges from 1.53±0.23 mm to 1.58±0.32 mm corewood to outerwood along the base bole, 1.33±0.23 mm to 1.52±0.36 mm corewood to outerwood along the middle bole and 1.37±0.18 mm to 1.58±0.20 mm corewood to outerwood just at the stem-top of the wood as shown in Table 4.8

This study shows the variations from the sizes of fibre length obtained that fiber length decreases at base to top, and with non-uniform rise at corewood to outerwood. This assertion was corroborated by Zobel and Van Buijtenen, (1989) who found that the variations in fibre length characterized by a rise in distance are mostly as a result of differences in the ratio of immature and mature timber in the tree, as the ratio of immature timber results in an increase in length. Jorge *et al.,* (2000) compared the rise in fibre length to an increase in thickness of the original transition with an increase in the age. Ishengoma *et al.,* 1995; Kibblewhite, 1984; Malan, 1989, and Muneri and Balodies, (1998), reported that the when there is a high proportion of juvenile wood in the top of the tree, such trees exhibit the characteristics associated with juvenile wood. In general, with increased stem diameter, there was a reduction in fibre length.

From this investigation, fiber length had 1.52mm mean, hence, *A altilis* indicates short fiber length lesser than 1.60mm considering any fiber lesser than 1.60mm is known as short while long fiber above 1.60 mm is known as long fiber. This is similar in fibre lengths of less than 1.60mm obtained by Oluwadare and Sotande, (2007) in the wood *Leucaena leucocephala* species, while Ogunjobi *et al.,* (2014) recorded 0.65mm in *Vitex doniana*. Meanwhile, 1.60mm in hardwood species is considered appropriate choice for papermaking.

Horn (1974) noted that the increase in fibre length in raw materials often increases the tearing strength of hardwood pulps and also expands the binding sites that act as part of its fibre function (Wangaard, 1973). Parameters are different with a significant influence on the paper's inter-fibre bonding, bulk density and fibre strength to a large degree, as the papermaking parameters for tropical hardwood pulp depend on the chemical composition and fibre properties of the timber species (H’ng Paik San *et al.*, 2000). Oluwadare and Sotande, (2007) in *Leucaena leucocephala* species, and Yanchuk and Micko (1990) researched findings for trembling Aspen wood in radial variation of wood density and fiber length concluded that with very little fluctuation, fiber length increases gradually across the pith and fibers magnitude of *A. altilis* categorised variety intended for hardwood, hence, the fibre morphology is comparatively good for the purpose of veneer production and paper manufacturing.

5.4.2 Fibre Diameter

The mean values of fibre diameter are 35.09±7.56 µm. The fibre diameter means value ranges 37.03± 9.22 µm at the base, 33.55± 5.09 µm, at the middle and 34.70±7.67µm, at the top. Radially, mean values ranges 44.77±10.29 µm to 31.57±7.02 µm corewood to outerwood of the base, 36.23±5.34 µm to 31.84±4.61 µm corewood to outerwood at the center, while mean ranges from 37.16±3.48 µm to 34.84±8.94 µm from corewood to outerwood at stem-top of the log as presented in table 4.8.

In this present study, it was observed that fiber diameter across the sampling direction reduces from the base to the center and then gradually rise to the stem-top, but radially rises to the wood-inner at the corewood and decreases to the outerwood, so there was no clear pattern of variance in both the sampling height and radial location corroborating Roger *et al.,* (2007) who stated that when tree age increases, the average diameter fibre also increases. As the tree ages to old age, the decrease in its diameter may be due to the thickness of the wood cell wall, physiological and molecular changes that transpire during the tree aging process in the vascular cambium (Pande *et al.,* 2007).

5.4.3 Lumen Width

The lumen width obtained for *A. altilis* 22.95±7.8 µm, with the average range value between 22.49±8.54 µm at the base, 23.01±7.89 µm at the middle and 23.36±7.53 µm at the top. Radially, Lumen width ranged between 27.12±10.84 µm to 18.80±4.96 µm corewood to outerwood at the base, 25.34±3.85 µm to 23.55±10.55 µm corewood to outerwood at the centre and 27.22±8.23 µm to 20.18±6.28 µm corewood to outerwood at the stem-top as presented in table 4.8

In this current research, there was rise from the base to top in lumen width, and this rises may be ascribed to a decrease in dimension of the cell and tree growth as it get to maturity especially in a fruit trees, but increase in lumen-width as the tree decreasing in age. Meanwhile, decreasing trend was observed in lumen width at the core to outer-portion at radial position of the study test samples and this was corroborated by research results obtained by Oluwadare and Sotande (2007) for *Leucaena* species and in *Vitex doniana* by Ogunjobi *et al.,* (2014). Again, the reduced dimensions in lumen width could possibly be as a result of raise in the piece of fibre which could be linked to the development of wood bark (Jorge *et al.,* (2000) and Roger *et al.,* (2007). Rao *et al,* (1998) examined radial variability in the microscopic properties of plantation trees of *Tecomella undulata* D.Don, and reported important peripheral variations in vessel frequency, vessel diameter, solitary vessel percentage, fiber length, fiber diameter, fiber lumen diameter, and ray frequency. Fibre lumen width affects the beating ability of pulp, the narrower of LM, the more difficulty in pulp beating due to the lower penetration of liquid into the empty portion within the fibre.

5.4.4. Cell Wall Thickness (CWT)

The cell wall thickness of a fibre usually has influence on the rigidity and strength of a paper produced. In this present study, the thickness in cell-wall mean of *A. altilis* was 6.11±0.68 µm, with the values ranges from 6.23±0.75 µm at the base, 6.23±0.71 µm at the middle and 5.88±0.53 µm at the top, while across the radial position, it ranged between 6.52±0.17 µm to 6.05±0.33 µm corewood to outerwood at the base, 6.07±0.67 µm to 6.37±0.68 µm corewood to outerwood at the middle and 5.72±0.68 µm to 6.08±0.26 µm corewood to outerwood at the stem- top as shown in Table 4.8.

