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Investigation of the Properties and Suitable Uses for Four Secondary, Lesser-used Wood Species Growing in The Blue Nile State, Sudan

دراسة الخصائص والاستخدامات المناسبة لأربعة أنواع من ألاخشاب الثانوية قليلة الاستخدام النامية فى ولاية النيل الأزرق , السودان

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Dedication

To

My family

Acknowledgment

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ABSTRACT

This investigation dealt with determination of some properties and suitable uses for four lesser used wood species grown in the Blue Nile State. Four of the secondary wood species which are available in reasonable quantities in Blue Nile State, but are not in common use were selected for this investigation. The selected species comprised: *Sterculia setigra* (tartar), *Acacia polyacantha* subsp. *campylacantha,* (kakamut), *Acacia seyal* var. *seyal* (talh) and *Diospyros mespiliformis* (goghan). Most of our forests are located in poor rural areas. Most of them are degraded natural forests which have been creamed. The remaining stock is composed of some secondary species which are not used even for firewood or charcoal. They are left for conservation. The demand for wood is rising. The aim of the present study is to increase the number of wood species in use and make it more economical to harvest and exploit natural forests sustainably. It is well known that wood processing and utilization are directly affected by wood basic properties. This is why there was a growing concern in combining studies on wood basic properties and wood quality attributes for the different uses. The basic properties determined included some anatomical fiber characteristics, namely: the proportions of the different cell types and their components, fiber diameter (FD), lumen diameter (LD), double cell wall thickness (DCWT), rankle ratio (RR), coefficient of fiber rigidity (CR) and fiber flexibility (FF), as well as fiber length (FL). Most of these properties were determined from macerated fibers, where wood chips from the different species were boiled in concentrated nitric acids in a water bath for ten minutes; the liberated fibers were washed in alcohol and water before

staining them with safranin for five minutes and mounting them on temporary glass slides using Canada balsam. Using these slides FL was determined using stereological techniques, while the cross-sectional measurements were determined by a digital reflecting microscope in Giad Material Research Laboratory. Cell proportions, on the other hand, were determined from cross sections prepared by standard procedure and measured using stereological techniques. Physical properties - density, permeability, tangential shrinkage, radial shrinkage and moisture content - in addition to glue bond strength were determined according to standard procedures and so was compression parallel to the grain. Texture and surface quality, however, were determined according to visual grading whereby samples from the different species were given arbitrary numbers from ten to one according to the surface quality and texture – ten being given to the finest texture and grain uniformity and one for the poorest surface. Analysis of variance and Duncan's Multiple Range test were carried out, looking for the level of significance of the variations in all properties between the species studied. Correlation analysis was also carried out to find relationships between wood basic properties (anatomical and density) and wood quality attributes for the different uses like wood strength, dimensional stability, permeability, gluability and appearance. Anatomical properties showed significant differences between the four species. FL was highest in Tartar (1.75mm) and lowest in kakamut (1.35mm). FD, however, ranged between kakamut (20.85 µm) and talh (12.94µm). LD was highest in kakamut (14.02µm) and lowest in talh (4.97µm). DCWT Ranged between talh (7.94µm) and tartar (6.60µm). Whereas the ratios (RR, CR) were highest in talh (1.75µm), (0.31µm) respectively and lowest in kakamut (0.52µm), (0.17µm), the opposite was the case with FF. Proportions of cell type and their component also showed significant difference between the four species. Physical properties also showed significant differences between the species studies. Talh had the highest density (0.82g/cm³) while tartar had the lowest density (0.38g/cm³). Tangential and radial shrinkage were highest in goghan (10.19), (5.41), respectively and lowest in talh (6.02), (3.06) respectively. Liquid absorption (AB) ranged between Tartar (207.94%) and talh (57.85%). Most of the absorption in tartar was along the grain and very little across the grain. Depth of penetration (PD) was deepest in goghan (1.94cm) and smallest in Tartar (0.21cm). The analysis of variance also showed significant differences in compression parallel to the grain where talh had the highest value, while tartar was the weakest. Glue bond strength (BS) ranged between goghan (27.141Mpa) and Tartar (0.751Mpa), indicating that only goghan and kakamut gave adequate bond strength. With regards to texture goghan had the finest texture and grain uniformity, followed by kakamut and talh while tartar had a moderately course texture. Both kakamut and talh were also figured. According to their quality attributes different wood species were assigned to different uses. Goghan was found suitable for structural uses, high quality furniture internal decorations, carving, handcraft, veneer and high quality plywood. kakamut on the other hand, had similar quality attributes to goghan and can be used for the same uses with preference to goghan. Talh was assigned for structural uses, fixed furniture for student seating and at camping sites. It can also be used for fiberboard and pulp and paper production. Tarar, however, was found suitable for non –load bearing partitions and as an insolating material in sandwich construction as well as for fiberboard and pulp and paper manufacturing. Its low density also makes it suitable for the manufacture of particleboard.

الملخص

استهدفت هذه الدراسه تحديد خصائص اربعه من انواع الاخشاب الاقل استخداما والناميه فى ولايه النيل الازرق بالسودان للوصول للاستخدامات المناسبه لهذه الانواع. وشملت انواع الاخشاب المدروسه كل من الطلح والجوغان والكاكموت والترتر.معظم الغابات المتبقيه فى السودان غابات طبيعيه متدهوره تحتوى على انواع ثانويه من الاشجار لا تستخدم حتى كحطب وقود او تحول لفحم نباتى وتترك لاغراض الحمايه فقط. لذلك تهدف هذه الدراسه لزيادة عدد انواع الاخشاب المستفاد منها وجعل عمليه حصاد واستغلال الغابات الطبيعيه عمليه اقتصاديه ومستدامه. ومن المعروف ان عمليات تصنيع واستخدام الاخشاب مربوط بطريقه مباشره بالخصائص الاساسيه للاخشاب لذلك كان الاهتمام بربط دراسه الخصائص الاساسيه للاخشاب بمقاييس النوعيه المطلوبه للاستخدامات المختلفه. شملت الخصائص الاساسيه المدروسه بعض الخصائص التشريحيه والكثافه كما شملت الخواص الداله على نوعيه وجودة الخشب, قوة ومتانة الأخشاب, نفاذيه الاخشاب, معدلات الانكماش المماسى والقطرى, قوة وصلات المواد اللاصقه بالاضافه لنوعيه السطح والقوام. بعض الخصائص التشريحيه اجريت على الياف محرره تم عزلها بغلى حبيبات الخشب فى حمض النيتريك المركز فى حمام مائى لمدة عشره دقائق ومن ثم صبغه الالياف المحرره بماده السفرانيين لمده خمس دقائق وغسلها بالكحول والماء وتحميلها على شرائح زجاجيه باستخدام ماده كندا بولسم وفحصها تحت المجهر لاجراء القياسات المطلوبه. وقد تم قياس طول الالياف باستخدام الوسائل الاستريولوجيه. أما بقية الخصائص التشريحية فقد تم قياسها بواسطة مجهر إلكتروني عاكس بمركز جياد لأبحاث المواد. وتم تحديد الخصائص ا الفيزيائيه والمكانيكيه والتكنولوجيه والتى تمثل الخواص الداله على جوده الاخشاب باستخدام طرق قياسيه ماعدا القوام ونوعيه السطح والتى تم تحديدها بطريقه تدريج بصرى حيث اعطت ارقام إعتباطيه لكل عينه حسب نعومه السطح والقوام والارقام من 1-10 بحيث يمثل الرقم 10 اكثر العينات نعومه فى القوام والرقم 1 اسوأ درجات القوام وتم حساب المتوسط لكل نوع. بعد الحصول على البيانات المطلوبه تم اجراء تحليل التباين واختبار دنكن بالإضافه الى تحليل الترابط لتحديد العلاقات الممكنه بين الخصائص الاساسيه والخصائص الداله على نوعيه وجوده الاخشاب. وقد اظهرتحليل التباين للخصائص فروقا معنويه فى معظم الخصائص المدروسه بين الانواع الاربعه من الاخشاب. ففى الخصائص التشريحيه حظى الترترباطول الالياف (1,75مم) وكان الكاكموت اقصرها اليافاً (1,35مم) وتفاوت قطر الالياف بين (20,85ميكرون) للكاكموت و

(12,94ميكرون) للطلح وكان لقطر الفراغ الخلوى نفس التوجه -اعلاه للكاكموت واقله للطلح. وكان سمك الجدار الخلوى المزدوج اعلاه للطلح (7,94ميكرون) وأدناده فى الترتر (6,60ميكرون) وبلغت نسبه رانكل ومعامل قساوة الالياف اعلاها فى الطلح (1,75 و 0,31ميكرون على التوالى) وادناها فى الكاكموت (0,52 و 0,17 ميكرون على التوالى) والعكس كان صحيحاً بالنسبه لمعامل مرونه الالياف اى ان اعلاها كان الكاكموت واقلها الطلح. فى حاله الخصائص الفيزيائيه بلغت الكثافه اعلاها فى الطلح (0,82جم/سم³) وادناها فى الترتر (0,38جم/سم³). وجاء الانكماش المماسى والقطرى اعلاهما فى الجوغان (10,19% و 5,41% على التوالى) واقلهما فى الطلح (6,02% و 3,06% على التوالى). وتفاوتت نسبه امتصاص السائل بين الترتر (207,99%) والطلح (57,85%) حيث كان معظم الامتصاص فى الترتر فى التجاه الطولى الموازى للالياف ونسبه بسيطه فى الاتجاه العمودى للالياف لذلك كانت النفاذنه فى التجاه العرضى اقلها فى الترتر (0,21سم) بينما كان عمق التغلغل فى الاتجاه العرضى اعلاه فى الجوغان (1,94سم) واقله فى الترتر (0,21سم). واظهر تحليل التباين ايضا فروق معنويه فى مقاومه الانضغاط الموازى للالياف بين انواع الاخشاب الاربعه حيث كانت اعلى قيمه من نصيب الطلح (840كجم/سم²) وادناها من نصيب الترتر (210,70كجم/سم²). اما قوة وصلات المواد اللاصقه فقد كانت اعلاها فى الجوغان والكاكموت (27,141ميقاباسكل و24,956ميقاباسكل على التوالى) وادناها فى الترتر والطلح (0,751ميقاباسكل و 3,959ميقاباسكل على التوالى). مما يوحى بان قوة الربط فى الجوغان والكاكموت تعادل مقاومه القص الموازى للالياف فى النوعين اعلاه. وفيما يختص بقوام الاخشاب ونعومه السطح فقد اظهرت النتائج ان الجوغان كان اكثرها نعومه واتساقا للسطح يليه الكاكموت ثم الطلح واخيراً الترتر. وقد تم تخصيص الانواع المختلفه للاستخدامات المناسبه لها حسب الصفات الداله للجودة الخاصه بها واتضح من ذلك ان الجوغان يصلح للاستخدامات الانشائيه بكل اشكالها من اطر وابيام والاستخدامات التجميليه الداخليه فى المنازل, بالاضافه الى استخدامه لانتاج انواع الاثاث المنزلى والمكتبى الفاخر وصناعه نوعيه جيده من الابلكاش والقشره. وجاء الكاكموت فى المرتبه الثانيه بصفات جوده قريبه من الجوغان واستعمالات شبيهة مع افضليه بسيطه للجوغان اما الطلح فيمكن ايضا استخدامه للاغراض الانشائيه فى الهياكل الخشبيه والابيام بعد معالجته ضد الافات الحشريه كما يمكن استخدامه لانواع اثاث اقل جوده مثل اثاث المدارس والاثاثات الثابته فى مواقع الرحلات والمعسكرات ولكن باستخدام موصلات ميكانيكيه بدلا عن مواد لاصقه نسبه لضعف وصلات المواد اللاصقه لهذا النوع من الخشب كما يمكن استعماله فى مجالات تحمل اوزان مثل

مسطبات التحميل واعمده المناجم وغيرها. وبما ان قوة وكثافه الترتر منخفضه فيمكن استعماله فى المواقع التى لا تتعرض لاوزان عاليه فى الفواصل الداخليه وكماده عازله. ويمكن استخدامه لصناعه الواح الخشب المضغوط والواح الخشب الليفى بدرجاته المختلفه

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List of Abbreviation

P_L per	Number of intersections of test lines with fiber boundaries
	Unit test line
N_A	Number of interceptions of features per unit test area
Pp	Point fraction (number of points per test point
Pp V	Volume fraction of vessels
Pp F	Volume fraction of fibers
PpP	Volume fraction of Parenchyma
Ppcw	Volume fraction of cell wall
Ppcl	Volume fraction of cell lumen
Pp FL	Volume fraction of fiber lumen
FL	Fiber length
FD	Fiber diameter
LD	Lumen diameter
DCWT	Double cell wall thickness
RR	Rankle ratio
CR	Fiber coefficient of rigidity
FF	Fiber flexibility
DEN	Density
Com	Compression parallel to the grain
AB	Absorption

PD	Depth of penetration
BS	Glue bond strength
GD	Service quality (grade)
TF	Tear factor
Sh B	Sheet bulk
BL	Breaking length
Spp	Species
D.m	*Diospyros mespiliformis*
A.p	*Acacia polyacantha*
A.s	*Acacia seyal var seyal*
S.s	*Sterculia setigera*

CHAPTER ONE

INTRODUCTION

1.1 Background

Wood is a renewable natural resource which played and is still playing an important role in human life. Being a natural material it is very variable. This variability is due, mainly, to variations in anatomical structure. This variability also makes wood such a versatile material that it could be used in different forms and for many purposes. It is believed that up to 10 southands products could be obtained from wood (Nasroun, 2005).

Wood is available in most countries as a versatile, naturally sustainable resource of raw material and has traditionally been used for making houses, tools, furniture, artwork, and paper. Today, wood is mainly used for construction purposes, but the amount of wood consumed differs substantially among different countries. It can be argued that the use of wood for construction is determined by the availability and tradition. Increased focus on environmental issues has resulted in the emergence of new sustainable building practices and design (Minke, 2009); (Ritchie and Thomas, 2009) and (Nyrud and Bringslimark, 2010).

Wood is an ancient construction material and its use in the Sudan has been more traditional than technical. The favourable cost position of wood has not demanded an application of technology until recently. A complete understanding of materials, like wood, is a key to its efficient use and good engineering design. This is particularly true with our tropical hardwoods which exhibit an enormous variability being a natural material (Nasroun, 1979).

Wood is the oldest engineering material in the world. Wood is both of an old and modern source of energy. In addition to its use for heating and cooking it was used in ancient times for smelting metal ores, in this manner many forests were destroyed in Europe and elsewhere. Today about half of the world production of wood is used as fuel. Wood as a source of energy is advantageous because it is a renewable material. It is also important to note that processing wood in industries consumes less energy in comparison to other materials, 50 times more energy is required to produce an equal quantity of aluminium, 30 times more to produce plastics and 10 times more to produce steel. Wood is a heat-insulating material also. Wood remains to be a large fraction of the energy consumption relative to fossil fuels and other sources of energy in Sudan. Expected uses include: wood pellets to produce heat, steam or electric power or hummer milled and compressed (Tsoumis, 2009).

