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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

CHARACTERIZATION AND GRADING OF SOME POTENTIAL ETHIOPIAN TIMBERS BASED ON EN 338 (2009)

A Thesis in Structural Engineering

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A Thesis

Submitted in Partial Fulfillment of the Requirements for the **Degree of Master of Science**

The undersigned have examined the thesis entitled '**Characterization And Grading Of Some Potential Timber Based On EN-338(2009)**' presented by **SAMUEL MULUGETA KEBEDE**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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ABSTRACT

The paper is aimed at the characterization and grading of two potential timbers species in Ethiopia using EN-338 (2009) strength classification for Euro code 5 timber design. The timber species namely Cupressus lusitanica mill and Eucalyptus globulus labill were obtained from Gullele Botanic Garden (GBG). Physical and mechanical properties of the selected timber species were determined in according with EN 13183-1 (2002), EN-373 (1957) and EN 408(1995) on small clear specimens. Three point bending tests based on EN 373 (1957) with specimen size 2x2x38 cm was carried out using a universal testing machine (UTM). Mechanical properties of timbers such as bending strength, modules of elasticity and compressive strength of each timber species were determined. Strength grading of timber species was conducted by adjusting the material property value at 12 % moisture content equivalent.

Forty five samples from each species, 15 sample from bottom, 15 from middle and 15 from top for each species were tested.

Compression stress parallel to the grain samples were prepared and tested. The experimental results were compared with the analytical values. The analytical compressive strength value was derived by the formula from EN-338 and these values were used to verify the test results.

Finally, the timber species were then graded according to EN 338 (2009). And hence Cupressus lusitanica mill and Eucalyptus globulus labill were assigned to C-16 and D-24 class, respectively.

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CHAPTER 1 INTRODUCTION

1.1 Back Ground of the Study

For the purpose of construction, one can choose a construction material out of different materials. Selection of one building material over the other depends on a lot of factors. These factors include functional, technical, financial and strength requirements in addition to the type of facility used for production or processing them. Out of different construction materials, timber is one of the construction material that designers can choose from and are promoted to use as environmentally visible option compared to other structural materials such as reinforced concrete and steel.

Along the history, wood is used as a wide spread as a construction material. The followings are its properties that makes it preferable. It has good strength, it is light in weight which is good feature for earthquake design, it is easily workable, and it has aesthetic value. [1]

Wood carries several properties that makes it an excellent construction material.one such properties is its thermal properties, which give it an advantage in terms of its resistance to high temperature. Unlike other materials, which can expand or even collapse in high heat, wood actually dries out and become stronger as the heat increase. In addition the heat conductivity of wood is relatively low in comparison to other material such as aluminum, marble, steel and glasses. This give wood an advantage in terms of being used in various application such as matches, hardware equipment handle, wall covering and ceiling.

Timber is a natural and renewable building material. It has very good ecological values. The energy used to convert trees in to wood and finally in to structural timber is lower than that required by steel and concrete. Moreover, timber is unique because it does not corrode as concrete reinforcement. [2] Due to the above advantageous characteristics of timber, it has been used as structural material for long time.

In Ethiopia, even if there is a code for building and constructing with timbers, the construction industry is not comfortable with timber. Also the characteristics of timber in Ethiopia has been done according to the former Ethiopian building code of standard. In this study an experimental investigation was carried out and a concise summery of the information about characteristics and grade of two selected species in Ethiopia according to European Structural timber-strength classes is presented.

Finally after the experiment and the analysis, Cupressus lusitanica and Eucalyptus globulus were graded to C-16 and D-24 strength class respectively.

1.2 Objective

The main objective of this research is to investigate physical and mechanical properties of timbers that grow in Ethiopia and grade them according to EN-338(2009).

The specific objectives of this research are the following;

- Determination of physical property for Cupressus lusitanica Mill and Eucalyptus globulus labill
- Determination of mechanical property for Cupressus lusitanica Mill and Eucalyptus globulus labill
- Grading of the above two species according to EN- 338 (2009)
- Comparing the two values for the compression stress parallel to the grain. The one found from the experiment with the other which is found by the analytic one.
- To estimate adjustment factors for moisture content as per EN-384.

