Sudan University of Science & Technology

College of Graduate Studies

Derivation of Design Stresses for *Boswellia papyrifera* (Gafal) Wood grown in Blue Nile State- Sudan

إشتقاق الإجهادات التصميمية لخشب القفل النامي فى ولاية النيل الأزرق - السودان

A Dissertation submitted in partial Fulfillment of the Requirement of the M.Sc. in Environmental Forestry

By

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November 2017

بسم الله الرحمن الرحيم

Dedication

To our great prophet Mohamed (peace and prayers be upon him)

To those who gave me….Name and taught me how life could be

My affectionate mother……………

My dear father……......

To those who led me through life ……..My brothers and sisters

To my first love………………………..My wife Batool

To my daughters Sara , Asawir and Ragad.

For all those I present this small effort with sincere love

Acknowledgement

I am fully indebted to my supervisor **Prof. Tageldin Hussein Nasroun** for his valuable efforts, guidance, help, and continuous encouragement during the research period. Thanks are due to **Dr. Elamin Al-hadi** in **Forest Research Center**.

I would like to acknowledge the contribution of **Taqi allah Mohammed Ismail Ahmed** who has provided valuable assistance and suggestions, improving and completion of this work. Thanks are due to **Ammar Khalil Mohamed and Ahmed Ibrahim.** I would like to express my gratitude to all those who gave me the possibility to complete the Dissertation.

Abstract

This study aimed at explaining the procedure for deriving design stresses for timber and providing engineers with some of the information which will help them in designing timber structure. Timber is a very variable material affected by many factors, this makes it important to determine mechanical properties by standard methods using small clear specimens. As clear wood is not available for use, it is important to apply all the necessary reduction factors to reach design stresses. Both static bending and compression parallel to the grain tests were carried out according to standard procedures. Static bending test was carried out according to Sudanese standard no. 5175/20/2012 adopted form ISO 3133/1975 while compression parallel to the grain was carried out according to ISO standard procedure no. 3787/1979. The basic stresses for the two properties were derived first by using two reduction factors to the mean ultimate stresses from test results to cater for wood variability, safety and duration of load. The Factors influencing strength were studied for grading the timber and assigning strength ratio to each grade. Grade (or design) stresses were then calculated by multiplying basic stress by the strength ratio for each grade. These Results revealed that the basic stress for bending for gafal wood was 10.8 MPa and 13.6 MPa for compression parallel to the grain. Grade (design) stresses in MPa were as follows:

	Grade 1	Grade 2	Grade 3	Grade 4
For Bending	8.64	7.02	5.40	4.32
For compression	10.53	8.55	6.58	5.26

These results indicate that gafal wood with its low density and low strength values can only be used for light constructions as columns and non-load bearing members in wood frame buildings. It can also be used as raw material for many wood industries.

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CHAPTER ONE

INTRODUCTION

1.1. Background

Wood differs from other construction materials because it is produced in a living tree. As a result, wood possesses material properties that may be significantly different from other materials normally encountered in structural design. Although it is not necessary to have an in-depth knowledge of wood anatomy and properties, it is necessary for the engineer to have a general understanding of the properties and characteristics that affect the strength and performance of wood in bridge applications. This includes not only the anatomical, physical, and mechanical properties of wood as a material, but also the standards and practices related to the manufacture of structural wood products, such as sawn lumber and glulam . Wood is a natural renewable resource. Its biological origin makes it such a variable material that man has very little control over its properties (Nasroun, 1981).

In the broadest terms, trees and their respective lumber are classified into two general classes, hardwoods and softwoods. Hardwoods normally have broad leaves that are shed at the end of each growing season. Softwoods have needlelike leaves that normally remain green year-round. The classification as hardwood or softwood has little to do with the comparative hardness of the wood. Several species of softwoods are harder than many low- to medium-density hardwoods. With few exceptions, the structural wood products used in bridge applications throughout North America are manufactured primarily from softwoods. Although hardwoods are not widely used at this time, structural grading procedures for hardwoods have been developed recently, and their use is increasing in some regions of the country (American Institute of Timber Construction,1983).

The strength of material such as wood refers 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.

Elastic properties relate a material's resistance to deformation under an applied stress to the ability of the material to regain its original dimensions when the stress is removed. For an ideally elastic material loaded below the proportional (elastic) limit, all deformation is recoverable, and the body returns to its original shape when the stress is removed. Wood is not ideally elastic, in that some deformation from loading is not immediately recovered when the load is removed; however, residual deformations are generally recoverable over a period of time. Although wood is technically considered a viscoelastic material, it is usually assumed to behave as an elastic material for most engineering applications, except for time-related deformations (creep) (Desch and Dinwoodi, 1996).

For an isotropic material with equal properties in all directions, elastic properties are described by three elastic constants: modulus of elasticity (E), shear modulus (G), and Poisson's ratio (μ). Because wood is orthotropic, 12 constants are required to describe elastic behavior: 3 moduli of elasticity, 3 moduli of rigidity, and 6 Poisson's ratios. These elastic constants vary within and among species and with moisture content and specific gravity. The only constant that has been extensively derived from test data, or is required in most bridge applications, is the modulus of elasticity in the longitudinal direction. Other constants may be available from limited test data but are most frequently developed from material relationships or by regression equations that predict behavior as a function of density (Barnes and Winandy, 1986).

Strength properties mean the ultimate resistance of a material to applied loads. Wood strength varies significantly depending on species, loading condition, load duration, and a number of assorted material and environmental factors. Because wood is anisotropic are either or tropic or entropic, mechanical properties also vary in the three principal axes. Property values in the longitudinal axis are generally significantly higher than those in the tangential or radial axes. Strength related properties in the longitudinal axis are usually referred to as parallel-to-grain properties. For most engineering design purposes, simply differentiating between parallel- and perpendicular-to-grain properties is sufficient because the relative tangential and radial directions are randomized by the primary sawing process (i. e., conversion from logs to boards). Toughness, or resistance to impact, is an essential requirement of timber for hammer handles, shafts and many sports goods. To resist suddenly-applied loads the timber must be tough, a property particularly associated with hickory and ash, and more recently with the South America timber paumarfin. **(**Jamala, *et al.,* 2013).