Most of our forests are located in poor rural areas. Most of them are degraded natural forests which have been creamed. The remaining stock is composed of some secondary species which are not used even for firewood or charcoal. They are left for conservation. The demand for wood is rising. Therefore we must find ways and means of rationalizing wood utilization by finding suitable uses for some secondary species which are not in use now. There are some criteria for selecting wood species for any particular use, depending on the specifications required for that use. A system has been devised that allows for the comprehensive description of species in terms of identity, distribution, availability, timber properties and utilization (Desch and Dinwoodie, 1996). Forest products can contribute basic materials for important sectors (and help national economy) in building construction, furniture, publishing and print media, packaging, shipping, transportation and communication (Wenger *et al,* 2010).

1.2. Research Problem

After the independence of South Sudan two thirds of Sudan forest area remained in South Sudan and we are left with only 1/3 of the area. This, in addition to the increasing population and increasing demand for wood, it was necessary to widen the spectrum of species in use by using some of the secondary species which are not in common use because their properties were not determined. A good understanding of a material and its properties is a key to its development and rational use.

1.3 Objectives

General Objective

The general objective of this study is to increase the number of wood species in use and make it more economical to harvest and exploit natural forests.

Specific Objectives

To determine some physical, mechanical and technological properties of four of the secondary hardwood species growing in Blue Nile State.

To specify tentative criteria for assigning different wood species to different uses.

To assign the different species to the recommended uses according to their properties and quality attributes.

CHAPTER TWO

LITERATUR REVIEW

2-1 General

Timber has been used by man since the early days of recorded history, first as a means of constructing a shelter for himself, later as a hunting tool in the form of spear or bow, and later still as a widely used artifact of industrialized society with uses ranging from truck sides and bottoms, electrical sockets and plug tops, tool handles, sports equipment, boats, railway sleepers and musical instruments, to name but a few (Desch and Dinwoodie, 1996). From primitive times to today, wood remains the construction material of choice (Barnett and Jeronimidis, 2003).

Although experience and availability have often dictated which species of timber should be used for a particular purpose, a much more detailed knowledge of the properties of timber is required for efficient utilization, for the exploitation of unfamiliar timbers and to aid in the selection of species for afforestation projects (Forest Products Research, 1969).

Wood properties can be subdivided into two groups: microscopic and macroscopic. Microscopic properties are linked to the anatomical structure of wood as well as its chemical composition, while macroscopic properties are primarily growth-related features and include knots, compression wood and spiral grain (Megraw, 1986). These macroscopic features are often used as the basis for visual grading of wood products, particularly sawn timber. The frequency, size and condition of knots are arguably the most important growth-related feature affecting the suitability of wood for a number of end-products, particularly sawn timber. Knot characteristics are in turn directly related to branching habit. Timber quality is that combination of physical and chemical characteristics of a tree or its parts that permit the best utilization of the wood for the intended use. In this definition, the intrinsic quality of the wood is evaluated solely in terms of its suitability for various products or end uses (Schilz, 1963).

To illustrate the concept of timber quality more clearly, consider the elements that it is composed of. According to the accepted definition of timber quality, the wood for specific end uses possesses those attributes which make it suitable for those uses. Each element may influence or affect the wood characteristics, starting with environment, it is well known that site has considerable influence on the ring width, percent of summerwood, and taper, among other things, and these in turn may affect the quality of the tree or its parts for a specific use. Silvicultural operations can modify the environment, which again directly affects the characteristics of the tree and wood. Pruning and thinning are silvicultural operations which have considerable influence on the type of wood produced (Englerth, 1966).

Genetic improvement of many wood properties is possible because of the genetic variation in the forest population. Growth rate, summerwood percentage, form, concentricity, and branching are some examples of heritable characteristics. Biological agents, such as insects, fungi, birds, and mammals, may cause damage to high-quality trees and wood (infrequently they may enhance specialized uses).

Decayed wood is decidedly objectionable for most uses and should be avoided. Likewise, insect galleries in the wood are the cause for rejection for many uses. Bird pecks, common in some species, are undesirable in many uses of solid wood. Poor harvesting, conversion, and processing methods may lower the quality of the tree, the wood, or the product in a number of ways (Englerth, 1966).

2.2. Wood Structure

Wood is a complex biological structure, a composite of many chemicals and cell types acting together to serve the needs of a living plant. Attempting to understand wood in the context of wood technology, we have often overlooked the key and basic fact that wood evolved over the course of millions of years to serve three main functions in plants conduction of water from the roots to the leaves, mechanical support of the plant body, and storage of biochemical (Raven and other 1999).

The fibrous nature of wood strongly influences how it is used. Wood is primarily composed of hollaw cells, parallel to each other along the trunk of a tree. When lumber and other products are cut from the tree, the characteristics of these fibrous cells and their arrangement affect such properties as strength and shrinkage as well as the grain pattern of the wood. There is no property of wood, physical, mechanical, chemical, biological, or technological that is not fundamentally derived from the fact that wood is formed to meet the needs of the living tree. The wood anatomical expertise is necessary for a researcher who is using a solid wood beam is different from that necessary for an engineer designing a glued-laminated beam which in turn is different from that required for making wood-resin composite or wood flour (Forest Products laboratory, 2010).

Wood is a product of a complex biological system, the tree, and as such it is a highly variable material. Its anatomical structure and properties vary from species to species, from tree to tree of the same species, and even from one part of a single tree to the other. It has been shown by many investigators that property differences are closely related to structure at both macroscopic and microscopic levels. Thus utility of a piece of wood for a specific application is dependent upon its properties which, in turn, are influenced by structure (Ifju, 1982).

2.2.1. Cells types

Wood cells-the structural elements of wood tissue- are of various sizes and shapes and are quite firmly cemented together. Woods are described as softwoods and hardwoods, depending on the type of tree from which they are cut. Softwoods and hardwoods are made up of different cell types and as a result have different structures. Softwoods have a generally uniform structure with tracheids forming the bulk of the wood (Moore, 2011). Tracheids are elongated cells with pointed tips, thick secondary cell walls and no living cell contents atmaturity. They are arranged in radial files reflecting the pattern of the fusiform cambial cells from which they are derived. Their cell tips are arranged in an irregular pattern when viewed tangentially, as a consequence of the pseudo-transverse longitudinal anticlinal divisions in the cambium. This permits long distance transport of water from cell to cell through pores in the radial walls, a feature that would not be possible if the cell tips did not overlap. It also provides for much greater along-the-grain strength in the timber. Some softwoods also have axial resin canals and/or axial parenchyma cells (Walker, 2006).

Axial parenchyma cells are not common in softwoods. All softwoods have un iseriate, and/or partly or fully biseriate rays built up of ray parenchyma, and in the case of *Pinus*, *Picea*, *Larix*, *Pseudotsuga* and *Tsuga*, ray tracheids as well. Hardwoods separate the functions of conduction and support into two different cell types: vessel elements joined end to end form long tubes termed vessels for long distance water transport, and elongated fibers are modified for support. The arrangement of these two cell types within each growth ring, along with axial parenchyma in a range of patterns, leads to an infinite variety of anatomies in hardwoods (Barnett and Jeronimidis, 2003). Hardwood fiber, while produced from derivatives of the cambial fusiform initials in much the same way as softwood tracheids, differ in that they undergo significant elongation by cell tip intrusive growth prior to secondary cell wall deposition. This intrusive elongation of the fiber tips is particularly important when the fibers are derived from a storied cambium (Forest Products laboratory, 2010).

2.2.2. Cell wall structure

The cell wall is a non-living, largely carbohydrate matrix extruded by the protoplast to the exterior of the cell membrane. The plant cell wall protects the protoplast from osmotic lysis and often provides mechanical support to the plant at large (Esau, 1977) ;(Dickison, 2000).

Cell walls in wood give wood the majority of its properties, the cell wall itself is a highly regular structure, from one cell type to another, between species, and even when comparing softwoods and hardwoods. The cell wall consists of three main regions: the middle lamella, the primary wall, and the secondary wall (Forest Products laboratory, 2010). The tracheid wall comprises an amorphous middle lamella, a primary wall and a multi-layered secondary wall overlaid in some species with various types of thickenings and warty depositions. The orientation of the cellulose microfibrils in these various wall layers varies considerably and strongly affects the wall properties. The middle lamella is an intercellular region and adheres the walls of adjacent cells together. In enlarging and differentiating cells, this zone comprises largely pectic compounds. In fully differentiated tissues, lignin comprises a significant percentage of the middle lamella. The middle lamella zone is very strong and cells subject to load usually fail by trans- or inter-wall failures (depending on the direction of the load) rather than by cell separation at the middle lamella. It is, however, reasonably easily digested in the laboratory using cell maceration techniques or during industrial processing using chemical separation. The primary or outermost layer of the cell wall is normally very thin and remains plastic prior to the deposition of the secondary wall. It is often difficult to distinguish from the middle lamella using microscopy and hence the term compound middle lamella is often applied to both regions. The primary wall is capable of permanent extension during cell expansion and as a consequence its predominant cellulose microfibril angle is random except at the cell corners. The microfibrils are bound into the matrix complex of hemicelluloses and pectinaceous material. The primary wall also becomes lignified following secondary wall deposition. The secondary wall is laid down after the primary wall and usually shows three distinct layers, S1, S2 and S3. S2 layer is arguably the most important cell wall layer in determining the properties of the cell and, thus, the wood properties at a macroscopic level (Panshin and deZeeuw 1980). The structure of the tracheid cell wall determines the mechanical and physical properties of softwoods. The polylaminate structure is ideal for compressional loading. Hardwood vessels have a wall structure rather different from both tracheids and fibers. Here the microfibrils of the S2 wall layer are aligned at close to 90° to the long axis of the vessel element, and the cell ends are perforated with membrane free openings in various arrangements in order to facilitate the rapid movement of water (Butterfield *et al.,* 2000).

The very large microfibril angle is presumably an adaptation to the fact that the vessels are under internal water tension. Density, as influenced by cell wall thickness, has long been known to affect stiffness in wood, and the microfibril angle in the dominant S2 wall layer governs two major wood properties, namely axial stiffness and longitudinal shrinkage. The complex architecture of the wood cell wall determines the strength and stability of the standing tree, and therefore also the mechanical properties of solid wood (Zimmermann, *et al*, 2007).

2.2.3. Chemical composition

The chemical components of wood may be classified as:

(i) Structural components – These components make up the structure of cell walls and are responsible for the form of cells and for most of the physical and chemical properties of wood. Removal of a structural component from the cell wall requires chemical or mechanical treatments to depolymerize, at least partially, and solubilize it. The cellular characteristics and the wood properties are substantially altered in this process. The structural components of wood are cellulose, hemicelluloses and lignin. Dry wood is primarily composed of cellulose, lignin, hemicelluloses and minor amounts 5% to 10% of extraneous materials. Cellulose, the major component, constitutes approximately 50% of wood substance by weight. Cellulose is a high molecular weight linear polymer of the 6 carbon sugar (hexose), β-glucose (Walker, 2006). During growth of the tree, the cellulose molecules are arranged into ordered strands called fibrils, which in turn are organized into the larger structural elements that make up the cell wall of wood fibers. Lignin constitutes 23% to 33% of the wood substance in softwoods and 16% to 25% in hardwoods. Although lignin occurs in wood throughout the cell wall, it is concentrated toward the outside of the cells and between cells. Lignin is often called the cementing agent that binds individual cells together. Lignin is a three-dimensional phenyl propanol polymer, and its structure and distribution in wood are still not fully understood. On commercial scale, it is necessary to remove lignin from wood to make high-grade paper or other paper products. The hemicelluloses are associated with cellulose and are branched, low-molecular-weight polymers composed of several different kinds of pentose and hexose sugar monomers. Hemicelluloses play an important role in fiber-to-fiber bonding in the papermaking process. The exact role of hemicelluloses in the plant cell wall is uncertain but in the most general terms they provide a link between the cellulose and lignin, which in turn affects the mechanical behavior of wood and its dimensional stability (Moore, 2011).

The component sugar of hemicelluloses are of potential interest for conversion into chemical products. Extraneous materials are not structural components. Both organic and inorganic extraneous materials are found in wood. The organic component takes the form of extractives, which contribute to such wood properties as color, odor, taste, decay resistance, density, hygroscopicity and flammability. Extractives is the collective term given to the different classes of chemical compounds that can be extracted from wood or bark by means of polar and non-polar solvents. They include tannins and other polyphenolics, colouring matter, essential oils, fats, gums, resins, waxes, starch and other substances (Wilson and White, 1986).

This component is termed extractives because it can be removed from wood by extraction with solvents such water, alcohol, acetone, benzene or other

(ii) Extractive components – These are non-structural components that are contained in cell lumina, cellular voids or channels. The organic extraneous components are largely soluble and may be removed from wood by use of solvents with adequate polarity, without appreciably changing the cellular structural characteristics. They are commonly referred to as extractives. Most of the extractives are secondary metabolites, compounds that play other roles in the tree, besides those involved in growth and cell development namely the protection of the tree against pathogens or other biotic attacks. Their presence is responsible for the natural durability of solid wood. Wood chemical composition varies with geographical origin, genus and species. The chemical components and their assembly in the cell wall are related directly to the properties of wood, and their effect may be either positive or negative, depending on end-use. In timber, the role of lignin is associated with compressive strength and that of cellulose with tensile and bending strength, and changes in their contents are bound to affect these properties. For solid wood the most important chemical factors affecting quality are the extractives, since their presence affects the processing and use of wood. The major contribution of extractives in the use of solid wood is certainly in the natural durability they impart. Exposed in use, either in the soil, above ground or immersed in water, wood is susceptible to attack from a number of fungi, insects and marine organisms (Zabeland and Morrell, 1992). Large amounts of extractives, particularly when they are located inside the cell walls, can increase the density and diminish shrinkage and swelling, at least of the heartwood, with beneficial consequences for wood utilization (Tsoumis, 1991).

The combined effect of higher durability and lower dimensional variation makes heartwood a valuable material for structural applications. The accumulation of extractives within the cell walls, and particularly in the pit membranes, makes the wood less permeable, making the drying of wood or its preservative treatment more difficult. Extractives can affect the wettability of wood surfaces and thereby the application of paints and adhesives. Extractives impart color to wood and their alteration by external factors, such as light or water, can lead to discoloration or more dull and less attractive appearance (Uprichard, 1993).

2.3. Quantitative Analysis of Wood Structure

The presently accepted practice of wood characterization is based on anatomical structure that serves as the principal method of identification (Panshin and deZeeuw, 1980). An understanding of wood anatomy is very important to understanding of wood as a material (Toong *et al*, 2014). Structural characteristics considered in the identification keys seldom give a quantitative assessment of the anatomical elements. Furthermore, successful use of the identification keys requires special skills and long training to achieve the desired consistency in making a series of subjective two-way decisions as to the size, distribution, and shape of the anatomical elements. Thus conventional identification methods often fail to give numerical assessments of wood structure needed for predicting properties and performance of wood in various applications or processes. Since wood anatomy and identification involve the recognition of shapes, sizes, and distribution of elements or features, it should greatly benefit from a quantitative treatment of these features.