1.3 Limitation

Timber properties vary by a lot of factors. Among a lot of factors, the followings are the major ones, the place where the timber grows and the age of the timber at the time of cutting. From the above perspective this thesis have the following limitations. First the characterizations is only done on the timbers found from Gullele botanical garden (GBG).The two species which were selected for the experiments were taken from Gullele botanical garden, which is found around Addis Ababa. The botanical garden topography data, altitude above mean see level, rainfall amount, temperature amount and other descriptions are presented in this thesis under section 2.3.2 briefly. Second the age at time of cutting were specific. The age of the trees which were taken for the experiments were 15 and 7 for Cupressus lusitanica and Eucalyptus globulus respectively.

1.4 Material and Methodology

Experimental program was made to find out bending stress, modules of elasticity, compression stress parallel to the grain, moisture content and density. Samples tested for bending stress, modulus of elasticity and compression parallel to the grain were prepared in the following manner,

- Test specimen with size of 2x2x38 cm at location of bottom, middle and top part of tree, for bending and modulus of elasticity test,
- Test specimen with size of 2x2x6 cm at location of bottom, middle and top part of tree for compression parallel to the grain test.

In preparation and testing EN-357 (1973), EN-408 (1995), EN 384- (2004), EN 338- (2009) standards and other related materials were used as a guide line.

1.5 Organization of the thesis

The thesis is organized in five chapters. Chapter one is devoted to brief description of the thesis background, objectives, scope, limitation and methodology. After chapter one, the second chapter contain literature review on timber characteristics, the selected species main futures and the description of the location where the samples taken.

The third chapter deals with the experimental program made in the sample preparation and test set up for bending capacity, modulus of elasticity, compression parallel to the grain , density and moisture content tests. The fourth chapter gives laboratory test results. Also it deals with analysis and discussion on mechanical properties and grading of the two timbers according to EN338 (2009). And the last chapter contain conclusions and recommendations.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Forests have benefited human throughout history. Humans have benefited from the forest by creating economical values. They also created social, cultural and ecological values out of the forest and by the forest. For instance, about 70% of the economy of the countries such as Canada, Finland and Sweden has been on wood forest products [3]

Wood is one of the major natural product that is found from forests. Wood properties are significant towards selecting and determine rational utilization of timber species. Not knowing this have led to uneconomical utilization of the scarce forest resource in the Ethiopia.

Even if there are a lot of timber species in Ethiopia, the wood properties and the respective quality of most of the tree species grown in the country are not well known to the customers at large and the wood based-forest industries in the particular. [3]

The selection of one forest product over the other are largely determined by the different characteristics of each wood species and wood based products. Understanding the characteristics of the wood and technology of rational utilization are very crucial.

In Ethiopia currently, there is a rapid development of industrial, commercial and residential buildings and high deficit between supply and demand of wood and wood -based products in the country that has led to importing of lumber with hard currency.

The forests of Ethiopia due to a number of reasons, including inappropriate utilization, has been alarmingly depleted and have become very limited in distribution species diversity and quality of forest products. Lack of information and appropriate utilization technology on wood and its suitability for different end use are the challenges and gaps in forest products processing and utilizations. [3]

For example, logging waste has been estimated at about 20% in the form of long –stump and large tops due to sever felling damage, buckling and extraction techniques. The overall commercial loss during harvesting and further processing operation has been estimated at about 75 %. [3]

2.2 Characteristics of Timbers

The wood suitable for construction of building or for other engineering purpose is called timber. Depending up on mode of growth, the trees may be classified as endogenous and exogenous trees. The tree that grow in wards by depositing each layer of longitudinal fibrous mass are known as endogenous tree e.g. banana, palm, bamboo, cane and etc. These are not suitable for engineering works except bamboo.

The tree can grow out wards by the addition of one concentric ring every year, are known as, exogenous tree. These rings are known as annual rings because one such ring is added to the tree every year. So the age of the tree can be found out by counting the number of such rings. The timber obtained from these trees is extensively used for engineering works. Depending up on the hardness of the timber, exogenous tree can be classified as hard wood and soft wood. [4]

Different types of construction projects call for different kinds of timber, both hardwood and softwood are used for everything from structural to decorative. Softwood and hardwood are distinguished botanically in terms of their reproduction, not by their end use or appearance. All trees reproduce by producing seeds, but the seed structure varies. In general, hardwood comes from a deciduous tree which loses its leaves annually and softwood comes from a conifer, which usually remains evergreen. Hardwoods tend to be slower growing, and are therefore usually denser.