1.2 Research Problem:

Timber is a very variable material affected by many factors; this makes it important to determine mechanical properties by standard methods using small clear specimens. As clear wood is not available for use, it is important to make all the necessary reduction factors to reach design stresses

1.3 Research Objectives:

- **General Objective:**

This study aimed at explaining the procedure for deriving timber design stresses and providing engineers with information which will help them in designing timber structures.

- **Specific Objectives:**

1- To determine bending stress and compression parallel to the grain stress for *Boswellia papyrifera* wood using small clear specimens.

2- To study the effect strength-reducing factors on these mechanical properties.

3- To Use these factors for grading the timber and determining the design stresses for *B. papyrifera* wood.

CHAPTER TWO

LITERATURE REVIEW

2.1 General Principles:

The application of a small load to a sample of wood will cause that sample to deform; the application of additional small loads will cause further deformation of the sample and it will be found that the increments in deflection are proportional to the increments in load. Applied load /deformation = a constant, within the elastic limit. The value of this constant will vary with the size of the sample; hence it is necessary to express load in terms of the cross-sectional area over which it is applied, and deformation in terms of the initial length of the sample.

Load (N)/cross-sectional area (mm^2) = stress (N/mm^2)

And deformation (mm)/original length (mm) = strain (unit less)

Hence Stress (δ)/ strain (ε) = constant = modulus of elasticity.

The modulus of elasticity (also known as young's modulus in the case of bending) is denoted by E and expressed in units of N/mm^2 (Kollmann and Cote, 1996).

E is frequently referred to as stiffness of wood, a popular term which conveys an appropriate image. This is a misleading common mistake, because the term stiffness is the product of the modulus of elasticity and the second moment of area (I) = that is, stiffness = El. Timbers with the highest slope of the stress/strain curve (within the elastic limit) will have the highest stiffness. However, above that limit departure from linearity occurs. If an applied load above the limit of proportionality is removed, the sample will not return to zero deformation, but will follow a line lying parallel to the initial linear region and terminating on the horizontal axis at some finite deformation, thus permanent deformation has been induced in the sample. More load will lead to more permanent deformation and finally to the failure of the sample. The stress level (load divided by cross-section area) at which failure occurs is deemed to be the strength of the wood, and the value of this will depend on the mode of stress application, for example, tension or compression. The limit of proportionality also varies with the mode of stress application. In longitudinal tensile stressing (tension parallel to the grain) the limit occurs at about 60-65 percent of the failure stress, while in longitudinal compressive stressing the limit is much lower at 30-50 percent (Desch and Dinwoodi, 1996).

2.2 Mechanical Properties of Wood

Mechanical properties of wood are measures of its resistance to exterior forces which tend to deform its mass. The resistance of wood to such forces depends on their magnitude and the manner of loading (tension, compression, shear and bending). In contrast to metals and other materials of homogeneous structure, wood exhibits different mechanical properties in different growth directions (axial, radial and tangential) and therefore, it is mechanically anisotropic (Tsoumis, 2009). Before discussing the mechanical properties of wood, it is useful to explain certain basic concepts regarding the mechanics of materials in general. Force is any action that tends to move a body at rest, or change its shape or size, or if the body is moving, to change the speed or direction of its movement. Under the action of exterior forces which tend to change its form, a body al rest exercises resistance. This resistance (i.e., the interior forces which develop inside its mass in reaction to the forces acting on the exterior) is called interior stress or simply stress. These stresses are equal and opposite to the exterior stresses. A force (or load) is expressed in Newtons (N) or pounds (Ib). A force per unit area is called stress; it is expressed in N/mm^2, Pascal (Pa), or $lb/in.^2$ (psi) and is calculated from the following relationship:

S = P/A ………………………………………………………… (1)

S = stress (N/mm^2,MPa, $lb/in.^2$ or psi)

P = force or load (N, 1b)

A = loaded area (mm^2, $in.^2$)

The mechanical properties of wood make it a material that can be used to construct a variety of structures, ranging from conventional residential buildings to modern large-scale structures like domes, bridges, or industrial complexes. Worldwide, more buildings are constructed wood than with any other structural material. Wood is available for structural applications in many forms. The most obvious is sawn lumber, which is wood that has been manufactured by simply cutting it directly from a log. Structural applications are those in which strength is usually the primary criterion for adequacy of material. The term strength has many meanings in common usage, but in the setting of structural materials, strength is defined as the ability to carry or resist applied loads or forces. The strength of wood determines its mechanical performance and is an important factor in drying. Machining, bending, gluing, and fastening (Barnett and Jeronimidis, 2003).

Structural uses of wood products include floor joists and rafters in wood-frame houses, heavy timber construction, beams and stringers, power line transmission poles, plywood roof sheathing and subflooring, glulam beams and decking in commercial buildings, particleboard flooring in mobile homes, steps and rails of wooden ladders, sailboat masts, and frames of upholstered furniture. The strength and resistance to deformation of a material are referred to its mechanical properties (Haygreen and Bowyer, 1996).

There are three basic stresses: tensile, compressive and shearing. Tensile and compressive stresses are also called normal stresses. A body is under tensile stress when the forces acting tend to increase its length. If the forces are acting in the opposite direction, the body is under compressive stress and tends to become shorter. Shearing stresses develop when the forces tend to cause a part of the stressed body to slide onto the adjacent part of the same body. Under the influence of exterior forces which generate the above stresses, the stressed body tends to change shape and size. This change is called deformation (Tsoumis, 2009)

In the application of design to the structural use of timber it is necessary to design against both static failure stress and excessive deflection, the latter being a manifestation of the elastic properties of wood. Either of these two parameters may be the limiting factor in a particular design. Additionally, it is frequently necessary to carry out impact testing of a prototype component in order to determine that there is sufficient resistance in the designed structure to the application of dynamic loads. 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 with the mode of load application; the principle modes are tension, compression (parallel or perpendicular to the grain), bending and shear. Unlike the position with strength, modulus of elasticity in tension, compression and bending is similar. The value for modulus of elasticity for all three modes of load application in each of the three principle planes of wood is usually adopted.