The observed values 6.11±0.68 µm in this study is higher than the reported value 1.94 - 4.99 µm by Ogunkunle, (2010) for *Ficus* species, 2.90 µm for *Leucaena leucocephala* by Oluwadare and Ashimiyu, (2007), and a bit lower to 5.00- 10.00 µm reported by PPRI, (2011) for pine.

It was observed that the cell-wall thickness values variations are consistent from the base to the middle and slightly reduced to the top along the sampling direction and radial levels. Hence, this is similar to the variations reported for *Tectona grandis* wood species by Izekor, (2010), *Vitex doniana* wood species by Ogunjobi *et al.,* (2014) and for *Leucaena lencocephala* wood by (Oluwadare and Sotande, 2007) and for *Triplochiton scleroxylon* by

(Ogunsanwo, 2000). As a consequence, a rise in the axial direction of thickness in cell-wall and a decrease in radial direction of cambium rapid cell division of *A.altilis* wood may result in the cabium increases in diameter (Frimpong-Mensah, 1992; Corsan, 2002; Bowyer *et al.*, 2003, and Roger *et al.*, 2007). Meanwhile, large CWT has a positive influence on the paper's characteristic bursting and tensile strength, and folding endurance (Syed *et al.*, 2016). Therefore, *A.altilis* wood is suitable for paper production and would produce paper of high strength.

5.4.5 SLENDERNESS RATIO (SR)

Slenderness ratio is one of the main factors that determine suitability of a woody material to be considered for paper manufacturing.It is measured by comparing the ratio of fibre length to fibre diameter (Akgul, 2009). In this study, the mean value of slenderness ratio of *A. altilis* was 44.79±11.49, with the average mean values ranges 44.52±10.94 at the base, 45.41±12.64 at the middle and 44.43±11.3 at the top. The slenderness ratio shows a pattern of increases at base to middle and a slight decrease to the top along the sampling direction, while radially, mean values ranges 35.13±6.91 to 51.18±10.54 corewood to outerwood at the base, 37.09±7.29 to 48.30±12.84 corewood to outerwood at the middle, 37.11±6.02 to 48.76±13.61 corewood to outerwood at the stem-top as shown in Table 4.10

A. altilis have a suitable slenderness ratio of 44.79. This is slightly lower to values obtained for slenderness as reported by Dutt and Tyagi, (2011), 55.18 was obtained in *Eucalyptus grandis*, 52.66 in *Eucalyptus tereticornis* and 53.33 in *Eucalyptus camadulensis* respectively. Meanwhile, in this study, slenderness ratio value is slightly higher than 35.85 in *Ricinodendron heudelotii* by Ogunleye *et al.*, (2017), Oluwadare and Sotannde, (2007) reported 42 in *Leucaena leucocephala* but slightly higher than few traditional raw material sources for paper manufacturing.

In the current analysis, there was no significantt effect on the slenderness ratio of the fibres in *A.altilis* on the variance values of both sampling direction and radial location at 0.05 % likelihood stage. Interaction influence involving sampling and the radial direction was not important at 0.05% probability levels. Akgul and Tozluogu (2009) noted that an element determining the fitness of the wood content for paper production is the ratio of it slenderness that is calculated by the relation of the flexural strength with the fibre orientation.

Xu *et al.,* (2006), opined that the slenderness ratio must be greater than 33 to be well thought-out as appropriate pulp production and paper making material, because SR greater than 33 in fiber of a paper will produce a higher tear resistance rate, while (Samariha *et al.,* 2011) observed a thin fibers generate a strong slenderness ration that is connected to the density of the paper sheet and the digestibility of the pulp (Onay *et al.,* 2001) in turn said, increase tearing resistance since thin fibers are readily collapsed to provide good surface contact and fiber to fiber bonding (Ogbonnaya *et al.,*1997). However, in this analysis, the values for SR fibers are higher than the expected values 33; consequently, good and strong papers can be produced by *A.altilis* wood.

5.4.6 FLEXIBILITY

Flexibility could be termed as the percentages ratio of lumen width to fibre diameter. In the determination of the strength properties of paper, flexibility coefficient is one of the most critical derived parameters and, this is proportion of fiber diameter to lumen diameter. Meanwhile, degrees of fiber bonding in paper sheet produced are defined by flexibility (Huber *et al.,* 2008; Samariha *et al.,* 2011). For both hardwood and softwood, the acceptable flexibility coefficient values classified by Smook (2003) are between 55-70 % and 55-75% respectively. Fibers with a flexibility coefficient or more than 75 % is commonly referred to as extremely elastic, whereas those with a flexibility coefficient ranges from 55% to 75% are known as flexible Bektas and Tutus, (1999).

In this study, mean value of flexibility coefficient obtained was 63.59%. The flexibility coefficient increase consistently at base to the centre, and reduce slightly to the top. The values obtained compared favourably to the recorded values of 63% for *Leucaena leucocephala* by Oluwadare and Sotannde, (2007), 63.33% recorded value for *ficus exasperata* by (Anguruwa, 2018), while higher value were obtained 79% for *Gmelina arborea,* (Ogunkunle and Oladele, 2008) and 63%-79% in *ficus species* (Ogunkunle, 2010). Similarly in line with Ogunjobi *et al.,* (2014) for the lower value 55.05% recorded for *Vitex doniana*.

Sing *et al.,* (2011) stated that, a fiber with a large bonding surface area will have high flexibility coefficient values, and during the processing of paper, the fibre will collapse easily and thus generating good strength paper. Therefore, the values of the flexibility coefficient reported in this study are well thought-out versatile and, therefore, fulfill the specifications of the manual for pulping and paper production according to Foelkel, (2009).

5.4.7 Runkel Ratio (RR)

The RR cmay well be considered as an imperative determinant factor for the generation of paper and from pulp of known characteristics in terms of comparison and mash output (Ohshima *et al.* 2005). RR is measured from thickness of the cell-wall ratio width lumen divided by th lenght of fibre within the timber board. It is known that, the acceptable ratio for RR is ≤ 1 which indicates the suitability of the wood for paper production. Therefore, when there is lower value of RR, it reveals how thinner the fibre cell walls is, and this thin fibres are better for paper production (Istek, 2006 and Oluwadare and Sotannde, 2007).

