STRUCTURAL CHARACTERIZATION OF TIMBER SPECIES FOR ENGINEERING APPLICATIONS IN KENYA

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A thesis submitted in partial fulfillment of the requirements for the award of Degree of Master of Science in Structural Engineering of Masinde Muliro University of Science and Technology.

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DECLARATION

This thesis is my original work prepared by none other than the indicated sources and support and has not been presented elsewhere for a degree or any other award.

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance of Masinde Muliro University of Science and Technology a thesis entitled "**Structural Characterization of Timber Species for engineering applications in Kenya"**

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ABSTRACT

Timber has been a key material in construction for centuries, offering strength, durability, and versatility. In Kakamega County, Kenya, both indigenous and exotic timber species are used in construction, with cypress and eucalyptus being the most commonly utilized due to their superior strength. The selection of these species for engineering applications is influenced by factors such as availability, growth rate, and cost. However, no characterization of these timber species has been conducted.This study investigated the structural characterization of timber for engineering applications, specifically focusing on the engineering properties of cypress and eucalyptus from Kakamega County. It aimed to determine the types of species predominantly used in construction, evaluate their strength properties, and classify them into specific grades based on EC 5 standards. Field visits to forests, timber yards, construction sites, and the Kenya Forest Research Institute (KEFRI) revealed that cypress and eucalyptus were favored for construction due to their strength, with eucalyptus being more common because of its faster growth and lower cost. In contrast, Grevillea was less used due to its susceptibility to insect infestation.Logs from the two species were tested for mechanical properties, with 720 samples subjected to compression, bending, and tensile strength tests. The results classified cypress as a softwood (strength class C20), suitable for high-strength applications such as roof trusses, while eucalyptus was classified as a hardwood (strength class D24), commonly used in structural products such as railway ties and mine timbers. Understanding these properties helped optimize the use of timber in construction and ensured that the appropriate species were selected for the correct engineering applications in compliance with Eurocode 5.

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LIST OF ACRONYMS

BS 5268: British standard for timber design

CP 112: The Standard for Code of practice for the structural use of timber

CPR: Construction Products Regulations

EC5: Eurocode 5 standard for Timber design

EN 1995: European standard for timber design

EN 338: European Standard for timber

Fc: compression parallel-to-grain

Fc⊥: compression perpendicular-to-grain

Ft: tension parallel-to-grain

F_{cmax90}: Maximum compressive strength perpendicular to the grain

B: width

GS: General Structural grade

KEBS: Kenya Bureau of Standards

KEFRI: Kenya Forestry Research Institute

KS 02-771: Kenyan Standard Specification for Softwood Timber Grades for Structural Use

KS 002- Kenyan standard code

L: length

MC: Moisture content

M.O.E: Modulus of elasticity

MOPW: Ministry of Public Works

M.O.R: Modulus of rapture

NDT: Non-destructive techniques

SDT: Semi-destructive techniques

S.G: Specific gravity

SPSS: Statistical Package for Social Sciences

SS: Specific Structural grade

UTM: Universal Testing Machine

UK: United Kingdom of Great Britain and Northern Ireland

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Timber is a material prepared for use in building and other applications. It has been in use for a long period of time; for example, Noah built an ark using Gopher wood in 3000 BC. As stated in Genesis 6:14: “Make thee an ark of gopher wood; rooms shalt thou make in the ark, and shalt pitch it within and without with pitch” (King James Bible). Timber can be used for beams and columns, as well as floors and roofing. Advancements in the variety of accessible timber components and their usage in diverse structural aspects have occurred alongside rapid developments in building engineering over the years.

Modern structural designers are able to attain the efficiency and integrity in building structures required today due to the availability of new and innovative timber-based materials (Jimoh et al., 2017). Timber is one of several materials available to construction engineers and is marketed as an environmentally friendly alternative to other building materials like steel and reinforced concrete (Hu et al., 2019). Timber is a good eco-friendly building resource because it is renewable, organic, and natural. It has minimal embodied energy and serves as a carbon sink. Both concrete and steel require significantly more energy to process compared to converting trees into structural timber. Furthermore, timber is exceptional due to its resistance to corrosion (Hu et al., 2019). The degradation of steel thickness and integrity, or the exposure of reinforced concrete, may occur as a consequence of abrasion and corrosion, which is seldom the case with timber (Rajeev et al., 2019).

1.1.1 Structural Grading of Timber

Structural grading is the process by which timber is sorted into groups and stress grades with similar structural properties in each group (Ridley-Ellis et al., 2016). Structural grading is essential in ensuring that timber meets the requirements for structural integrity, durability, and strength. Typically, structural grading involves grouping timber into stress grades with comparable structural attributes (Ridley-Ellis et al., 2016). This grading provides fundamental details regarding the durability of structural timber, as well as the applicable requirements. Each piece of timber is evaluated using a precise set of guidelines. The regulations are developed by matching the strength properties of graded timber to characteristics determined through laboratory testing. Timber should not be used structurally in construction if it is not strength graded.

Timber, a traditional structural material, has been employed for extensive periods. Amidst the rapid evolution in construction practices, there have been concurrent advancements in various types of timber components and their utilization in structural applications. The contemporary era witnesses the availability of new, sophisticated timber products, providing structural engineers with the means to meet the performance and efficiency requirements of modern building designs (Hanhijarvi et al., 2005). In Kenya, the structural design of timber follows Eurocode 5 guidelines. However, it is noteworthy that the grading in Eurocode 5 was conducted using North American and UK machinery and tree species from those regions (Ridley-Ellis et al., 2016). These trees experience different environmental conditions (e.g., climate, soil) compared to those in Kenya, resulting in variations in growth rates and nutrient composition. Trees that develop in varying climatic conditions possess distinct properties and strengths, which can lead to misclassification during design and potentially cause structural failure (Ramage et al., 2017).

On the other hand, the Kenyan Standard Code of design has heavily borrowed from UK standard codes (Al-Ansari et al., 2014). However, it lacks National Annexes to provide local parameters for design. Consequently, research is necessary to establish grading properties for local tree species to obtain locally relevant design parameters. Such research will help address challenges encountered in the construction industry, including structural defects and failures.

Timber stands out as a natural resource in contrast to other structural materials like reinforced concrete and steel. It boasts commendable ecological attributes, being both natural and renewable, while also serving as a carbon sink and possessing low embodied energy. The energy required to convert trees into structural timber is significantly lower than that needed for steel and concrete. A distinctive quality of timber is its resistance to corrosion, which, when coupled with abrasion, can lead to steel thickness loss or exposure of concrete reinforcement (Rajeev et al., 2019).

Timber species are categorized into two types: softwoods and hardwoods, as shown in Table 1.1. Softwoods (Figure1.1) are derived from coniferous trees, while hardwoods (Figure 1.2) originate from deciduous trees. Hardwoods generally have higher density than softwoods. The Structural Timber Association notes that softwood is commonly used in timber structures due to its ready availability, ease of manipulation, cost-effectiveness, and rapid growth rates (Ramage et al., 2016). Hardwoods, on the other hand, are utilized in exposed structures and cladding applications where durability and specific aesthetic characteristics are essential (Hoover et al., 2017).

Table 1.1Tree species found in Western Kenya

NO.	Name of species	Type of wood
1	Cedar	Softwood
2	Eucalyptus	Hardwood
3	Cypress	Softwood
4	Bamboo	Hardwood
5	Neem tree (Mwarubaini)	Hardwood

Source: (Kenya Forestry Research Institute [KEFRI], 2010)

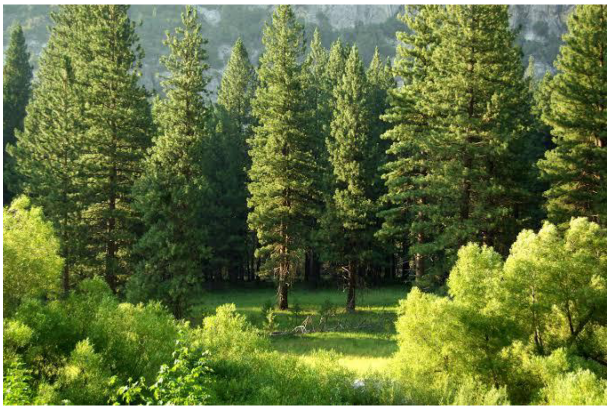

Figure 1.1 Exotic tree species in Kakamega forest(www.trees.com)

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Figure1.2 Eucalyptus tree species (www.botanicals.com)

1.1.2 Characteristic strength

Characteristics such as strength, stiffness, and density play a crucial role in the design of load-bearing structures. Additionally, physical attributes related to moisture content, shape, and appearance are integral aspects of overall quality (Ridley-Ellis et al., 2016). Generally, structural timber undergoes classification into specific strength classes, as exemplified in standards like BS5268-2:2002 and BSEN338. This classification is based on prescribed characteristic values, wherein each timber strength class is associated with specific values for relevant material properties. Timber categorized into a strength class is commonly referred to as a timber grade. The graded material is then introduced to the market (Al-Taie et al., 2014).

Due to insufficient knowledge on tree species, durability and strength characteristics, and the building elements required for safe construction and design, some engineers have been hesitant to use timber as a structural material (Rubik et al, 2009). This has led to increased opposition to the use of wood for long-term constructions.

When designing load-bearing structures, designers pay close attention to the material's stiffness, strength, and density (Hu et al., 2019). The physical characteristics of appearance, form, and moisture retention are also essential standards for quality. This highlights the need for timber to meet standards for structural integrity, durability or strength.

The Construction Products Regulations (CPR) mandate that all timber products bear the structural integrity mark and be supported by a Declaration of Performance (DoP), in light of the harmonisation of the major strength grading standard (Ridley-Ellis, 2016). The Eurocodes for structural design has been largely applicable in the design of timber buildings in Europe and several parts of the world. Although Kenyan structural timber design is based on Euro code 5, the grading in that standard was carried out using North American and UK testing equipment and their tree species, which may be different from the Kenyan context. In Kenya, particularly western Kenya, grading and characterising timber species for structural uses has lagged behind other regions of the world. Since Kenya's soils, climate, and environmental activities differ from those of the UK's, for instance, Kenya has a tropical climate with a temperature range of 21°C–27°C while the UK has a maritime climate with a temperature range of 10°C–23°C (Blab et al, 2017). As a result, trees of the same species that are cultivated in several locations may have some physical and chemical differences. In Kenya, compared to the countries on which the Euro code 5 originated, the differences in environmental and climatic factors affect pace of development, maturity, and nutrient composition of trees. Additionally, there are no National Annexes to give design guidelines for the local area. Consequently, in order to determine local specifications, research on the grading characteristics of local tree species is required. These will aid in addressing issues brought about by the construction sector, such as the reasons behind structural flaws.

Kenyan Standard Specification for Softwood Timber Grades for Structural Use, KS 02-771:1991, considers the visual stress grading method as the primary method for grading of timber in Kenya. The fundamental stresses of the small samples are converted to grade stresses through the application of the KS 02-771 strength ratios. In accordance with KS 02-771, there are two standard structural timber grades: General Structural grade (GS) and Specific Structural grade (SS). The strength ratios for KS 02-771 and BS 4978 visual strength grades are the same. The grades of laminated timber have also been established. The code permits a modest amount of variation in grading because it depends on the graders' individual experiences, which can vary. The code KS 02-771 or the explanatory notes on the code16, a report by the MOPW that also provides the assessment method for factors affecting strength, provide all the information on the grading procedure.

Currently, Kenya does not have an exclusive code of practice for grading and characterisation of timber structures, allowing for flaws in the classification process. Ordinarily, each code of conduct or standard is solely applicable to the country or countries for which it was formed because timber is a natural and varied material. The Kenya Bureau of Standards (KEBS) is responsible for creating, disseminating, promoting, and enforcing standards in Kenya. To help with the creation of timber standards, this body has established a panel for standardisation that includes representatives from universities, the Ministry of Public Works, and any other interested parties, like the building sector. However, KEBS has no clear standard guideline since the code of practise for the use of timber in structures is currently at the drafting stage. The related British standards have been frequently cited in the Kenyan timber codes that have already been produced and those that are still in the drafting stage. For instance, the Kenyan Standard Specification for Grading Softwood Timber for Structural Use, or KS 02-771, is quite similar to the British equivalent code, BS 4978. The code permits a modest amount of variation in grading because it depends on the graders' individual experiences, and which can vary.