2.3 Testing Structural Sizes:

This approach for the derivation of working stresses for structural timber commenced in the mid-1970s and has now been applied to most of the structural softwoods and to one or two species of hardwoods used in the (UK Ministry of Technology, 1972). The test procedures for the assessment of the strength and elastic properties of test specimens of structural size are set out in BS 5820:1979. Before testing, the test specimens are normally conditioned to a constant mass at a temperature of 23 ± 3^{0}c and a relative humidity of 60 ± 2 percent: these conditions are slightly different from those in BS373 for the testing of small clear test pieces and will result in differences in moisture content between the two sets of test specimens.

Static bending: unlike the static bending test for small clear samples where the test pieces were loaded in the middle of the sample (three-point or Centre-point loading), the test for structural sized timber employs a four-point loading test in which the distance between the two loading points equal to the distance between one loading point and the nearer support; this particular configuration is referred to as 'third-point bending'. The distance apart of the reaction supports is 18 times the nominal depth of the specimen, though if this cannot be achieved, the geometry of the test may be modified within specified limits. Separate tests on the same test piece are carried out for determining strength and modulus of elasticity, each with its of loading.

In the test for modulus of elasticity which is carried out first, a record of load- deflection is made.

The modulus of rupture in four-point bending is calculated from the following equation:

$Fm = f max\ a/2w$.. (6)

Where

Fm is the bending strength, in N/mm^2

f max is the bending maximum load, in N

a is the distance between one inner load point and the nearest support, in mm

w is the section modulus determined from the actual dimensions of the section, in mm^3.

2.4 Factors Affecting Wood Strength

Clear straight-grained wood is used for determining fundamental mechanical properties; however, because of natural growth characteristics of trees, wood products vary in specific gravity, may contain cross grain, or may have knots and localized slope of grain. Natural defects such as pitch pockets may occur as a result of biological or climatic elements influencing the living tree.

These wood characteristics must be taken into account in assessing actual properties or estimating the actual performance of wood products. From the point of view of economics, a defect in wood is any feature that lowers its value on the market. It may be an abnormality that decreases the strength of the wood or a characteristic that limits its use for a particular purpose. There is a certain amount of risk in classifying an abnormality as a defect because what is judged to be definitely unsuitable for an application may prove to be ideal for a different or special use (Kollmann and Cote, 1968).

2.4.1 Natural Defects

Timber contains many natural gross features which have the effect of reducing the strength of timber containing them. The most important of these features are knots, slope of grain, checks, shakes and splits. Timber without any of these gross features — known as clear timber — is both scarce and costly. To refuse to use pieces of timber containing one or more of these gross features would lead to prohibitively uneconomical designs. It is in fact uneconomical to use clear timber, and that timber containing gross features (natural defects) may be safely used provided that the size of the feature is strictly specified and controlled. This control is achieved by grading the timber according to the size of the defects present. Since these grades are a measure of the strength of the member, they are known as stress grades. Before investigating the strength reducing effects of gross features, a method of measuring their size must be defined (Booth and Reece, 1967).

2.4.2 Knots

A knot is originally a branch which is embedded in the stem during lateral growth. After sawing the cross-section of the branch appears on one surface of the board as a knot. The portion of a knot visible on the surface of a piece of timber is only a section of the complete knot and the shape of this section will depend on the direction of the cut. Since the complete knot is approximately a cone starting from the Centre of the tree, the visible sections will be approximately circular, elliptic or parabolic. A further distinction is made depending on the location of the knot. In beams, for example, a knot occurring at the neutral axis will have less effect than one at the extreme fibers (margins). Using these distinctions knots can be classified as edge, face, margin, splay, and arris knots. The definition, method of measurement and magnitude of each of these knots is given in (Booth and Reece, 1967). Knots do not themselves reduce the strength of a piece of timber. It is the disturbance of the grain occurring around the knot that causes the reduction and the size of the knot is a measure of this disturbance. In addition to the size of the knot, its position in relation to the stress distribution in the member is important. If we define the 'knot ratio' as the ratio of the size of the knot to the width of the face or edge on which it occurs, then tests have shown that there is an approximately linear relationship between 'knot ratio' and 'strength ratio' (Nasroun, 1981). Knots have less effect on the modulus of elasticity than on strength. The area of disturbed grain around the knot certainly has less stiffness than the straight grained portions, but in general the total volume of the member occupied by knots is small and the overall stiffness of the member is governed by the straight grained timber. The shear strength of timber is only reduced by a small amount by knots and indeed in some cases the knots may slightly increase the shear strength by disturbing the continuity of the grain. The strength in compression perpendicular to the grain is not reduced by the presence of knots. The disturbance of the grain is not important in this case and the knots themselves are usually harder than the surrounding material.

2.4.3 Slope of grain

In isotropic materials the elastic constants and strength properties are the same in all directions, but in anisotropic materials like crystals and wood the elastic constants and other mechanical properties vary with direction relative to the grain. Almost all the mechanical characteristics of wood depend on the grain direction, i.e. strength, toughness and elasticity. In lumber industry, the sawing of a log is often done with precision along the grain in order to obtain the best possible strength and form stability.

The grain direction of wood is usually parallel to the longitudinal direction of the stem. Slight deviations, caused by external forces and environmental factors, may occur. The effects of wind and crown development are some of the reasons causing a phenomenon known as spiral grain (Kollmann and Cote, 1968).

Natural features, such as knots or clusters of knots, are often referred to as defects of wood in the lumber industry.