In this current study, the mean values for Runkel Ratio of *A. altilis* are 0.60±0.23, with the mean values at the base, at the middle and at the top 0.58±0.22, 0.65±0.24 and 0.72±0.24, respectively. This demonstrates that Runkel Ratio rises at the base to the stem-top been presented in Table 4.10. Radially, the mean values ranges from 0.46±0.22 to 0.71±0.29 core- wood to outerwood at the base, 0.55±0.20 to 0.72±0.27 corewood to outerwood across at the centre and 0.47±0.13 to 0.65±0.27 corewood to outerwood at the stem-top. This shows in radial position that trend in Runkel Ratio of the fibres was consistent, it decreased at corewood to the outerwood as presented in Table 4.10.

From the morphological indices of *A. altilis*, it shows that it has good felting power based on the values obtained is ≤1; therefore, good pulp and papermaking resources may be obtained from the wood. The outerwood had a higher Runkel ratio, is well within the acceptable range for porous paper production.

From the values obtained in this study, it is therefore in line with the research findings by Oluwadare and Sotannde, (2007) who reported 0.59 for *Leucaena leucocephala,* 0.99 for *Anthonatha macrophilia* and *Dalium guinensis* by Ezeibekwe *et al*. (2009), 0.28 for *Ficus spp* and 0.68 for *Gmelina arborea* by (Ogunkunle, 2010). Similarly, Razak *et al*, (2012) reported 0.97 for *Gigantochloa scoretechinii,* 0.84 for *Vitex doniana* (Ogunjobi*, et al*. 2014), 0.85 for *Anogeissus leiocarpus* by (Ogunjobi *et al.*, 2014), while Manahil and Abdelazim, (2015) reported 0.65 in *Eucalyptus camaldulensis* and Anguruwa, (2018) reported 0.79 in *F. exasperata*.

5.4.8 Rigidity Coefficient

The current study, reveals rigidity coefficient means was 0.18±0.04 %, and it shows variations in both sampling height and radial location that patterns in the coefficient of rigidity of the fibers is inconsistent, a rise from base to middle-stem and then reduces to the top-stem, also increased from corewood to wood-inner and then decreased to outerwood.

The rigidity coefficient is an essential factor that governs the wood fibre's flexibility and coarseness. Agnihotri *et al.*, (2010) noted that the coefficient of rigidity predicts tensile and bursting strengths, as well as paper folding strength, paper produced from it is supposed to have greater bonding between its fibers.

Similarly, fibers with a little rigidity coefficient offer a higher amount of conformability producing lower bulky or higher density sheets. Therefore, for the purposes of packaging, printing, wrapping and writing, these fibers with a low rigidity coefficient are perfect (Dutt and Tyagi, 2011).

The result was corroborated with Oluwadare and Sotannde, (2007) who reported 0.19 for *Leucaena leucocephala species,* and for pulp and papermaking, as result of this *A.altilis* wood is further considered appropriate and an acceptable raw material.

5.4.9 Form Factor (FF)

The average total F-factor of *A.altilis* is 250.73±53.25. The F-factor means values at the base, to the middle and to the stem-top ranges from 255.60± 46.59, 242.43± 63.96 and 254.15±48.79, respectively. This indicates decreases from base to the middle and slightly increased from middle to the stem-top as shown in Table 4.10, while radially, mean values ranges 240.28±55.12 to 261.95±50.94 from corewood to outerwood along the base, 220.73±46.20 to 243.61±92.75 from corewood to outerwood along the centre and 246.84±60.74 to 259.87±36.22 at corewood to outerwood along the stem-top as shown in Table 4.10.

Akgul and Tozluogu (2009) found that greater F-factor (flexibility) is calculated by dividing the length of the fiber to the thickness of the wall; this reveals that flexibility is considered to be good for papers obtained from fibers with greater F-factor. In this study, the trend in F-Factor of the fibres was not consistent; in radial position, it decreased from corewood to inner-portion and then increased toward the outer-portion.

In this current study, the mean F-factor was 250.73; which is higher than 140.38 values reported for *fagus orientalis* but similar to 240.55 values for *Pine nigra* wood species by Akgul and Tozluogu (2009) and this coroborated Kar, (2005) reported for *Populus euramericana* and *Populus tremula* had 235.92 and 206.78 respectively.

5.4.10 Muhlsteph's Proportion (MP)

The overall *A. altilis* mean is 58.86±10.62 %. The Muhlsteph's proportion means ranges from 57.60±11.04 %, 61.23±9.76 % and 57.74±11.05 % at the base, at the middle, and at the top, respectively. The values obtained reveals that Muhlsteph's proportion increases from base to the centre and marginally reduced to the stem-top of the timber as shown in Table 4.10

The trend observed for the Muhlsteph's proportion of the fibres was not consistent; in radial position, it increased from corewood to innerwood steadily, then decreased toward the outerwood, hence, muhlsteph's proportion increases from base consistently to the centre and marginally decreased toward the stem-top as shown in Table 4.10.

According to Agul and Tozluogu (2000) who stated the specifications for fiber quality and quality class II of fibres, hence, *A.altilis* had 58.86% muhlsteph's mean, it within the efficiency class II. Meanwhile, muhlsteph ratio values obtained is marginally lesser than 61.2 reported by Bektas *et al.*, (1999), in *Pinus brutia* and Agul and Tozluogu, (2000) reported 76.68 value in species of *Fagus orientalis* while a bit higher to 47.28 reported in *Pine nigra* wood by (Agul and Tozluogu, 2000). It is also consistent with the values 57.39 gotten by Anguruwa, (2018) for *F. exasperata*. It's important to remember that when wood fibres have a lower value, it means they have a thinner cell wall. Thinner wall fibers are far more easily damaged during processing, but they have a positive effect on the paper density and break resistance properties of the pulp produced. (Casey, 1961). As a result, in the paper industry, thin wall fibres are preferred, among which *A. altilis* species can be classified.