This study thus focuses on the structural characterisation and grading of timber based on their strengths and properties. With an emphasis on tree species from Kakamega forest in Kakamega County in Western Kenya (due to the tropical climate), the study sought to establish the engineering strength properties of soft and hard wood timber species, mainly the eucalyptus, cypress and the neem trees, based on their popularity in building and construction. Eventually, the study compared the resultant grades of the tested species from Kakamega forest with similar specie grades already established in the Euro code 5 standards

1.2 Problem Statement

Structural Timber Design in Kenya should be based on Euro code 5 however the grading in EC 5 was done in accordance with North American and UK strength testing equipment and tree species from the same region(Ridley-Ellis et al., 2016). These trees are exposed to different kind of environment (e.g., climate, soils etc.) compared to that of Kenya, therefore the rate of growth maturity and nutrient composition varies. Trees grown from different climatic conditions will exhibit different properties and strength, hence may lead to wrong classification during design, which may in turn lead to the structural failure. On the other hand, the Kenyan Standard Code of design has heavily borrowed from UK standard codes (Al-Taie et al., 2014). It also lacks National Annexes to provide local parameters for design. Therefore, there is need for research to be conducted on grading properties of local tree species in order to obtain local design parameters. These will help to address the problems caused in the construction industry such as: structural defects and failures. For example; in Kenya; Splitting and cracking of wooden power transmission poles have been reported in Kenya and other countries, leading to financial losses and risks if it happens while the pole is in service (Muthike & Ali, 2021; Mugabi & Thembo, 2018).

Characterization and grading of timber species for structural applications have been limited in Kenya, especially western Kenya compared to other parts of the world. Since Kenya has climate, soils and environmental activities different from that of UK, for example, Kenya has tropical climate whose temperature ranges from 26ºC-27ºC while UK has a temperature maritime climate that ranges from 10ºC-23ºC. This means that tree of similar species grown from different areas may exhibit some difference in physical and chemical characteristics. Strength grading of timber in Kakamega county will help to identify and reject the poorer species of timber to in order to improve and guarantee the properties of what is passed. It is therefore necessary to do tests on properties of timber from tropical region and characterize them accordingly. Therefore, this research aimed at characterization and grading of timber species from Western Kenya) and compare with relative strength grades according to EN 1995-1-1: 2004+A1, Euro code 5.

1.3 Research Objectives

1.3.1 Main Objective

The main objective of this study is to structurally characterize timber species for engineering applications in Kenya

1.3.2 Specific Objectives

i. To establish the variety of tree species applied in the construction industry in Kakamega County.
ii. To determine the strength properties of cypress and eucalyptus timber species from Kakamega County
iii. To characterize cypress and eucalyptus timber species to specific grades based on EC 5, from Kakamega County for engineering applications.

1.4 Research Questions

i. Which timber species are used in construction in Kakamega County?
ii. What are the strength properties of eucalyptus and cypress timber species from Kakamega County?
iii. What are the characteristic grades of eucalyptus and cypress timber species?

1.5 Justification of the Study

Kenya, with a burgeoning population nearing 50 million, is experiencing substantial urbanization as citizens migrate from rural to urban areas in pursuit of higher-paying opportunities amid economic growth. This shift has generated a demand for increased housing in cities like Nairobi, Mombasa, and Kisumu (Masyuko, 2020). Recognizing this housing need, the Government of Kenya (GOK) has prioritized Affordable Housing as one of its top four concerns, aiming to add 500,000 homes over the next five years (Mary, 2020). To achieve this goal, the use of low-cost construction materials, such as timber, is envisioned due to its environmental friendliness, cost efficiency, ease of use, strength, and durability. Timber finds application in various construction elements, including beams, columns, piles, rafters, falsework, scaffolding, and formwork.

In adherence to Article 42 of the Constitution (2010), which guarantees citizens a clean and healthy environment, attention must be given to how buildings are planned, designed, and constructed. Timber design is a crucial aspect of construction, warranting further research into local timber, considering the empirical nature of many design parameters and expressions. The physical and mechanical properties of timber vary widely, not only between species but also within the same species across different environments. Strength grading, as outlined by Ridley-Ellis et al. (2016), becomes essential to ensure the safety and economical use of structural timber.

In Kenya, the grading of trees follows a system set by the UK technical committee for Building and civil engineering structures, leading to potential variations in physical and chemical characteristics, especially given the differing climates of the two regions. The study emphasizes the importance of investigating the physical and mechanical properties of timber in Kakamega County to enhance the identification and rejection of inferior timber species, ultimately guaranteeing the desired properties in the approved materials. Despite the global advancements in timber products for structural engineering, Kenya lags behind in structural characterization and engineering grading of timber species, prompting the necessity for localized research to address climate and environmental differences. This will help to avoid wrong classification which affects the design process. When the design process is messed up with, it leads to wrong construction which in turn leads to structural defects. These defects when full grown may cause structural collapse hence loss of lives and property. It is therefore necessary to do tests on properties of timber from tropical region and characterize them accordingly. Therefore, this research is aimed at characterization and grading of timber species from Kenya, and compare with relative strength grades according to EN 1995-1-1: 2004: Eurocode 5 for structural applications.

1.6 Significance of the Study

Understanding the characteristics of timber and its grading is crucial for making informed choices regarding its suitability for specific purposes (Lightaddmin, 2020). These properties are influenced by factors such as the timber species, growth conditions, and processing methods. Evaluation of key properties is essential to ensure both the safety of buildings and the economical use of the material (Ellis, 2020). By identifying and rejecting inferior timber species, the overall quality of approved materials can be enhanced and guaranteed. Such insights empower structural engineers to meet the contemporary demands for performance and efficiency in building designs.

1.7 Scope of Work

This study focused on the structural characterization and grading of timber based on its strengths and properties. The research primarily examined tree species from Kakamega Forest in Kakamega County, Western Kenya, due to its tropical climate. The study aimed to establish the engineering strength properties of softwood and hardwood timber species, mainly eucalyptus, cypress, and neem trees, as these species were widely used in construction. The research involved testing these species for their mechanical properties, comparing them with strength grades in Eurocode 5, and evaluating their suitability for structural applications. The findings contributed to the establishment of standardized grading criteria for timber in Kenya and enhanced the use of locally available materials in construction.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

The physical and mechanical attributes of wood exhibit significant variability, not only across different species but also within the same forest, among trees of the same forest, and even within an individual tree. For structural timber, it is imperative to assess specific key properties to ensure building safety and the economical utilization of the material, a process known as strength grading (Lightaddmin, 2020). The mechanical and physical properties of timber can differ widely not only between different species but also within a single species, particularly in the case of fast-growing timber like Sengon, which possesses a notable range of properties (Lightaddmin, 2020).

In the European context, structural grading follows the guidelines outlined in the European standard EN 14081-1:2016, categorizing timber into distinct strength grades. These grades are determined by collective characteristic properties, with D-classes referring to deciduous trees and C-classes to coniferous trees, and a common European structural grade being C24 (Lightaddmin, 2020). Timber, a traditional structural material, has witnessed advancements in various components and applications, with new advanced products enabling engineers to meet contemporary demands for performance and efficiency (Ridley-Ellis et al., 2016).

Timber assigned to a specific strength class, such as BS5268-2:2002 or BSEN338, undergoes classification based on prescribed characteristic values for relevant material properties. Such classified timber is referred to as a timber grade, and it is introduced to the market as a graded material. Understanding timber properties and grading is crucial for making informed choices in selecting the material for specific purposes, considering variations influenced by species, growth conditions, and processing methods (Lightadmin, 2020). Grading is the realistic means of ensuring quality within desired limits for timber, as opposed to other materials like steel, concrete, plastics, and wood fiberboard, where material quality is achieved through altering raw material composition or environmental conditions. In summary, comprehensive knowledge of timber properties and grading is essential for the optimal selection of timber for various applications (Ambrose et al, 2009)

Timber strengthening and grading according to EN 1995-1-1(2004): Eurocode 5, is based on four key grade determining properties; Strength, Stiffness, Density moisture content and Specific gravity

The physical properties (moisture content and density) and mechanical properties (strength properties and stiffness properties) are determined in the laboratory and machine grading of the timber species carried out. The properties will be determined according to EN 1995-1-1(2004).

2.1.2 Uses of timber in construction

Timber is a structural material with structural applications. It is used as sawn wood, veneers and plywood and fiberboards i.e. Timber framed buildings, fencing and floorboards, furniture, pallets, light construction works like doors, windows, flooring and roofing (Ambrose et al, 2009) as shown in figure 2.1.

Figure 2.1 Structural use of timber (DeStefano, 2019.)

When constructing railway sleepers, fencing poles and gates, timber plays takes a permanent role in the construction. Other temporary works such as scaffolding, centering, shoring, strutting and permanent materials also requires timber.

According to the Kenya Forestry Research Institute (KEFRI), uses of timber have been classified into five categories: construction, furniture/joinery, poles/posts, tools/implement handles and others. Some of tree species used in construction include: Apodytes dimidiate, Euchalyptus saligna,Cassipourea malosana, Croton megalocarpus,Dodonaea angustifolia, Euchalyptus regnans,Euchalyptus grandis, Euchalyptus paniculata, Harungana madagascariensis, Hymenaea verruccosa, Julbernardia magnistipulata, Cupressus lustanica, Cymometra webberi among many others. In construction industry, timber is majorly used for roofing, scaffolding and door frames. Different timber species are used for different purposes for example, cypress is used for roofing, and mahogany is used for door frames while mangrove (round poles) is used for scaffolding.

2.1.3 Advantages and disadvantages of timber

Wood remains a favored construction material due to a range of advantages. Its exceptional strength-to-weight ratio, surpassing that of concrete and steel, makes it a preferred choice. Wood can be easily shaped and machined with low energy consumption, and jointing is achieved effortlessly using simple fastening devices. Additionally, wood exhibits low heat conductivity, effectively insulating against electricity, and boasts good acoustic properties. It is resistant to oxidation, withstands mild concentrations of acids, and experiences minimal thermal contraction and expansion. With its global availability at affordable prices and status as a renewable resource, wood stands out in construction. However, considerations are essential due to its hygroscopic nature, anisotropic properties, susceptibility to burning and decay, and variable structure influenced by factors like species, age, heredity, and growth conditions. These factors emphasize the need for careful considerations when utilizing wood in construction projects (Mukui, 2001).

However, some disadvantages of timber include shrinking and swelling with moisture changes, damage by fire if not treated, and is vulnerable to pests (Parinas, 2018).

2.1.4Test specimens

2.1.4.1 Eucalyptus

Eucalyptus wood is also known as eucalyptus hardwood and is one of the fastest growing trees in Kenya. It is gorgeous, environmentally friendly, easy to work with and incredibly practical. It is less expensive compared to mahogany, hickory, cherry woods etc. Eucalyptus is a strong, durable and sustainable material. It is the most commonly used wood species on Kenyan construction industry. Ramage et al. (2017) discuss the potential of using timber, including eucalyptus, in modern construction. They highlight wood's favorable strength-to-weight ratio and its renewability as a building material. Eucalyptus can be used in construction of shade structures and also can be used to make a delightful roof for an outdoor dining area of retreat parks.

2.1.4.2 Cypress

Cypress is yellowish brown softwood with a straight grain and medium texture to coarse texture. It is durable and a good rot resistance material. It has a good gluing, finishing and paint-holding properties. Philokyprou et al. (2017) describe the cypress tree (Cupressus spp.) in relation to its significance in architecture, cultural heritage, and landscaping, particularly in Mediterranean regions like Cyprus. Cypress trees are known for their tall, slender form, evergreen foliage, and resilience to harsh climatic conditions. It is commonly used as; Exterior construction, Docks, Boat-building, Interior trim, Veneer, Ceiling making etc.

2.2 Structural Timber Properties and Characterization

Saporiti et al, 2011 carried out an investigation on Assessment of the structural properties of timber members in situ – a probabilistic approach. They carried out assessment of the structural performance of existing timber structures. The author discussed the possibilities/advantages of using a probabilistic approach to obtain a more reliable prediction of the reference properties of these timber members in situ. The presented approach combined information from common non-destructive techniques (NDT), such as visual assessment and ultrasounds, and those from semi-destructive tests (SDT), as meso-tension specimens and wood cores. An application of this approach to maritime pine (Pinus pinaster Ait.) and chestnut (Castanea sativa Mill.)

timber pieces of structural dimension was presented. The study was dependent on the capacity to evaluate the physical and mechanical properties of structural timber elements in situ.

Jimoh et al, 2017 also carried out an investigation on “Characterization and grading of two selected timber species grown in Kwara state Nigeria.” The investigation was carried out in Nigeria and *Azadirachta indica* and *Xylopia aethiopica* species were used. Basic physical properties of the samples like moisture content, specific gravity and density were determined. Tensile strength, modulus of rupture, modulus of elasticity, compression, shear and hardness were the mechanical tests carried out according to BS 373 (1957), CP112 (1971), NCP2 (1973), and BS 5268. A. Indica was graded into strength class D40 while X. Aethiopica was grade into strength class D70. The author recommended more research work for determining the suitability of other widely grown trees in Nigeria for use as structural timbers in construction.