From the experimental investigation and analysis, the two selected species for the experiments fall to different categories. One of them is hard wood and the other one is soft wood. Eucalyptus globulus is hard wood and Cupressus lusitanica is soft wood.

The main difference between the hard wood and soft wood is presented in the following table 2.1. The conclusion made that Eucalyptus globulus is hard wood and Cupressus lusitanica is soft wood will be understood after seeing the two species description under section 2.3.1

Table 2-1: differences between hard wood and Soft wood

Characteristics	Hardwood	Softwood
Originate from	Deciduous tree	Evergreen tree
Example	Eucalyptus G.	Cupressus L.
Density	Typically denser (But not always)	Usually lighter(But not always)
Color	Generally dark	Almost always light
Structure	Lower sap	Higher sap
Grain	Close	Loose
Fire resistance	Good	Poor
Leaves type	Broad leaves	Pointed Leaves

Parts of the timber trees

When we see by cutting the trunk of a fully developed exogenous tree, the following parts are made visible. [4]

Outer bark: Timber tree has outer most covering which is called bark. It is dry and dead layer of timber .It prevent the tree from external weathering effects.

Inner bark: This layer is next to outer bark and covers the cambium layer. It is responsible for the transportation of the food manufactured in the leaves up to roots through the branches and trunk. It is always moist and wet.

Cambium layer: This layer is found between inner bark and sap wood known as cambium. In this zone, the growth of the tree occur and build up the wood.

Annual rings: The rings of the wood fibers arranged in approximately constrict circle around the pith steam are known as annual tings because one such ring is added every year.

Pith or heart: The inner most part of the timber is known as pith of heart. It is the first formed portion of the stem of tree. It consist cellular tissues.

Sap wood: The portion of the trunk which is comparatively young in age, carries sap from the roots to the leaves provides food material is known as sap wood. Sapwood is lighter in color, weaker and more liable to decay.

Medullary rays: These are thin horizontal ray radiating from the pith towards the bark. They carry the sap from outside to the inner part of the tree and nourish it. They keep the annual rings tightly, gripped together.

2.3 Diversity of timbers in Ethiopia

Ethiopia has different timber species. There are about 1,000 tree and shrub species in Ethiopia of these about 360 indigenous and home grown exotic tree species can supply lumber for construction and manufacturing furniture. [3]

The annual capacity to produce timber in Ethiopia has been estimated at 4,500- 5,000 m3, the recovery rate for most sawmill is about 35-55 %. [3]

There is a huge deficit between the demand and supply in the country. The deficit (84.2 million m3) has been projected between the supplies about 10.6million m3 and a demand of wood (94.8 million m3) by 2014. [3]

In Ethiopia timber harvesting focus on few species. In the Past Timber harvesting from the natural forests has focused mainly on few available species, including juniperus procera, pdocarpus falcatus, hagenia abyssinina and cordia fricara which covered about 85 % of the demand.

2.3.1 Selected species for the experiments

The two selected species for the experiments are Cupressus lusitanica Mill and Eucalyptus globulus Labill

Table 2-2: selected Timber species Nomenclature

Number	Scientific name	Local name
1	Cupressus lusitanica Mill	Yfrenje tede
2	Eucalyptus globulus Labill.	Neche bahir zaf

Description of the selected species

1. CUPRESSUS LUSTANICA MILL

Main futures: The tree can grow up to 30 m high; It has smooth-to orange brown bark, soon planking and exfoliation leaves on ultimate branch lets in opposite, imbricate pairs, the facial one rather similar to the laterals ,differentiating only in size.[3]

Places where it grow: The species is found in altitudinal range of 1,750-2,300 m, but certainly at a wider range of altitude. In Ethiopia, it is found in Arsi, Gonder, Harergea, Kefa, Shewa, and Tigray (and almost certainly everywhere)

The species is exotic in Ethiopia and indigenous in Brazil, EI Salvador, Guatemala, Honduras and Mexico. Currently it is widely cultivated in east Africa, Mediterranean and throughout countries in the tropics and sub tropics. [3]