5.5: Photo Micrographic Description of the *A. altilis* wood

Vessels are predominantly solitary, radial multiples of three are present, vessels are obliquely arranged, tyloses are present. Wood cells are radially arranged. Axial parenchyma cells are both paratracheal and apotracheal, paratracheal vasicentric, apotracheal diffuse.

Rays are mostly multiseriate, 5-6 cell wide, Sheath cells present, Rays are heterocellular, Ray to vessel pit vestured. Intervascular pits vestured, Fibre is medium-walled, Traumatic cell observed, Deposits of gum present and intercellular canals observed

The findings of Richter and Dallwitz (2000), Raturi *et al.*, (2001) and Purkayastha, (1996) are in line with the observed features in the *Artocarpus species*, hence, all these characteristics can be regarded as physiognomies of the *Artocarpus* genus.

5.5.1 Vessel length (µm) (VESSELS MORPHOLOGY)

Vessels contain single cells joined end to end to form longitudinal tubes in the wood structure, varying in length from a few centimeters to several meters. In hardwoods, vessels perform the primary conducting aspect and the cells are fully open or perforated, a vessel varies between hardwood species in size and cellular morphology. For papermaking, the diffuse-porous category is normally used. In this analysis, elements of the vessels are mainly solitary, located in radial multiples in the wood fibro-vascular bundles. There are obliquely arranged vessels.

Average length of vessel *A. altilis* is 252.46±66.99 µm; at the base, 240.04±69.00 µm at the middle and 264.64±49.06 µm at the top. The length of vessel mean values ranges from the base to the top. The length of the vessel axially shows a decreasing trend from base to center and a slight rise to the top as shown in Table 4.12

Vessel length in this study was found to be 252.46±66.99µm, and compare favourably with Singh *et al.* (2017) who reported the vessel length of 284.4 µm in *Artocarpus* species, Pavin *et al.* (2020) 248 µm for *Artocarpus hirsutus* and the vessel length of teak was also found to be 279 µm (Xu *et al.*, 2006).Richter, and Dallwitz, (2000) reported similar values for *Artocarpus species* (Terap). This is less than 400 µm as stated by Paavilainen (2002) in Eucalyptus species, but confirms the outcome of Sharma *et al.*, (2013). A vessel-picking problem in papermaking causes a large vessel (Asikainen, 2015).

According to Carlquist (2001), the availability of moisture and the freezing effect on xylem anatomy, the geographical position of a wood sample could affect the composition or phenology, such as the exposure to slope, precipitation, the deciduous character, the size of the leaf and the seasonal effect on the wood stem. As a fruit tree, it could also be concluded that the above disparity can be due to the availability of moisture and a wood's geographical position. Therefore, the observed vessel length of *A. altilis* wood uses in the manufacture of pulp and paper is beneficial.

5.5.2 Vessel diameter (µm)

The present results had a mean vessel diameter 230.62±59.44 µm which corroborate the research findings values obtained 160-370 µm for *Artocarpus* species by Richter and Dallwitz. (2000), Pande *et al.* (2005) reported 194.93 µm to 291.52 µm for *Artocarpus* *hirsutus,* Singh *et al.* (2017) reported similar result for *A. heterophyllus, A.chaplasha, A. nitidus and A. lakoocha* 213±76.8 µm, 215.3±163.9 µm, 213.7±66.5 µm and 277.7±93.8 µm, respectively.The obtained values implies that wood element with large vessels proportions will dry faster than their counterparts with small size vessels or pores. Also, the rate of preservative inflow and chemical absorption into the woods during chemical treatability operations is similarly faster in woods with large vessels sizes than woods with small vessels dimensions. Again from this study, *A.altilis* wood was observed to have tyloses at the top stem, which could slow than the rate of chemical preservatives inflow during their treatability operation and dullness of kerfs of the teeth of the saw blades during planning on the plaining machines, therefore carbide-tipped saws is recommended for such wood above 50% of the timber log. Hence the wood of *A. altilis* can be easily seasoned and treated.

5.5.3 Vessel Frequency (mm^2)

The mean vessel frequency of *Artocarpus altilis* is 2.46±0.58 mm^2.The vessel frequency mean value ranges from 2.54±0.61 mm^2, 2.54±0.65 mm^2 and 2.30±0.44 mm^2 at the base, at the middle and at the top, respectively. The vessel frequency across the sampling location shows a steady pattern of reduction at base to the top as presented in Table 4.12. Radially, the means values range from 2.51±0.79 mm^2 to 2.52± 0.38 mm^2 at corewood to outerwood along the base, 2.34±0.48 mm^2 to 2.83±0.87 mm^2 corewood to outerwood along the middle and 2.36±0.50 mm^2 to 2.27±0.35 mm^2 at corewood to outerwood along the stem-top as shown in Table 4.12

Vessel frequency was found in this present study to be 2.46 mm^2. This is in line with the value reported for *Gmelina arborea* 5.20 mm^2 and in *F. thonningii* 3.60 mm^2 by Ogunkunle *et al.* (2008), in *Artocarpus hirsutus* 2-3 mm^2 by Pavin *et al.,* (2020) and in *F. exaperata* 3.59mm^2 by Anguruwa, (2018). Similar vessel frequency was also reported by Cardoso *et al.,* (2015) for *Tectona grandis*. From this result, most of the vessels were found to be solitary and importantly related to water conductivity. This might be due to the higher frequency of vessels; smaller the diameter, greater the chance for grouping of vessels (Vijayan, 2017).