Mukui A.K, 2001 examined “Variability of engineering strength properties of Kenya pines.” He did investigation on Kenyan Pines from the central part of Kenya. The author carried out investigations on effects of moisture content on the strength of timber and the size factor on timber strength. The theoretical part of the study covered the review of strength testing and results obtained by others and the properties of wood and timber as an engineering material. Various strength properties were studied together with the effects of strength educing defects. The author derived basic stresses for the timber according to BS 373.

The Kenya Forest Research Institute (KEFRI) examined strength properties and groups of major commercial timbers grown in Kenya. The strength properties (based on two physical and four mechanical parameters) were assessed for 49 timber species grown in Kenya based on small clear specimens. Data on mean values were computed from which other statistical information on minimum, mean and maximum strength values were generated. The relationships between physical and selected mechanical properties were also analyzed using regression analysis. The species were further classified into four strength groups based on a method developed in Australia. The results confirmed the influence of moisture content and specific gravity on strength properties. There was an observed increase in specific gravity and mechanical strength properties on drying, a fact which favors the use of dry timber. The results also confirmed that both specific gravity and stiffness are useful in predicting strength properties of timber. The results obtained are shown in table 2.9.

The Kenya Forest Research Institute (KEFRI) also examined Variation in Wood Density and Strength Properties among Markhamia Lutea (Sprague) Half Sib Families from Western Kenya.Wood samples of forty two (42) half sib families of *Markhamia lutea* were drawn from a 4-year old progeny test at Kakamega and assessed for variation in wood properties. The mother plus trees had been selected from partially isolated populations in the Lake Victoria belt of Kenya. The main objective of the progeny trial was to test breeding values for various traits, including wood properties, of the selected trees for advanced breeding and to estimate genetic parameters. Incomplete block design in 3 replications with 8 tree line plots was used. Results on growth performance and stem straightness revealed significant variations in diameter and height and no significant variation in stem straightness among the progenies, (ICRAF,1996) The study reported here involved analysis of wood specific gravity, bending strength (modulus of elasticity [MOE] and modulus of rupture [MOR]), compression (crushing) strength. Wood samples for specific gravity determinations were obtained at 1.3 m height. Other properties were based on the butt logs. Specific gravity was determined using the water displacement method (Brown et al, 1952) while the other properties were determined according to British Standard No. 373:1957. No significant differences ($P < 0.05$) were obtained for all the properties studied. Averages for specific gravity were highest for South Nyanza provenance and lowest for Busia provenance. The range in specific gravity was 0.37-0.44 (18.9%) while the ranges in strength values were: MOR 67.7-85.3 MPa (26.0%) and compression 31.9 - 40.9 MPa (28.2%). It was concluded that at 4 years, selection can be done for height and diameter but little gain may be expected from provenance and individual tree selection for specific gravity and strength properties. It was recognised that the reported results relate to juvenile assessments (rotation age for this species is about 40 years). It is therefore recommended that these studies be repeated at later ages towards half rotation age.

Oubedoulaye et al (2017) examined "Mechanical Characteristics of Kenyan Borassus Aethiopum Mart timber as Reinforcement for Concrete." The researcher examined the mechanical properties of Borassus Aethiopum Mart timber and the adhesion of the Borassus concrete interface. The results of tests conducted on the upper and lower parts of the wood of Borassus Aethiopum Mart from Kenya show compressive strengths of 56.551 ± 18.247 MPa and 60.730 ± 12.84 MPa, shear strengths of 7.657 ± 3.009 MPa and 8.131 ± 1.713 MPa, 12.4 kN and 5.41 kN in hardiness for the moisture content of 29.495 ± 6.685% and 21.274 ± 1.647% and a density of 802 ± 101 kg / m3 and 965 ± 24 kg / m3. Young's moduli and breaking stresses are 3387.27 MPa and 108.23 MPa for the lower part and 3167.11 MPa and 77.65 MPa for the upper part. The pull-out test results reveal that the adhesion stress at the Borassus-concrete interface is 2.021 MPa.

Most of the researchers focused on the properties of timber, variation of physical and mechanical properties and the property relationships of a few selected commercial timber species. The characteristic strength of these properties was not determined hence grading was not done. On the other hand, species were neither graded nor recommended for engineering applications.

2.3 The Need to Develop Local Parameters for Structural Design

The building code functions as a legal document, establishing a baseline for safety and health standards in constructions to ensure the public resides in secure buildings. Recognizing the paramount importance of constructing buildings under safe conditions dates back to ancient civilizations. Various countries around the world have encountered diverse disasters such as fires and earthquakes, prompting builders to devise methods for secure construction to avert disasters. Over time, these methods evolved into codes and standards. Since the mid-20th century, many countries have formulated local codes (Al-Taie, 2014).

As an example, Kenya's construction standards are encapsulated in KS CODE 009, a framework currently acknowledged having several deficiencies. The emphasis has predominantly been on explicating principles pertaining to the development, adoption, and implementation processes of the code (Al-Taie et al., 2014; Fashina, Sheikh, Fakunle, & Opiti, 2020). Notably, the Kenyan Standard Code of design heavily draws inspiration from UK standard codes and notably lacks National Annexes that would provide local parameters for design considerations. Therefore, there is a pressing need for research, particularly on grading properties of local tree species, to establish local design parameters.

2.4 Timber Strength Grading in Kenya

Like many engineering materials, the structural application of timber is regulated by specific codes of practice and standards that have evolved through extensive testing and accumulated experience. Due to the inherent natural variability of timber, each code or standard is designed for applicability to the specific country or countries for which it was developed. While codes of practice from one region may be adopted for use in other regions, this should be approached with caution and necessitate certain modifications to accommodate variations in material quality, grading, technological levels, jointing, and workmanship.

Notably, the Kenyan timber codes, both existing and in draft form, have drawn extensively from their corresponding British standards. For example, KS 02-771, the Kenyan Standard Specification for Grading Softwood Timber for Structural Use, shares similarities with the equivalent British code, BS 4978, in many aspects.

The primary method used to evaluate the quality of timber in Kenya is the visual stress grading technique outlined in KS 02-771:1991, the Kenyan Standard Specification for Softwood Timber Grades for Structural Use. In this approach, strength ratios are applied to fundamental stresses derived from small clear specimens to determine grade stresses. KS 02-771 has established two standard grades for structural timber, namely, the General Structural grade (GS) and the Specific Structural grade (SS). Notably, the strength ratios employed in KS 02-771 align with those used in BS 4978 visual strength grades. While the code allows for a minor deviation in grading, this flexibility is contingent upon the experience of the graders, which may vary. Comprehensive details regarding the grading process can be found in the KS 02-771 code or in explanatory notes provided in a report by the MOPW (Ministry of Public Works), which also details the method for assessing factors influencing strength.

2.6The flaws in the Kenyan Timber code of Design

Due to the inherent natural variability of timber, each code of practice or standard is specifically designed for the country or countries it was developed for. In Kenya, the Kenya Bureau of Standards is responsible for the development, publication, sale, and enforcement of standards. To aid in the preparation of timber standards, this body has established a timber standardization panel comprised of members from universities, the Ministry of Public Works, and other stakeholders like the construction industry. Currently, a draft Kenyan code of practice for the structural use of timber is under development.

The existing Kenyan timber codes, including those in the draft stage, have drawn extensively from corresponding British standards. For instance, KS 02-771, the Kenyan Standard Specification for Grading Softwood Timber for Structural Use, bears similarities to the equivalent British code, BS 4978, in various aspects. The code acknowledges a slight deviation in grading, recognizing that it depends on the experience of graders, which may vary.

2.7 Factors Affecting Timber Strength

Factors affecting strength of timber include: knots, rensin and pockets, fissures, wormholes, distortion of shape, and wane. Knots interrupt the continuity of the fibers and thus reduce timber strength Rensin and pockets; these tubular spaces formed by separation of secreting cells. Bark pockets are formed when bark is enclosed in a tree trunk. Fissures; these are commonly known as splits, checks and shakes and elsewhere cracks. Slope of the grain; The tendency of fibres of certain trees tends to grow around the pith in a spiral formation thus angling away from the true vertical. This has serious implication on the strength and stability of the timber converted from such trees. In some trees, the pith may not be straight but may ‘wander’ significantly.

Wormholes are acceptable in timber as long as they do not compromise the strength to a degree that jeopardizes the timber's performance. Active infestation is not permitted, and wood wasp holes are prohibited. Inherent abnormal defects are faults originating in certain timbers during tree growth. In softwoods, compression wood is the primary concern, while hardwoods may exhibit tension wood, thunder shake, and brittle heart. Any such abnormalities posing a risk of significant strength reduction should result in rejection. However, if the strength reduction is visibly less than that caused by accepted defects in the grade and the defect won't progress post-conversion and drying, the piece may be accepted.

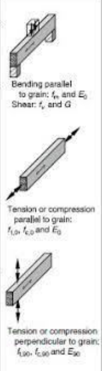
Excessive distortion of shape, including bowing, springing, twisting, or cupping, warrants rejection. Wane, the unsawn part typically found on timber edges, is generally not extensive enough on timber used for structural purposes to significantly diminish strength. However, if a specified cross-section is absent, some strength loss occurs. Wane is measured as a fraction of the surface dimension, accounting for occurrences on both surfaces when present. Both surfaces must be checked.

2.8 Grade classes

The European system outlines twelve strength classes for sawn softwood timber, denoted as C14, C16, C18, C20, C22, C24, C27, C30, C35, C40, C45, and C50 as shown in table 2.1. The numerical value following "C" signifies the characteristic value of bending strength for timber species graded in that specific class. Similarly, hardwood timber has classes D18, D24, D30, D35, D40, D50, D60, and D70, with "D" indicating the characteristic value of bending strength (in MPa) for timber pieces graded in each class. The characteristic value, denoted with subscript "k," represents the fifth percentile value, ensuring that 5% of graded pieces may have a lower strength than the indicated value, and at least 95% exceed it. To enhance safety, an additional material safety factor of 1.3 is applied to structural timber. Another safety factor addresses load uncertainty. Beyond (1) bending strength requirement, the European system (EN 338, CEN 2003a) establishes criteria for two other properties: (2) density (characteristic value) and (3) bending stiffness (mean value of modulus of elasticity [MOE]). These three properties, collectively termed grade-determining properties, are crucial in the classification of timber.

Table 2.0.1 Strength classes of timber according to EN 338

	Strength class	Characteristic strength properties (N/mm²)						Stiffness properties (kN/mm²)				Density (kg/m³)	
		Bending ($f_{m,k}$)	Tension 0 ($f_{t,0,k}$)	Tension 90 ($f_{t,90,k}$)	Compression 0 ($f_{c,0,k}$)	Compression 90 ($f_{c,90,k}$)	Shear ($f_{v,k}$)	Mean modulus of elasticity 0 ($E_{0,mean}$)	5% modulus of elasticity 0 ($E_{0,05}$)	Mean modulus of elasticity 90 ($E_{90,mean}$)	Mean shear modulus (G_{mean})	Density (ρ_k)	Mean density (ρ_{mean})
Softwood and poplar species	C14	14	8	0.4	16	2.0	3.0	7.0	4.7	0.23	0.44	290	350
	C16	16	10	0.4	17	2.2	3.2	8.0	5.4	0.27	0.50	310	370
	C18	18	11	0.4	18	2.2	3.4	9.0	6.0	0.30	0.56	320	380
	C20	20	12	0.4	19	2.3	3.6	9.5	6.4	0.32	0.59	330	390
	C22	22	13	0.4	20	2.4	3.8	10.0	6.7	0.33	0.63	340	410
	C24	24	14	0.4	21	2.5	4.0	11.0	7.4	0.37	0.69	350	420
	C27	27	16	0.4	22	2.6	4.0	11.5	7.7	0.38	0.72	370	450
	C30	30	18	0.4	23	2.7	4.0	12.0	8.0	0.40	0.75	380	460
	C35	35	21	0.4	25	2.8	4.0	13.0	8.7	0.43	0.81	400	480
	C40	40	24	0.4	26	2.9	4.0	14.0	9.4	0.47	0.88	420	500
	C45	45	27	0.4	27	3.1	4.0	15.0	10.0	0.50	0.94	440	520
	C50	50	30	0.4	29	3.2	4.0	16.0	10.7	0.53	1.00	460	550
Hardwood species	D18	18	11	0.6	18	7.5	3.4	9.5	8.0	0.63	0.59	475	570
	D24	24	14	0.6	21	7.8	4.0	10.0	8.5	0.67	0.62	485	580
	D30	30	18	0.6	23	8.0	4.0	11.0	9.2	0.73	0.69	530	640
	D35	35	21	0.6	25	8.1	4.0	12.0	10.1	0.80	0.75	540	650
	D40	40	24	0.6	26	8.3	4.0	13.0	10.9	0.86	0.81	550	660
	D50	50	30	0.6	29	9.3	4.0	14.0	11.8	0.93	0.88	620	750
	D60	60	36	0.6	32	10.5	4.5	17.0	14.3	1.13	1.06	700	840
	D70	70	42	0.6	34	13.5	5.0	20.0	16.8	1.33	1.25	900	1080



Subscripts used are: 0, direction parallel to grain; 90, direction perpendicular to grain; m, bending; t, tension; c, compression; v, shear; k, characteristic.