Conventional wood anatomy distinguishes between two types of elements with respect to the direction of the tissues they are a part of in the tree. On this basis, all woods have longitudinal and transverse elements. The longitudinal elements may be vessels, various types of fibers, tracheids, or parenchyma cells. The transverse tissues, the wood rays, may contain tracheids or parenchyma elements or both. Relative size and size-distribution within the growth increments, or annual rings, of these elements are used for identification. A quantitative approach should also provide the necessary basis for the calculation of probabilities. Although conventional descriptive anatomy can be used for distinguishing between species of wood, it does not provide any information for the prediction of properties. Description in qualitative terms is a one-way street providing basically one result, a possible identification, with certainty related only to the knowledge and experience of the anatomist. Stereology was first defined by Hans Elias (1961) as follow: stereology deals with a body of methods for the explorations of three –dimensional space, when only two-dimensional sections through solid bodies or their projections on a surface are available. Thus stereology can also be called extrapolation from two-to three dimensional spaces. By adopting a generalized, geometrical approach, stereological techniques appeal equally for a wide spectrum of different fields. Stereology is a branch of morphometry, which is used to obtain three-dimensional data from two-dimensional sections from virtually any type of structure (biological structure, metallurgical, etc.. (Baddeley and Jensen, 2004).

Recently quantitative characterization using stereological techniques is used in the body of structure-property relationships (Nasroun, 1978). The quantitative characterization of the anatomical structure of wood includes cross sectional measurements, and fiber length of each species. The structural parameters which can be obtained from stereological counts are the average volume fraction (Pp) for cell wall and cell lumen as well as cell types. The parameters also included the number of intersections of boundaries of each cell type per unit test line (P_L) and the number of each cell type per unit test area (N_A) (Nasroun and Elzaki,1987). The basic structural parameters computed from stereological equations are: fiber length, cell diameter, lumen diameter, double cell wall thickness, Rankle ratio, Co-efficient of cell rigidity, fiber flexibility index and fiber density index. Computing methods used are shown below:

The average fiber length (FL) can be calculated from counts made on macerated fibers as follows:

$$FL = \prod \bar{P}_L / 2N_A \quad \ldots\ldots 1$$

Where (P_L) is the number of intersections of test lines with cell boundaries per unit test line.

(N_A) is the number of fibers per unit test area.

Average cell diameter ($\bar{d}$) =

$$\bar{d} = \bar{N}_L / \bar{N}_A = \bar{P}_L / 2N_A \quad \ldots\ldots 2$$

Where: ($\bar{N}_L$) is the average number of interceptions with features per unit line.

Average lumen diameter ($\bar{L}D$)

$$\bar{L}D = \sqrt{\frac{4\bar{P}p\ (lumen)}{\prod N_A}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.... 3$$

Where: ($\bar{P}$ p) is the average volume fraction.

Double cell wall thickness = d − LD ……………………….4

Rankle ratio = DCWT / $L\bar{D}$ ………….. ……………… 5

Co-efficient of cell rigidity = DCWT / $\bar{d}$ ………………..…………… 6

2.4. Physical Properties

2.4.1. Wood texture

The texture of wood related to the size of the cells and their arrangement. Texture cannot be quantified and use is made of such qualitative terms as coarse, fine, uneven and even texture. The differentiation between coarse and fine texture is based on the dimensions of the vessels and the width and abundance of the rays. Timbers in which the vessels are large or the rays wide are said to be coarse textured but when the vessels are small and the rays narrow the wood is said to be fine textured. Where the arrangement of the types and sizes of cells remains constant throughout the growing season, the wood is said to be even textured. The term can also be applied to those softwoods in which wall thickness does not change across the growth ring.

Where there is contrast in cell size across the growth ring or contrast in wall thickness across the growth ring the wood is said to be of uneven texture. Figure relates to the ornamental markings produced on the longitudinal surface of wood as a result of either its inherent structure or its induced structure following some external interference. The four principal structural features controlling figure are grain, growth rings, knots and rays. Color in the wood is caused largely by various extractives present in the cell walls of the heartwood. Color may be used to assist in the identification of woods but great caution has to be exercised not only because of the variation in color that can be obtained among trees of the same species, but also, and possibly more important, because the color of most woods changes on exposure to light. Under sunlight most timbers will lighten appreciably, and a few timbers darken on exposure. Lustre depends on the ability of the cell walls to reflect light. Some timbers possess this property in a high degree, but others are comparatively dull (Desch and Dinwoodie, 1996).

2.4.2. Permeability

Permeability is defined as a measure of the ease by which a liquid or gas is able to move through wood (Siau, 1984); (Kamke and Lee, 2007). It is varying according to a range of factors such as chemical and anatomical characteristics, flow direction and type of fluid, among others. In wood, diameter, frequency and distribution of vessels, fiber length, and type of pit affect permeability, as well as the deposition of extractives, which may cause partial or total occlusion and become a barrier to liquid or gas flow. Regarding flow direction, wood permeability is of great variability, and the longitudinal-to-transverse permeability ratio is high. The explanation for this lies in the structure and orientation of the vessels, which facilitate longitudinal flow and play a major role in the movement of liquids. Depending on the type of fluid that moves through the wood, permeability also presents different magnitudes. Silva *et al*, 2010 reported that the higher the fluid viscosity, the lower the flow and permeability. It is important to distinguish between permeability and porosity. Porosity refers to the relative proportion of void space in a material, but not necessarily to the ease with which fluid can move through it (Walker, 2006). Porosity is related to basic density, whereas permeability is related to wood structure and the direction of flow (radial, tangential and longitudinal) (Petty, 1970).

The values of permeability also depend on the viscosity of the liquid or gas being considered; the permeability is lower for more viscous liquids than for less viscous liquids and gases. low permeability directly affects chip impregnation in chemical pulping, preservative treatment, bonding, water absorption, panel finishing and, mainly, the quality of drying (Lehringer *et al.,* 2009; Taghiyari *et al*., 2010; Tarmian and Perré, 2009) cited by(Rezendle, *et al*, 2018)

2.4.3. Density and specific gravity

Density (or specific gravity) is one of the most important physical properties of wood (Desch and Dinwoodie 1996) (Bowyer *et al* 2003). Density is the mass contained in a unit volume of a material, and specific gravity is the ratio of the density of the material to the density of water. Specific gravity is also called relative density (Tsoumis, 2009). Density is expressed as weight per unit volume. In the metric system, density is measured in grams per cubic centimeter (g/m^3) or kilo-grams per cubic meter (kg/m^3). Density and specific gravity are numerically identical, because the density of water is 1 g/cm³. In the English system, it is measured in slugs per cubic foot (Brown *et al*,1952) but it is seldom used as such, instead, density is expressed as weight per unit volume [i.e., in pounds per cubic foot (Ib/ft³)], and this is sometimes called weight density. In units of this system, the density of water is 62.4 pounds/ft³ and therefore specific gravity of a material may be found by dividing its weight density by 62.4. Wood density is considered a very important attribute because it is known to influence several physical and mechanical properties of material (Genet *et al*, 2013).

Density is directly related to other properties and therefore is important as an index of wood quality (de Zeeuw, 1965). Perhaps the single most important property controlling the mechanical performance of a piece of wood is its density. Density affects hygroscopicity, shrinkage and swelling, mechanical, thermal, acoustical, electrical, and other basic wood properties, as well as properties related to the industrial processing of wood. The shrinking and swelling behavior of wood is also affected by density, although the relationship is not as direct as in the case of strength properties. Density is used also as a wood quality value, i.e. it is related to the suitability of wood to different end-use purposes. Structural timber needs a high density and strength. Low-density wood may be more suitable for pulp and paper products than for construction. Density is a useful indicator of pulpwood quality because of its relationship to certain wood and fiber properties such as thickness of cell wall. The yield of pulp is directly related to density (Barnett and Jeronmidis, 2003).

Wood specific gravity, or density, varies with species and generally is the prime wood quality consideration for industry, higher values yielding stronger woods and more pulp (Stamm and Sanders, 1966). The density and specific gravity of wood are influenced by moisture content, structure, extractive and chemical composition (Kellogg, 1981).

One must consider that wood is a hygroscopic material, which swells and shrinks with changes in moisture content. Increasing moisture content increases the density of wood. The density of wood varies, depending on the amount of material (cell wall)² and voids (cell cavities) present in a certain volume. The variation is great especially in tropical wood (Tsoumis, 2009). The basic density of common wood species is 330–600 kgm^{-3}, and hardwoods usually have higher density than softwoods. The density of wood is a measure of the quantity of cell-wall material contained in a certain volume, and is an index of void volume. Differences in density and void volume derive from anatomical differences, such as differences in cell types (tracheids, vessel members, parenchyma cells) and their quantitative distribution, thickness of cell walls and size of cell cavities. The relationship of specific gravity and structure is examined on the basis of factors which can be easily measured, such as width of growth rings and proportion of late-wood(Tsoumis, 2009).

Vessel diameter and frequency tend to be inversely proportional to wood density, particularly in ring-porous species having large diameter early wood vessels. Thus, woods having relatively high fiber: vessel ratios yield more dense woods than those with lower ratios. In many cases, softwood trees do indeed possess low-density woods and hardwoods high-density woods, but this is not always the case. There are far more hardwood than softwood species in the world, though the latter are often better known as production forest plantation species. The density of oven-dried cell wall material for all woody plants is about 1500 kg/m^3. Wood with thicker-walled cells has a higher density than wood with thinner-walled cells of comparable size (Moore, 2011).

2.4.3.1. Variation of density

A piece of perfectly dry wood is composed of both the solid material comprising the cell walls and the cell cavities which contain air and small quantities of gum and other substances. The relative density (specific gravity) of the solid material of the cell walls has been found to be similar in all timbers. Different timbers however, vary in mass from about 160 to 1250 kilograms per cubic meter this variation is caused by differences in the ratio of cell wall to cell cavity. This ratio is controlled by both the relative proportions of the thinner-walled vessel and parenchyma cells and thicker-walled fibers and the extent of development of the secondary walls of the fibers; generally both factors operate to produce this very wide range in density among timbers. The range in densities of softwood timbers is much lower than that for the hardwood timbers and equally as important, the density range of softwoods is encompassed by that of the hardwoods; that is some of the hardwoods are less dense that the softwoods. The density of wood varies under the influence of moisture, structure, extractives and chemical composition. Variation exists within a tree, between trees of the same species, and between species (Panshin and de Zeeuw, 1980).

Variation of density within a tree

The density of wood varies in the trunk of tree and also between trunk, branch and root wood. Within a trunk- which is the main tree component there is a vertical variation (from base to top of a tree) and a horizontal variation (from pith to bark).In the vertical direction, there is a tendency for reduction of density with tree height, especially in softwoods. The reduction is attributed to various factors mechanical and biological. As a general rule the heaviest wood is found at the base of the tree, and there is a gradual decrease in density in the samples from successively higher levels in the trunk. At any given height in the trunk there is usually a general increase in density outwards from the pith, fairly marked in the rings near the pith, but slowing down considerably thereafter. Horizontal variation is interrelated to vertical variation. In each horizontal level, the influence of age is more clear, however, considering that the wood produced a different stages of tree life (juvenile, mature, over mature) differs in density.

In addition to the range in density that occurs among timbers of different species there is considerable variation in density between different samples of the same species. Variation between trees of the same species is influenced by environmental conditions (soil, climate, tree spacing) and heredity. Environmental conditions change during the life of a tree and therefore they affect both between and within tree variation. The effect of environment is basically expressed through changes of ring width and proportion of latewood. The evaluation of environmental factors (moisture, temperature, nutrients) is not easy (Kozlowski, 1971).

Heredity affects density in the sense that certain trees, under the same growth conditions, produce wood of high or low density, and that this property may be inherited. Density variation between species is basically due to differences in anatomical structure. Species differ with regard to cell types and their proportional participation. In addition, differences in extractives and chemical composition of cell walls may influence density.

2.4. 4.Effect of moisture content on wood

All the physical properties of wood are influenced by its moisture content. The moisture present in practically each piece of wood influences density. Below the fiber saturation point, where wood shrinks and wells water molecules enter the cell walls causing the wood to swell. Swelling moves the microfibrils apart, reducing the cell wall mass per unit volume and weakening the wood. Wet wood is also weaker than dry wood (Wilcox, *et al*, 1991).The moisture in wood exists in two basic forms: bound water which is dissolved or adsorbed in the hygroscopic cell wall and free or capillary water which is situated in the voids within the wood. An equilibrium is established between the moisture content of wood and the relative humidity of the ambient air. Tiemann (1906) has defined the fiber saturation point as the moisture content at which the cell wall is saturated while the voids are empty (Siau, 1995).

Wood is a hygroscopic material (i.e. it has the property to attract and retain moisture). In the living tree, wood contains large quantities of water. As green wood dries, most of the water is removed. Wood exchange moisture with air, the amount and direction of the exchange gain or loss depend on the relative humidity and temperature of the air and the current amount of water in the wood. This moisture relationship has an important effect on wood properties and performance. One of the important variables influencing the performance of wood is its moisture content. The amount of water present not only influences its strength, stiffness and mode of failure, but it also affects its dimensions, its susceptibility to fungal attack, its workability as well as its ability to accept adhesives and finishes. Moisture impairs wood's dimensional stability, strength and durability. It also affects sawing, planning, finishing and all other kinds of wood processing. The integrity of glue bonds depends on wood moisture at the time of the gluing operation and thereafter (Wilcox, *et al*, 1991).

Moisture content of the wood is defined as the weight of water in wood expressed as a fraction, usually a percentage, of the weight of oven-dry wood. Weight, shrinkage, strength and other properties depend upon the moisture content of wood. In trees, moisture content can range from 30% to more than 200% of the weight of wood substance. In softwood, moisture content of sapwood is usually greater than that of heartwood. In the hardwoods, the difference in moisture content between heartwood and sapwood depends on the species. There is considerable variation within and between trees. Variability of moisture content exists even within individual boards cut from the same tree. For wood to perform well, its moisture content must be reduced to a level corresponding to at least 12 percent of oven-dry mass. Wood in service is virtually always undergoing at least slight changes in moisture content. Changes in response to daily humidity changes are small and usually of no consequence. Wood should be installed at moisture content levels as close as possible to the average moisture content it will experience in service, the equilibrium moisture content. This minimizes the seasonal variation in moisture content and dimension after installation, avoiding problems such as floor buckling or crack in furniture. The in-service moisture content of exterior wood primarily depends on the outdoor relative humidity and exposure to rain or sun. The in-service moisture content of interior wood primarily depends on indoor relative humidity, which in turn is a complex function of moisture sources, ventilation rate, dehumidification (eg: air conditioning), and outdoor humidity conditions. The recommended moisture content of wood should be matched as closely as is practical to the equilibrium moisture content. When veneers are bonded with cold-setting adhesives to make plywood, they absorb comparatively large quantities of moisture. To keep the final moisture content low and to minimize redrying of the plywood the initial moisture content of the veneer should be as low as practical. Hot pressed plywood and other board products usually do not have the same moisture content as lumber.