5.6 Chemical Composition

5.6.1 Cellulose Content (%)

Cellulose has been known as a major factor due to its high degree of polymerization and linear orientation; it is accountable for strength in the wood fiber. The wood of the trees has an estimated ratio of 2:1:1 consisting of cellulose, lignin and hemicellulose. Cellulose microfibrils give the cell walls tensile strength during tree growth, while the lignin from the cellulose fibrils provides them with rigidity (Agu *et al.,* 2012). Along the sampling direction, cellulose was uppermost from base and lowest at middle with recorded values of 47.83 and 47.13 respectively. The mean of cellulose content in *A. altilis* was 47.44%. This was slightly higher than 42.9% obtained in *Triplochiton scleroxylon* (Ogunsanwo, 2000) and (Thomas, 1997) for Softwood (42%) and hardwood (45). The thicker the cell wall the higher the amount of lignocellulosic biomass, cellulose and lignin, and organic matter which is the major constituent wall. However, since the tensile strength of paper is unswervingly comparable to that of cellulose, the suitable crude protein for the manufacturing of pulp and paper exceeds 40% (Madakadse *et al.,* 1999).

This is because uniformity in specific gravity along the radial plane indicates uniformity which is considered an important factor in structural wood utilization. The observed variation trend in axial direction in this work corroborated the report of Uprichard *et al.,* (1993) that development of S_2 layers and average length of fibre, contributes to the content of cellulose amount in wood as proportion of fibre, mean wall thickness increases which is a factor that determines the wood properties of the tree. According to (Panshin and deZeeuw, 1980), the inconsistency recorded along the axial direction might be connected with the influence of other chemical components of wood such as extractive content which can mask predicted pattern of other wood properties. This axial direction pattern is comparable to what was found in this research. Hence, this observation has a great implication on the utilization potentials of *A. altilis* as an indigenous species satisfactorily suitable for light structural construction and pulp and paper production.

5.6.2 Hemicellulose Content (%)

Hemicellulose significantly acts as a medium for the cellulose and it increase the packing density of the wood cell wall. (Wilson and Mandel, 1960) reported that high hemicellulose content is desirable because it contributes immensely to the strength of paper.

Along with the sampling height, hemicellulose was highest at the stem-base and lowest at the stem-middle with recorded values of 27.83 % and 27.18 % respectively. The mean of hemicellulose content in *A.altilis* WSD was 27.44 %. The result range obtained is comparable to the study by Cao *et al.,* (2014). This makes it highly suitable in the manufacture of dissolving paper; however, as the removal of hemicellulose will take only milder pre-hydrolysis conditions. In this present study, the observed hemicellulose value for *A.altilis* is better and suitable to produce a paper of good quality strength.

5.6.3 Lignin Content (%)

Lignin, an oxidized substance, not only keeps together the fibers, but also functions inside the fiber cell wall as a tightening agent for cellulose molecules. All three elements of the cell wall contribute to the strength of wood to varying degrees. The tubular structure and polymeric structure together are responsible for the majority of wood's physical and chemical properties (Abdul Khalil *et al.,* 2010).

Along the sampling height, lignin was maximum at the base and lowest at the middle having recorded values of 16.13 % and 15.68 % respectively. The mean lignin content in *Artocarpus altilis* wood is 15.88 %. The decreasing trend of lignin content reported in this study agrees with a similar report by Osadare, (2001) in *pinus caribaea* grown in Nigeria. The decreasing lignin values at the base to the top of the timber might be due to the degree of the growth and maturation of the wood. According to Syed *et al.,* (2016) most paper manufactures preferred the wood that has about <15 % lignin amount because during the bleaching process, the fibres are more flexible, porous and lighter in colour. It is also noted that for fleshy tissue and sheet manufacturing, Low lignin content is closely linked to lignocellulosic materials, along with consistency, bleachability and many other fiber attributes.

Lignin content of *A. altilis* was 15.88 %. It was observed the values generally falls slightly lower within reported range values for pulp softwood species 20.8-31.3 % and hardwood pulp 18.2-30.9 % by ((Palermo, 2015; Sixta *et al.,* 2006; Marques *et al.,* 2010; and Cao *et al.,*2014). Oluwadare, *et al,.* (2016) reported the lignin values of 28.0-24.57 % in *Gmelina arborea* and 31.77-31.70 % in *Tectona grandis.* (Anttonen *et al.,* 2002) obtained

23.4-34.5 % for *Eucalyptus globules* but similar to the value in *Gigantochloa scortechinii* while 12.48-16.12 % and 18.2-20.59 % for *F. exasperata* by (Anguruwa, 2018)

In this study, the lignin content is low; therefore, less delignification process required, low liquor consumption and short cooking cycle, pulp time, low heat and low biochemical cations for Kappa number required (Cordeiro *et al.,* 2004; Dutt *et al.,* 2011; and Cao *et al.,* 2014).

5.6.4: Ash Content (%)

Ash is considered impurity that may not burn, likewise, wood with high ash content are not suitable for pyrolysis. The outcome of this research revealed that the ash content *A.altilis,* with observed mean values of 0.934 % and 0.916 % respectively, hence, it highest from base and lowest at middle. The average amount of ash in *A.altilis* WSD was 0.923 %.

The values for ash content obtained in this study for *A. altilis* is higher than other but similar to (Mukesh *et al.,* 2015) reported for *A. altilis* leaves to 9 %. Mitchual *et al.* (2014) reported a range of 0.61-5.04 w.t% for some tropical hardwoods, Eulaliopsis binate 6.0 w.t/% by (Dutt *et al.,* 2011). Sawdust from stumps 6-8 %, and sawdust from wood waste 6-10 % by (Hindi, 2010)

Kim *et al.,* (2001) observed that the combustion volume and efficacy of a fuel reduces with high ash content. Calcium, magnesium, potassium and phosphorus are macronutrient elements. Micronutrients such as copper, iron, sodium manganese, sulphur, and nitrogen are also absorbed by heavy metals during growth, resulting in ash such as zinc, lead, cobalt and cadmium (Hindi, 2010 and Osabor *et al.,* 2009). This suggests that higher ash content in biomass could obstruct the bio-oil yield of a pyrolysis process (Jahirul *et al.,* 2012). The high ash content and the low volatile matter of the hardwood sawdust make it unsuitable for use as feedstock for bio-oil production.

