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Structural Characterization and Grading of Timber Species for Engineering Applicability in Kenya

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ABSTRACT

An investigation was carried out in Kakamega County to determine the characteristic grade of eucalyptus and cypress timber species that are commonly used in construction. The physical and mechanical properties of two timber species for structural use; eucalyptus and cypress were determined. Six logs of each species were obtained from different areas of Kakamega County, sliced into 2” by 12” size before seasoning under a shade and their structural strength properties were determined at a moisture content of 12%. These logs were cut into test samples for the determination of their strength properties. A total of 800 samples (100 samples for each test) free from visible defects were used for each species. Basic physical properties of the samples like moisture content and density were determined. Tensile strength, compressive strength parallel the grain, compressive strength perpendicular to the grain, and bending strength were the mechanical strength tests carried out according to Eurocode 5 (1995) and BS 5268 (2002) specifications on Universal Testing Machine (UTM). Results were analyzed statistically using Statistical Package for Social Sciences (SPSS) while grading was done according to Eurocode 5 (EC5). Cypress was graded into strength class C20 while eucalyptus was graded into strength class D24. Strength class C20 is used in load-bearing structures that require high strength, such as roof trusses and floor systems. D24 is a common structural grade for a variety of structures exposed to high environmental conditions.

Keywords*: Characterization, Grading, Mechanical Properties, Structures, Timber Species.*

ABSTRACT. Karakterisasi Struktural dan Pemeringkatan Jenis Kayu untuk Penerapan Teknik di Kenya. Penelitian dilakukan di wilayah Kakamega untuk menentukan karakteristik mutu spesies kayu eukaliptus dan cemara yang umum digunakan dalam konstruksi. Sifat fisik dan mekanis dua spesies kayu untuk penggunaan struktural; eukaliptus dan cemara ditentukan. Enam batang kayu dari setiap spesies diperoleh dari berbagai daerah di wilayah Kakamega, dipotong menjadi ukuran 2” x 12” sebelum dikeringkan dan sifat kekuatan strukturalnya ditentukan pada kadar air 12%. Batang kayu dipotong menjadi sampel uji untuk penentuan sifat kekuatannya. Sebanyak 800 sampel (100 sampel untuk setiap pengujian) yang bebas dari cacat yang terlihat digunakan untuk setiap spesies. Sifat fisik dasar dari sampel seperti kadar air dan kepadatan ditentukan. Kekuatan tarik, kekuatan tekan sejajar serat, kekuatan tekan tegak lurus serat, dan kekuatan lentur adalah uji kekuatan mekanis yang dilakukan menurut spesifikasi Eurocode 5 (1995) dan BS 5268 (2002) menggunakan Universal Testing Machine (UTM). Hasil dianalisis secara statistik menggunakan Statistical Package for Social Sciences (SPSS) sementara pemeringkatan dilakukan menurut Eurocode 5 (EC5). Kayu cemara dinilai dalam kelas kekuatan C20 sementara kayu eukaliptus dinilai dalam kelas kekuatan D24. Kelas kekuatan C20 digunakan untuk struktur penahan beban yang membutuhkan kekuatan tinggi, seperti rangka atap dan sistem lantai. D24 adalah kelas struktural umum untuk berbagai struktur kayu yang ekspose.

Kata Kunci*: Karakterisasi, Gradasi, Sifat Mekanik, Struktur, Jenis Kayu.*

1. INTRODUCTION

Timber is material prepared for use in building and other applications. It has been in use for a long period of time, for example Gen 6:14, Noah built an ark using timber (Gopher wood) in 3000BC. Advancements in the variety of accessible timber components and usage in diverse structural aspects have happened concurrently with the rapid advancement in building engineering throughout the years. Modern structural designers are able to attain the efficiency and integrity in building structures that are required today because to the availability of new and innovative timber-based materials (Jimoh, and Aina, 2017). Timber is an option among several materials available to construction engineers, and it 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 energy content and serves as a carbon sink. Both concrete and steel demand a lot more energy than it does to transform trees into timber, which is then turned into structural timber. Furthermore, timber is exceptional because it is unlikely to corrode (Hu et al., 2019). Degradation of steel thicknesses and integrity, or exposure of reinforced concrete may occur as a consequence of abrasion and corrosion, which is seldom the case with timber.