Slope of grain is caused by methods of conversion (sawing) or due to methods of tree growth. There are many forms of grain disturbance: inclined, wavy, spiral or others. Measuring the grain direction on logs and sawn timber is difficult in the absence of sophisticated techniques. Simonaho, et al. (2004) introduced a new optical method for grain direction determination in wood, from laser light generated scattering pattern on the surface of wood. They observed the correlation between the characteristics of the scattering pattern and the grain direction angles in a three dimensional domain. The orientation and shape of the scattering pattern were shown to depend on the grain direction. In straight-grained timber, the fibers or tracheid's are more or less parallel to the vertical axis of the tree. In addition to being a contributory factor in strength, straight-grained timber makes for ease of machining and reduces waste. On the other hand, it gives rise to ornamental figure. In irregular grained timber, the fibers are at varying, and irregular, inclinations to the vertical axis in the log, and is said to have irregular grain. It is a very common defect and, when excessive, seriously reduces strength, besides accentuating difficulties in machining. Irregular grain, however, often gives rise to an attractive figure (Simonaho, et al., 2004). Spiral grain is produced when the fibers follow a spiral course in the living tree. The twist may be left-or-right-handed. Interlocked grain or interlocked fiber as it is often called, results from the fibers of successive growth layers being inclined in opposite directions, producing the familiar figure know as ribbon or stripe figure on radial cut surfaces.

The sensitivity of stiffness to the angle of the grain appears to be similar to that for strength. In ordinary practice the margin of safety in design and use of timber is such that an appreciable degree of tolerance in regard to sloping grain can be accepted for most purposes, except in those cases where the level of stress in service is high, such as sports goods, tool handles, ladder stiles and scaffold boards. Thus for example, in British standard (BS 1129), portable timber, ladders, steps, trestles and light weight staging's, it is specified that in the stiles of single section ladders, extending ladders and lightweight staging's, the combined slope of grain in the two longitudinal planes shall not be steeper than I in 10 for all the specified softwoods, excluding Douglas Fir where because of its superior strength the maximum combined slope of grain is specified as I in 8, which also applies to most of Sudanese hardwoods.

The directions of vessel lines, gum veins, resin ducts and seasoning checks are useful in indicating slope of grain in a piece of timber, but in the absence of these features visual inspection alone can be very misleading and difficult. Direction of the grain may be detected by raising a few fibers with the point of a penknife, or by noting the spread of an ink spot. For accurate determination of slope of grain a specially designed scribe, consisting of a cranked rod, with swivel handle, and an inclined needle at the end of the rod, should be used. Determination should be made on both the face and edge of a piece of timber. The use of the scribe is explained and illustrated in British standard BS1129 (1982).

The effect of diagonal (inclined) and spiral grain is most pronounced in the case of members subjected to tensile stresses. Since the tensile strength parallel to the grain may be as 40 times that perpendicular to the grain, it is evident that inclined grain causes an appreciable reduction in strength. For compression, parallel to the grain the reduction is not so pronounced, since the perpendicular strength is between 1 / 3 to 1 / 10 that of the parallel value. In shear the effect of the inclined grain is negligible and ill may slightly increase the strength by disturbing the continuity of checks. Tests undertaken by Wilson (1935), on Sitka spruce, Douglas fir and white ash gave curves. Static bending tests were made on 900 specimens of stika spruce, 450 of Douglas fir and 900 of white ash, each 2in X 2in X 48in at moisture contents between 6 per cent and 7per cent. Slopes of grain, ranging from 1 in 4 to 1 in 40 were obtained by cutting the specimens at the appropriate angles to the axis of the tree. Following the bending tests, specimens were cut from the broken ash pieces and tested in compression parallel to the grain. In structural sizes the effect of inclined grain is much greater than in small clear specimens, since stresses caused by shrinkage during seasoning are greater in members containing zones of disturbed grain. The reduction in strength of structural size due to inclined grain is assumed to be twice that obtained for small specimens.

The following formula-known as Hankinson's formula- is suitable for computing the tensile strength of wood ($\delta\gamma$) in which the direction of the grain is inclined at an angle ɣ to the direction of the load:

$$\delta\gamma = \delta,, X\delta \perp / \delta,,. sin^n\gamma + \delta \perp cos^n\gamma \qquad (7)$$

n = constant ranging (2 to 2.5)

In which $\delta_{,,}$ represents the tensile strength parallel to the grain ($\gamma = o$), $\delta \perp$ the tensile strength perpendicular to the grain(γ =90) and n=constant

Which has shown that values of n between 1.5 and 2 are satisfactory Kollmann (1934).

It can be seen that tensile strength is much more reduced by cross grain than bending or compressive strength. For the design and statistical computation of engineering structures in wood the knowledge of the dependence of crushing strength on grain orientation is often very important. For very dry or oven-dry wood even rather small angles between fiber direction and direction of the force applied reduce the strength remarkably. The reason is the increased brashness due to drying and more pronounced difference between young's moduli in very dry early wood and latewood. Again Hankinson's formula can be used for calculating the compressive strength of wood ($\delta\gamma$) at an angleγ to the direction of the load. The exponent n in Hankinson's formula may be chosen as 2.5. The differences between the compressive strength along the grain and the compressive strength perpendicular to the grain become smaller the denser and the more homogeneous are the woods. Wangaad(1950) stated that the decrease in tensile strength does not become appreciable until a slope of 1: 25 is reached; in compression, the slope may approach 1:10 before the reduction of crushing strength is evident. In shear the weakening effect of cross grain may be neglected. conducted a series of tests at the forest products laboratory to determine the effect of spiral grain on the strength of wood.

Generally the values for toughness and impact bending of coniferous species are higher for radial than for tangential blows (Markwardt and Wilson, 1935). No such clear differences could be found for broad leaved tree species. Slope of grain reduces the shock resistance of wood remarkably. An angle of only 5^0 causes a 10% decrease in toughness, an angle of 100 leaves only half the shock resistance.

2.4.4 Fissures

The strength of timber is also affected by fissures which include checks, split and shakes. A check is the separation of the fibers along the grain forming a crack or fissure in the timber across the growth rings and in a radial direction. The cause of checks is the unequal shrinkage which takes place when the moisture content is reduced during seasoning. A shake is the separation of the fibers along the grain occurring between and parallel to the growth rings. The cause of shakes is uncertain but they rarely develop unless they were present to a certain extent before the tree was felled. A split is the separation of the fibers along the grain forming a crack or fissure that extends through the piece from one surface to another. All these fissures reduce shear strength only. They have no effect on other mechanical properties (Nasroun, 1981).