In the present study, high ash content observed in *A. altilis* sawdust could come from other contaminants during handling and transportation. Increase ash content lowers the heating value and makes it unsatisfactory for fuelwood and charcoal production. This could also contribute to the incessant dullness of the saws and blade during machining operation but suitable as forest fertilizer.

5.6.5: Mineral Content

5.6.6 Atomic Absorption Spectrophotometer (AAS)

As a prerequisite for its suitability, wood species for pulp and paper processing are expected to be evaluated for mineral elements, therefore these mineral elements were determined; Potassium (K), Phosphorus (P/PO4) Magnesium (Mg), Cupper (Cu), Calcium (Ca), Iron (Fe), Aluminium (Al), Zinc (Zn) and Lead (Pb). The findings presented in Table 4.16 reveals that the mineral elements in the samples of wood sawdust had a substantial effect on the mineral content over the height of the sample ($p<0.001$). Sodium had the highest concentration with average values of 206.25 mg/100g, followed by Calcium 121.58 mg/100g, P/PO4 76.53 mg/100g, Magnesium 45.28 mg/100g, Potassium 31.33 mg/100g, Aluminum 0.67 mg/100g, Copper 0.48 mg/100g, Zinc 0.55 mg/100g and lead was the least with an average value of 0.05 mg/100g.

Sodium is the most abundant in the wood of *A.altilis* while and the lead was the least. The high contents of magnesium cause low volatile yield and demethoxylation of lignin of fuel materials during pyrolysis and could support dehydration of holocellulose (Fahmi *et al.*, 2008; Bridgwater, 2012; Akinrinola *et al.*, 2014). The high contents of Calcium and other elements are similar to the report on proximate composition of *A. altilis* pulp flours (Appiah *et al.,* 2011; Mbata *et al.,* 2009; Osabor *et al.,* 2009; Akanbi *et al.,* 2009; Vitabase, 2009; Charles *et al.,* 2005; Ferrao *et al.,* 1987 and Hindi, 2010). Therefore, the high concentration of mineral elements in the wood of *A. altilis* can be attributed to being a fruit tree, and this is advantageous in reducing the thermo-chemical conversion during pulping and recovery of cooking liquor process.

5.6.7. Silica Content

In WSD of *A. altilis,* sampling position had no major effect on variations in silica material. P= 0.00021. The particular pattern of variation along sampling direction does not match the silica content found in wood sawdust; it was highest with 0.58 % at the stem base and lowest with 0.47 % at the mid-stem. The average silica content percentage was 0.53 %.

In this study, it was observed that the silica content is derived from the ash content but slightly higher to Sudanese hardwood like *Acacia mellifera* 0.1 %, *Eucalyptus tereticornis* 0.1 %, *Moringa oleifera* 0.4 % and *Acacia Senegal* 0.1 % by (Khider and Elsaki, 2012) but lower to some hardwood species reported such as 0.71 %, *Albizia adianthifolia*, 0.66 %, *Detarium macrocarpum*, 0.87%, *Celtis zenkeri.* When silica content in wood is more than

0.5% it is harmful to cutting tools and machinability of wood materials is greatly influenced (Pettersen, 1984 and Gottwald, 1973). Torelli *et al*, (1995) reported that high silica content causes nasal irritations on the wood technician and wood user during wood processing. The silica content stored in the wood of *A. altilis* varied among sampling height, this implies that environmental conditions and soil type may determine the quantity of silica deposited in plant structures. Generally, in this study 0.53 % is the percentage of silica embedded in this wood and cannot be considered problematic during pulp and paper production.

5.7 DURABILITY TEST

5.7.1 Grave Yard Test (Ground Contact)

The measure of resistance of untreated wood to bio-deteriorating microbes refers to natural resilience without treatment with chemical preservatives; some wood species have an intrinsic capacity to withstand the attack of bio-deteriorant agents (Vittanen *et al.,* 2006; Francis and Norton 2006, and Wong *et al.*, 2005). The result indicates the mean percentage weight loss of *A.altilis* was 24.50±9.24 %, and the average mean ranged from 26.57±10.05 %, 22.28±8.82 % and 24.65±8.66 % for the wood at base, the middle and top, respectively. This reveals that weight loss reduced at base to the middle, thereafter increased toward stem-top as shown in Table 4.18. Across the tree bole, weight loss ranged from 27.42±20.38 % to 27.81±2.40 % at corewood to outerwood along the base, 23.99±7.46 % to 21.78±9.68 % corewood to outerwood along the centre,while 22.32±7.07 % to 24.62±5.46 % corewood to outerwood along the stem-top of the wood as shown in Table 4.18

The durability test pattern of *A.altilis* was not consistent; it reduces from base to center and slightly rises to the top, thereafter decreases from corewood to wood-inner in radial position and then rises slightly outerwood. Based on established and classification of durability test of wood to, as high density range (high density >700 kg/m^3); medium density range (medium density > 450 kg/m^3) and low density ranges (low density < 450 kg/m^3).

In this study, *A.altilis* density is 581 kg/m^3 which fall within the classified density of medium density wood; however, the resistance of the wood species has been observed to vary with density, indicating that density may have a greater impact on the natural resistance of *A. altilis* wood. This research findings is in line with (Owoyemi *et al.,* 2014) who reported that since the mode of termites attack is biting and chewing, the natural conflict of wood to termites is primarily determined by density, which is a measure of the hardness of the wood. (Rowell, 2005) stated that indigenous wood species' natural resistance could not be dependent on density alone, but the presence of toxic extractives within the wood may also be attributed factors since wood extractives consist of organic and inorganic components. According to (Miller, 1999 and Rowell, 2005) indicated that certain wood characteristic like decay resistance, wood density, colour, flammability, odour, taste and hygroscopicity may be affected by organic extractive components.