Anatomical properties: The species is very attractive and decorative grained wood. It has whitish to yellow sap wood and brown to dark to brown heart wood. The paler sapwood is distinct from yellowish to brown heart wood; which is about 50 to 100 mm wide, when seasoned has a slight cedar like odor grain is usually straight and the texture fine and fairly even; freshly felled timber has a cedar like scent. [3]

Working properties: it can works readily with machine and hand tool with little dulling effect. It is difficult to drill or mortise cleanly. Nails are easily inserted but tends to split, holds exceptionally well and also screws holds well. It is easily sands and glue well and take a good finish. [3]

Can be used: It has a wide range of uses. The species produces an excellent general purpose softwood timber for low grade buildings, cheap furniture, boxes, crates shuttering, poles, posts, shelves, general carpentering and joinery, doors and window, external work and light construction where the timber is contact with the ground, long fiber pulp, paper and plywood, earthwork, hydraulic engineering application and fire woods. Improved use will be possible when knot free timber with more consistent physical and mechanical properties is available. [3]

Figure 2-1: Cupressus lusitanica naming the random selected trees

2. Eucalyptus globlus Labil

Family: Myrtac eae, Common name: Bahir-zaf, Nechi Bahirzaf

Main futures: The trees can grow usually up to 45 m high, sometimes reaching 70 m and with a diameter of 1.5 to 2.5 m. The Stem is usually Straight and cylindrical and branches up to 2/3 of its total height. It has a barks usually smooth, white to cream, yellow, bluish gray or gray, peeling from the trunk throughout, but with accumulated grey-brown, not peeling bark for up to one meter from the trunk base. Adult leaves green are uniform in color. [3]

Places where it grow: the species is found in trial plots, pilot plantation, wood; lots, shutter belt, large scale plantation and frequently as isolated tree in the farm and covering altitudinal range of 1700-2800 m.

The species is exotic in Ethiopia and indigenous to New South Wales and Victoria, Australia. It is also reported from Bolivia, Eretria, Mediterrian countries, and Mountain habitat of East African, Peru and Zambia and in other part of the world. The most planted species outside of Australia as of 1973. [3]

Anatomical Properties: The wood pale grayish to creamy; yellowish and easily distinguishable from the reddish brown heart wood. It is moderately strong and elastic, it is also fire resistant. [3]

Working properties: It can be worked with machine and hand tools with medium resistance to the cutting blades. It is moderately resistance with saw burning and saw marks on the cut surface. It is also resistant to nailing but holds nail properly with slight splitting and screw holding ability is quite good. It finishes well. [3]

Can be used: the species is used for all application requiring hard wood. It can be used boxes, light and heavy construction, piers and docks, ships, railway cars, decking floor, furniture and cabinet work, building, fencing, electric transmission, telegraph poles and post, pile, axe and other tool handle, cheap board, short fiber pulp for paper making, large sized logs for veneer and ply wood, fuel wood and charcoal The species is an important source of pulp for the production of printing, writing specially tissue papers. [3]

2.3.2 Place where the selected species taken

The two species selected for the experiment are found from Gullele botanic garden .Since timber property is affected by the place where it grow, it is necessary to describe the Gullele botanic garden (GBG).

Its Location is North West of Addis Ababa at the upper catchments (Entoto), Distance from Addis Ababa municipal is 8 km. The botanical garden was established in 2009 by proclamation No. 18/2009 of A.A. It is Governmental Organization Owned by Addis Ababa city Government with collaboration of Addis Ababa University (AAU).

Total area designated by law is 705 ha. The Topography-is Sloppy and semi-sloppy and the Altitude range is from 2600 up to 2950 above mean see level. The Average annual rain fall is from 1100 up to 1300mm.The Annual Temperature is within the range of 15-18 Degree Celsius and the Climate is mild weather to cold. The Vegetation cover is Forest and semi forest.

The Soil depth is Shallow dominantly rocky and the types of soil is Shallow red soil. The Dominant plant species are Eucalyptus globules and Juniperus procera and the dominant wild animal is hyena also the dominant wild bird is White head kure.

2.3.3 Place where the specimens prepared

The final specimen preparing process for the experiments starting from ripping the logs up to testing were done at Ethiopian wood technology research center which is found in Addis Ababa around Saris. Here some facts about the center are presented.