2.4.5. Shrinkage

Shrinkage is dimensional changes or movements caused by loss of bound water, (Wilcox, *et al*, 1991). Above the fiber saturation point (30% moisture content), wood is dimensionally stable. Below this point, wood shrinks as moisture is lost from the cell walls (Rijsdijk and Laming, 1994). Wood shrinks if it loses moisture below fiber saturation point (Nasroun, 1979). Water held in wood below its fiber saturation point is chemically bonded to the matrix constituents of the microfibrils comprising the cell wall. Removal of this water requires the application of a considerable amount of energy in the form of heat and the direct consequence of the reduction in moisture is to cause the wood to shrink. The degree of shrinkage in the three principal axes is different: shrinkage in the tangential direction is on average about twice as high as that occurring in the radial direction, while shrinkage in the longitudinal direction is much lower than that in the transverse direction (Siau, 1995).

It is possible to explain the difference in shrinkage in the three principal planes in terms of the basic structure of wood. The difference between longitudinal and horizontal shrinkage is due basically to the microfibrillar angle of the S2 layers of the cell wall. As the water is removed from the matrix surrounding the crystalline core of the microfibrils, so they move closer together and the horizontal component of this movement is several times greater than the longitudinal component. Longitudinal shrinkage influences overall dimensions of wood-frame building (Wilcox. *et al*, 1991).

In some timbers tangential shrinkage is only slightly greater than radial, while in others it can be as much as six times as great. Differences in shrinkage between tangential and radial directions have been accounted for by a number of factors among the more important are: (1) the restricting effect of the ray on the radial plane (2) the difference in degree of lignifications between the radial and tangential walls (3) small differences in microfibrillar angle between the two walls and (4) the increased thickness of the middle lamella in the tangential direction compared with that in the radial direction. None of those variables on its own is able to account for the total extent of differential shrinkage all four variables (and possibly others) probably contribute to the differences but it is not possible to estimate their relative contributions. Differential shrinkage has a direct bearing on the amount of distortion that occurs in the commercial drying of wood.

The other major wood quality trait under the influence of microfibril angle is longitudinal shrinkage. Longitudinal shrinkage increases with microfibril angle but in a highly non-linear relationship. Longitudinal shrinkage is always less than transverse shrinkage. Tangential shrinkage in turn is around 1.5 to 2.5 times that of radial shrinkage (Walker, 1993).

Cellulose microfibrils do not change in length or cross section with changes in moisture content, but the amorphous matrix of the cell wall does show a tendency to change. The cellulose microfibrils therefore act to restrain the matrix from shrinkage in the direction parallel to the microfibril angle. However, since wood in service would not be in the oven-dry condition, practically, the shrinkage would be expected to be only half that great. Low shrinkage makes wood more dimensionally stable, less prone to warping and better able to hold finishes (Wilcox. *et, al*, 1991).

The shrinkage of wood is affected by a number of variables. In general, greater shrinkage is associated with greater density. The size and shape of a piece of wood can affect shrinkage, and the rate of drying can affect shrinkage for some species (Forest Products laboratory, 2010).

2.4.6. Calorific value

Wood is combustible under suitable conditions it will burn and its constituents undergo oxidation with the liberation of energy in the form of heat. Energy yield, measured as heating value, is one of the most important wood quality characteristics for energy plantations (Kenney *et al*. 1990). The ash content of biomass is known to vary between tree species and tree components (Hytönen and Nurmi 2015). High wood density entails a higher heating value per volume, whereas high ash content decreases the heating value of biomass. In addition, high amounts of ash can also affect the clogging of the ash handling mechanisms of power plants and may lead to higher cleaning and maintenance requirements of the boilers (Niu *et al*. 2016). The fuel value of a timber depends largely on the amount of wood substance in a given volume, that is, on the density, the chemical composition of the wood substance and the state of dryness of the wood. High wood density entails a higher heating value per volume, whereas high ash content decreases the heating value of biomass (Sheng and Azevedo 2005). As a general rule the denser the timber the higher is its potential fuel value, but this may be modified by the presence in the wood of such substances as resin. The fuel value of resin is about twice that of wood substance and other things being equal, resinous woods have a higher fuel value than non-resinous woods. The wet wood has a much lower heating value than dry wood of the same species, because much heat is lost in transforming the contained moisture into steam. The heat value of wet wood is generally of the order of 40—60 per cent of that of the oven dry wood, depending on the amount of water present.

In comparing the heat value of wood with that of coal it is found that on an oven dry basis, coal will yield about 1.6 times as much heat as an equal mass of wood. This assumes a 100 per cent efficiency in the burning of wood which is probably an over-estimate. Another disadvantage of wood as a fuel compared with coal is its greater volume and hence higher costs in transportation, handling and storage. Charcoal produced by the controlled burning of wood under reduced availability of oxygen is an alternative fuel to ordinary wood; it has a higher fuel value than wood both on a volumetric and a weight basis. The advantages of charcoal over wood as a fuel are largely economic ones, associated with low transport and handling charges per joule of heat produced; the saving is more than offsetting its cost of manufacture.

2.5. Mechanical Properties of Wood

The strength of a material such as wood refers to its ability to resist applied forces that could lead to its failure, while its elasticity determines the amount of deformation that would occur under the same applied forces. These forces may be applied slowly at constant rate whereby we refer to the inherent resistance of the material as its static strength, or they may be applied exceptionally quickly, when we refer to the resistance of the material as its dynamic strength (Desch and Dinwoodie,1996).

The mechanical properties of wood are its fitness and ability to resist applied or external forces. By external force is meant any force outside of a given piece of material which tends to deform it in any manner. It is largely that such properties that determine the use of wood for structural and building purposes and innumerable other uses of which furniture, vehicles, implements, and tool handles are a few common examples. It requires no special knowledge to appreciate that the strength of a timber has an important bearing on suitability for a particular purpose. A timber for beams, posts, or struts in buildings should possess different qualities from one required for spokes, hubs, or axles of carts; timber for sports goods and tool handles would not necessarily make good chopping blocks or bearings for machinery, and so on (Desch, 1973).

Knowledge of these properties is obtained through experimentation either in the employment of the wood in practice or by means of special testing apparatus in the laboratory. Every stress produces a corresponding strain, and within a certain limit the strain is directly proportional to the stress producing it. The same intensity of stress, however, does not produce the same strain in different materials or in different qualities of the same material (Recored, 1914). If the load is small the deformation is small, and when the load is removed there is a complete or partial recovery to the original size and shape, depending on the elasticity of the material. Up to a point the deformation or strain is proportional to the load; this point called the limit of proportionality. Beyond this limit the deformation increases more rapidly than load. The point beyond which it is impossible to increase the load without establishing a permanent change in shape, or permanent set, is called the elastic limit. As wood is not a perfectly elastic material it is more usual to determine the load at the limit of proportionality. The load required to cause such failure is called maximum load. It is important to appreciate that the word strength has little meaning unless qualified in some way; wood has several types of strength, and a timber strong in one respect may be comparatively weak in another (Desch. 1973).

Variability, or variation in properties, is common to natural materials. Because wood is a natural material and the tree is subject to many constantly changing influences (such as moisture, soil conditions, and growing space), wood properties vary considerably, even in clear material (Forest Products laboratory, 2010). Since the properties of timber vary widely, not only between species but also between pieces of the same species, the opportunity has been taken to include the standard deviation of the properties. This is a measure of the variability within a species, and it used in the calculation of grade stresses (Forest products research, 1969).

Macroscopically, wood can be described as an orthotropic or anisotropic material with three main directions: longitudinal direction (L), while radial (R) and the tangential (T) directions in the transverse plane. The mechanical properties of wood in the radial direction are slightly higher than in the tangential direction, and both radial and tangential properties are about one order of magnitude lower than the properties in the longitudinal direction. The difference between the mechanical properties of wood in radial and tangential directions can be explained by the cell shape in the cross-section plane (namely, the irregular hexagonal cell which causes the anisotropy in the transverse plane), and/or by the effect of rays in the radial direction (Mishnaevsky and Qing, 2008).

2.5.1. Bending strength

Timer is probably stressed in bending more than in any other mode. There are many examples of where timber is used as a beam, of which the more common are floors and seiling joists, roof truss members, table tops and chair bottoms. Static bending is a measure of the strength of a material as beam. In the resting position the upper half of a beam is in compression and the lower half in tension. Midway between the upper and lower surfaces is the neutral axis where both compression and tensile stresses are theoretically nil. A shearing stress operates along the neutral axis (Decsh and Dinwoodie, 1996).

Strength in static bending is an important mechanical property, because in most structures wood is subject to loads which cause it to bend. The typical case is of wood as a beam b hent under external forces, which act transversely to its axis. Under their action three stresses develop- tension, compression and shear. These stresses are axial, tension stress tend to lengthen the wood fibers, compression stress tend to make them shorter and shear stress tend to make the upper part of the beam slide over its lower part. In the usual case of simple beam, tension and compression stresses are respectively highest in lower and the upper surfaces gradually diminishing toward the center and are zero in the neutral plane (Tsoumis, 2009).

Inversely shear stress are highest in the neutral plane and zero at the surfaces. The distribution of stresses along the length of the beam depends on the manner of loading (center, third- point or uniform. Bending strength, also called the modulus of rupture (MOR), is an index of the maximum load a bending member can be expected to support before failing weighted for the effects of span, width and depth (Wilcox *et al*, 1991). The bending strength of wood is usually presented as a modulus of rupture (MOR) which is the equivalent stress in the extreme fibers of the specimen at the point of failure assuming that the simple theory of bending applies.

The MOR in three- point bending test is calculated from the following equation:

$MOR = 3PL / 2bd^2$ ……….. …………………………………………….. 7

Where MOR is the modulus of rupture, in N/mm^2

P is the maximum load, in N

L is the length of span, in mm

b is the width, in mm

d is depth, mm

2.5.2. Modulus of elasticity

Stress/ strain = a constant = modulus of elasticity

Also known as Young's modulus is expressed in units of N/mm^2. M O E is a material constant characterizing one piece of wood. It will be similar for other samples from the same part of the tree it will vary between different species. M O E is frequently referred to as the stiffness of wood, a popular term which conveys an appropriate image. The term of stiffness is the product of MOE and the second moment of area (I): that is stiffness = (M O E) I. The toughness of a material is a measure of the energy required to propagate cracks in it and is quantified in units of J/mm^2. A measure of the toughness or impact resistance can be obtained by measuring the area under the load- deflection curve to maximum load – a measure of the work done or capacity to store energy before failure. The strength of wood will vary within mode of load application; the principal modes are tension, compression (both of which can be parallel or perpendicular to the grain), bending and shear. Unlike the position with strength, modulus of elasticity in tension, compression and bending is similar and common value for modulus of elasticity for all three modes of load application in each of the three principal planes is usually adopted. In the case of shear, within the elastic range of wood, shear stress is proportional to shear strain, namely:

Shear stress α shear strain

Shear stress/ shear strain = constant = modulus of rigidity and expressed in N/mm^2.

2.5.3. Compression strength

The compression strength of a piece of wood can be measured in the longitudinal direction (parallel to the grain) or in the radial and tangential directions (perpendicular to the grain). The maximum compressive strength parallel to the grain is a measure of the strength of wood when used as a stud or column (Moore, 2011). High strength in longitudinal compression is required of timber used as columns, props and chair legs, though on account of the lengths of these items in relation to their cross- sectional area they frequently buckle at high stresses and fail in bending rather than true compression. Compression parallel to the grain strength indicates the maximum load that each square inch of wood can be expected to support as a column with the load being applied to the end grain direction (assuming that the column does not buckle) (Wilcox et al, 1991).

Timber unlike most other materials is significantly weaker in longitudinal compression than in longitudinal tension with values as low as one- quarter. The strength of a piece of wood in compression is closely related to its density though influenced by its moisture content. The strength of the relationship between density and compression strength increases with increasing distance from the pith, which is possibly due to greater variation in microfibril angle in those samples taken from close to the pith (Bryan and Pearson, 1955). Compression perpendicular to the grain measures wood's ability to resist cross- grain crushing. Wood is relatively weak in this property. In fact a comparison of this with the compression parallel to the grain demonstrates clearly wood's anisotropy – wood tends to be about 10 times as strong in compression parallel to the grain as opposed to perpendicular to the grain (Wilcox *et al*, 1991). Resistance to crushing is an important property in a few selected end uses such as railway sleepers, rollers, wedges, bearing blocks and bolted timbers. Those timbers which are high in density have high compression strength across the grain. The test of compression perpendicular to the grain is seldom carried out this strength is determined from the hardness test of the timber since it has been established that there is very high correlation between the two properties (Desch and Dinwoodies, 1996).

2.6. Wood Utilization

The utilization of wood is examined with regard to products of primary manufacture (technology of production, properties of products).Wood is the harvested material most commonly used in buildings and building products. Dimensional lumber is used in framing the majority of residential buildings and many commercial structures. Wood products such as plywood, particleboard, and paper are used extensively throughout the construction industry (Kim *et al,* 1998).

The use of wood-based composite panels as building construction material is usually to function both as structural and non-structural components. In building construction and interior design, acoustic panels are commonly used as partitions, ceiling boards and flooring systems (Smith 1989). Natural materials are generally lower in embodied energy and toxicity than man-made materials. They require less processing and are less damaging to the environment. Many, like wood, are theoretically renewable. When natural materials are incorporated into building products, the products become more sustainable (Kim, *et al,* 1998). Timber is one product amongst many designers can choose from. Many of these are promoted as environmentally viable options, but few have production processes as simple and low impact as most solid timber products. Manufacturing processes generally utilize all of log to produce a range of products with different values. Solid wood products such as appearance grade veneer or sawn timber are higher value products than reconstituted wood products such as particle board, fiber board or paper. However, milling solid wood products, such as flooring and furniture, requires straight logs with few defects such as rot or knot. In contrast, the manufacture of reconstituted wood products reduces logs of any shape or portion to woodchips or flakes before further processing back into products such as particle board, fiber board or paper. Higher uniformity of chemical, mechanical, and physical properties and higher specific gravity (density) are among the properties of wood that will remain desirable. Uniformity contributes to more efficient processing and more uniform end product quality, whereas higher specific gravity increases pulp through put and is correlated with higher strength properties in solid-sawn wood products (Wenger *et al.* 2010).

Wood quality is a complex concept that incorporates various aspects related to wood defects, wood anatomy and the physical and mechanical properties of wood (Romagnoli, *et al,* 2014). Wood quality, as understood within both dictionary and practical contexts, has to do with the degree of excellence – in relation to some preconceived application(s). Because quality assessment is multi-faceted and depends on the intended application, there is no absolute measure. Quality assessment by the woodsmen who fell and process the trees and by the mill workers who decide how logs should be used involves experienced observation and snap-judgment integration of particularfeatures, based largely on subjective experience (Barnett and Jerohimidis, 2003). Timber quality is that combination of physical and chemical characteristics of a tree or its parts that permit the best utilization of the wood for the intended use. In this definition, the intrinsic quality of the wood is evaluated solely in terms of its suitability for various products or end uses. This concept, which is generally accepted worldwide is not an attempt toward an all-inclusive unambiguous and completely satisfactory definition to all persons for all purposes. Instead it provides a useful basis on which to analyse and evaluate the technological aspects of quality involved with the utilization of forest timber (Englerth, 1966).