In this study, *A. altilis* wood can be classified as moderately resistant to termite attacked based on the visual examination and classification of resistance, especially the portion buried in the graveyard and this has no significant impact irrespective of the sampling height and radial position. Consequently, the above ground stakes could not be visibly attacked by termite proofing the fact that the *A. altilis* is resistant as shown in Plate 4, at the end of the 12-month field evaluation, it was found that preservative therapy or some other safety methods may be required while in operation to increase its service life. This is similar to (Owoyemi *et al.*, 2014) reported for *Khaya grandifiliola* and *Pachystela brevipes* as medium density wood. This result also confirmed the affirmation that no wood is absolutely immune from been attacked by termites, while the degree of resistance only varies (Daniel *et al.*, .2009: Mike, 2010).

5.7.2 FUNGI RESISTANCE TEST

From this present study, the result shows the percentage weight loss of fungi resistance in *A. altilis* for White rot and Brown rot were 4.70±2.12 % and 5.47±2.89 % respectively. Axially, white rot mean values ranges from 4.49±2.12 % at the base, 4.76±2.48 % at the middle and 4.85±1.79 % toward stem-top, it reveals that percentage weight loss rises from base toward the stem-top, and radially ranging values from 4.84±2.92 % to 4.29±1.33 % at corewood to outerwood at the base, 5.59±3.57 % to 4.57±1.56 % corewood to outerwood at the middle and 4.68±2.07 % to 5.58±1.86 % corewood to outerwood toward stem-top for white rot fungi as shown in Table 4.22.

While brown rot values ranged between 5.31±2.53 % at the base, 5.58±2.90 % at the middle and 5.51±2.04 % at the top, this shows that percentage weight loss rise from base to the middle and slightly reduces to the top. Radially, percentage weight loss ranged between 5.12±2.25 % to 4.23±2.01 % at corewood to outerwood at the base, 6.01±6.15 % to 4.62±1.79 % corewood to outerwood at the middle, while 5.70±1.81 % to 5.97±1.64 % at corewood to outerwood at the top for white rot as shown in Table 4.22

The trend observed in this study shows that percentage weight loss of fungi resistance of *A. altilis* was not consistent for Brown rot in radial position, it decreased from corewood to wood-inner and then increased toward the outerwood.

Decay can be characterized as either wet rot or dry rot; but in damp wood, both can occur together or when wood is permitted to remain permanently or regularly damp. Nair, (2017) stated that wood decay is activated during the digestive process by enzymes secreted by the fungal hyphae. Large quality losses are caused by fungi in both timber manufacturing and wood utilisation. Meanwhile, the variations in the nature of the injury are typically due to the behavior of various fungal species and the type of damage caused (FAO, 1986).

Protection must be given during processing, merchandising, and use in conditions that enable wood-degrading species to grow. Fungi, insects, bacteria, and marine borers are among the species that can degrade wood. Insects can also cause damage to wood, so they must be considered in many cases. Termites are the most common insect pest of wood, although they pose a lesser threat than fungi on a national scale.

Both White and Brown rot develops on susceptible wood when the moisture content of the wood remains above about 22% regularly for prolonged periods. However, Brown rot fungi possess a unique ability to attack the cellulose fraction of wood while avoiding the surrounding lignin while White rot fungi have the ability to degrade lignin up to 100% of timber weight. Cellulose and hemicelluloses are also degraded and degraded wood become whitish. This study offers evidence that this could not obviously be accomplished by brown rot fungi due to high extractives in *A.altilis* wood. With this consequence, an eco-friendly natural preservative alternative for the safety of *A.altilis* is useful.

The Analysis of Variance in Table 4.23 reveals that the sampling direction has no important effect (p=0.985), along radial plane on the fungi attack resistance (p=0.282) at 0.05%. The effect of interaction between sampling height, radial position and fungi reveals no significant influence between them at 0.05% likelihood levels.

For the regression model, the coefficient of determination (R^2) of wood density revealed that not all mechanical properties could be significantly predicted from density even after logarithms data transformation. The wood density of samples is moderately correlated, although the determination coefficient was poor, the mechanical properties of MCS//, MOR, MOE, Shear test and Impact bending, especially for MCS//, IM and MOR (0.18, 0.54 and 0.60). Results further showed that MOE and Shear test was best predicted with coefficient of determination of logarithms (0.82 and 0.80). Hence, are liable prediction of wood strength properties based on density is not possible for individual parameters due to its low predictive ability, even if the significance of the correlation is high due to the high number of degrees of freedom. The relationship between wood density and mechanical properties has been acknowledged as part of because density is a measure of the relative amount of solid cell wall of the wood while the correlations sometime are species dependent.

Wood density with low correlations with mechanical properties in some cases was attributed to the influence of microfibril angle (MFA). The reasoning is that density increases while MFA decreases with age, thereby impacting the mechanical tests and resulting in poor correlations when density alone is considered. The connection between density and mechanical properties, especially compression strength and MOR, can also be affected by high quantities of extractives and grain angle.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary and Conclusion

Investigations on the wood properties and natural durability of *A.altilis* wood (Fosberg) were carried out.

The study findings contributed to the knowledge on the potential of Breadfruit wood as a potential substitute to existing prefered timber. The following conclusions have been drawn based on the results of this investigation.

6.1.1 Physical Properties

The wood density of *A.altilis* is 581 kg/m^3 at 12 % air-dry moisture content, which ranges consistently jut at sampling and radial location. This means that quality wood is within the base and middle of the merchantable height area. Therefore, this timber is a medium density wood according to wood categorization as presented in Table 4.5

For both sampling position and radial location, *A.altilis* wood has a specific gravity of 0.58 and differs uniformly and significantly depicting liquor consumption will be small for the duration of pulping, while the delignification rate is estimated to be elevated.

Tangential shrinkage rise evenly at the base to the top of this analysis, and also rises radially from corewood to outerwood, similarly in shrinkage radially, the values rises uniformly at the base to the top, although it a steadily rise was observed radially from corewood to outerwood.

Both along and across the sampling position and radial location, volumetric shrinkage varied consistently and substantially. This demonstrates that, due to low reduction capacity, the *A.altilis* wood is mild and therefore ideal for both structural and non-structural applications.