Due to insufficient knowledge on tree species, durability and strength characteristics, and the building elements required for safe construction and design, some contemporary engineers have been hesitant to use timber in engineering construction (Gold and Rubik, 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.

Structural grading is one way of ensuring that timber meets the structural integrity, durability, and strength requirements. Usually, structural grading entails grouping of timber into stress grades with comparable structural attributes in each group (Ridley-Ellis et al., 2016). The grading gives fundamental details on the durability of structural timber, as well as the requirements that are to be applied in the context of grading. Each piece is evaluated using a precise set of guidelines. The regulations are created by matching strength properties of graded timber to characteristics determined through laboratory testing. Timber should not be utilised structurally for construction purposes if it is not strength graded.

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 Euro codes for structural design have 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 machinery 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 26°C–27°C while the UK has a maritime climate with a temperature range of 10°C–23°C (Blab and Sandhaas, 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 LA and LB 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 Ministry of Public Works (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 like the British equivalent code, BS 4978. The code permits a modest amount of variation in grading because it depends on the graders' individual experiences, 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 and cypress 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.

2. METHODOLOGY

800 samples of timber from different tree species taken from Kakamega County were tested and analysed for strength at Masinde Muliro University of Science and Technology laboratory using the universal strength-testing machine. A visit was conducted at different locations within the county, including the Kakamega forest, local timber yards, construction, local tree farms and the Kenya Forestry Research Institute (KEFRI) to ascertain the timber species that are mostly grown and used in construction works within the county, and from which the samples were collected. The sampled logs were saw-milled into 12” by 2” 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 EC5 standard testing procedures for small clear samples. Samples selected for bending strength tests were standardised at 50 mm x 50 mm cross-sections, while the samples for the compression tests were standardised at 40 mm x 40 mm cross-sections. The samples for tensile strength test were standardized at 86 mm by 18 mm cross section and 30 mm by 5 mm in the middle as shown in Figure 1.

Figure 1. Test Sample for Tensile Test

2.1. Moisture Content Test

Moisture content test was conducted to understand the characteristics of the timber at optimal moisture. The samples to be tested for moisture content were dried in an oven for temperatures of approximately 103^{0}C until their weight was constant. The moisture content was then determined by subtracting the dry weight from the initial weight and expressed as a percentage using the equation (1). The test was done according to Eurocode 5 of the standard.

$$M.C = \frac{W1 - Wo}{W1}\ x\ 100\% \quad (1)$$

M.C : moisture content

w_1 : initial weight of the sample of test

w_0 : dry weight of sample

2.2. Density Test

Similar specimens were used to determine the moisture content of the sample densities. This was achieved by obtaining the sample mass and volume according to Eurocode 5 of the standard. The density was calculated using the equation (2).

$$p = \frac{M}{V} \quad (2)$$

p : timber density

M : mass of the specimen

V : volume of the specimen

2.3. Compressive Strength Parallel and Perpendicular to the grain

The compressive strengths were conducted on the samples parallel to the grains of the 40 mm x 40 mm specimen. As such, the specimens were placed on the strength testing machine with their lengths vertical and compressed to failure as given in Figure 2.

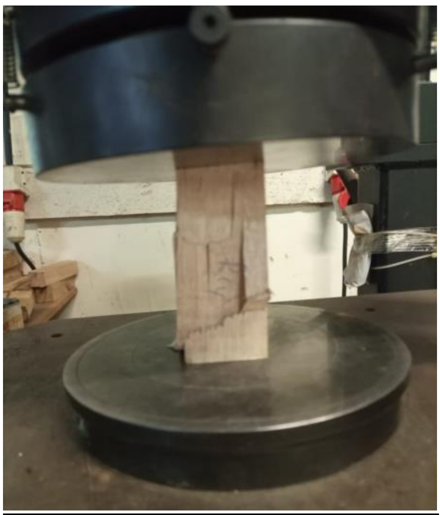

Figure 2. Compressive Strength Test of a Specimen

The compressive strength parallel to the grain was determined using the equation (3).

$$F_{c,o} = \frac{F\ max}{A} \quad (3)$$

$F_{c,o}$: ultimate compressive strength

F_{max} : maximum compressive load

A : cross-sectional area

For compressive strength testing for samples perpendicular to the grain, the specimen lengths were placed perpendicular to the direction of the load, and then compressed to failure. The maximum compressive strength ($F_{c,90}$) was then calculated using the equation (4).

$$F_{c,90} = \frac{Fc,max90}{bl} \quad (4)$$

$F_{c,90}$: maximum compressive strength

$F_{c,max90}$: maximum compressive load perpendicular to the grain

b : width of specimen in mm

l : length of the specimen in mm

The compressive strength tests were conducted according to Eurocode 5 of standard.