Two aspects should be considered in timber quality research. One is to find better methods of identifying quality characteristics that can be used in grading and sorting wood for different uses, and the other is growing trees tailored for future use. In both, the end-use requirements of the wood should be known. An understanding of both aspects depends upon: (1) the definition of timber quality, (2) the factors that influence it, (3) the recognition of these factors, and (4) the evaluation of their qualitative effect. Although the end-use requirements of the product are of primary importance, the processing requirements should also be considered. This inclusion does not conflict with the accepted definition of timber quality, since good machining, for example, is essential for the best utilization of wood for some uses. According to the accepted definition of timber quality, the wood for specific end uses possesses those attributes which make it suitable for those uses. Each element may influence or affect the wood characteristics. Starting with environment, it is well known that site has considerable influence on the ring width, present of summerwood, and taper, among other things, and these in turn may affect the quality of the tree or its parts for a specific use. Silvicultural operations can modify the environment, which again directly affects the characteristics of the tree and wood. Pruning and thinning are silvicultural operations which have considerable influence on the type of wood produced. Genetic improvement of many wood properties is possible because of the genetic variation in the forest population. Growth rate, summerwood percentage, form, concentricity, and branching are some examples of heritable characteristics. Biological agents, such as insects, fungi, birds, and mammals, may deteriorate otherwise high-quality trees and wood. Decayed wood is decidedly objectionable for most uses and should be avoided. Likewise, insect galleries in the wood are cause for rejection for many uses. Bird pecks, common in some species, are undesirable in many uses of solid wood. Basically, timber quality is dependent on the suitability of various tree and wood characteristics for the end-use requirements of a product.

Many properties of wood are well known through centuries of use. On the other hand, the variations in these properties as they might affect the performance of end uses are known only imperfectly. Species differences are generally recognized, such as information on decay resistance, gluability, and strength properties, but little information is available on variations within and between trees of the same species. Allowances, therefore, are often made to account for these variations. Some of this information, moreover, was obtained on laboratory specimens rather than on the actual performance of the product. The selection of wood for specific uses often times is a rule-of-thumb operation based on experience rather than on scientific information. Performance requirements are dependent on one or more of the tree and wood characteristics. Therefore, recognizable gradations in the requirements, as well as in the wood characteristics, are needed to sort the materials for the most suitable use. The inherent properties of a species or a group of similar species has been and still is one of the best criteria for selecting the most suitable wood for certain purposes. The main difficulty in this has been the variability in the characteristics of a species. Anything done to narrow this will improve the quality of timber for most uses. Usually, difficulty is experienced in processing or in the performance of a product when the wood characteristics deviate from the normal. In considering the relationship of use-requirements to wood characteristics, that of appearance is most nebulous. Usually appearance has little or no connection with the actual performance or the function of a product; usually it is based on the tastes of individuals. Realizing that species is of prime importance in selecting not only for appearance but for other requirements as well, the tree and wood characteristics within a species influencing appearance most are: Growth rate--ring width, Uniformity of growth, taper, Sapwood or heartwood, type of grain, texture of wood, extractives--kind and amount, wood rays—(type),Knots—(type, number, size, location), Tension wood—(amount and location), (Bird's eye, pith burls, etc), Bark pockets, Decay, Insect galleries,(Flag worms, spots), (Mineral streaks and stains)and (Checks, splits, ring shake). These characteristics affecting the appearance apply to the entire range of solid wood products: only one or two wood characteristics may govern the appearance of a specific product.

Unresolved problem of utilization of some types of forest resources is of great interest. The changing pattern of wood raw material supplies for forest industries is one important feature of wood processes. Nearly 50% of world forest land is covered with secondary species and they contribute less than 20% of the total world use of industrial wood and consequently contribute far less than their potential to the economic development of the countries in which they occur- mainly developing countries. The situation in Sudan is even worse than this average. The percentage of these species may reach more than 80% (Nasroun, 2017).

Due to the dwindling supplies of prime species in Europe and other factors the industry will focus on tropical forest resources. Heterogenity of tropical woods, however, should be harmonized to be able to use mixed tropical hardwoods in pulped paper production. Unused tropical hardwoods species processed to structural lumber, veneer, plywood, laminated structural elements according to their properties. Mobile sawmills diffusion preservation treatment make gluable wood species suitable for joinery, furniture and ordinary plywood. In addition to the main industries secondary species field outlets to areas of production of charcoal, heating and power generation. Industrial charcoal with 82% fixed carbon can also be produced. The marketing of potential hardwood products and technology their manufacture must therefore command the attention of researchers (Industrial hardwood processing). The utilization of secondary hardwood species is a global problem, however, there is no global solution and therefore the exchange of views and experiences in this field could be beneficial to all.

2.6.1. Round-wood products

Round-wood products are poles, piling, masts, posts and some mine timbers in the form of pit props. All keep their cylindrical, tree-trunk form and they produced by felling the trees, topping, delimbing, cross-cutting (to reduce length) and debarking. They may be rounded by machines to acquire a smooth surface and better appearance and machined (drilling holes, etc…) and air-dried in preparation for preservative treatment. Such treatment is necessary because round-wood products are used in contact with the ground, and exposed to weather and to destructive organisms. Posts are used for fences and road guard rails. Fence posts often made of woods that possess a natural durability. Otherwise they have to be treated with preservation. Mine timbers are used in round or sawn form. Wood species are selected for high natural durability and adequate strength. The ability to provide audible warning before failure is a major advantage of wood in mines (Bois, 1977). Round timbers can also be used as structural elements in buildings particularly rural buildings that are based on post and beam or portal frame structural forms (Thepaut and Hislop, 2004). They can also be used in other structural forms such as space-frames, towers, domes, bridges, and pre-stressed pole structures. There is a certain replacement of wood by other materials because wood may decay, burn or be consumed by insects and marine borers. The replacement is limited, because wood has unique advantages which in the products under consideration are: low initial cost, availability in directly usable form, ease of processing with tools and machines, favorable relationship of strength to weight, satisfactory natural durability of certain species for short-term service, and possibility to considerably increase the durability by preservative treatment (Tsoumis, 2009).

2.6.2. Manufactured products

2.6.2.1. Lumber

Lumber is a solid wood product made by lengthwise sawing of logs. Transverse sawing is secondary and is applied to reduce length or remove defects. Lumber is produced in varying dimension and used in building and other structures and products. Three types of sawing machines are used to produce lumber: frame saw, band saw and circular saw. The volume of round wood input in a sawmill is transformed to lumber with recovery that varies from about 30 to 70% (Tsoumis, 1973). The rest is changed to sawdust, slabs, trimming, or chips. The importance of a high yield of lumber is obvious considering the price differential between lumber and residues or chips. The yield is calculated on the basis of log and lumber volumes according to the following relationship:

$$Y\% = \frac{\text{Lumber m}^3}{\text{Log m}^3} \times 100 \qquad \ldots\ldots 8$$

The volume of lumber produced from a certain volume of logs is affected by several factors related to wood (log diameter, length, taper, defects, diameter grouping in cant sawing by frame saw), machines (kerf, condition and maintenance of equipment, sawing variation), sawing pattern (lumber dimensions, number of saw lines), depth of cut and abilities, training and experience of machine operators. The quality of lumber depends primarily on quality of logs, but it may be influenced, within limits by sawing. This possibility exists especially when the head saw is band or circular because with these machines lumber dimensions (thickness, width) and direction of sawing (by turning the log) may be selected during sawing (Tsoumis, 2009).

Quality may also be influenced by sawing with a frame saw, by properly positioning the log so that defects, such as knots or reaction wood, are distributed to as few lumber boards as possible. In addition to defects the condition of the surface of lumber constitutes a quality feature. Lumber with rough surfaces makes a bad impression to customers, creates more waste in planning, and may favor fungi and insects by providing nests for spores and eggs. Rough surfaces result from unequal setting of teeth, improper tension of blades, high feeding speed, or defective machines.

2.6.2.2. Veneer

Veneer is term applied to thin sheets of wood usually 0.5-1.0 mm and sometime up to about 10 mm in thickness. Veneer are sometime used as such in certain products (matches and match boxes, novelties), but usually they are glued into plywood or laminated wood products. Use of veneered wood originated long ago. In ancient Egypt, small veneer pieces of valuable woods were used for decorative purposes in combination with other materials such as precious stones, metals and animal horns. Technically all species may be used for production of veneer. There are two categories of veneer woods-decorative and utility. The distinction is not clear because woods of the second category may be used to produce decorative veneer by special processing methods or suitable utilization of growth abnormalities. Decorative species due to color and grain have a greater value because they are used to surface furniture, interior plywood paneling and related products.

In contrast utility (non- decorative) species are used for partitions of furniture and cabinets, and other structural uses, or in products coated with paint or other materials. The preparation of veneer logs includes cross-cutting, sorting by grade and size, debarking and heating to facilitate their processing. There are three methods of producing veneer; rotary cutting (peeling), slicing and sawing. The yield of veneer depends on the method of production, log characteristics and shrinkage of the wood. The yield is generally low the volume of sheets may be less than 50% of the original round wood volume. Log diameter is especially important; large diameters give a higher yield (U.S. Forest Products,1962) ; (Tsoumis, 2009).

2.6.2.3. Plywood

Plywood is a panel product made by gluing a number of veneer sheets together or gluing veneer sheets to a lumber-strip core; it is characteristic of plywood that the grain direction of successive layers is at right angles- but the central layer (core) of all- veneer plywood is often made by gluing two sheets with parallel grain. The term plywood mainly refers to an all – veneer construction, lumber-strip core plywood (core plywood, face-glued block-board) is made in comparatively small quantities. In general, the number of plywood layers is odd, but may be even 4 or more when two central veneer sheets are glued parallel (Forest Products Laboratory, 2010) .

Popularity of plywood exceeds many composite materials on the basis of wood. In addition to the construction and furniture industries, it is used in car building, aviation and automotive engineering, in the construction of vessels and creation of missiles (Shamaev, *et al*, 2018).

Veneer sheets are selected according to the intended use of plywood. In decorative plywood (furniture, wall paneling), face veneers are of higher grade and value, and they are selected for their figure and color, whereas core and back layers are of lower-grade veneer of the same or other species. In plywood for constructional purposes (sheathing, concrete form), the main criterion is strength and not the appearance of the product. Decorative veneers are mainly produced from hardwoods and they are usually made by slicing. Utility veneers are made from both hardwoods and softwoods always by rotary cutting. Usual thickness is 0.6-0.8 mm for decorative veneers and 1.5-3.0 mm for utility veneers. Most veneers are dried to less than 5% moisture content; over-dried veneer, 2% or less in moisture content is brittle and tears easily when handled (Sellers, 1985).

The anisotropy of shrinkage and swelling which characterizes wood is largely reduced in plywood. The high shrinkage and swelling of wood in tangential and radial directions is considerably reduced due to positioning of successive layers at a grain angle of 90˚. In thickness, the shrinkage of plywood is not substantially different from that of solid wood-under the assumption of same growth-ring arrangement (tangential-radial) and same moisture content change. An investigation of panels made of three veneers, equal in thickness, and hardwood species showed that shrinkage was 10-25 times lower in length or width in comparison to thickness (U.S. Forest Products Laboratory, 1964).

In general, the shrinkage of plywood depends on numbers and thickness of layers, species of wood or wood and magnitude of moisture content change. Shrinkage and swelling may cause surface checking of plywood due to tension or compression stresses resulting from moisture change. Placement of successive layers with their grain at right angles tends to reduce the difference in mechanical properties of plywood panels, in length and width, in comparison to solid wood. In plywood, modulus of rupture in the parallel direction is shown to be reduced by 18% and modulus of elasticity by 4%, but transverse values of these properties are about double in comparison to solid wood. Other properties also differ between plywood and solid wood, for example, thermal expansion in length and width of plywood is different because the axial expansion of solid wood is lower in comparison to transverse. In the direction of thickness no substantial differences exist with regard to thermal or electrical or acoustical properties in comparison to solid wood. Plywood and solid wood show some small difference in hygroscopicity. Different types and grades of plywood exist depending on the quality of joints and the quality of veneers. Plywood panels may be surfaced with metals, plastics or other materials, or their veneers may be impregnated to achieve a superficial hardness, or resistance to microorganisms, fire, or other destructive agents (Tsoumis, 2009).

2.6.2.4. Laminated wood

Laminated wood (or laminated timber, glued laminated timber or glulam) is produced by gluing two or more layers or boards or lamellae of wood with their grain parallel. This is the main difference between this product and plywood, where the grain of two successive layers usually forms a right angle. Laminated veneer lumber has the potential to be used in structural and non-structural applications such as construction and furniture industry, material for flooring and numerous other areas (Ozarska, 1999).

Laminated wood products present the following advantages:

Production of various sizes and shapes, this advantage offers great possibility for architectural design.

Improved utilization of wood by reduction of waste due to the possibility of utilizing relatively small dimension wood

Improved strength, because it is easier to dry wood of smaller thickness without degrade in comparison to solid wood of large dimensions.

Improved strength is also accomplished by removal of defects.

Improved durability, due to the possibility of better preservative treatment of lamellae for protection against fungi and insects, or by placement of durable species on exposed surfaces.

Laminated timbers of large thickness are resistant to fire. The factors that are important in the production of laminated wood are: species, quality, dimensions, moisture, mechanical preparation, and in certain cases preservative treatment of wood. After preparation of the wood, production of laminated wood includes end-joining, spreading the adhesive, assembling the lamellae pressure (by control of temperature, if needed) and final processing (Tsoumis, 2009).

2.6.2.5. Particleboard

Particleboard is a wood-based panel product manufactured under pressure and temperature from particles of wood or other lignocellulosic fibrous materials and binder. It has found typical applications as furniture, cabinets, flooring, table, counter and desktops, office dividers, wall and ceiling, stair treads, home constructions, sliding doors, kitchen worktops, interior signs, bulletin boards, and other industrial products. (Marzbani *et al*, 2015), (Maloney, 1977). Particleboard is 57% of total consumption of wood-based panels consumed and it is continuously growing at 2–5% annually. Particleboard consumption significantly increases each year. According to a report from Food and Agricultural Organization (FAO) of the United Nations, during 1998 world consumption of particleboard was 56,2×106 m3 and in 2012 it had risen to approximately 98×106 m3 (FAO 2012).

Particleboard is a panel product made by gluing particles together (small pieces of wood or other lingo-cellulosic material), wood is the main source. Wood is a very variable material both between and within species and not just in appearance but more importantly in density, strength and durability. Although the strength properties of particleboard are generally lower than nature lumber, they are more consistent (Nemli, *et al*, 2005).

Particleboard is produced in thickness that range from 2 mm to 4 cm and preferably in the density range of 0.50-0.80 g/cm³. Softwoods and medium-density hardwoods (0.40-0.60 g/cm³) are preferred, but heavier hardwoods are not excluded. Wood density affects energy consumption, wear of knives and board density. Board density is a major factor considering that wood will be compressed to produce boards having a density 5-20% higher than of the wood in order to obtain maximum bond and sufficient strength and durability according to intended use (Mitlin, 1969).