2.5 Factors Other Than Defects

2.5.1 Duration of load

Increase in the rate of load application in a mechanical test result in increased values of strength and stiffness. The effect is greater in testing 'green' wood where strength values can be some 50 percent higher than those of wood at 12 percent moisture content, a result quite contrary to that obtained when using normal rates of load application. It is often stated that wood ages and loses strength: provided that the wood has not been attacked by fungi nor subjected to longer periods at high temperature, then the statement is quite erroneous and there is no loss in strength of a piece of wood in an unstressed state (Pearson, 1972).

The situation, however, is quite different if a load is kept on a piece of wood for a long time. We are all familiar with the sagging bookshelf. The initial load of the books is insufficient to cause the bookshelf to break, if left on the shelf for a long period of time, the sag or defection increases until, failure generally occurs. It is important to appreciate that failure has occurred at a much lower level of stress than would have occurred under short-term test: there is thus an 'apparent' loss in strength with time under load. It had been demonstrated by experimentation followed by mathematical projection that in order to ensure that a piece of wood will still carry its imposed load for 100 years, then that imposed load must be no greater than 50 percent of the load the timber would fail at in the short-term test, In all structural applications a load-endurance factor is incorporated in the design and 'this is usually applied as one of several contributing parts to an overall safety factor (Jonathan Simm, 2004).

2.5.2 Moisture content

Above the fiber saturation point losing free liquid water filling the coarse capillaries in vessels, tracheid's and other elements of the wooden tissues does n affect' strength and elastic properties. Below the fiber saturation point shrinkage c swelling occurs thus increasing or reducing cohesion and stiffness. The considerable influence of moisture on the elasticity of wood makes it necessary to reduce all values to standard moisture content. Much timber used for structural purposes is unseasoned and is used in moisture content (say 20-25percent) and for this reason the strength properties of green timber with moisture content above the fiber saturation point are used to compute the basic stresses. When it is known that the structural member will remain in a dry condition (less than 10 percent moisture content) then higher stresses are permitted within certain limitation. Modulus of rupture like longitudinal compression strength. Increases appreciably per I percent reduction in moisture content, while side hardness is almost insensitive to moisture change. Only slight differences occur between different timbers(Browning,. 1975).

A full explanation of the effect of moisture on strength in terms of the basic structure of the wood is still not available but it is generally accepted that the overall increase in strength with reduction in moisture below fiber saturation point is because of the shortening and consequent strengthening of the hydrogen bonds linking together the micro fibrils. Longitudinal tensile strength, however, is insensitive to change in moisture content since tensile strength is a function of the structure of the crystalline core of the micro fibril which is unaffected by changing moisture content (Browning, B.L. 1975).

NY: Robert E. Krieger Publishing Company..

2.5.3 Temperature

The strength and stiffness of wood are also influenced by its temperature. For most of the strength properties a good rule of thumb is that an increase in temperature 1^0 c produces a 1 per cent reduction in their ultimate values. This effect of temperature is dependent on moisture content, the effect being considerably greater, the higher the moisture content (Gerhards, 1982).

The effect of temperature is more pronounced with some strength properties compared with others: thus the longitudinal compression strength increases almost three folds with a drop in temperature from 180 to 15^0c. It should be appreciated that long-term exposure to elevated temperature results in a marked reduction in strength, stiffness and also toughness, the effect being greater with hardwoods than softwoods. Even exposure to cyclic change in temperature over long periods has been shown to result in thermal degradation (Dodds and Moore, 1984).

2.5.4 Density

Almost all mechanical properties of wood are closely connected to density, some more so than others. In fact, density is most likely the best single predictor of mechanical properties of clear, straight-grained, defect- free wood. Properties such as elasticity in bending and maximum crushing strength parallel to the grain increase linearly, other increase through a power function, and some are only slightly affected. Dependence of material properties on density is certainly well known, but no other structural material relies so heavily on natural-growth characteristics to impart density. In wood, density is a reflection of the amount of cell wall material present per unit area, and this in turn is a function of the type and size of cells and the amount of latewood versus early wood in the piece under consideration, among other factors. Additionally, relative percentages of latewood and early wood are functions of growth condition and tree genetics. As a result, density varies within individual pieces and across wood types. In structural applications, density is commonly calculated as weight per unit volume, not mass per unit volume. Weight density, or weight of wood per unit volume, is usually calculated assuming that both the weight and the volume are taken at the same moisture content (Barnett and Jeronimidis, 2003).

The specific gravity or relative density of actual wood substance is, for practical purposes, the same for all species. The amount of wood substance per unit volume, however, varies greatly, depending on the anatomical structure of the wood. Apart from the effect of the presence of extraneous materials such as resins and, gums, the specific gravity of a timber is a major factor in determining its strength. In general, species with a high specific gravity have correspondingly high strength values. Variation in specific gravity occurs not only between species but also between pieces of the same species. Specific gravity-strength relations based on results of tests on small clear specimens of timber have been determined by many research workers in other laboratories and institutes. Specific gravity is affected by anatomical structure which, in turn affects strength properties as well as other physical properties of wood as indicated by Nasroun (1987); Nasroun and Alshahrani (1998) ; Nasroun (2005). The rate of growth can be used as a guide to the density, and hence to the strength of a piece of timber. In the case of softwoods the annual growth rings are visible for the naked eye and the number of rings per inch can usually be counted.

Wane is the rounded part of the surface of the trunk of the tree appearing on the arras of a converted piece of timber. The method of measurement is given in (Booth and Reece, 1967, Nasroun, 1981). Having defined the method of measuring the various defects, the next stage is to determine the relationship between the size of the defect and the reduction in strength that it causes.

2.6 Timber Grading

Lumber grading is based on some natural defects like slope of grain, knots, fissures and others. These defects are developed on standing trees and resulting logs. The need for complete understanding of all factors affecting hardwood timber quality is great. To isolate and examine the basic determinants of the quality of a log and thus of a tree, it is necessary to set up a standard. A theoretical standard would be a straight, cylindrical tree trunk consisting entirely of absolutely perfect wood. Such a phenomenon is never found in nature, because every tree has taper and a pith center. A practical standard for quality comparison is a log with the following specifications:

- It is a butt log, round or only slightly oval in cross section.