2.9 Tree Species Found in Kenya According to Kenya Forestry Research Institute (KEFRI)

The table 2.2 shows the local names, trade names, scientific names and some properties of some of tree species grown in Kenya according to Kenya Forestry Research Institute (KEFRI)

Table2.0.2Kenyan timber species

Tribe	**Local Name**	**Trade Name**	**Tree Types**	**Scientific Name**	**Density(g/cm^3)**	**Mor(Mpa)**
Luo	Bao	Sidney bluegam, saligna gam	Exotic	*Euchalyptus saligna*	0.65	111
Luhya	Mudarakwa	Mexican cypress	Exotic	*Cupressus lusitanica*	0.46	68
Luhya	Wakhuisi	Grevillea, silky oak	Exotic	*Grevillea robusta*	0.54	56
Luhya	Mutere	Musizi	Indigenous	*Measopsis eminii*	0.72	133
Luhya	Liembe	Mango	Exotic	*Mangifera indica*	0.71	Medium/low
Luhya	Lusiola	Lusiola	Indigenous	*Markhamia lutea*	0.57	80.1
Kisii	Omobunduki	Pine	Exotic	*Pinus radiate*	0.49	65
Kikuyu	Muiruthi	Lusui , Giant diospyros	Indigenous	*Diospyros Abyssinica*	0.48	86

Maasai	Olerai	River acacia	Indigenous	*Acacia elatior*	0.84	-

2.10 Properties of timber

Table 2.3 presents mechanical properties of various wood species, focusing on their static bending and compression grain characteristics. The data includes:Species: The type of wood tested,S.S (Strength Scale): A relative strength rating,M.C (%) (Moisture Content): The percentage of water present in the wood, S.G (Specific Gravity): A measure of wood density compared to water, M.O.R (Modulus of Rupture in MPa): Indicates the maximum bending stress before failure, M.O.E (Modulus of Elasticity in MPa $\times 10^3$): Represents wood stiffness, S.S (Shear Strength): Wood's resistance to shear forces and C.S (Compression Strength in MPa): The wood's ability to resist compression along the grain. Each species demonstrates unique mechanical properties, making them suitable for different structural and load-bearing applications.

Table2.0.3Timber properties according to KEFRI

	STATIC BENDING					**COMPRESSION**	
SPECIES	**SS**	**M.C(%)**	**S.G**	**M.O.R(Mpa)**	**M.O.E(Mpa $\times 10^3$)**	**S.S**	**C.S(Mpa)**
Euchalyptus saligna/grandis	22	12.0	0.651	110.6	10.4	27	62.9
Cupressus macrocarpa	12	9.5	0.433	69.5	8.4	12	43.1
Azandiracta indica	5	12.0	0.699	86.3	9.974	6	58.932

Euchalyptus globulus	6	12.0	0.734	106.3	10.5	6	54.9
Euchalyptus fastigata	6	10.34	0.608	101.519	13.921	6	71.179
Euchalyptus telegnaisis	4	10.4	0.511	80.051	9.69	6	51.93
Acacia decurrens	3	12.0	0.848	120.9	14.1	4	74.9

2.11 Research Gap

Most existing studies have primarily focused on the physical and mechanical properties of timber, investigating variations across different species and regions. These studies have also explored the relationships between strength properties and influencing factors such as moisture content, density, and specific gravity. However, there remains a significant gap in research regarding the comprehensive grading of indigenous timber species in Kenya for structural applications. Although some investigations have been conducted on selected timber species, the characteristic strength values essential for strength grading have not been determined comprehensively. Additionally, current research has not adequately addressed the development of local grading parameters tailored to Kenya's construction industry. The absence of a well-established timber grading system specific to Kenya leads to reliance on foreign standards, which may not fully account for the variability in local tree species. This highlights the necessity for further research aimed at grading local timber species and establishing robust design parameters to enhance structural reliability in construction.

2.12 Conceptual Framework

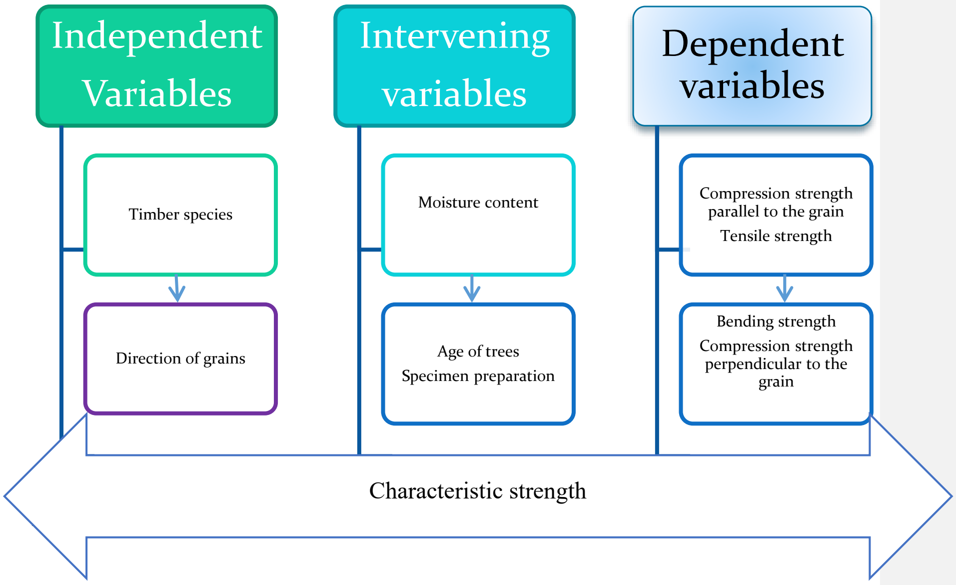


Figure 2.12: Conceptual Framework

Figure 2.12 shows the conceptual framework with dependent variables, independent variables and intermediate variables of this study. The study is hinged on three major key pillars. These pillars include; determination of timber species majorly used in construction, mechanical properties of timber and grading of timber for engineering applications. The independent variables are timber species and direction of grains. The intervening variables include moisture content and the age of the trees.. The structural strength of timber is basically determined through testing of various mechanical strengths. The tests which are ordinarily carried out include compressive strength, tensile strength and bending strength. The mechanical properties of timber are derived from mechanical strengths. The characteristics strength; strength of timber below which not more than 5% of the test results are expected to fail was used, will be determined.

To achieve this, SPSS Statistics is a statistical software suite was used for analysis. Out of 100 samples, the 5th percentile was picked as the characteristic strength

Classification of the selected timber species to specific grades was done according to Eurocode 5 standard.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Area of Study

This research was conducted in Kakamega County which is found in the western part of Kenya as shown in figure 3.1. Unlike UK (temperate region), Kakamega climate is classified as tropical and its average temperature is 25.8^{0}c therefore may exhibit trees with different properties. The Latitude longitude coordinates for Kakamega are: 0°17'3.19"N, 34°45'8.24"E.

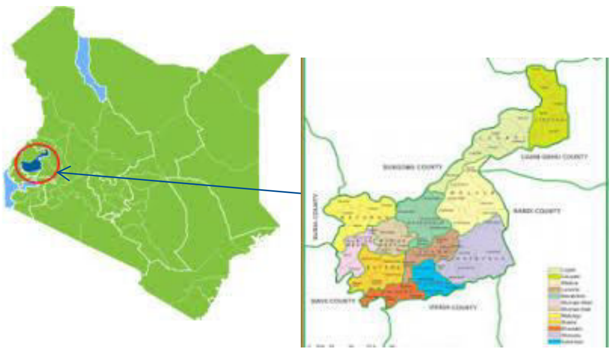


Figure 3.1 Kakamega County map

The study is justified in the area selected because the tropical climate of Kakamega County, with its average temperature of 25.8°C, implies that tree species in this region may have developed unique properties to withstand the specific environmental conditions. Conducting a structural characterization and grading study on these tree species for engineering applications is crucial to ensure that construction materials are well-suited and resilient to the prevailing climate, contributing to the long-term stability and safety of structures.

Likewise, Kakamega County's diverse ecosystem likely hosts a variety of tree species. Understanding the specific types of tree species commonly used for construction in the region (Objective i) can lead to optimized resource utilization. This knowledge can guide local builders and engineers in selecting suitable species, thereby reducing waste and potential environmental impact.

Furthermore, determining the strength properties of commonly used timber species (Objective ii) is essential for ensuring the reliability and safety of structures. The mechanical characteristics of these species under the influence of the local climate can impact the structural integrity of buildings and other construction projects. This study can provide valuable data for engineers to make informed design decisions.

Along the same vein and in support of the second objective, Eurocode 5 is an internationally recognized standard for timber engineering design. By determining the grade of timber species according to Eurocode 5, this study can help align construction practices in Kakamega County with global engineering standards. Standardization promotes consistency, quality, and compatibility with construction practices in other regions, facilitating international collaboration and knowledge exchange.

Likewise, a comprehensive understanding of the strength properties and grading of timber species can contribute to the growth of local industries related to construction and woodworking. With accurate data on the engineering potential of specific tree species, businesses can make informed decisions regarding production, processing, and utilization of timber, thereby stimulating economic growth and job creation within the county. Moreover, a well-informed approach to timber utilization can help prevent overexploitation of certain species and promote sustainable forestry practices. This, in turn, contributes to the conservation of local ecosystems, biodiversity, and natural resources.

3.2 Establishment of Tree Species in Construction

An investigation was carried out to determine the common timber species found in the County, their advantages, disadvantages and how they are used in construction. In order to achieve this, visitations were conducted to the following stations: Kakamega forest, Local tree farmers, Timber yards, Construction site within the County and the Kenya Forestry Research Institute (KEFRI).

3.2.1 Kakamega forest

The following research questions were used to guide the investigation

i. What are the types of tree species found in the forest?
ii. How often are trees grown and harvested at the forest? What are their uses?
iii. What is the most preferred tree species in construction?

3.2.2 Timber yards

At the timber yards, the following checklist was used during investigation:

- The types of trees used to make timber
- The timber species preferred for construction
- The amount of timber purchased on daily basis
- The methods used to preserve timber.

3.2.3 Local tree farmers within the County

The following checklist was used during investigation:

- The most planted/ grown tree species for construction
- The maturity age of trees species used in construction
- The importance of tree species grown

3.2.4 Construction sites

At the construction sites, the following checklist was used to guide the research

- The type of timber used at the construction site.
- How timber was used at the construction.
- The source of timber.
- The method used to preserve timber.

3.2.5 Kenya Forestry Research Institute (KEFRI)

Kenya Forestry Research Institute (KEFRI) was established as a state corporation in 1986 under the Science and Technology Act Chapter 250 of the Laws of Kenya to focus on forestry research. KEFRI Karura has a workshop that provides wood services such as timber drying, sawing of logs and beams and timber loaning and splitting. It also has laboratories that provides services such as: soil testing, wood chemistry and anatomy services, timber testing and DNA analysis and molecular analysis. KEFRI was visited in order to investigate the work done by other researchers on timber.

3.4 Field Sampling

The species majorly grown within the county include: *Cupressus Lustanica* (cypress), Species were sampled from Kakamega region. Sampling plots were chosen from regions of Kakamega County and the chosen trees species (eucalyptus, and cypress) of ages 5-10 years within each plot were sampled. The trees were selected from different regions of Kakamega County 6 logs for eucalyptus and 6 logs for cypress were harvested.

3.4.1 Sample Preparation

In sample preparation, Stratified Random Sampling was applied. Stratified Random Sampling involves setting the sample size in each stratum to be proportional to the number of sampling units within that stratum. This method results in a self-weighted sample, eliminating the need for additional weighting to estimate unbiased population parameters (Arnab, 2017). Proportional allocation ensures that population parameter estimates are at least as precise as those obtained from simple random sampling (Arnab et al, 2017). The precision gains from stratified random sampling can be substantial, especially when differences between strata means are significant, with the magnitude of gains increasing as these differences grow. This approach is particularly advantageous for obtaining precise estimates in larger strata, as it allocates larger sample sizes to these more extensive segments of the population (Singh et al., 2015).