6.1.2: Mechanical Properties

The finding shows the values (MOR) ranged uniformly from base to top in this current study and decreased statistically significantly at the sampling direction and radial location at the corewood to the outerwoodbase. The modulus of elasticity (MOE) ranged non-uniformly over the sampling level and radial area; it reduced just at base to the middle and rose just to top marginally. It demonstrates that the wood is acceptable for use in the furniture industry.

Complete compressive strength test (MCS//) decreases just at base to stem-top and subsequently decreased from the corewood to outerwood

Shear strength varied uniformly throughout the sampling height from base to top, but not standardized around the bole, decreased from corewood to the wood-inner and increased marginally to the outerwood. Due to this factor, *A.altilis* wood can be easily peeled therefore, suitable for veneer production in Nigeria.

Impact Bending Strength parallel to grain rises uniformly from the base to the top and consequently rises at corewood to the outerwood portion.

6.1.3. Anatomical Characteristics

From the result of this present study, all the fibre morphology and derived morphological indices of *A.altilis* wood are found within the ranges that are suitable and sufficient for the production of pulp and paper. It is implies that wood of *A. altilis* wood can perform similar role of substitutes and in reducing the amount of important pulp fibre to paper manufacturing Nigeria.

Bulk of the fibres had their fibre lengths, fibre diameter, Lumen width, Cell-wall thickness, fineness, versatility, runkel ratios; coefficient of rigidity, form-factor and muhlsteph’s ratio ranges 1.52 mm, 35.1 µm, 22.95 µm, 6.11 µm, 44.79, 63.59 %, 0.60, 0.18 %, 250.73 and 58.86 %, respectively.

Higher dimension in vessel length, vessel diameter and vessel frequency respectively implies that the *A.altilis* wood can be easily treated with preservative chemicals and drying rate will be faster due to this observation.

6.1.4: Chemical Composition and Extractives Components.

Cellulose, hemicellulose, lignin contents, low percentage ash and silica content showed that *A. altilis* wood for pulping requires mild process. There is a lower soluble compound in the extractive content of *A.altilis* and that would enhance the pulp output and supply a lower solvent usage throughout paper production and reduced pulping industrial waste discharge.

Finding from this study showed that cellulose, hemicellulose and lignin content is high, which implies that pulping and bleaching could need higher amount of chemical, likewise quality paper and higher pulp yield may be produced but not suitable as fuel wood because of high ash content but could serve as fertilizer if properly enhanced.

Finding in this study also showed that *A.altilis* wood contains mineral elements with sodium and calcium having highest while lead had the lowest.

6.1.5 Natural durability

Apparently from this study, it was observed that termite visited the wood of *A.altilis* stakes, parts buried under ground are susceptible to moderate termite attack while the part above the ground appear to remain moderately sound.

For the fungi, the corewood appears to be more resistant to fungi attack while the outerwood is moderately resistant to fungi attack.

Knowledge of wood properties variations therefore is important in order to make appropriate and adequate utilization of *A.altilis* wood. Consequently, this present investigation presented basic data about specific, engineering and refined microstructure, chemical characteristics, toughness and resilience, and fungi resistance of *A.altilis* wood which serve as a base for its wood quality assessment for efficient and better utilization. Hence, the wood is suitable for light construction such as post, joists, rafter, flooring, plywood, veneer, packing boxes and crates, panelling and furniture.

6.1.6 Mechanical and Density properties interaction of Breadfruit Wood

a. Density correlated positively with all Shear strength test strength properties, closely attributed to maximum compression strength (MCS/), rupture modulus (MOR), impact bending (IM) and elasticity modulus (MOE), lowest correlated with volume.

b. Modulus of elasticity (MOE) and impact test were the most correlated pair, with r^2 = 0.82 and 0.80 respectively but highest compression strength parallel to grain (MCS//), impact bending (IM) and modulus of rupture (MOR) correlated least with r^2 = 0.18, 0.54 and 0.60.

6.2: Recommendations

A.altilis wood has important potential as building resources suitable to replace the preferred timber. The guidelines below are intended to provide guidance on the prospective establishment and use of *A.altilis*, primarily, and other hardwoods.

This investigation showed that, under no criterion, the quality of *A.altilis* wood is unsatisfactory; therefore, it is recommended to encourage and facilitate the uses for plywood, including the use of low-strength bearings, and in the manufacture of veneers, as this is expected to increase uninterrupted uses in Nigeria.

Newsprint manufacturers in Nigeria should exploit thefull utilisation of *A. altilis* wood for pulp and paper production having potentials in substituting or supplementing *Gmelina arborea* which is an exotic species.

To enable optimal use and added values to the products, timber consumers and producers ought to have fundamental understanding of the strength characteristics of *A.altilis* timber.

Heavy structural and construction work should be done with *A. altilis* wood from the base log due to its high strength values at that portion of the wood which decrease gradually through the mid-log toward the crown- point.

From this study *A.altilis* wood can be suitably used for outdoor applications due to its moderate resistant to termite and fungi above the ground surface.

Government should properly fund and provide basic instruments for non-destructive determination of strength to research institutions responsible for disseminating research breakthrough.

6.3 Further Research Area

Further research studies to investigate the machining properties, gluability and drying schedules of the wood should be carried out.

In order to thoroughly examine the radial variance patterns of these properties in the organisms, research activities should include pith eccentricity and ring width analysis of the properties.

Further research efforts should concentrate on the continued use of *A.altilis* (not only as a fruit tree) and other related species, thus increasing the amount of logging of *A.altilis* species.

6.4 CONTRIBUTION TO KNOWLEDGE

This research has provided baseline information on *Artocarpus altilis* wood physico-mechanical, anatomical, chemical and natural durability as a potential LUS to the preferred timbers. Comprehensive knowledge of wood properties and durability test now facilitate the use of the tree species in development of alternative materials for light structural and non-structural construction. Basic information on the internal structure of the wood species provided it as alternative raw material for paper making. Also, technical information on the elemental composition of the wood was therefore provided. This will lead to the development of effective utilization of LUS sector in Nigeria.

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