2.4. Bending Strength Test

The bending strength test was done using a three-point loading method as shown in Figure 3.

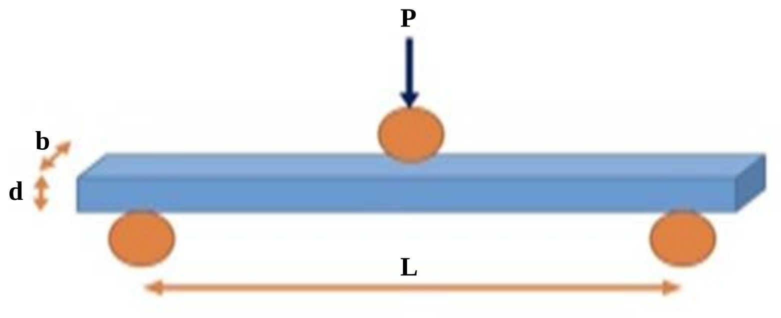

Figure 3. Three Point Load Test Arrangement

Specimens were positioned with their growth rings paralleled to the loading direction, as shown Figure 4. The loading force was then applied to failure. The bending strength was done according to Eurocode 5 of standard and calculated using the equation (5).

$$\text{Bending strength} = \frac{3P_{max}\,L}{2bd^2} \quad (5)$$

P_{max} : maximum applied load (N)

L : bending span (mm)

b : width of specimen (mm)

d : depth of the specimen (mm)

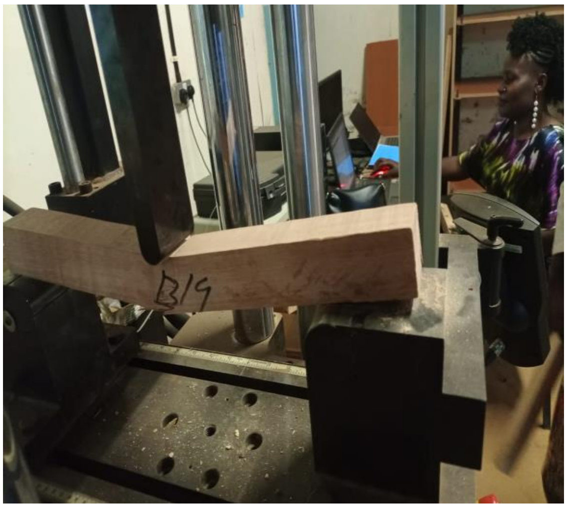

Figure 4. Beam Failure During the Bend Test

2.5. Tensile Strength Test

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 5 mm face of the specimen ends at a rate of 0.05 mm/sec, and constantly increased until failure as shown in Figure 5. The tensile strength test was done according to Eurocode 5 of the standard.

Figure 5: Failure During Laboratory Tensile Test

The ultimate strength was then calculated using the equation (6).

$$F_{t,o} = \frac{Fmax}{A} \qquad (6)$$

$F_{t,o}$: tensile strength parallel to the grain in N/mm^2

F_{max} : maximum load (N)

A : cross section area (mm^2)

2.6. Timber characterization

Characteristics strength: 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.

3. RESULTS AND DISCUSSIONS

3.1. Physical properties

The result of the density tests as shown in Table 1. Density is a very important physical property since it is used in classification of wood. It is used to determine whether the wood is a hardwood or softwood.

Table 1. Densities of Eucalyptus and Cypress Timber

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

The density for eucalyptus and cypress is 0.485 g/cm^3 and 0.40 g/cm^3 respectively. Eucalyptus density varies between 0.39 g/cm^3 and 0.55 g/cm^3 while cypress varies in between 0.32 g/cm^3 and 0.52 g/cm$^{3.}$ Eucalyptus therefore can be used as a hardwood while cypress can be used as softwood.

3.2. Strength properties

The strength properties of timber include compression strength parallel to the grain, compression strength perpendicular to the grain, bending strength and tensile strength as illustrated in Table 2.