- It is 16 feet long and about 24 inches or more in diameter at the top end.

- The wood is straight grained.

There is no requirement as to other characteristics of the wood, i.e., whether heart or sap, uniform or variable in density or color.(Lockard *et al*, 1963). Tree size is markedly important because the factors that reduce quality take a greater toll in small timber than in large timber. For example, the same number of overgrown log knots is obviously less damaging when scattered through a log averaging 3 to 4 per thousand board feet than when contained in logs averaging from 6 to 10 per thousand board feet.

When timber is produced at the sawmill, the individual pieces differ widely in strength, and it is not uncommon for one piece to be three or more times as strong as another of the same size and species. There are two main reasons for this. First, the strength of timber is closely related to the density of its fiber material. There are wide variations in this characteristic between trees and, to a lesser extent, even within a single tree. The second reason is that other growth features in particular knots and slope of grain have an adverse effect on strength, and the extent, size and location of these differ in each piece of timber. Although a considerable amount of research is being carried out, with some success, to minimize knots and improve density by silvicultural means, timber is, and will remain a variable material. If timber was to be used for structural work just as it is produced then it would be necessary to assign very low stress values to allow for the occasional weak pieces which occur. To avoid this some form of selection is needed, and the first attempts to achieve this began around 1900 when the engineers introduced clauses in their specifications for structural timber which imposed limits on the size of knots. Since then extensive investigations have been undertaken to obtain quantities definitions of the influence of moisture content, knots, slope of grain, rate of growth and density on strength and to formulate rules which would enable an estimate to be made of the strength of a piece of timber by a visual inspection of its surfaces. The selection of timber on the basis of such rules has come to be known as stress grading and more recently, it has been necessary to identify this method of selection as visual stress grading in order to distinguish it from other, newer methods (Curry, 1969).

2.6.1 Visual stress Grading:

Visual stress grading is simply an attempt to divide the range of timber produced at the sawmill into a number of groups or grades, so that with a common factor of safely higher stress values can be used for pieces in the better grades. Quite complex grading rules have been drawn up and to apply them with speed and accuracy, specially trained graders are needed.

Timber organizations have been formed for the training and certification of graders and to ensure that standards of grading are achieved and maintained. In the United Kingdom provisions are made for four visual stress grades, and these are specified in the British Standard and CP 112: (1967) the structural use of timber, together with the corresponding grade stress values for a number of softwood and hardwood species. The grades are designated 75, 65, 50 and 40 grades, the figures indicating the percentage of the basic stress for clear timber which is applicable to each of the grades.

Although the strength ratios are decided somewhat arbitrarily, account is taken of the values used in other countries and of the need to ensure that the grades do not result in too much timber been classified as unsuitable for structural work. Acceptable values having been decided, limits are then established for the various factors which influence strength so that the required strength ratio for each grade is achieved. These limits constitute the grading rules, and a piece of timber can then be graded by locating the defect that is likely to produce the greatest weakening effect and, from the rules, deciding the grade to be assigned to the piece (Booth and Reece, 1967).

2.6.2 Machine stress grading

The existence of a highly significant statistical relation between modulus of rupture and modulus of elasticity for clear specimens of Pinus radiate was established. It was realized in America and Britain that these relations offered the possibility of developing a machine to stress grade timber. It was considered that there would be practical difficulties in sensing stiffness when timber was deflected in the depth rather than across the width, so initially the tests were made to determine the modulus of elasticity with the samples of timber loaded in both directions and with the modulus of rupture determined as a joist. The material used was commercial samples of European redwood and whitewood, and the investigations led to the following conclusions:

a- The relations between modulus of rupture as a joist and modulus of elasticity yielded correlation coefficients better than 0.7

b- The relations were equally good irrespective elasticity was measured as a board or as a joist.

c- Modulus of elasticity gives a better index of bending strength than does a measure of knot size or knot area ratio, the factors on which visual stress grading are principally based.

It can be shown that grading by defluxion gave much higher yields in the better or alternatively, if the same yields were maintained as for visual grading, a substantial increase in the grade stress values would have been justified. The maximum defluxion would be identified and, on the basis of the modulus of rapture / modulus of elasticity relations, this would be translated to a grade stress value for the timber used either as aboard or as a joist. The relations for modulus of rupture as a board and as a joist to modulus of elasticity as a board would differ and would have to be determined separately.

CHAPTER THREE

MATERIAL and METHODS

3.1 Material

The material used for this investigation is *Boswellia papyrifera* (gafal) wood which belongs to a tropical family called Burseraceae (Fitchl and Admasu, 1994). The tree is distinguished by the presence of resin ducts in the bark (Groom 1981). *B. papyrifera* a deciduous tree which reaches up to 12 m in height, with a round crown and a straight regular bole. The bark is whitish to pale brown, peeling off in large flakes; slash red-brown and exuding a fragrant resin. (Verghese, 1988). The wood is fine grained with medium density. It is suitable for making match boxes and splints, particleboard, plywood, veneer, pencils, picture frames…etc.

3.2 Methods:

Gafal logs were sawn and samples were selected, from which small clear specimens were prepared. Compression parallel to the grain tests specimens were prepared with dimension 20×20 ×60 mm. Static bending test specimens were 20×2 0× 300mm. Static bending test was carried out according to Sudanese standard no. 5176/2012 (adopted form ISO 3133/1975). Compression Parallel to the grain test was carried out according to ISO Standard Procedure no. 3787/1979. The mean ultimate stresses for short duration and the standard deviations were obtained from the tests results as starting points for deriving basic stresses in two steps :In step one using a statistical method the minimum ultimate stress (X min)below which there is a specified probability of a specimen failing was calculated, to cater for the problem of wood variability and safety. The second step was to apply another reduction factor to cater for duration of load and more safety and get to the basic stress.