In addition to wood density, extractives are important because they affect gluability (rate of resin curing) and the color of the product. Moisture content of the material is an important factor, because it affects particle dimensions and cost of drying, moisture should be near the fiber-saturation point or a little higher (30-40%). The production of particleboard permits efficient utilization of wood. The yield is higher (75-90% or more) in comparison to lumber or plywood (on the average about 50%) (Moslemi, 1974).

The dimensions of the particles affect the properties of product. Particles length, width and thickness are all important. For example, modulus of rupture and modulus of elasticity in static bending are found reduced with increasing thickness and increased with increasing particles length. Width has no substantial influence on properties. Particles moisture is one of the most important factors in particleboard manufacturing. The amount of moisture after drying usually is 3-6% depending on resin type and amount. Adhesion of particles is usually done by use of urea-formaldehyde for interior-type particleboard (furniture, floor underlayment in housing, etc..) and phenol-formaldehyde for exposed and structural particleboard. The destruction of the natural structure of wood by transformation to particles, changes its anisotropy with regard to properties. Particleboard is produced in low density (0.25-0.40 g/cm^3), medium density (0.40-0.80 g/cm^3) and high density (0.80-1.20 g/cm^3). Boards of high density are heavy, and difficult to handle. Board density is basically affected by the density of wood, as previously explained under raw material and turn it affects all other physical and mechanical properties of the product. In all boards, as in solid wood shrinkage and swelling is higher when made with heavier woods. Mechanical properties are affected by many factors such as density, quantity of adhesive, particle dimensions and orientation, and moisture content (Moore, 2011).

2.6.2.6. Fiberboard

Fiberboard is different from particleboard because wood, or other lingo-cellulosic material is used in the form of fibers instead of particles and an adhesive is not always needed for bonding. There are two types of fiberboard – insulation and compressed this distinction is based on density and method of production. The properties of fiberboard depend mainly on its density. Resin content and manufacturing modifications are also important. In all types of fiberboard and because of a preferred orientation of fiber length in the direction of production, shrinkage and swelling along the length of panels is smaller than thickness shrinkage and swelling. (Tsoumis, 2009).

2.6.2.7. Pulp and paper

Paper is produced from wood fibers; use of other plant or synthetic fibers is limited. All wood species –softwoods or hardwoods can be utilized. Availability in needed quantities and cost are the decisive factors for selection of species. There are three pulping methods- mechanical, chemical and chemo-mechanical. The pulp is subjected to a series of treatments, which include screening and cleaning, thickening, bleaching, beating and refining, coloring, and addition of various chemicals to improve self-adhesion of the fibers. The properties of pulp and paper vary due to differences in raw materials and production methodologies. For wood and other plant fibers, cell morphology is a fundamental factor of influence; thus, fiber length, fiber diameter, lumen diameter, and cell-wall thickness are very important (Amidon, 1981).

Fiber length is one of the quality parameters for pulpwood, and it has been extensively studied in relation to tree age and within-tree position (Hudson *et al*, 1995). Fiber length generally influences the tearing strength of paper, the greater the fiber length, the higher will be the tearing resistance of paper (Fardim and Duran, 2004). Paper made from fiber that are too short will have insufficient common bonding area between fibers, and as a result there will be points of weakness for stress transfer within the sheet, and the paper will be low in strength (Haygreen and Bowyer, 1982). Fiber diameter and wall thickness influences the fibers flexibility (Dutt and Tyagi, 2011). Thick walled fibers adversely affect the bursting and breaking strengths, and folding endurance of paper. Fiber lumen width affects the beating of pulp. The smaller the fiber lumen width, the poorer will be the beating of pulp because of the penetration of liquids into empty spaces of the fibers. Pulp is evaluated by chemical and physical tests. Chemical tests include determination of cellulose and noncellulosic content and physical tests measure fiber characteristics and resistance to water flow through the pulp. The pulp is chemical product when produced by chemical or semi chemical pulping. During pulping by chemical processes the middle lamella is the greater part of which is lignin is dissolved, and the fibers of wood are separated. In pulp and paper successful large scale operations based on mixed tropical hardwoods – no general solution each available species mix has to be studied economically and technically.

2.6.3. Other wood and forest products

Other products of wood include products of secondary manufacture (by mechanical and chemical processing). Wood is examined as a source of energy. The use of wood as source of thermal energy is based on the production of heat when wood burns. Products of secondary mechanical processing include: furniture, building components and structures (doors, windows, wooden houses, flooring), containers, railroad ties, means of transportation, musical instruments, athletic equipment, wood carving, wood flour and others (Tsoumis, 1987). All these products are produced by previously described basic processes (sawing, cutting, drying, gluing and sometimes preservation) and they are made by further processing of lumber, veneer, plywood, laminated wood, particleboard or fiberboard. Products of chemical processing are those produced by chemical modification of wood. Such products are pulp and paper, products of cellulose and other chemical constituents of wood, products of pyrolysis, hydrolysis, gasification and other products (Tsoumis, 2009).

CHAPTER THREE

MATERIAL AND METHODS

3.1 Materials

Four of the lesser used wood species which are available in reasonable numbers in Blue Nile State and other parts of Sudan were selected for this investigation. The selected species comprised:

Sterculia setigra (tartar), *Acacia polyacantha subsp. Campylacantha* (kakamut)*,* *Acacia seyal* var. *seyal* and *Diospyros mespiliformis* (goghan) .

Sterculia setigera ;

Family: Sterculiaceae

Arabic name: Tartar, Faider, Telieh

A deciduous savanna tree up to 12 m high. It is most easily recognized by its bark, leaves and fruits. Distributed in South Darfur, South Kordofan, Blue Nile and White Nile. In some of these places it is found in pure stands. The timber is among the low density timbers which are rare in Sudan and can be used where heavy weight is a problem.

Acacia polyacantha:

Family: Leguminosae subfamily Mimosoideae,

Latin name: *Acacia polyacanthasubsp .camplacantha*

English name: Falcon’s claw acacia

Arabic name: Kakamut, Um siniena (Vogt, 1995).

The tree is up to 15 m high and the trunk can be 70 cm in diameter. The bark is yellow- brown, flaking or fissured (Elamin, 1990).

Distributed in Blue Nile Prov., Kordofan Prov.

The timber is hard and durable and is used in the round for beams and rafters in local building. Sapwood white, heartwood red with blackish streaks. Difficult to saw or plane but easy to polish (Maydell, 1986).A potential use is for railway sleepers. It also used for fuel and charcoal, produces a gum. The wood ashes yield a potash which is used sometime as a substitute for salt (Dalziel, 1937).

Acacia seyal var. seyal

Family: Leguminosae subfamily Mimosoideae,

Arabic name: Talh

The redish bark of this tree is recognizable even at a distance. The inflorescence is a bright yellow, axillary pedunculate, globose head. Pods are slightly curved, thin and long (Vogt,1995). The tree is the most abundantly naturally occurring in Sudan. The wood is used mostly for charcoal production and in ladies sounas.

Diospyros mespiliformis;

Family: Ebenaceae

English name: African ebony

Arabic name: Goghan, Jokhan, Abu sebela

Evergreen tree which varies greatly in height, depending on site conditions. It has a distinctive black scaly bark. Distributed in (Gallabat); Blue Nile Prov. (Fung); South Kordofan Prov.(Nuba Mountains); South Darfur State. It is used for rifle butts, artificial legs, mortars, turnery and furniture. In Nigeria it has also been used for tool handles, vehicle body parts and flooring blocks (Sahni, *et al,* 1968).

3.2 Methods

3.2.1 Sampling

Sampling of test material was carried out according to the Sudanese standard *5172: 2012, Wood- sampling methods and general requirement for physical and mechanical testing of small clear wood specimens.*

3.2.2. Anatomical Properties

Most of anatomical properties were based on macerated wood materials. Chips were taken from the four species and macerated to isolate the fibers. The wood chips were macerated by heating them in 60% nitric acid. The cook was allowed to heat in a water bath for ten minutes the acid was removed and the fibers washed by water several times. Then the macerated fibers were stained by safranin for five minutes and then the fibers were washed first by alcohol followed by water several times. The stained fibers were mounted on four glass slides for each species using Canada Balsam. The prepared slides were left to dry before microscopic examination for measuring the following anatomical parameters.

3.2.2.1. Fiber length determination

To determine the fiber length the stereological technique was used. The slides were projected from the microscope stage through a camera projector onto a computer screen with a square grid (2oX20cm) fixed on the screen. The grid consists of seven equidistant parallel lines each measuring 20 cm. The stereological counts made included points of intersection of test lines with the fiber boundaries per unit test line (P_L) and the number of fibers per unit area (N_A). From these parameters the fiber length was calculated using the following equation:

Fiber length $= \Pi P_L / 2N_A$

Where:

P_L: points of intersection of test lines with the fiber boundaries per unit test line

N_A: Number of fibers per unit area

3.2.2.2. Cross-sectional dimensions and ratios

The same slides prepared for macerated fibers were used for determining fiber diameter (FD), lumen diameter (LD) and double cell wall thickness (DCWT). These basic anatomical properties were measured by using an electronic reflecting microscope (Olympus Instructions GX71 Inverted System Metallurgical Microscope) at Giad's Material Research Center.

Using the above mentioned parameters three important ratios were calculated. These included; Rankle ratio (RR), Coefficient of fiber rigidity (CR) and fiber flexibility (FF) from the following equations:

RR = DCWT/LD ……………………………………………..9

Where:

RR: Rankle ratio

DCWT: double cell wall thickness

LD: Lumen diameter

CR = DCWT/ FD. ………………………………………...10

Where:

CR: Coefficient of fiber rigidity

DCWT: double cell wall thickness

FD: Fiber diameter

FF = LD/ FD ………………………………………...11

Where:

FF: fiber flexibility

LD: Lumen diameter

FD: Fiber diameter

3.2.2.3. Volume fractions of cell types and their components

Temporary cross-sectional slides were prepared from randomly selected samples from each species using the sliding microtome. The sections were stained by soaking them in safranin for five minutes and washed by alcohol and water several times. The sections were mounted on glass slides using

Canada Balsam as temporary slides. The slides were allowed to dry and examined under the microscope for cell types proportions and their components using stereological techniques. This technique involved projecting the image of the slide from a microscope stage through a camera on to a computer screen with a square grid imposed on the projected image. The grid was 10 × 10 cm with four equidistant horizontal lines criss-crossing four vertical lines resulting in 16 intersection points representing the total test points. A point count was made for components of all cell types; vessel wall, vessel lumen, fiber wall, fiber lumen, parenchyma wall and parenchyma lumen. The volume fraction for each feature is represented by the number of test points falling on a feature divided by the total test points (Pp). From the proportions of cell components the proportion of cell types (vessel, fibers and parenchyma) and the proportions of their components (Cell walls and cell lumens) were worked out.

3.2.3. Compression parallel to the grain

From the sawn timber of the four species adequate pieces were taken randomly for preparing the different test specimens. For the compression test many test specimens were prepared from which seventy specimens were selected randomly and tested in compression parallel to the grain in accordance with ISO 3787: 1976 standard: *Wood- Determination of Ultimate Stress of Compression Parallel to the Grain.* The test was carried out using Universal testing machine (Testometric. ROCHDALE- ENGLAND- M500-50CT). The test specimens were at equilibrium moisture content (6%).

3. 2. 4. Physical properties

Shrinkage

Fifteen specimens measuring 20×20×20 mm were randomly selected and tested for tangential and redial shrinkage according to Sudanese standard 1748: 2013, *Wood – determination of radial and tangential shrinkage*. Shrinkage values from fiber saturation point (30%) to oven dry condition (0% moisture content). Values of longitudinal shrinkage are not estimated because they are usually very slight.

Density

Twenty clear specimens were selected randomly from the remaining compression test samples measuring 20×20×60mm. These were used for determining wood density according to Sudanese standard 5174: 2012, *Wood – determination of density for physical and mechanical tests*. The density was determined for air dry samples at equilibrium moisture content (6%).

Permeability

Ten samples measuring 50×50×20 mm were selected randomly from sapwood of the different species at 7% moisture content. The weight of the samples was recorded before soaking in test solution using fuchsin acid dissolved in water giving a dark red color to facilitate measurement of liquid penetration .Then the test solution containing the test samples was heated in a water bath for two hours; after that the solution and the samples were allowed to cool down over night. The test specimens were weighed again to determine the absorption percent and measure the depth of lateral penetration.

3.2.5. Technological properties

3.2.5.1. Gluing properties

Ten specimens were tested for their adhesion strength according to Sudanese standard 1339: 2015, *Adhesives - Wood-to-wood- Determination of shear strength by compressive strength*.

3.2.5.2.Texture

Ten clear samples measuring 20×20×60 mm each were randomly selected from samples prepared for compression test. The samples were visually evaluated for their texture, grain uniformity and smoothness. The evaluation was based on arbitrary numerical values given to each specimen based on the quality of the above mentioned parameters. The numerical values varied in the range 1- 10; ten being the finest texture and the best surface quality while one represents the roughest surface. The specimens used were clear specimens – without any defect to confine the evaluation on textural features and touch smoothness of the wood surface.

3.2.6. Statistical Analysis

SAS package was used to carry out analysis of variance followed by Duncan's Multiple Range Test (D M R T) for significant differences in all properties studied and mean separation. Correlation analysis was also carried out to find relationships between wood basic properties (anatomical and density) and wood quality attributes for the different uses like wood strength, dimensional stability, permeability, gluability and appearance.