Characteristic compressive strength parallel to the grain for eucalyptus is 26.87 N/m^2 while the mean strength parallel to the grain is 34.37 N/mm^2 therefore this could be applied in structural elements like columns. Characteristic compressive strength perpendicular to the grain for eucalyptus is 6.45 N/m^2 while the mean strength perpendicular to the grain is 13.5 N/mm^2, therefore this could be applied in structural elements like beams.

Table 2. Strength Properties for Eucalyptus and Cypress

Percentiles	5	10	25	50	75	90	95
Eucalyptus:	Strength (N/mm^2)						
Compression parallel to the grain	26.875	27.375	30.625	34.500	41.565	46.850	49.688
Compression perpendicular to the grain	6.450	7.510	10.000	13.500	17.500	24.000	
Bending	23.200	23.200	26.800	31.600	34.000	35.400	
Tensile	14.200	15.200	16.000	16.600	17.300	18.400	19.300
Cypress:	Strength (N/mm^2)						
Compression parallel to the grain	15.891	20.968	21.875	25.000	28.125	34.375	
Compression perpendicular to the grain	7.000	8.125	0.500	11.125	13.281	14.775	
Bending	20.200	20.800	22.000	23.680	26.680	29.200	
Tensile	12.200	13.300	14.200	15.200	16.400	17.200	18.300

Characteristic compressive strength parallel to the grain for cypress is 15.891 N/m^2 while the mean strength parallel to the grain is 25 N/mm^2. Characteristic compressive strength perpendicular to the grain for cypress is 7 N/m^2 while the mean strength perpendicular to the grain is 11.125 N/mm^2.

Characteristic bending strength for eucalyptus is 23.2 N/m^2 while the mean bending strength is 31.6 N/mm^2. Characteristic bending strength for cypress is 20.2 N/m^2 while the mean bending strength is 23.68 N/mm^2

Characteristic tensile strength for eucalyptus is 14.2 N/m^2 while the mean tensile strength is 16.6 N/mm^2. Characteristic tensile strength for cypress is 12.2 N/m^2 while the mean tensile strength is 15.2 N/mm^2.

3.3. Grading of Timber

According to Eurocode 5, timber whose density varies between 290 kg/m^3 and 460 kg/m^3 is classified as a softwood while that whose density varies between 461 kg/m^3 and 900 kg/m^3 is classified as a hardwood. The grading result as shown in Table 3, bending strength is the determining property for timber characterization.

Table 3. Classification and Characterization of Eucalyptus and Cypress Timber

Timber Species	Density (g/cm^3)	Wood Classification	Characteristic Bending Strength (N/mm^2)	Strength Characterization /Timber Grade
Eucalyptus	0.485	Hardwood	23.2	D24
Cypress	0.435	Softwood	20.2	C20

4. CONCLUSIONS

Laboratory experiments were conducted on eucalyptus and cypress timber species according to Eurocode 5 standard. From the results, the physical and mechanical properties were established and the variation in these properties among the species was shown by subjecting the results obtained to SPSS Analysis. These two timber species were successfully characterized and graded according to Eurocode 5.

a. The average densities for eucalyptus and cypress are 485 kg/m^3 and 400 kg/m^3 respectively. The characteristic compressive strength parallel to the grain for eucalyptus and cypress are 26.73 N/mm^2 and 15.896 N/mm^2 respectively. The characteristic compressive strength perpendicular to the grain for eucalyptus and cypress are 6.45 N/mm^2 and 7 N/mm^2 respectively.
b. The characteristic bending strength for eucalyptus and cypress are 23.2 N/mm^2 and 20.2 N/mm^2 respectively.
c. The characteristic tensile strength for eucalyptus and cypress are 14.2 N/mm^2 and 12.2 N/mm^2 respectively.
d. The grade stress for eucalyptus is D24 while cypress C20, these species were classified according to cotyledons. They are therefore suitable for construction.

Recommendations based on research results:

a. From the physical and mechanical properties of cypress, it has been classified to strength class C20; hence it can be used in domestic and commercial construction projects. Strength class C20 is also used in load-bearing structures that require high strength, such as roof trusses, beams, and floor systems.
b. From the physical and mechanical properties of eucalyptus, it has been classified to strength class D24. 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.

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