Using the properties Gaussian distribution, we can easily calculate the ultimate stress below which there is a specified probability of a specimen failing, but it is more difficult to decide what's an appropriate probability, to take into account the variability of timber. It is assumed that for most strength properties the chance of getting lower value than the statistically estimated minimum 1 in 100% is reasonable. Using the properties of the Gaussian distribution 98 per cent of the results lie within the range determined by the mean ± 2.33times the standard deviation or, put another way, 1 per cent of the results lie below the value computed from the mean minus 2.33 times the standard deviation .(Booth and Reece, 1967). The minimum ultimate stress was obtained from the following equation:

$X_{min} = X_{mean} - k.\sigma$ ………………………………(1)

Where X_{mean} is the mean ultimate short duration stress from test results.

σ = the standard deviation.

K = a constant that depends on the selected probability as shown in Table1 and represents the number of standard deviations to be deducted from X_{mean} to get X_{min}.

3.1 Table 1. K-values for the different probabilities to be selected

Probability %	50	20	10	5	2.5	1	0.1
k-values	Zero	0.68	1.28	1.65	1.96	2.33	3.00

Source: B. S. 373, 1986.

k-value for 1% probability is 2.33

$X_{min} = X_{mean} - 2.33\sigma$ ……………………………….(2)

The second step for deriving the basic stress is the application of a combined reduction factor to cater for both duration of load and more safety. This factor was applied to the statistically estimated minimum (X_{min}). Equation 2 applies for both bending and compression parallel to the grain, whereas the above mentioned factor varies between the two properties .$X_{\mathbf{min}}$ was divided by the appropriate factor for each property. According to Booth and Reece (1967) the reduction factor for bending is 2.25 and 1.40 for compression parallel to the grain. Therefore, basic stress (B.S.) for bending was calculated from the following equation:

B. S. (bending) $= X_{\mathbf{min}} / 2.25$…………………..(3)

While basic stress for compression parallel to the grain (C//g) was calculated from:

B. S. (C//g) $X_{\mathbf{min}} / 1.40$………………………..(4)

Stress-grading of timber.

So far we are dealing with the strength of small clear specimens. Grading rules were used to check the effect of strength reducing defects on the strength and using these to determine grade (design) stresses.

Tentative grading rules were suggested by Nasroun (2005), for some hardwoods grown in Sudan, (table2) this can be used for calculating grade (design) stresses for gafal. The table shows four grades of timber, below each grade the permissible sizes of defects for the particular grade are listed, with the strength ratios for the four grades at the bottom of the table.

3.2 Table 2. Tentative grading rules

Defect	Grade 1	Grade 2	Grade 3	Grade 4
Slope of grain for bending	$1/16$	$1/12$	$1/9$	$1/6$
Slope of grain for compression parallel to the grain	$1/12$	$1/10$	$1/8$	$1/6$
Knot ratio	$1/4$	$3/8$	$1/2$	$5/8$
Strength ratios %	80	65	50	40

From this table and the above equations, grade (or design) stresses can be calculated from the following equation:

Grade stress = Basic stress x strength ratio………………..(5)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Ultimate Stresses

Appendices A and B show the results of the static bending test and compression parallel to the grain, respectively with average short duration ultimate stress values and standard deviations. Table 2 depicts the summary of these test results.

4.1 Table 3. Summary of test results

Property	Ultimate Stress (MPa)				MOE (MPa)	
	Max.	Min.	Mean	St. D.	Mean	St. D.
Bending	45.76	28.47	36.50	5.22	6414	1431
Compression parallel to the grain	38.25	20.02	27.75	4.00	1437	417

4.3. Basic Stresses

Form table (2), equations (1) , (2) and (3) the basic stress for bending is as follows:

Basic stress (bending) = $\frac{36.5-2.33\times5.22}{2.25}$ =10.8 MPa

From table 2, Equations (1) , (2) and (4) the basic stress in compression parallel to grain (C//g) is as follows:

Basic stress(C//g) $= \frac{27.75 - 2.33 \times 4}{1.40} = 13.16\ MPa$

Basic stress is the stress which can safely be permanently sustained by clear wood.

4.3. Grade Stresses

As clear wood is not available for structural sizes, grade stress was calculated for the two properties as follow:

Bending grade stresses (MPa)

Grade $_1$ = 10.8 $\times$ 0.8 = 8.64

Grade $_2$ = 10.8 $\times$ 0.65 = 7.02

Grade $_3$ = 10.8 $\times$ 0.5 = 5.4

Grade $_4$ = 10.8 $\times$ 0.4 = 4.32

Compression parallel to the grain grade stresses (MPa)

Grade $_1$ = 13.16 $\times$ 0.8 = 10.53

Grade $_2$ = 13.16 $\times$ 0.65 = 8.55

Grade $_3$ =13.16 $\times$ 0.5 = 6.58

Grade $_4$= 13.16 $\times$ 0.4 = 5.26

These results can be summarized in table 4

Table 4.2 Grade stresses (MPa) for the two properties.

Property	Basic stress	Grade 1	Grade 2	Grade 3	Grade4	Mean Modulus of elasticity
Bending stress	10.8	8.64	7.02	5.4	4.32	6414
Compression parallel to the grain	13.16	10.53	8.55	6.58	5.26	1437

Although the mean ultimate bending stress was slightly higher than the of humid *Sclerocarya birrea* 32.7 MPa, which was recorded in Nasroun (2005), the basic stress in bending was less than expected because the number samples tested was rather small and this resulted in a large standard deviation and thereby a smaller basic stress than that of humid. The situation could change if adequate number of samples was tested. However, the results are comparable to results obtained for home-grown Pinus radiata with regards to mean ultimate bending stress (42.2 MPa) and mean ultimate compression parallel to the grain (24.1 MPa). This indicates that gafal wood could be used for light construction, light furniture for schools, offices and shoes. it was, also successfully peeled to veneer and used for match boxes and splints. it could also be used for making plywood and other wood panels.

According to a Sudanese standard prepared in SSMO for local structural timbers , the results were higher than those for gafal. In this standard *Faiderbia albida* (Haraz) wood was in the lowest strength group for structural timbers; to compare it with gafal bending grade 1, gafal was even less than grade 4 haraz. It is, therefore, risky to stress any gafal member in bending. In compression parallel to the grain, however grade 1 in gafal was better than grade 3 in haraz and, therefore, can be used as columns in light constructions, as well as in non-load bearing members.