3.2.7. Pulp and paper

For wood and other plant fibers, cell morphology is a fundamental factor determining the quality of pulp and paper produced from them; thus, fiber length, fiber diameter, lumen diameter, and cell-wall thickness are very important in this respect (Amidon, 1981); (Tsoumis, 2009). Pulp and paper quality is closely associated with fiber characteristics. Some relationships were established in previous studies in the form of mathematical models to quantify these relationships. An attempt was made to use some of the anatomical characteristics obtained from this investigation (tables 1, 2 and 3) to validate these models and estimate the paper properties for the paper to be produced from the four species. The models used were as follows:

The model for breaking length (B.L) for unbeaten pulp was:

B.L (m) = 301 + 22835 Pp cl -- 3473 F. length ……………………..(12)

Where:

P_p cl : Volume fraction of cell lumen

The model for tear factor (TF) for pulp beaten for 30 minutes was:

T.F = - 9.4 + 59.8 × F. length ………………………………….……(13)

The model for tear factor for unbeaten pulp was:

T.F = - 46.8 + 391 Pp FL + 2579 DCWT …………………………...(14)

Where:

P_PFL : Volume fraction of fiber lumen

DCWT : Double cell wall thickness

The model for sheet bulk for unbeaten pulp was:

Sheet bulk (g/cm^3) = 0.88 + 81 × DCWT + 1.4 × DEN ………………..…(15)

Where:

DCWT: Double cell wall thickness

DEN : Density

The model for sheet bulk for pulp beaten for 30 minutes was:

Sheet bulk (g/cm^3) = 0.67 + 219 ×DCWT + 2.3 DEN - 49 F D ……....... (16)

Where:

FD: Fiber diameter

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Anatomical Properties

Fiber length

ANOVA showed very significant differences between species in fiber length ($P<0.0001$). Table (1) shows the means separations for fiber characteristic

Where; *Sterculia setigera* (1.75 mm) had the highest mean value of fiber length with significant difference from all other species. Followed by *Acacia seyal* var seyal (1.59 mm) and then *Diospyros mespiliformis* (1.52 mm) without significant difference between the two. *Acacia polyacantha* (1.35mm) had a significantly lower mean value of fiber length. The mean fiber length values of tartar are slightly lower than those reported by (Gamal, 2007) while that of talh and Joghan are higher. Also the mean fiber length values of talh are greater than those obtained by (Nasroun, 1978)

Cross sectional parameter

The analysis of variance results indicated that there were highly significant variation in fiber diameter between the species studied ($P< 0.0001$). Table 1 shows that *Acacia polyacanatha* had the highest mean value of fiber diameter of the studied species (20.85 µm) with significant difference from all other species, followed by *Diospyros mespiliformis* (15.05µm) and then *Sterculia setigera* (14.34 µm) without significant variation between them .Lastly *Acacia seyal* var seyal (12.94 µm) without significant difference from *Sterculia setigera* and with significant difference from *Acacia* *polyacanatha* and *Diospyros mespiliformis.* The obtained mean fiber diameter values of tartar, talh and goghan were lower than those reported by (Gamal, 2007) also the mean fiber diameter of talh was lower than that reported by (Nasroun, 1978).

In the lumen diameter ANOVA analysis showed highly significant differences between the four species ($P< 0.0001$). The highest mean value of lumen diameter of the four species was recorded by *Acacia polyacanatha* (14.02 µm) with significantly different from others followed by *Diospyros mespiliformis* (7.81µm) and *Sterculia setigera* (7.74µm) without significant difference between the two but with significant difference from others. Talh (4.97µm) had the lowest value of lumen diameter with significant variations form all other species studied. The mean fiber lumen diameter for talh was slightly lower than that obtained by (Nasroun, 1978) (Gamal, 2007) While the mean fiber lumen value of goghan and tartar were also lower than those reported by (Gamal, 2007).

ANOVA showed moderately significant difference in double cell wall thickness (DCWT) between species studied. ($P = 0.0451$), Where *Acacia seyal* (7.94 µm) had the highest mean value of DCWT with significant variation from all species studied followed *Diospyros mespiliformis* (7.25µm) , *Acacia polyacantha* (6.85µm) and *Sterculia setigera* (6.60µm) without significant differences between them and with significant difference from *Acacia seyal*. The mean DCWT values of talh, goghan and tartar were lower than those reported by (Gamal, 2007) also the mean for talh was slightly lower than that obtained by (Nasroun, 1978).

Table (1). Fiber dimensions

Spp	Dimensions			
	FL(mm)	FD(μm)	LD(μm)	DCWT(μm)
Goghan	1.52B	15.05B	7.81B	7.25AB
Kakamut	1.35C	20.85A	14.02A	6.85B
Talh	1.59B	12.94C	4.97C	7.94A
Tartar	1.75A	14.34BC	7.74B	6.60B

FL= Fiber length, FD = Fiber diameter, LD = Lumen diameter, DCWT =Double cell wall thickness, Spp = Species, Goghan = Diospyros mespiliformis, Kakamut = Acacia polyacantha, Talh = Acacia seyal var seyal, Tartar = Sterculia setigera

Fiber indices

Analysis of variance results showed highly significant differences in Rankle ratio (RR) between the four species ($P < 0.0001$). The highest mean value of Rankle ratio was recorded for talh (1.75) with significant difference from all species followed by goghan (0.98) and then tartar (0.90) without significant variation between the two. Kakamut (0.52) had the lowest mean value of RR and was significantly different from all species. The mean RR of talh was greater than those reported by (Gamal, 2007) (Nasroun, 1978) while the mean RR for goghan and tartar were less than those obtained by (Gamal, 2007).

The analysis of variance results indicated that there were highly significant differences in coefficient of fiber rigidity (CR) between species ($P < 0.0001$). The results given in table 2 show that talh (0.31) had significantly the highest mean value of CR followed by goghan (0.24) and tartar (0.23) without significantly different from each other. Lastly kakamut (0.17) had the lowest mean value of CR with significant difference from all others. The mean C R of talh was higher than that reported by (Nasroun, 1978)

ANOVA for fiber flexibility (FF) showed highly significant differences between the four species ($P < 0.0001$); where kakamut (0.67) had the highest mean value of FF with significant variation from other species followed by tartar (0.54) and goghan (0.52) without significant difference between the two; the lowest mean value of FF was recorded for talh (0.39) with significant difference from all other species. The mean FF of talh was lower than that obtained by (Nasroun, 1978)

Table (2). Fiber indices

Spp	Ratios		
	RR	CR	FF
Goghan	0.98B	0.24B	0.52B
Kakamut	0.52C	0.17C	0.67A
Talh	1.75A	0.31A	0.39C
Tartar	0.90B	0.23B	0.54B

RR = Rankle ratio, CR = coefficient of rigidity, FF = Fiber flexibility, Spp = Species, Goghan = *Diospyros mespiliformis,* Kakamut = *Acacia polyacantha,* Talh = *Acacia seyal var seyal,* Tartar = *Sterculia setigera*

Volume fractions of cell types and their components

ANOVA results showed no significant difference in volume fraction of vessels (Pp v) between the species studied, but Pp V was highest in goghan (0.08) and kakamut (0.08)followed by tartar (0.07) lastly talh (0.05) without significant differences between all species studied. Table (3) shows the results of DMRT for volume fractions of cell types and their components. In volume fraction of fiber (Pp F) ANOVA results showed very significant variation between species studied ($P < 0.0001$). Goghan (0.81) had the highest mean value in Pp F with significant difference from all other species. Followed by kakamut (0.62), talh (0.54) and tartar (0.34) with significant differences between all of them. Analysis of variance showed highly significant differences between the four species in volume fraction of parenchyma (Pp P) ($P < 0.0001$). Based on DMRT tartar (0.59) was significantly the highest mean value followed by talh (0.42), kakamut (0.30) came next and lastly goghan (0.10) with significant difference between all of them.

Also analysis of variance showed highly significant variation in volume fraction of cells wall (Ppcw) between the four species ($P < 0.0001$). The highest mean value in Ppcw was recorded by goghan (0.70) with significant difference from others followed by kakamut (0.62) with significant difference from all species studied, followed by tartar (0.52) and talh (0.51) without significant difference between the two but with significant difference from other species. In volume fraction of cells lumen (Ppcl) ANOVA results showed highly significant difference between the species studied ($P < 0.0001$). Where tartar (0.50) had the highest mean value in Ppcl followed by talh (0.48) without significant difference between the two and with significant difference from the remaining species studied. Kakamut (0.39) came next with significant variation from all species studied. Lastly goghan (0.31) with significantly different from the species studied. The results concerning Pp cw and Pp cl are rather odd because of the fact that talh with the highest density should have the highest Pp cw and the lowest Pp cl. This discrepancy was due to the poor quality of the sections prepared for this purpose because the only available microtome was in a bad condition.

The analysis of variance showed significant difference in volume fraction of fiber lumen (Pp FL) between the four species (P = 0.0015). Tartar (0.18) had the highest mean value in Pp FL with significant difference from all other species. Followed by kakamut (0.13), talh (0.10) and goghan (0.09) without significant variation from each other. The highest proportion of Pp FL is reflected in density where tartar has the lowest density among the four species studies.

Table (3) Volume fractions for cell types and their components

Spp	Pp V	Pp F	Pp P	Ppcw	Pp cl	Pp FL
Goghan	0.08A	0.81A	0.10D	0.70A	0.31C	0.09B
Kakamut	0.08A	0.62B	0.30C	0.62B	0.39B	0.13B
Talh	0.05A	0.54C	0.42B	0.52C	0.48A	0.10B
Tartar	0.07A	0.34D	0.59A	0.51C	0.50A	0.18A

PpV = Volume fraction of vessels, PpF = volume fraction of fiber, PpP = volume fraction of Parenchyma, Ppcw = Volume fraction of cells wall, Ppcl= Volume fraction of cells lumen, PpFL = Volume fraction of fiber lumen, Spp = Species, goghan = *Diospyros mespiliformis*, Kakamut= *Acacia polyacantha*, Talh = *Acacia seyal var seyal*, Tartar = *Sterculia setigera*.

4.2. Physical and Mechanical Properties

Table (4) shows the results of analysis of variance for physical and mechanical properties. The ANOVA results showed highly significant differences in density between the four species ($P<0.0001$). Based on DMRT talh (0.82 g/cm^3) had the highest mean value of density with significant variation from the four species, this value is close to what was fond by Nasroun (1982) (0.80g/cm^3) followed by kakamut (0.74 g/cm^3) and goghan (0.74 g/cm^3) without significant difference from each other but with significant variation form others. Tartar (0.38 g/cm^3) had the lowest mean value with significantly difference from all species studied.

The analysis of variance showed highly significant differences in compression parallel to the grain between the four species ($P<0.0001$);

where the highest mean value was associated with goghan (840.00kg/cm^2) which was not significantly different from kakamut (838.94kg/cm^2) and talh (838.94kg/cm^2), lastly tartar (210.70kg/cm^2) had the lowest mean value with significant variation form all other species studied.

The ANOVA results showed very significant differences in tangential shrinkage between the four species ($P<0.0001$). Goghan (10.19%) had the highest mean value with significant difference from others followed by tartar (7.70%), kakamut (6.76%) and talh (6.02%) without significant difference from each other.

The analysis of variance also showed very significant differences in radial shrinkage between the species studied (P< 0.0001); where goghan (5.41%) had the highest mean value with significant variance from the species studied followed by tartar (4.33%) without a significant difference from kakamut (3.43%) and with significant difference from others. lastly talh (3.06%) without significantly different from kakamut but with significant difference from other species studied

The analysis of variance also showed highly significant differences in liquid absorption (AB) (P<0.0001) and depth of penetration (P<0.0001). Based on DMRT the highest liquid absorption value of (207.94%) was found in tartar with significant variation from other species followed by goghan (82.51%) and kakamut (78.82%) without significant difference from each other but with significant difference from others. Talh (57.85%) had the lowest mean value with significant variation from all species studied. This agrees with the fact that talh had the highest density and the highest DCWT in its anatomical structure. Most of the absorption in tartar was along the grain and very little across the grain. In Depth of penetration (PD) goghan (1.94 cm) had the highest mean value with significant variation from others followed by kakamut (1.75 cm) and talh (1.75 cm) without significant difference from each other. Tartar (0.21 cm) had the lowest mean value which was significantly different from all species studied.

Table (4). Physical and mechanical properties studied

Spp	DEN g/cm³	Com Kg/cm²	Shrinkage		Permeability	
			T (%)	R (%)	AB (%)	PD(cm)
Goghan	0.74 B	840.00 A	10.19 A	5.41 A	82.51 B	1.94 A
Kakamut	0.74 B	838.94 A	6.76 B	3.43 BC	78.82 B	1.75 B
Talh	0.82 A	838.94 A	6.02 B	3.06 C	57.85 C	1.75 B
Tartar	0.38 C	210.70 B	7.70 B	4.33 B	207.94 A	0.21 C

DEN = density, Com = compression parallel to the grain, T = tangential, R = Radial, AB = Absorption, PD = Depth of penetration, Spp = Species, Goghan = *Diospyros mespiliformis*, Kakamut= *Acacia polyacantha* ,

Talh = *Acacia seyal var seyal*, Tartar = *Sterculia setigera.*

4.3. Texture and gluability

The ANOVA result showed significant differences in wood texture between the four species (P=0.0080). Table (5) shows the means separation values for gulability and texture; where *Diospyros mespiliformis* (8.50) had the highest mean value in texture with significant difference from talh and tartar followed by *Acacia polyacantha* (7.10) and *Acacia seyal* (6.50) without significant difference between the two and lastly *Sterculia setigera* (4.10) with significant difference from goghan and kakamut. These results show that goghan had the finest texture, grain uniformity as well as surface smoothness .It was followed by kakamut which had a moderately fine texture, the wood was also figured. The same with talh which had moderately fine texture and figured. Tartar, on the other hand, had a moderately course texture but it was also figured.

The analysis of variance showed very significant differences in glue bond strength between the four species (P<0.0001); where *Diospyros mespiliformis* resulted in the strongest bond (27.14 MPa) followed by *Acacia Polyacantha* (24.95 MPa) without a significant difference between them but with significant difference from the other two species. *Acacia seyal* came next (3.96 MPa) with significant difference from All species followed by *Sterculia setigera* (0.75 MPa) also with significant difference from others.

Table (5) Glue bond strength and texture

Spp	Glue bond strength(MPa)	Texture
Goghan	27.141 A	8.50 A
Kakamut	24.956 A	7.20 A B
Talh	3.959 B	6.40 BC
Tartar	0.751 C	5.10 C

Spp = Species, Goghan = *Diospyros mespiliformis,* Kakamut= *Acacia polyacantha*, Talh = *Acacia seyal var seyal*, Tartar = *Sterculia setigera*

4.4 Correlation analysis relating all studied properties

Tables (6&7) show the correlation matrix relating all studied properties. Each cell contains the correlation coefficient (R) and the significance level. It is well known that wood processing and utilization are directly affected by basic wood characteristics. The results of the correlation analysis aimed at relating some wood quality attributes, like strength, dimensional stability, gluability, permeability and surface appearance with basic properties, namely anatomical properties and density. The table shows only the significant correlations. Some of the expected correlations did not appear in the table because they were not significant. This is why some indirect relationships were described. For instance, double cell wall thickness is positively and highly correlated to rankle ratio (R R), fiber coefficient of rigidity (C R) and density, while density is positively and highly correlated to compressive strength parallel to the grain ($R = 0.9338$ at $P< 0.0001$); compressive strength being one of the wood quality attributes for structural utilization. This is due to the fact that density and double cell wall thickness are the best indicators for the percentage of solid wood material compared to the cavities in wood. For the same reason density was negatively and highly correlated to the amount of liquid absorbed (A B) ($R = - 0.9579$ at $P<0.0001$). Double cell wall thickness was also negatively correlated to liquid absorption which is one measure of wood permeability, which, in turn is another quality attribute for glue bonding, wood treatment with preservatives and finishing of furniture parts. Permeability will also be negatively correlated to rankle ratio and coefficient of fiber rigidity which were highly correlated to double cell wall thickness.

Glue bond strength was positively correlated to lumen diameter and fiber flexibility, both of which are indicators of permeability due to the high proportion of cavities compared to cell walls. This will allow the glue to penetrate into the wood and result in joints as strong as the shear strength of wood. Lumen diameter and fiber flexibility are negatively and highly correlated to rankle ratio and fiber coefficient of rigidity and double cell wall thickness the three of which should be negatively correlated to permeability and glue bond strength. Glue bond strength is an important quality attribute in furniture and plywood manufacturing as well as any wood products where glued joints are used.