The researcher divided Kakamega region into stratas based on geographical regions/zones. Within each stratum, random selection was done of a representative number of construction sites or households. This ensured that a diverse range of tree species used for construction is captured across different areas of the county.

The sampled logs were saw-milled into 12inches cross-section sizes, then seasoned under a shade for about three months. As at the time of laboratory testing, the samples were at 12% moisture content, being the equilibrium moisture content for most timber at the time of use in Kakamega County. The used samples were free of any visible defects. The strength tests were conducted in accordance with the Eurocode 5 standard testing procedures for small clear samples. Samples selected for bending strength tests were standardised at 50mm x 50mm cross-sections, while the samples for the compression tests were standardised at 40mm x 40mm cross-sections. The samples for tensile strength test were standardized at 86mm x 18mm cross section as shown in table 3.1.

Table3.1Number of samples per test

Property	No of samples per specie	Sample size (mm)
Compression parallel to the grain	100	40×40×100
Compression perpendicular to the grain	100	40×40×100
Bending test	100	50×50×300
Tensile test	60	86 × 18 × 2

Total number of samples per specie=360 samples

The total number of samples used for all species: 360×2=720 samples

3.5. Test Procedures

All tests were conducted following the testing procedures outlined in the EC 5 standard for small clear samples. The specimens used for compression tests had a cross-section of 40mm × 40 mm, while those for bending strength tests had a cross-section of 50mm × 50mm. These specimens were carefully selected to be free from any strength-reducing defects. Random sampling within the county was employed to ensure the specimens were representative of the entire population. Testing was performed under dry conditions, with a moisture content below 15%, which represents the equilibrium moisture content for Kenya. At this moisture level, timber density and dimensional characteristics remain stable and do not impact the test outcomes. Supplementary tests were conducted to determine densities and moisture content for each strength test. The relationship between density and other strength properties was explored, revealing that higher density correlates with greater strength and stiffness. High density indicates a higher proportion of wood substance, particularly in the cell wall material, contributing to the timber's strength. Subsequently, a statistical analysis of the test results was conducted to extract the required information.

3.5.1 Laboratory Testing

The standard procedures for mechanical strength testing on small, clear timber specimens were conducted at the Structural Engineering laboratory of Masinde Muliro University of Science and Technology. The universal strength-testing machine was employed for these tests, with the fitting of suitable accessories for each specific test. Prior to the commencement of testing, samples were properly labeled, and their dimensions and weights were recorded. Additionally, the room temperature and humidity levels were documented before initiating any test.

3.5.2 Moisture Content Test

To assess moisture content, a knot-free and resin pocket-free full cross section was utilized. A portion of the test piece was extracted, weighed, and then subjected to drying in an oven at a temperature of 103°C until a consistent weight was achieved. The water content was determined by subtracting the dry weight from the initial weight, and the moisture content was calculated by dividing the amount of water by either the dry weight or the total weight. The moisture content (MC) of the pieces was expressed as a percentage using the provided formula:

$$M.C = \frac{W1-Wo}{W1} \; x \; 100\% \text{.........................} \text{ (i)}$$

Where M.C is the moisture content

W_1 = Initial weight of the sample of test

W_0 = Dry weight of sample

3.5.3 Density test

The same specimen used for moisture content was used the mass of each specimen is recorded form a sample scale balance while the volume is calculated based on direct measurement of length, width and thickness of the specimen using a Vernier caliper.

The density of each specimen is calculated by the formula;

$$p = \frac{M}{V} \text{..............} \text{ (ii)}$$

Where, p = timber density

M = mass specimen

V = volume of specimen

3.5.4 Compressive Strength (Parallel to Grain)

Specimen for this test measured 40 x 40 x 100mm and was prepared. The specimen was placed on the testing machine with its length parallel to the direction of the load and the load was applied until failure occurred. The compressive strength parallel to the grain was determined using the formula given below;

$F_{Co} = \frac{F\ max}{A}$............... (iii)

Where F_{Co} is the ultimate compressive strength

F_{max} is the maximum compressive load

A is the cross-sectional area

N/B care was taken to ensure that the specimen placed in such a way that the load was truly centric load.The load at failure is the maximum compressive load (F_{max}). The compressive strength parallel to the grain was obtained by dividing the maximum compressive load by the cross- sectional area of the specimen (A). Ultimate compressive strength (f_{c0}) = $F\ max/A$

3.5.5 Compressive strength perpendicular to grain

The specimen was placed on the testing machine with its length perpendicular to the direction of the load. The load was applied until failure occurred. The load at failure is the maximum compressive load compressive load ($f_{c,\ max90}$). For compressive strength testing for samples perpendicular to the grain, the specimen lengths were placed perpendicular to the direction of the load, then compressed to failure. The maximum compressive load ($F_{c,max90}$) was then calculated using the formula below;

$F_{c,90} = \frac{Fc,max90}{bl}$..............(iv)

Where $F_{c,90}$ is the maximum compressive load,

F_{cmax90} is the maximum compressive load perpendicular to the grain

b width of specimen in mm and *l* is the length of the specimen in mm

3.5.6 Bending Strength

Using a three-point loading method, specimens were positioned with their growth rings paralleled to the loading direction. The loading force was then applied to failure. The modulus of rapture/bending strength was calculated using the formula below;

$$MoR = \frac{3P\ maxL}{2bd2}$$

Where Pmax is the maximum applied load (N)

L is the bending span (mm)

B is the width of specimen (mm)

D is the depth of the specimen (mm)

3.5.7 Tensile Strength (Parallel to the Grain)

Tensile strength test was conducted with specimens placed with their lengths parallel to the direction of the loading. The loading was applied at a cross-sectional area of 30 mm x 5mm face of the specimen ends at a rate of 0.05 mm/sec, and constantly increased until failure.

The ultimate strength was then calculated using the formula;

$$F_{t,o} = \frac{Fmax}{A} \ldots\ldots\ldots\ldots\ldots\ldots (v)$$

Where ft,o is the tensile strength parallel to the grain in N/mm^2

F_{max} is the Max load, (N),

and A is the Cross sectional area (mm^2)

3.6 Timber characterization

Characteristics strength of timber below which not more than 5% of the test results are expected to fail was used. To achieve this, SPSS Statistics is a statistical software suite was used for analysis. Out of 100 samples, the 5th percentile was picked as the characteristic strength. Classification of the selected timber species to specific grades was then done according to Eurocode 5 standard

CHAPTER FOUR

5.0 RESULTS AND DISCUSSIONS

This chapter discusses the tree species used in construction, the physical and mechanical properties of eucalyptus and cypress timber and the characteristic grades of eucalyptus and cypress timber species.

4.0 Tree Species in Kakamega forest Used in Construction

Kakamega County has a total area of 28,755.30ha, a forest cover of 9.86%. It has 7 Forest Stations as shown in the figure 4.1.

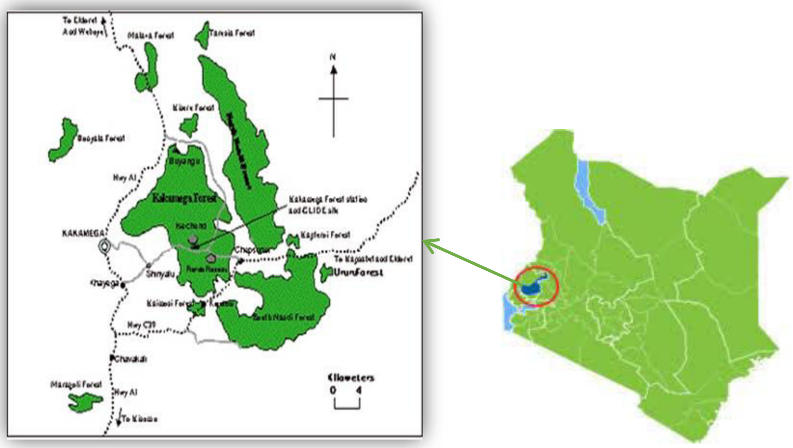


Figure 4.1 Kakamegaakamega forestry map

Kakamega Forest Station-18,733.00ha, -Bunyala Forest Station-825.60ha, -Malava Forest Station-718.80ha, -Lugari Forest Station-2,163ha, -Nzoia Forest Station-3,619.0ha, & -Turbo Forest Station-2,612.2. Kakamega County lies on an altitude 1250-2000m above sea level on the Southern part and other areas on the average of 1625m above sea level. It has six gazetted forest areas as shown in table 4.1

Table 4.0.1Timber species in Kakamega forest

Name of Forest	Gazette No.	Area (ha)
Kakamega Forest Station	LN 14 OF February, 1933	18,733.00
Malava Forest Station	LN 14 of February, 1933	718.80
Bunyala Forest Station	LN 421 OF 1956	825.60
Nzoia Forest Station	GN 145 OF 1968 LN 175/132	3,619.00
Turbo Forest Station	GN 145 OF 1968 LN 175/132	2,612.20
Lugari Forest Station	GN 3 OF 1977 LN 175/177	2,163.00
Misango Hills	LN NO. 23 OF 23RD February, 2010	103.70
	Total	**28,775.30**

The species majorly grown in these forests include: Cupressus Lustanica (cypress), Painas patula (pines) Blue gam (Eucalyptus) and a few indigenous species. Since no logging is allowed from the forest since 2013 to date, the timber for construction is majorly obtained from farmers within the County.

4.2 Timber Species Used in Construction within Kakamega County according to Timber yards and local farmers

Timber Species used in Construction within Kakamega County according to Timber yards and local farmers are shown in table 4.2 and figure 4.2.

Table4.0.2 Quantities of timber sold in Kakamega County timber yards in m^3

Timber species	**Timber Yards**						**Total**	**%**
	1	2	3	4	5	6		
Eucalyptus	2125	1800	2100	2190	2105	2410	12650	55%

Cypress	1340	1025	1290	1380	1300	1705	8050	35%
Gravilleah	190	150	140	230	190	240	1150	5%
Lusiola	110	70	35	130	115	165	690	3%
Mutere	25	30	35	65	35	40	230	1%
Neem	40	5	35	50	40	60	230	1%
Munyama	35	40	35	55	35	30	230	1%

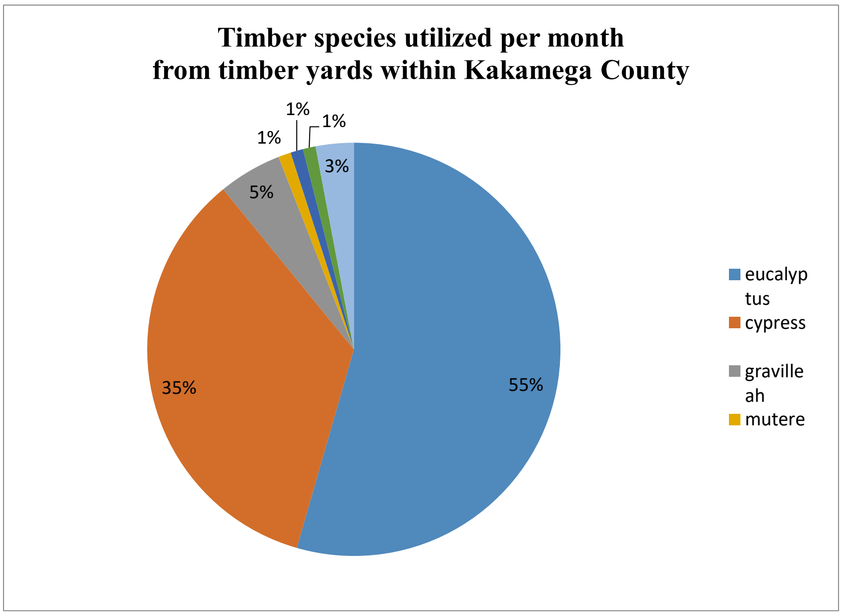


Figure 4.2 Quantity of timber purchased monthly from Kakamega County timber yards

From the figure 4.2~~7~~ shown, tree species majorly used in production of timber within Kakamega County include: exotic species: Euchalyptus saligna(Eucalyptus-55%), Grevillea robusta(Grevilleah-5%), and Cupressus macrocarpa(Cypress35%-), for indigenous species: Markhamia lutea(Lusiola-3%), Measopsis eminii(Mutere1%-), Ficus sycomorus(Mukhuyu-1%), Trichilia emetic(Munyama-1%) and neem(1%). Those that are majorly used in construction industry are eucalyptus and cypress due to their strength characteristics.