CHAPTER Five

Conclusion and Recommendations

1-Gafal wood belongs to the lowest strength group among Sudanese the timbers.

2- According the results obtained gafal wood should not be stressed in bending.

3- Good grades of gafal , however, could be used as columns or non-load bearing members in light construction.

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إشتقاق الإجهادات التصميمية لخشب القفل النامي في ولاية النيل الأزرق في السودان

المستخلص

إستهدفت هذه الدراسة توضيح طريقة إشتقاق الإجهادات التصميمية للأخشاب وتوفير بعض المعلومات التي تساعد المهندسين في تصميم الإنشاءات الخشبية. علماً بأن الأخشاب تعتبر من المواد الطبيعية متباينة الخصائص لأنها تتأثر بعوامل كثيرة، وهذا يجعل من المهم تحديد الخواص الميكانيكية بالطرق القياسية باستخدام عينات صغيرة خالية من العيوب. ونسبه لقله الخشب الإنشائي الخالي من العيوب، فمن المهم تطبيق جميع عوامل التخفيض اللازمة للوصول إلى إجهادات التصميم. تم إختبار مقامة الإنحناء الإستاتيكي والإنضغاط الموازي للألياف لخشب القفل باستخدام عينات صغيرة خالية من العيوب باستخدام طرق قياسية للاختبارات. بعد ذلك تمت معالجة مشكلة تباين الأخشاب كمادة طبيعية ومدة التحميل وصولاً للإجهادات القاعدية. ومن ثم تمت دراسة تأثير العوامل أو العيوب المؤثرة على هذه الخصائص الميكانيكية. وبالرجوع إلى قواعد ترتيب الأخشاب حسب حجم العيوب فيها ونسبة الإجهاد المقابلة لكل عيب تم ترتيب الجهود التصميمية لخشب القفل ا في أربعة درجات بإجهادات مختلفة. أظهرت النتائج على أن الإجهاد القاعدي للإنحناء كان10.80 ميقا باسكال والإجهاد القاعدي للإنضغاط الموازي للألياف بلغ 13.16 ميقا باسكال ومن هذه الإجهادات تم حساب أربعة درجات من خشب القفل لكل خاصية وجاءت الإجهادات التصميمية للدرجات المختلفة كما يلي:

	درجة أولى	درجة ثانية	درجة ثالثة	درجة رابعة
مقاومة الإنحناء	8.64	7.02	5.40	4.32
مقاومة الإنضغاط	10.53	8.55	6.58	5.26

وأظهرت النتائج بأن خشب القفل بانخفاض كثافته وقوته يمكن إستخدامه في الإنشاءات الخفيفة كأعمدة أو الجزاء غير المعرضة للأحمال في مباني الهياكل الخشبية. كما يمكن استخدامه كمادة خام لصناعات عديدة واستخدامات عامة أخرى قياساً بكثافته المنخفضة.

Appendices:

Appendix A: Test results for static bending.

Sample Number	Maximum load(kN)	Ultimate bending stress (MPa)	Modulus of elasticity (MPa)
1	0.550	34.625	6141.475
2	0.560	34.532	6246.809
3	0.720	44.238	7068.171
4	0.480	29.999	4698.230
5	0.830	45.761	8389.315
6	0.880	30.271	7277.555
7	0.470	28.656	4639.220
8	0.770	42.776	6072.783
9	0.560	34.532	6559.149
10	0.200	28.474	2423.663
11	1.280	40.093	9202.081
12	0.560	34.782	7904.925
13	0.060	37.750	7315.227
14	0.650	40.837	7011.796
15	0.420	29.823	6361.803
16	0.360	32.395	4832.315
17	0.420	30.141	5829.043
18	0.610	38.662	7679.536
19	0.650	40.603	6009.125
20	0.640	39.856	4852.628
21	0.640	39.669	6864.122
22	0.340	40.049	7557.2
23	0.790	42.044	6582.892
Average	**0.58**	**36.5**	**6413.9**
SD	**0.24**	**5.22**	**1430.8**

Appendix B: Test results for compression parallel to the grain**.**

Sample number	**Maximum load (kN)**	**Ultimate compressive stress(MPa)**	**Modulus of elasticity(MPa)**
1	8.550	22.836	1007.034
2	10.790	28.478	1312.236
3	10.820	27.798	1645.520
4	7.470	25.797	1193.762
5	18.270	31.127	2288.061
6	14.560	38.251	1626.953
7	11.120	30.102	1599.660
8	11.210	30.126	1553.741
9	6.810	26.001	774.335
10	10.170	26.828	1582.664
11	9.930	26.316	1526.516
12	10.000	26.958	1451.513
13	6.740	28.001	935.859
14	8.470	22.390	1327.697
15	12.970	33.028	1556.342
16	9.350	24.882	1085.657
17	11.790	30.911	1462.376
18	11.270	29.654	1269.816
19	7.960	21.359	1365.402
20	7.600	20.018	1034.821
21	10.880	28.760	1803.658
22	9.370	24.769	901.735
23	9.040	23.921	949.551
24	9.040	24.589	933.621
25	10.330	27.236	1094.968
26	11.850	31.180	1394.764
27	12.070	32.539	1380.524
28	16.980	29.257	2013.317
29	9.530	25.127	1324.914
30	12.000	31.917	1574.380
31	10.730	28.613	1347.290
32	10.010	26.721	1266.456
33	9.020	24.128	1219.245
34	10.320	27.706	1952.829
35	10.170	27.632	1148.533

36	16.400	33.442	2597.538
37	10.980	29.523	1424.344
38	8.480	22.731	1183.892
39	9.600	25.054	1365.756
40	7.370	23.714	984.532
41	16.500	32.228	2484.960
42	10.670	29.433	1481.829
43	12.880	35.343	2469.348
44	11.680	30.765	1845.030
45	8.630	23.181	1151.190
46	11.530	31.050	1581.597
47	8.060	21.262	968.414
48	10.180	26.813	1510.693
49	8.480	22.416	1090.186
50	13.370	35.875	1806.273
Average	**10.6**	**27.75**	**1437**
SD	**2.56**	**4.00**	**417.4**