Table (6) Correlation matrix relating anatomical properties and density with each other

	LD	DCWT	RR	CR	FF	FL	DEN
LD	1.000		-0.7490 <0.0001	-0.8931 <0.0001	0.8922 <0.0001	-0.5999 0.0053	
DCWT		1.000	0.6170 <0.0001	0.5565 <0.0001	-0.5581 <0.0001		0.2247 0.0450
RR	-0.7490 <0.0001	0.6170 <0.0001	1.000	0.9352 <0.0001	-0.9352 <0.0001		0.2013 0.0733
CR	-0.8931 <0.0001	0.5565 <0.0001	0.9352 <0.0001	1.000	-0.9987 <0.0001	0.5047 0.0232	
FF	0.8922 <0.0001	-0.5581 <0.0001	-0.9752 <0.0001	-0.9957 <0.0001	1.000	-0.4983 0.0253	
FL	-0.5999 0.0053			0.5047 0.0232	0.4983 0.0253	1.000	-0.5563 0.0109
FD	0.9136 <0.0001	0.2242 0.0456	-0.4881 <0.0001	-0.6561 <0.0001	0.6547 <0.0001	-0.4867 0.0295	
DEN		0.2247 0.0450	0.2013 0.0733			-0.5563 0.0109	1.000

LD = Lumen diameter, DCWT = Double cell wall thickness RR = Rankle ratio, CR = Coefficient of fiber rigidity, FF = fiber flexibility, FL = Fiber length, FD = Fiber diameter, DEN = Density

Table (7) Correlation matrix relating anatomical properties and density with quality attributes

	LD	DCWT	RR	CR	FF	FL	DEN
Com						-0.7369 0.0002	0.9338 <0.0001
AB		-0.2436 0.1290				0.6657 0.0014	-0.9579 <0.0001
PD						-0.7220 0.0003	
BS	0.5208 0.0185	-0.2149 0.3628	-0.3928 0.0866	-0.4927 0.0273	0.4830 0.0310	-0.7621 <0.0001	
GD						-0.6682 0.0013	0.6359 0.0026

LD = Lumen diameter, DCWT = Double cell wall thickness RR = Rankle ratio, CR = Coefficient of fiber rigidity, FF = fiber flexibility, FL = Fiber length, FD = Fiber diameter, Com = Compression parallel to the grain, DEN = Density, AB = Absorption, PD = Depth of penetration BS = glue bond strength, GD =Service quality (grade)

Property- Use Relationship

Wood is a natural variable and versatile material which can be used for thousands of products from purely structural purposes to purely decorative purposes; from high technology industrial products to small scale cottage industries and handcrafts. It is well known that wood processing and utilization are directly affected by wood properties (Pashin and Dezeeun, 1980). In recent years there has been interest in combining studies on wood properties and wood products quality to start solving the unresolved problem of utilization of the so-called secondary wood species.

Each end use for wood has unique set of quality attributes which are affected by basic wood properties, and in turn affect the value recovery chain from tree to product (Zhang, 2003). The results of this investigation covered some anatomical, physical, mechanical and technological properties for four lesser used species from Blue Nile State .These properties were matched with quality attributes for some important current end-uses such as structural uses, different qualities of furniture, wood flooring, paneling, wood moulding, turning, pallets as well as important manufactured products such as pulp and paper, veneer, plywood and other panel boards.

Structural uses

Engineering or structural use required strength, stiffness, dimensional stability and durability as main quality attributes. The different wood species under investigation were different in meeting these requirements.

Acacia seyal var seyal (talh) is the most abundantly naturally occurring tree in Sudan which can be easily naturally regenerated to produce sustainable production in areas with 400 mm rainfall and above if protected. In spite of all this, talh is used only for the production of charcoal and for women's sounas. This is due to the fact that talh is very vulnerable to attack by insect borers immediately after it is felled. This is not a big problem since the wood can be treated with preservatives. unfortunately the trend in Sudan was to use wood without applying any technology- no seasoning, no preservative treatments. This is the cause of the big losses in our wood resources.

The results of this study showed that talh wood is moderately resistant to fluids and can be treated with the hot-and –cold open tank method. But because this wood is attacked by insect borers immediately after it is felled and because the longitudinal permeability of wood in the direction parallel to the grain is much higher than the lateral permeability across the grain, it may be better to treat the green logs by the sap displacement method in the forest immediately after it is felled. The density and mechanical properties (wood strength) as represented by compression parallel to the grain satisfy the strength requirement for structural and similar uses. The compression parallel to grain value (838.94 kg/cm^2) puts talh in the forth highest strength group among our local structural timber with six groups according to Sudanese standard 5332 (2012)

The high density (0.82 g/cm^3) which was close to what was obtained by Nasroun (2005) as a strong indicator of wood strength shows that other strength properties are also high. This shows that talh can safely be used in load bearing structures provided that it is treated with preservatives and dried to the equilibrium moisture content before using it. Because the glue bond strength was very low for talh glued joints should be avoided in joining structural components. Instead mechanical fastener such as nails, screws, bolts and metal plate connectors should be used. The strength of these connectors is positively and highly correlated to wood density. The high density of talh will ensure strong mechanically fastened joints. Talh can therefore be used safely for wood- frame buildings, if properly seasoned and treated with preservatives. Smaller pieces can be used for other load-bearing product like pallets, handles for agricultural implements and similar products which require strength. Preservative treated talh poles or studs can also be used as pit props in gold or coal mines.

Shrinkage values are useful in estimating roughly the dimensional allowances necessary in converting green timber. In general, no significant dimensional changes will occur if wood is fabricated or installed at a moisture content corresponding to the average atmospheric conditions to which it will be exposed. When incompletely dried material is used in construction, some minor dimensional changes can be tolerated if the proper design is used.) (Forest Product Laboratory, 2010). As talh has the lowest shrinkage values tolerances will not be high when it is used in construction.

For *Diospyros mespiliformis* and *Acacia polyacantha* also the density and mechanical properties (compression parallel to the grain) satisfy the strength requirement for structural uses. The values of compression parallel to the grain (840.00kg/cm^2) for goghan and (838.94kg/cm^2) for kakamut put goghan and kakamut in the same (forth) highest strength group as talh among our local structural timbers as shown in the above mentioned standard. Goghan's and kakamut's density was medium high (0.74g/cm^3) that is good index of all strength properties shows that also goghan and kakamut can be used in load bearing structures after being dried to equilibrium moisture content.

They can be used safely for wood-frame buildings as beams, columns, joists and purlins if properly seasoned. The glue bond strength was high for goghan and kakamut in addition to their fine textures and figured appearance they can be used in wall paneling and internal decorations. The results of this study showed that goghan wood is permeable and kakamut is moderately permeable. Thereby they can be treated with preservatives if the need arises. Permeability of goghan and kakamut is an indication of drying rate, meaning that these two species can be dried at a reasonably rapid rate without much degradation. It also facilitates treatment with preservatives and may positively affect finishing properties.

Being of low density Tartar wood can be used in non-load bearing positions. For the same reason it will have a low thermal conductivity and therefore suitable for insulation as in cold stores and as covers in sandwich constructions. Its lightness also makes it suitable for rafts lifebelts, fairing, filling and bulkheads in aero- planes manufacture where weight is an important factor.

Furniture and similar uses

For furniture others characteristics like machinability, surface quality, dimensional stability, gluability and permeability become more important. These important quality attributes for customers and manufactures are determined to varying degrees by basic wood characteristics for example durability depends on extractives, appearance determined by anatomical structure and chemical properties. These service related characteristics need to be considered with other quality attributes (Zhang, 2003). Among the studied wood species goghan is the most qualified to meet these attributes. Furniture is associated with daily living and personal use. It remains a reminder of the usefulness, durability and beauty of wood.

Goghan has a fine texture, smooth surface and straight grain as indicated by the high score (8.50 out of 10) obtained from visual appearance grading carried out in this investigation. This wood also showed a strong glue bond which will ensure that bonded furniture parts will hold for a long time. The results also indicated that this wood is permeable to liquids, which means that it can be treated with preservatives to prolong its life in service. All these attributes make goghan an ideal wood for high quality furniture, cabinetry, doors and similar household and office items. Associated with furniture are the wood panel boards. Due to its fine texture, straight grain and its glue bond strength the wood is good for manufacturing strong good quality plywood which can be used in furniture making and paneling. The veneers which are not used for making plywood can be used to cover furniture parts made from lower quality woods. Smaller sizes of goghan can be used for turned or molded furniture parts and antique furniture. As goghan wood has medium high density, the sizes of furniture parts should be much smaller than the sizes usually used. Kakamut showed similar properties to goghan in density, gulability and slightly lower in permeability. The wood is motley with moderately fine texture. The wood is also figured as appeared from the visual appearance grading. These things make the wood suitable to different qualities of household and office furniture from specialty furniture to custom furniture, as well as doors and turned furniture components. Again smaller dimensions should be used for furniture parts due to the medium high density. The wood could also be used for manufacturing veneers and high quality plywood.

Talh has a high density, moderately fine texture and figured, low glue bond strength, moderately resistant to impregnation ie low permeability.

Therefore it can be used for cheaper furniture, for school furniture and at camping sites. Because talh has high density the dimensions for furniture parts should be smaller than those usually used. Mechanical fastener should be used in jointing furniture parts due to it's low glue bond strength. Wood should be treated before it used. Talh has low permeability so it can be treated by the sap displacement method in the forest. Tartar has low density, moderately course texture and low glue bond strength. According to lateral permeability tartar was extremely resistant to impregnation but longitudinal absorption of water was quite high compared with other species. All these things make tartar suitable to use in concealed parts of the furniture.

Manufactured products

Particleboard

The factor of raw material used is by far the most important parameter affecting the quality of particleboard because it interacts with every other variable mentioned. It governs the type of particles generated; the material used also determines the formulation of the urea resin. The most important species variable governing particleboard properties is the density of the wood raw materials; it has been the main factor determining which species to use for manufacturing composition boards. In general terms, the lower density woods will produce panels within the present desired density ranges, usually with strength properties superior to boards made from higher density species. Light density woods can be easily compressed to medium density particleboard with the assurance that sufficient inter particle contacts and good bonding is achieved during pressing (Nasroun and El-Wakeel, 2003).Softwoods and medium-density hardwoods (0.40 - 0.60 g/cm^3) are preferred, but heavier hardwoods are not excluded (Tsoumis, 2009). Board density is a major factor considering that wood will be compressed to produce boards having a density 5-20% higher than of the wood in order to obtain maximum bond and sufficient strength and durability according to intended use (Mitlin, 1969). According to the results of this investigation and the obtained density values only Tartar can be used for the manufacture of particleboard. The other three species under investigation are too heavy to give strong boards. This in addition to the fact that both goghan and kakamut are too valuable to be used for particleboard.

Plywood

In decorative plywood (for decorative wall, furniture and cabinet panels) appearance is more important than strength (Tsoumis, 2009) (Forest Product Laboratory, 2010). Both of goghan and kakamut which have high bonding strength, fine texture and good surface quality can be used for manufacturing high quality plywood, which can be used for high quality furniture, cabinetry, paneling and joinery. They can also be peeled and used as veneers.

Pulp and Paper

With the increasing demand on pulp and paper a shift of supply to the developing countries is indispensible. In pulp and paper industry successful large scale operations are based on mixed tropical hardwoods. Each available species mix has to be studied economically and technically. Technically the anatomical properties studied (table 1, 2&3) were used in mathematical models obtained in previous studies to estimate some expected paper properties for paper to be produced from the species under investigation as in the following table.

Table (8) Results of some paper properties obtained from the above mentioned models

Spp	BL (m)	T F		Sh B (g/cm³)	
	Un beaten	Un beaten	30min beating	Un beaten	30min beating
Goghan	2101	7.217	81.50	1.98	2.46
Kakamut	4518	21.825	71.33	1.97	1.42
Talh	5740	12.674	85.68	2.09	2.67
Tartar	5641	40.60	95.25	1.47	1.63

BL = Breaking length, T F = Tear factor, Sh B = Sheet bulk, Spp = Species, Goghan = *Diospyros mespiliformis* , Kakamut = *Acacia polyacantha*, Talh = *Acacia seyal var seyal*, Tartar = *Sterculia setigera*

The breaking length obtained for the four species were higher than the values obtained by Nasroun (1978) for *Acacia nilotica and A. seyal var. seyal*, but slightly lower than four other species tested by the same author for unbeaten pulp. The tear factor results for unbeaten and beaten for 30 minutes were also comparable with the results of the above mentioned study. The same with sheet bulk. According to these results all species can be recommended for pulp and paper manufacturing. But again goghan should not be used for this purpose because it is too valuable for that. These results and others to come will enable us to group similar species for integrated paper industries use mixed hardwoods. Some of these results are higher than what was obtained by Nasroun 1978. This can be explained by the fact that fiber length obtained in this investigation (table 1) was greater than what obtained in the previous study.

Fiberboard

Fiberboard manufacturing is species tolerant and does not have any specific requirements with regards to raw material and almost any wood species can be used. This means that all species studied can be used for this industry. However, goghan is too valuable to be used for this industry and therefore should not be used for this purpose.

CHAPTER FIVE

CCONCLUSIONS and RECOMMENDATIONS

5.1.Conclusions

-The quality attributes for assigning the different species to the correct uses included; wood strength, stiffness, dimensional stability, gluability, permeability, texture and some fiber characteristic.

-Goghan acquired all the quality attributes for structural utilization, paneling, internal decorations, other decorative uses in addition to high quality furniture, veneer, decorative plywood, carving, handcrafts.

-Kakamut had similar quality attributes as goghan and can be used for all the above mentioned uses with slight preference to goghan.

-Talh with its high density and high strength value can be used for structural purposes. However, it must be treated with preservatives before use as it is susceptible to attack by insect borers. It can also be used for fixed furniture for student seating and at camping sites using mechanical fasteners as its gluing properties are poor. It can also be used to some species tolerant uses such as the manufacture of different types of fiberboard including MDF. It can also be used for pulp and paper as well as different forms of bio-energy. This, in addition to other load bearing items like pit props, pallets, tool handles etc…

-Tartar with its low density and low strength can only be used in non-load bearing partitions and as an insolating material in sandwiched construction. Its density makes it a good raw material for different types of particleboard.

It can also be used for manufacturing different types of fiberboard. It also has long fibers which makes it suitable for the production of pulp and paper. This in addition to the production of toys and other small items.

5.2. Recommendation

The vast majority of Sudan forests are natural degraded forests. They are stocked with secondary species which are not in use. When the time comes for the rehabilitation of these forests for sustainable management, these species will be removed. Therefore this kind of study should continue to determine the quality attributes for other similar species and assign each species to the appropriate uses with added value instead of burning them, and make it more economical to harvest and exploit natural forests.

Goghan, kakamut and tartar could be recommended for afforestation and reforestation programs while natural stands of talh should be properly tended and manage for sustainable production of saw logs or industrial wood.

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