4.3Physical and Mechanical Properties of Timber in Kakamega County

The physical and mechanical properties of timber are shown in this section.

4.4.1 Density of Eucalyptus

Table4.0.3Density of eucalyptus

Percentiles		5	10	25	50	75	90	95
	Density g/cm3	0.4033	0.4092	0.447	0.478	0.5155	0.5328	0.5484

On percentiles, the results show that 5% of densities of eucalyptus samples were less than 0.40330 g/cm^{3}as shown in table 4.3. This therefore shows that 95% of the remaining samples of tested for density of eucalyptus had density higher than 0.4033 g/cm^3

4.5.6 Density of Cypress

Understanding the density of cypress wood is a key factor in evaluating its suitability and performance in various construction and woodworking projects. This knowledge empowers professionals to make informed decisions about the appropriate use of cypress wood, ensuring that it meets the necessary structural requirements, offers longevity, and exhibits optimal performance in its intended applications.

Table 4.12: Density of Cypress

Table4.0.4 Density of cypress

Percentiles		5	10	25	50	75	90	95
Weighted Average	Density g/cm^3	0.3763	0.401	0.414	0.4475	0.5188	0.572	0.6415

On percentiles, the results show that 5% of densities of eucalyptus samples were less than 0.3763 g/cm^3as shown in table 4.4. This therefore shows that 95% of the remaining samples of tested for density of Cyprus parallel to the grain had density higher than 0.3763 g/cm^3**.** The values of the percentiles give an idea of the spread of density values, with the median (0.4475) representing the middle point of the data.

4.5.3Compression Strength Parallel to the Grain of Eucalyptus

The results provide valuable information about the strength characteristics of Eucalyptus timber tested parallel to the grain. These results can be used to assess the suitability of Eucalyptus timber for various engineering applications based on its mean, confidence interval, variability, and other statistical measures.

Table 4.0.5 Compression strength parallel to the grain of eucalyptus

Percentiles		**5**	**10**	**25**	**50**	**75**	**90**	**95**
Weighted Average		26.875	27.375	30.625	34.375	41.5625	46.875	49.6875

On percentiles, the results show that 5% of strength of eucalyptus samples parallel to the grain was less than 26.8750 N/m^2as shown in table 4.5. This therefore shows that 95% of the remaining samples of tested for strength of eucalyptus parallel to the grain had strength higher than 26.8750 N/m^2. These values provide insights into the distribution of the strength data. For example, the median (50th percentile) strength value of 34.375 represents the middle value, indicating that 50% of the tested Eucalyptus samples have strength values below this point. The given provide information about the distribution of the strength of Eucalyptus timber tested parallel to the grain. These values are valuable in determining the performance and suitability of Eucalyptus timber for specific engineering applications based on its percentile ranking and quartile values.

4.5.4 Compression Strength Perpendicular to the Grain of Eucalyptus timber (percentiles)

The results provide valuable information about the strength characteristics of Strength of Eucalyptus perpendicular to the grain. These results can be used to assess the suitability of Eucalyptus timber for various engineering applications based on its mean, confidence interval, variability, and other statistical measures.

Table 4.0.6 Compression strength perpendicular to the grain-eucalyptus

Percentiles		**5**	**10**	**25**	**50**	**75**	**90**	**95**
Weighted Average	STRENGTH	6.45	7.51	10	13.5	17.5	24	4.80E+04

On percentiles, the results show that 5% of strength of eucalyptus samples perpendicular to the grain were less than 6.4500 N/m^2 as shown in table 4.6 This therefore shows that 95% of the remaining samples of tested for strength of eucalyptus parallel to the grain had strength higher than 6.4500 N/m^2. The presence of an extremely high value in the 95th percentile (4.8005E4 or 48,005) compared to other percentiles indicates the presence of a significant outlier in the data set. This outlier significantly influences the calculation of the 95th percentile and is reflected in the wide difference between the 90th and 95th percentiles.

4.5.7 Compression Strength Parallel to the Grain of Cypress timber

The strength of Cypress wood parallel to the grain is crucial for making informed decisions about its appropriate use in different applications. Its remarkable strength, combined with other favorable properties, makes it a preferred material for a wide range of projects that require durable and reliable wood with exceptional load-bearing capabilities.

Table4.0.7 Compression strength parallel to the grain(cypress)

Percentiles		**5**	**10**	**25**	**50**	**75**	**90**	**95**
Weighted Average	Strength C PR	15.8906	20.9683	21.875	25	28.125	34.375	39.125

On percentiles, the results show that 5% of strength of cypress samples parallel to the grain was less than 15.89 N/m^2 as shown in table 4.7. This, therefore, shows that 95% of the remaining samples of tested for strength of eucalyptus parallel to the grain had strength higher than 15.89 N/m^2**.** The values of the percentiles give an idea of the spread of strength values, with the median (25.0000) representing the middle point of the data. The fact that the median is close to the 50th percentile and is also similar to the weighted average median indicates that the data distribution is not heavily influenced by outliers

Table4.0.8 Compression strength perpendicular to the grain(Cypress)

Percentiles		**5**	**10**	**25**	**50**	**75**	**90**	**95**
Weighted Average	Stress C PP	7	8.125	9.5	11.125	13.2812	14.775	.

On percentiles, the results show that 5% of strength of cypress samples perpendicular to the grain were less than 7 N/m^{2}as shown in table 4.8 bring the table here. This therefore shows that 95% of the remaining samples of tested for strength of cypress perpendicular to the grain had strength higher than 7 N/m^2

By comparing the 25th percentile and 75th percentile, one can assess the interquartile range, which provides a measure of the dispersion of the middle 50% of the data points. The values of the percentiles give an idea of the spread of stress values, with the median (11.1250) representing the middle point of the data. The fact that the median is close to the 50th percentile and is also similar to the weighted average median indicates that the data distribution is not heavily influenced by outliers.

Table4.0.9 Eucalyptus bending strength

Percentiles		5	10	25	50	75	90	95
Weighted Average	Bending strength	23.2	23.2	26.8	31.6	34	35.4	.

On percentiles, the results show that 5% of bending strength of eucalyptus samples was less than 23.2N/mm^2 as shown in table 4.9 This therefore shows that 95% of the remaining samples of tested for bending strength of eucalyptus had strength higher than 23.2N/mm^2. However, it's worth noting that the 95th percentile value is not provided for the weighted average method, which makes it difficult to assess the upper tail of the data distribution. Including the 95th percentile would have provided more information about the upper extreme values of the data.

Table4.0.10 Cypress bending strength

Percentiles		5	10	25	50	75	90	95
Weighted Average	Bending strength	20.2	20.8	22	23.68	26.68	29.2	31.72

On percentiles, the results show that 5% of bending strength of cypress samples were less than 20.2N/mm^2 as shown in table 4.10. This therefore shows that 95% of the remaining samples of tested for strength of cypress had bending strength higher than 20.2N/mm^2. The values of the percentiles give an idea of the spread of bending strength values, with the median (23.6800) representing the middle point of the data. The fact that the median is close to the 50th percentile and is also similar to the weighted average median indicates consistency in the data distribution. Comparing the weighted average percentiles and Tukey's Hinges, we observe that the values are relatively close to each other, suggesting a relatively stable and balanced distribution of the data.

4.5.9 Tensile test results

Table4.0.11 Tensile strength for cypress and eucalyptus

Percentiles		5	10	25	50	75	90	95
Tensile strength eucalyptus		14.2	15.2	16.0	16.6	17.3	18.4	19.3.
Tensile strength cypress		12.2	13.3	14.2	15.2	16.4	17.2	18.3

On percentiles, the results show that 5% of tensile strength of eucalyptus and cypress samples were less than 14.2N/mm^{2}and 12.2N/mm^2 as shown in table 4.23a respectively. This therefore shows that 95% of the remaining samples of tested for tensile strength of eucalyptus and cypress had tensile strength higher than 14.2N/mm^{2}and 12.2N/mm^2 respectively. The values of the percentiles give an idea of the spread of tensile strength values, with the median (15.2 and 16.6) representing the middle point of the data. The fact that the median is close to the 50th percentile and is also similar to the weighted average median indicates consistency in the data distribution.

4.7 Timber characterization

Timber characterization is the process of evaluating the properties of wood to determine its suitability for use in construction and other applications. Timber characterization involves measuring the physical, mechanical, and structural properties of wood which can help to determine how timber can be used and how to design timber structures. Properties majorly used for timber characterization are density and bending strength as shown in table 4.12.

Table 4.0.12 Timber Characterization

Timber species	Density g/cm^3	Wood classification	Characteristic bending strength	Strength characterization/timber grade
Eucalyptus	0.485	Hardwood	23.2N/mm2	D24
Cypress	0.435	Softwood	20.2N/mm2	C20

~~As shown in~~ table 4.12 shows, timber characterizing properties are density and bending strength. Cypress can be classified as softwood since its density varies between 290Kg/m^3 and 460kg/m^3 while eucalyptus can be classified as a hardwood since its density varies between 460kg/m^3 and 550kg/m^3.Cypress and Eucalyptus have a density of 435kg/m^3 and 485kg/m^3 respectively. According to their bending characteristic strength and with reference to Eurocode 5, eucalyptus can be classified into class D24 while cypress can be classified into class C20; hence they are suitable for construction.

4.14 Results discussions

4.14.1 Tree species used in construction

According to the Kenya Forestry Research Institute (KEFRI), uses of timber have been classified into five categories: construction, furniture/joinery, poles/posts, tools/implement handles and others. Some of tree species used in construction include: Apodytes dimidiate, Euchalyptus saligna,Cassipourea malosana, Croton megalocarpus,Dodonaea angustifolia, Euchalyptus regnans,Euchalyptus grandis, Euchalyptus paniculata, Harungana madagascariensis, Hymenaea verruccosa, Julbernardia magnistipulata, Cupressus lustanica, Cymometra webberi which agrees with the results obtained from this study.

KEFRI also conducted physical and mechanical properties of selected timber species as shown in the table below. The mechanical properties determined were, maximum compressive strength, maximum modulus of elasticity and modulus of rapture as shown in the table 4.13 while density values are shown in table 2.2 under literature review. …….bring table 4.13

4.142 Density results obtained in comparison to KEFRI

The data provided in Table 4.14 and Table 4.15(for KEFRI)bring the KEFRI FINDING HERE offers insights into the density variations of different tree species, particularly Eucalyptus and Cypress.

Table 4.14 density of eucalyptus and cypress

Sample	Observed	Density g/cm^3
Eucalyptus	Mean	0.485
	Std. Deviation	0.04
	Minimum	0.39
	Maximum	0.55
Cypress	Mean	0.40
	Std. Deviation	0.03
	Minimum	0.32
	Maximum	0.52

Table 4.15 Density of cypress and eucalyptus according to KEFRI

Tribe	Local Name	Trade Name	Tree Types	Scientific Name	Density(g/cm^3)	Mor(Mpa)
Luo	Bao	Sidney bluegam , saligna gam	Exotic	*Euchalyptus saligna*	0.65	111
Luhya	Mudarakwa	Mexican cypress	Exotic	*Cupressus lusitanica*	0.46	68

According to table 4.14:

a) Eucalyptus has a mean density of 0.485 g/cm³, with a standard deviation of 0.04. The density ranges from 0.39 to 0.55 g/cm³.

b) Cypress has a mean density of 0.40 g/cm³, with a standard deviation of 0.03, and a density range from 0.32 to 0.52 g/cm³.

c) This suggests that Eucalyptus is generally denser than Cypress, with slightly greater variability in density.

Comparison with Density Data from KFERI Table 4.15

Eucalyptus saligna (Sidney bluegum, saligna gum) has a higher density of 0.65 g/cm³, which is greater than the mean density of Eucalyptus in Table 4.14.

Cupressus lusitanica (Mexican cypress) has a density of 0.46 g/cm³, slightly higher than the mean density of Cypress in Table 4.14 but still within its range.

These differences could be due to species variations, environmental conditions, or measurement methodologies.

Key Observations:

Eucalyptus species tend to have a higher density than Cypress, indicating greater wood strength.

Density variations exist even within the same species, likely due to differences in location, growth conditions, and genetic factors.

The mean densities in this study are lower than those from KEFRI, suggesting potential variability based on sample selection.

4.143 Mechanical properties

Table 4.13 Mechanical properties of timber according to KEFRI.......LET ITMOVE UPWARDS

	STATIC BENDING					COMPRESSION GRAIN	
SPECIES	**S.S**	**M.C(%)**	**S.G**	**M.O.R(Mpa)**	**M.O.E(Mpa $\times10^3$)**	**S.S**	**C.S(Mpa)**
Euchalyptus saligna/grandis	22	12.0	0.651	110.6	10.4	27	62.9
Cupressus macrocarpa	12	9.5	0.433	69.5	8.4	12	43.1
Azandiracta indica	5	12.0	0.699	86.3	9.974	6	58.932
Euchalyptus globulus	6	12.0	0.734	106.3	10.5	6	54.9

4.143a Comparison of KEFRI results (Table 4.13) and general results obtained from this study:

KEFRI focused on static bending and compression parallel to the grain, while the result here presents bending and compression strengths at different percentiles.