History of forest product research in Ethiopian

Forest product research initially began in 1967 in Addis Ababa University under the then Ethio- Swedish, institute of building technology. However, the budget support was suspended and hence the research under taking was not lasted large. In 1969 with the support of Germen government wood strength research activities were initiated in Addis Ababa under the

Faculty of science with a similar reason, the initiative at science faculty was not lasted more than a year and discontinued.

Wood technology research center

The idea of establishing the current wood technology research center (WTRC) formerly wood utilization and research center (WUARC) was began when the state forest development enterprise established in 1971. At that time the forest industry advisory group for Africa (FIAG) suggested the importance of studying wood products and utilization. Then in 1979 the then WUARC was officially established with support from the Swedish international development agency (SIDA).

Facilities, Wood technology research center cover an estimated area of ca. 18,700 m^2.The center has the following facilities building intended for office, laboratories and demon station. In addition to timber processing and preservation, saw doctoring,

2.4 Characterization and Grading of Timber

Characterization of a timber can be done in the two way. First By preparing appropriate specimen type for each property and performing the test accordingly. These properties include ,Bending strength, Modulus of elasticity, Density, Tension parallel to the grain, Tension Perpendicular to the grain, Compression parallel to the grain, Compression perpendicular to the grain, Shear strength, Mean modulus of elasticity parallel to the grain, Mean modulus of elasticity perpendicular to the grain and Shear modulus.

The second one is preparing a test specimen for Bending, Modulus of elasticity, Density and then calculating the other properties value based on the above three values by using the formulas given in EN-338(2009) and EN-384(2004).

When doing the characterization, preparing the specimen for the tests can be done in two way. The first one is preparing a small clear specimen for each property base on EN-357(1973) and doing the test to get the result for each properties or by preparing a full size structure specimen and doing the tests.

Since timber properties vary by the amount of moisture content at the time of the test, knowing the amount moisture content is must.

In this work preparing small clear specimens and doing the bending strength, Modulus of elasticity, Density test and driving the other properties is selected to characterize the selected timber species.

Defining limit of, material properties for timber cannot be achieved in the same way as for manufactured structural materials such as steel, concrete, plastic and wood fiber board where a certain material quality is obtained by changing the composition of the raw materials. For timber, the only realistic way of obtaining quality within desired limit is by grade. [5]

This brings the need to have grading procedures for timber to meet the requirements for either visual appearances or strength or both. Strength property are essential for structural design although other properties may well come into consideration when assessing the overall performances of a component or a structure. [6]

In general, structural timber is assigned to a specific strength class, Several strength class system exist on an international scale, One of them is the EN 338 which constitute the classification of timber based on the prescription of characteristics value for the material properties. That is for every timber strength class, a characteristics value for every relevant material property is given. As a result of grading, timber is provided to the market as a graded material.

CHAPTER 3 EXPERIMENTAL PROGRAM

3.1 Introduction

The experimental program of this research is designed to obtain physical and mechanical properties. The tests were the bending capacity, modulus of elasticity and compression parallel to the grain. For all the above tests sample were taken from bottom, middle and top part of timbers, also the samples were prepared from the section of the timbers that contain heart and sap.

3.2 Physical and mechanical properties of timber

3.2.1 Introduction

The physical and mechanical properties of the timbers were determined according to EN-357 (1973), EN-408 (1995), EN-384 (2004) and EN 338-(2009).This study was carried out to investigate the bending capacity, modulus of elasticity and compression parallel to the grain direction. For this research, test samples were taken from Gullele botanic garden (GBG).

3.2.2 Mass by volume

Mass by volume of the timbers was determined according to EN 408(1995) standard using equation 3.1 and characteristic density value determined in according to with EN384 (2004) from equation 3.2. Forty five samples of each timber species were tested.

$$\varrho = \frac{M}{V} \qquad (3.1)$$

Where, ϱ = density (in kg/m^3)
M = mass (in kg)
V= volume m^3)

$$\varrho_k=(\varrho-1.65\boldsymbol{\delta}) \qquad (3.2)$$

Where, $\boldsymbol{\varrho_k}$ = characteristics density
$\boldsymbol{\varrho}$ **=** mean densities of all specimen
$\boldsymbol{\delta}$ = standard deviation of densities of all specimen (in kg/m^3)