Compression Strength Parallel to the Grain:

According to KEFRI, Eucalyptus saligna/grandis has compression strength of 62.9 MPa, while Cypress has the lowest at 43.1 MPa. The results obtained from this study for Eucalyptus and Cypress shows that Eucalyptus' compression strength ranges from 26.875 MPa (5th percentile) to 49.6875 MPa (95th percentile), whereas Cypress ranges from 15.89 MPa (5th percentile) to 34.375 MPa (90th percentile). These values align with those in Table 4.13, though this study provides a percentile breakdown, highlighting variability within samples. Overall, Eucalyptus demonstrates significantly higher compression strength than Cypress

Compression Strength Perpendicular to the Grain:

Eucalyptus: 6.45 MPa (5th percentile) to 48,000 MPa (likely a data entry error for 95th percentile) while Cypress has 7 MPa to 14.775 MPa.

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Cypress has slightly higher compression strength perpendicular to the grain at lower percentiles but is overall weaker than Eucalyptus.

KEFRI did not conduct the compression perpendicular to the grain test

Bending Strength:

According to KEFRI, Eucalyptus saligna/grandis has a bending strength of 110.6 MPa, while another source reports 69.5 MPa. A study on percentile data for Eucalyptus and Cypress found that Eucalyptus has a bending strength ranging from 23.2 MPa (5th percentile) to 35.4 MPa (95th percentile), whereas Cypress ranges from 20.2 MPa (5th percentile) to 29.2 MPa (95th percentile). The values from this study are significantly lower than those from KEFRI, likely due to differences in testing methods or sample sizes affecting strength measurements.

4.15 Overall Observations from KEFRI data verses the results obtained from this study

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Overally, KEFRI provides single average values for compression strength parallel to the grain, whereas this study offers percentile-based values, highlighting variability. In terms of bending strength, KEFRI reports higher values, likely due to different measurement conditions or standards. Additionally, Eucalyptus outperforms Cypress in both bending and compression strength, making it the superior choice for load-bearing applications. On the other hand, eucalyptus strength increases significantly at higher percentiles, showing its superior structural properties

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.0 Conclusions

This study carried out an investigation to establish the type of timber commonly used in construction, the strength properties of the selected timber and the characterization of the selected timber species. It was found that:

a) Tree species majorly used in production of timber production within Kakamega County include: Lusiola(3%), mutere(1%), cypress(35%), eucalyptus(55%), neem(1%), ,gravilleah(5%) and munyama(1%) etc. Those that are majorly used in construction industry are eucalyptus and cypress which are majorly used in construction due to their unique characteristics.

b) The average densities for eucalyptus and cypress are 485kg/m3 and 400kg/m3 respectively. The characteristic compressive strength parallel to the grain for eucalyptus and cypress are 26.73 N/mm2 and 15.896 N/mm2 respectively.

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c) The characteristic compressive strength perpendicular to the grain for eucalyptus and cypress are 6.45N/mm2 and 7N/mm2 respectively. The characteristic bending strength for eucalyptus and cypress are 23.2 N/mm2 and 20.2N/mm2 respectively while the characteristic tensile strength for eucalyptus and cypress are 14.2N/mm2 and 12.2N/mm2 respectively . These properties were tested at 12% M.C.

d) The grade stress for eucalyptus is D24, while that of cypress is C20. These species were classified according to their characteristic strength. They are therefore suitable for construction.

5.2 Recommendations

a) Since cypress is in class C20, it can be used in domestic and commercial construction projects. Strength class C20 is used in load-bearing structures that require high strength, such as roof trusses, beams and floor systems.

b) D24 is a common structural grade for a variety of structures. It can be used in for certain structural products such as timbers for railway and highway bridges, railway ties, mine timbers, and for pallets and containers.

c) Eucalyptus outperforms Cypress in both bending and compression strength, making it the superior choice for load-bearing applications.

d) Further research should be conducted to characterize the indigenous species majorly found in Kenya. Classification and grading of timber species should be done in order to develop Kenyan national annexes to obtain local parameters of design

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APPENDICES

Appendix 1: Compression test results

a) **Eucalyptus-parallel to the grain (40×40×100)**

Table 6.0.1 Eucalyptus-parallel to the grain

SAMPLE NO	MASS (grams)	Density g/cm³	LOAD(N)	STRENGTH(N/mm²)	EXTENSION(mm)
R1	68.6	0.429	61000	38.125	2
R2	73.7	0.461	56000	35	2
R3	77.8	0.427	43000	26.875	1.5
R4	71.4	0.446	65000	40.625	2.5
R5	70.5	0.441	56000	35	1.8
R6	67.4	0.421	52000	32.5	2.5
R8	68.7	0.429	65000	40.625	2.5
R9	69.3	0.433	61000	38.125	3.5
R10	63.0	0.394	55000	34.375	2.5
R11	72.0	0.45	54000	34.125	2.3
R12	76.0	0.475	53000	33.125	2.0
R13	72.2	0.451	61000	38.125	6.2
R14	63.5	0.397	60000	37.5	2.5
R15	71.1	0.444	64000	40	3
R16	70.6	0.441	65000	40.625	5.5
R17	68.0	0.425	50000	31.25	3.5
R18	71.1	0.444	60000	37.5	4
R19	67.4	0.421	55000	34.375	4
R20	67.7	0.423	54000	33.75	2

a) **Eucalyptus- perpendicular to grain**

Cross-sectional area: 4000mm²

Table 6.0.2 Eucalyptus perpendicular to the grain

SAMPLE NO	MASS (grams)	Density g/cm³	LOADING (N)	STRENGTH (N/mm²)	EXTENSION (mm)
R21	63.4	0.396	9000	2.25	1.0
R22	75.4	0.471			
R23	65.5	0.409	16000	4	1.0
R24	67.1	0.419	16000	4	0.5
R25	74.6	0.466	16000	4	2.6
R26	76.2	0.476	20000	5	1.0
R27	64.3	0.402	25000	6.75	2.5
R28	69.8	0.436	7500	1.875	0.5
R29	70.0	0.437	15000	3.75	1.5
R30	66.9	0.418	16000	4	0.5
R31	68.4	0.428	6000	1.5	1.5
R32	65.8	0.411	15000	3.75	0.5
R33	65.5	0.409	8000	2	0.8
R34	63.2	0.395	15000	3.75	0.5

R35	74.1	0.463	12000	3	0.6
R36	71.6	0.446	10000	2.25	0.5
R37	85.4	0.534	16000	4	1.4

b) Cypress- parallel to grain

Table 6.0.3 Cypress compression strength raw data

SAMPLE NO	Density g/cm^3	LOAD(N)	STRENGTH (N/mm^2)	EXTENSION (mm)
G1	0.52	40000	25	4
G2	0.429	25000	15.625	4
G3	0.468	35000	21.875	4
G4	0.409	35000	21.875	4
G5	0.465	20000	12.5	4
G6	0.446	39000	24.375	1.5
G7	0.451	43000	26.875	5
G8	0.416	45000	28.125	4
G9	0.423	30000	18.75	4
G10	0.443	35000	21.875	4
G11	0.422	38000	23.75	4
G12	0.463	34000	21.25	4
G13	0.434	40000	25	6
G14	0.438	33000	20.625	4.5
G15	0.445	53000	33.125	4
G16	0.414	33000	20.625	3
G17	0.389	35000	21.875	3
G18	0.412	33000	20.625	3
G19	0.446	45000	28.125	2
G20	0.438	32000	20	2

SAMPLE NO	Density g/cm^3	LOAD(N)	STRENGTH (N/mm^2)	EXTENSION (mm)
G21	0.405	25000	6.25	2.0
G22	0.379	10000	2.5	1.0
G23	0.401	5000	1.25	1.0
G24	0.434	15000	3.75	1.0
G25	0.428	10000	2.5	0.5
G26	0.387	8000	2.0	1.0
G27	0.469	11000	2.75	0.5
G28	0.396	20000	5.0	1.0
G29	0.465	15000	3.75	1.0
G30	0.476	27000	6.75	1.5
G31	0.442	28000	7.0	1.5
G32	0.451	18000	4.5	1.4
G33	0.381	12500	3.125	1.3
G34	0.382	13000	3.25	1.0
G35	0.418	9000	2.25	0.3
G36	0.422	10000	2.5	1.0
G37	0.423	17000	4.25	1.0

G38	0.406	10000	2.5	0.5

c) **Cypress-perpendicular to the grain**

Bending strength test results

a) **Eucalyptus (50×50×300)**

Table 6.0.4 Bending strength results raw data

SAMPLE NO.	MASS(g)	LOAD(N)	Extension (mm)	Strain	Stress(×10) N/mm^2	MOR	MOE N/mm^2	Density g/cm^3
B1	339.8	9000	11	0.11	1.8	32.4	16.36	0.453
B2	344.9	10000	9	0.09	2.0	36	22.22	0.459
B3	401.3	10000	13.5	0.135	2.0	36	14.81	0.535
B4	330.9	3800	3.0	0.03	0.76	13.68	25.33	0.44
B5	367.7	8000	7.9	0.079	1.6	28.8	20.25	0.489
B6	284.2	6000	7	0.07	1.2	21.6	17.14	0.379
B7	372.9	9800	11	0.11	1.96	35.28	17.82	0.496
B8	284.8	7000	11	0.11	1.4	25.2	12.72	0.380
B9	252.3	7000	4.9	0.049	1.4	25.2	28.57	0.336
B10	357.6	6500	7.5	0.075	1.3	23.4	17.33	0.476
B11	312.6	4300	5.5	0.055	0.86	15.48	15.64	0.416
B12	305.3	8000	12	0.12	1.6	28.8	13.33	0.407

B13	372.3	9000	11.5	0.115	1.8	32.4	15.65	0.496
B15	299.5	6300	7.5	0.075	1.26	22.68	16.8	0.399
B16	370.7	11000	11	0.11	2.2	39.6	20	0.494
B17	441.8	8200	4.5	0.045	1.64	29.52	36.44	0.589
B18	260.7	5500	7.5	0.075	1.1	19.8	14.67	0.348
B19	388.9	7800	11	0.11	1.56	28.08	14.18	0.519
B20	295.0	6300	6.2	0.062	1.26	22.68	20.32	0.393

b) Cypress

SAMPLE NO.	MASS	LOAD(N)	Extension (mm)	Strain	Stress(×10)N/mm^2	MOR	MOE N/mm^2	Density g/cm^3
A1	259.4	5410	9.2	0.092	1.082	19.48	11.76	0.346
A2	279.3	2650	3.3	0.033	0.53	9.54	1.606	0.372
A3	284.3	5260	7.8	0.078	1.052	18.94	13.49	0.379
A4	281.7	8440	17	0.17	1.688	30.38	9.929	0.376
A5	278.3	720	7.3	0.073	0.144	2.592	1.972	0.371
A6	278.8	7300	15.8	0.158	1.46	26.28	9.24	0.372
A7	267.6	4800	12.5	0.125	0.96	17.28	7.68	0.359
A8	295.6	4200	4	0.04	0.84	15.12	21	0.394
A9	274.4	4300	6.9	0.069	0.86	15.48	12.46	0.365
A10	276.6	6300	10	0.1	1.26	22.68	12.6	0.369

A11	299.4	2500	3	0.03	0.2	9	6.667	0.399
A12	304.0	5000	8.9	0.089	1.0	18	11.24	0.405
A13	293.6	4100	6.9	0.069	0.82	14.76	11.88	0.391
A14	277.1	4400	6.9	0.069	0.88	15.84	12.75	0.369
A15	308.6	7000	9	0.09	1.4	25.2	15.56	0.411
A16	298.5	7000	9	0.09	1.4	25.2	15.56	0.398
A17	290.4	7000	7.6	0.076	1.4	25.2	18.42	0.387
A18	307.1	9100	22.5	0.225	1.82	32.76	8.089	0.409
A19	268.9	2100	2.8	0.028	0.42	7.56	15	0.359
A20	305.4	7500	7.5	0.075	1.5	27	20	0.407
A21	319.7	5000	7.8	0.078	1.0	18	12.82	0.426

Appendix 2: Tensile test results

Section size: 86mm by 18mm by 2mm

Cross-sectional area: 1548mm^2

Table 6.0.5 Tensile strength results raw data

EUCALYPTUS SPECIMEN	LOAD(N)	Density g/cm^3	EXTENSION	Tensile Stress(×10) (N/mm^2)
T1	370	0.396	1	0.239
T2	2250	0.459	1.5	1.4535
T3	-	0.459		1.1309
T4	1750	0.438	6	1.1309
T5	430	0.409	8.5	0.27778
T6	1180	0.409	5.5	0.7623
T7	600	0.549	9.0	0.3876
T8	580	0.359	9.9	0.3746
T9	850	0.426	11.5	0.5491
T10	1600	0.471	11.5	1.0336
T11	1550	0.377	10.4	1.0013
T12	900	0.499	3.4	0.5814
T13	1500	0.368	4.5	0.96899
T14	1100	0.531	2.6	0.71059
T15	980	0.422	9.4	0.6331
T16	950	0.535	2.2	0.6137
T17	1060	0.329	3.8	0.68475
T18	750	0.380	3.2	0.4845
T19	1060	0.405	1.5	0.68475
T20	750	0.398	5.5	0.4845
T21	1600	0.676	5.1	1.0336
T22	530	0.659	2.1	0.3424
CYPRESS	LOAD	DENSITY	EXTENSION	TENSILE STRESS(×10)
T23	720	0.351	2.7	0.46511
T24	920	0.262	4.6	0.59431
T25	470	0.186	2.3	0.3036
T26	650	0.434	2.5	0.4199
T27	1620	0.313	9.2	1.0465
T28	1800	0.423	10.4	1.1628
T29	1650	0.201	4.2	1.06589
T30	1200	0.276	2.4	0.7752
T31	1900	0.338	4	1.2273
T32	550	0.276	2.4	0.3553
T34	1000	0.351	9	0.6460
T35	620	0.346	18	0.4005

SAMPLE NO	MASS (grams)	Density g/cm^3	LOAD (N)	STRENGTH(N/mm^2)	STRAIN	EXTENSION (mm)
R1	68.6	0.429	61000	38.125	0.02	2
R2	73.7	0.461	56000	35	0.02	2
R3	77.8	0.427	43000	26.875	0.015	1.5
R4	71.4	0.446	65000	40.625	0.025	2.5
R5	70.5	0.441	56000	35	0.018	1.8
R6	67.4	0.421	52000	32.5	0.025	2.5
R8	68.7	0.429	65000	40.625	0.025	2.5
R9	69.3	0.433	61000	38.125	0.035	3.5
R10	63.0	0.394	55000	34.375	0.025	2.5
R11	72.0	0.45	54000	34.125	0.023	2.3
R12	76.0	0.475	53000	33.125	0.02	2.0
R13	72.2	0.451	61000	38.125	0.062	6.2
R14	63.5	0.397	60000	37.5	0.025	2.5
R15	71.1	0.444	64000	40	0.03	3
R16	70.6	0.441	65000	40.625	0.055	5.5
R17	68.0	0.425	50000	31.25	0.035	3.5
R18	71.1	0.444	60000	37.5	0.04	4
R19	67.4	0.421	55000	34.375	0.04	4
R20	67.7	0.423	54000	33.75	0.04	2

Compression test results

c) Eucalyptus-parallel to the grain (40×40×100)

d) Eucalyptus- perpendicular to grain

Cross-sectional area: 4000mm^2

SAMPLE NO	MASS (grams)	Density g/cm^3	LOADING (N)	STRENGTH/STRESS (N/mm^2)	STRAIN	EXTENSION (mm)
R21	63.4	0.396	9000	2.25	0.025	1.0
R23	65.5	0.409	16000	4	0.025	1.0
R24	67.1	0.419	16000	4	0.125	0.5
R25	74.6	0.466	16000	4	0.065	2.6
R26	76.2	0.476	20000	5	0.025	1.0
R27	64.3	0.402	25000	6.75	0.0625	2.5
R28	69.8	0.436	7500	1.875	0.125	0.5
R29	70.0	0.437	15000	3.75	0.0375	1.5
R30	66.9	0.418	16000	4	0.125	0.5
R31	68.4	0.428	6000	1.5	0.0375	1.5
R32	65.8	0.411	15000	3.75	0.125	0.5
R33	65.5	0.409	8000	2	0.02	0.8
R34	63.2	0.395	15000	3.75	0.125	0.5
R35	74.1	0.463	12000	3	0.015	0.6
R36	71.6	0.446	10000	2.25	0.125	0.5
R37	85.4	0.534	16000	4	0.035	1.4

a) Cypress- parallel to grain

SAMPLE NO	Density g/cm^3	LOAD(N)	Strength (N/mm^2)	STRAIN	EXTENSION (mm)
G1	0.52	40000	25	0.04	4
G2	0.429	25000	15.625	0.04	4
G3	0.468	35000	21.875	0.04	4
G4	0.409	35000	21.875	0.04	4
G5	0.465	20000	12.5	0.04	4
G6	0.446	39000	24.375	0.015	1.5
G7	0.451	43000	26.875	0.05	5
G8	0.416	45000	28.125	0.04	4
G9	0.423	30000	18.75	0.04	4
G10	0.443	35000	21.875	0.04	4

G11	0.422	38000	23.75	0.04	4
G12	0.463	34000	21.25	0.04	4
G13	0.434	40000	25	0.06	6
G14	0.438	33000	20.625	0.045	4.5
G15	0.445	53000	33.125	0.04	4
G16	0.414	33000	20.625	0.03	3
G17	0.389	35000	21.875	0.03	3
G18	0.412	33000	20.625	0.03	3
G19	0.446	45000	28.125	0.02	2
G20	0.438	32000	20	0.02	2

a) Cypress-perpendicular to the grain

SAMPLE NO	Density g/cm^3	LOAD(N)	STRENGTH (N/mm^2)	STRAIN	EXTENSION (mm)
G21	0.405	25000	6.25	0.05	2.0
G22	0.379	10000	2.5	0.025	1.0
G23	0.401	5000	1.25	0.025	1.0
G24	0.434	15000	3.75	0.025	1.0
G25	0.428	10000	2.5	0.125	0.5
G26	0.387	8000	2.0	0.025	1.0
G27	0.469	11000	2.75	0.125	0.5
G28	0.396	20000	5.0	0.025	1.0
G29	0.465	15000	3.75	0.025	1.0
G30	0.476	27000	6.75	0.0375	1.5
G31	0.442	28000	7.0	0.0375	1.5
G32	0.451	18000	4.5	0.035	1.4
G33	0.381	12500	3.125	0.0325	1.3
G34	0.382	13000	3.25	0.025	1.0
G35	0.418	9000	2.25	0.0075	0.3
G36	0.422	10000	2.5	0.025	1.0
G37	0.423	17000	4.25	0.025	1.0
G38	0.406	10000	2.5	0.125	0.5

Bending strength test results

SAMPLE NO.	MASS (g)	LOAD(N)	Extension (mm)	Strain	Stress N/mm2 (×10)	MOR	MOE (×100) N/mm2	Density g/cm3
B1	339.8	9000	11	0.11	1.8	32.4	16.36	0.453
B2	344.9	10000	9	0.09	2.0	36	22.22	0.459
B3	401.3	10000	13.5	0.135	2.0	36	14.81	0.535
B4	330.9	3800	3.0	0.03	0.76	13.68	25.33	0.44
B5	367.7	8000	7.9	0.079	1.6	28.8	20.25	0.489
B6	284.2	6000	7	0.07	1.2	21.6	17.14	0.379
B7	372.9	9800	11	0.11	1.96	35.28	17.82	0.496
B8	284.8	7000	11	0.11	1.4	25.2	12.72	0.380

B9	252.3	7000	4.9	0.049	1.4	25.2	28.57	0.336
B10	357.6	6500	7.5	0.075	1.3	23.4	17.33	0.476
B11	312.6	4300	5.5	0.055	0.86	15.48	15.64	0.416
B12	305.3	8000	12	0.12	1.6	28.8	13.33	0.407
B13	372.3	9000	11.5	0.115	1.8	32.4	15.65	0.496
B15	299.5	6300	7.5	0.075	1.26	22.68	16.8	0.399
B16	370.7	11000	11	0.11	2.2	39.6	20	0.494
B17	441.8	8200	4.5	0.045	1.64	29.52	36.44	0.589
B18	260.7	5500	7.5	0.075	1.1	19.8	14.67	0.348
B19	388.9	7800	11	0.11	1.56	28.08	14.18	0.519
B20	295.0	6300	6.2	0.062	1.26	22.68	20.32	0.393

d) Cypress

SAMPLE NO.	**MASS**	**LOAD(N)**	**Extension (mm)**	**Strain**	**Stress ×10(N/mm^2)**	**MOR**	**MOE(×100) N/mm2**	**Density g/cm3**
A1	259.4	5410	9.2	0.092	1.082	19.48	11.76	0.346
A2	279.3	2650	3.3	0.033	0.53	9.54	1.606	0.372
A3	284.3	5260	7.8	0.078	1.052	18.94	13.49	0.379
A4	281.7	8440	17	0.17	1.688	30.38	9.929	0.376
A5	278.3	720	7.3	0.073	0.144	2.592	1.972	0.371
A6	278.8	7300	15.8	0.158	1.46	26.28	9.24	0.372
A7	267.6	4800	12.5	0.125	0.96	17.28	7.68	0.359
A8	295.6	4200	4	0.04	0.84	15.12	21	0.394
A9	274.4	4300	6.9	0.069	0.86	15.48	12.46	0.365
A10	276.6	6300	10	0.1	1.26	22.68	12.6	0.369
A11	299.4	2500	3	0.03	0.2	9	6.667	0.399
A12	304.0	5000	8.9	0.089	1.0	18	11.24	0.405
A13	293.6	4100	6.9	0.069	0.82	14.76	11.88	0.391
A14	277.1	4400	6.9	0.069	0.88	15.84	12.75	0.369
A15	308.6	7000	9	0.09	1.4	25.2	15.56	0.411
A16	298.5	7000	9	0.09	1.4	25.2	15.56	0.398
A17	290.4	7000	7.6	0.076	1.4	25.2	18.42	0.387
A18	307.1	9100	22.5	0.225	1.82	32.76	8.089	0.409
A19	268.9	2100	2.8	0.028	0.42	7.56	15	0.359
A20	305.4	7500	7.5	0.075	1.5	27	20	0.407
A21	319.7	5000	7.8	0.078	1.0	18	12.82	0.426

EUCALYPTUS SPECIMEN	**LOAD(N)**	**Density g/cm^3**	**EXTENSION**	**STRAIN**	**Tensile Stress(×10) (N/mm^2)**
T1	370	0.396	1	0.5	0.239

T2	2250	0.459	1.5	0.75	1.4535
T4	1750	0.438	6	3	1.1309
T5	430	0.409	8.5	4.25	0.27778
T6	1180	0.409	5.5	2.75	0.7623
T7	600	0.549	9.0	4.5	0.3876
T8	580	0.359	9.9	4.95	0.3746
T9	850	0.426	11.5	5.75	0.5491
T10	1600	0.471	11.5	5.75	1.0336
T11	1550	0.377	10.4	5.2	1.0013
T12	900	0.499	3.4	1.7	0.5814
T13	1500	0.368	4.5	2.25	0.96899
T14	1100	0.531	2.6	2.3	0.71059
T15	980	0.422	9.4	4.7	0.6331
T16	950	0.535	2.2	1.1	0.6137
T17	1060	0.329	3.8	1.9	0.68475
T18	750	0.380	3.2	1.6	0.4845
T19	1060	0.405	1.5	0.75	0.68475
T20	750	0.398	5.5	2.75	0.4845
T21	1600	0.676	5.1	2.55	1.0336
T22	530	0.659	2.1	1.05	0.3424

Tensile test results Section size: 86mm by 18mm by 2m

CYPRESS	**LOAD**	**DENSITY**	**EXTENSION**	**Strain**	**TENSILE STRESS(×10)**
T23	720	0.351	2.7	1.35	0.46511
T24	920	0.262	4.6	2.3	0.59431
T25	470	0.186	2.3	1.15	0.3036
T26	650	0.434	2.5	1.25	0.4199
T27	1620	0.313	9.2	4.6	1.0465
T28	1800	0.423	10.4	5.2	1.1628
T29	1650	0.201	4.2	2.1	1.06589
T30	1200	0.276	2.4	1.2	0.7752
T31	1900	0.338	4	2	1.2273
T32	550	0.276	2.4	1.2	0.3553
T34	1000	0.351	9	4.5	0.6460
T35	620	0.346	18		0.4005

~~Do these results reflect the number of samples used?~~

hat formatiert: Schriftart: 20 Pt., Schriftfarbe: Rot