3.2.3 Moisture Content

Moisture content and timber properties are highly related. The mechanical property, insect attack also durability of timbers are highly related to the moisture content. As the moisture content reduce, the strength of the element increases and less prone to modulus attack. The moisture content of the timbers was determined according to EN-13153-1(2002), EN-373(1957) and EN-408(1995), on a sample prepared by weighting and then drying the samples in oven at a temperature of 100±3℃.The moisture content of a test piece was calculated as the loss in mass, expressed as a percentage of the oven dry mass, according to the following equation.

$$M.C.\% = \left(\frac{m1-m2}{m2}\right) * 100\% \qquad (3.3)$$

Where, M.C = moisture content in%
m1 = the mass of the test specimen before drying
m2= the mass of the test specimen after oven drying

The specimen for moisture content was prepared for each mechanical specimen immediately after test near place of failure. After knowing the amount of moisture content, we will use adjustment factor to change the bending strength, modules of elasticity etc... Value to 12% moisture content equivalent if the moisture content at the time of the test is different than 12%. And adjustment factor for the properties of test results were applied from EN384 (2004).

3.2.4 Bending Strength and modulus of elasticity test

The bending capacity test were made for a portion of timber parallel to the grain obtained from different position of a timber. In the preparation of test samples EN373 (1957) and EN408 (1995) were used as guide line.

Specimen Preparation, size and specimen designation

EN 408(1995) recommend a test specimen of L= 19D, with I took and prepare of a sample with a depth of 2 cm, a width of 2 cm and 38 cm length, The specimen’s number for one species was 45, which 15 samples from each position of the tree. 15 from bottom, 15 from middle and15 from top. Also the samples was prepared by considering the tree components which have both heart and sap together. This was done by using the following basic hints on the trees. The specimen with both heart and sap has different color that is visible.

Specimen designation

The specimen designation used in this study are shown in Table 3.1. The designation were based on the followings. T is for Cupressus lusitanica which is locally known as yefrenje tede and B is foe Eucalyptus globulus which is locally known as barezaf.

Table 3-1: specimen designation for bending and modulus of elasticity tests

No.	Specimen Name	Specimen Designation
1	TB1	Ted (Cupressus L.) prepared specimen from bottom part of the tree ,specimen number 1 out of 15 specimen
2	TB15	Ted (Cupressus L.) prepared specimen from bottom part of the tree, specimen number 15 out of 15 specimen
3	TM1	Ted (Cupressus L.) prepared specimen from middle part of the tree, specimen number 1 out of 15 specimen
4	TM14	Ted (Cupressus L.) prepared specimen from middle part of the tree, specimen number 14 out of 15 specimen
5	TT1	Ted (Cupressus L.) prepared specimen from top part of the tree specimen number 1 out of 15 specimen
6	BB1	B'zaf (Eucalyptus G.) prepared specimen from bottom part of the tree, specimen number 1 out of 15 specimen
7	BB7	B'zaf (Eucalyptus G.) prepared specimen from bottom part of the tree, specimen number 7 out of 15 specimen
8	BM1	B'zaf (Eucalyptus G.) prepared specimen from middle part of the tree ,specimen number 1 out of 15 specimen
9	BM15	B'zaf (Eucalyptus G.) prepared specimen from middle part of the tree ,specimen number 15 out of 15 specimen
10	BT1	B'zaf (Eucalyptus G.) prepared specimen from top part of the tree, specimen number 1 out of 15 specimen

Bending and Modulus of elasticity Test set up

The test was done in Ethiopia wood technology and research center. The test was done by three point loading. The rate of loading for bending strength and modulus of elasticity 0.11 mm/sec.

Figure 3-1: Test set up for bending strength and modulus of elasticity test

Bending strength and Modulus of elasticity formula

Bending strength and modulus of elasticity values after a three point test, were determined by the following formulas,

For bending strength value [7, 8]

$$f_m = \left(\frac{3 * p_{max} * l}{2 * b * d^2}\right) \qquad (3.4)$$

Where: P,max = maximum load that each specimen carry in (N)

f_m = bending strength in ($\frac{N}{mm^2}$)

b = width of the specimen in (mm)

d = depth of the specimen in (mm)

l = span of the specimen in (mm)

For modulus of elasticity value [7, 8]

$$\text{Emi} = \frac{P' l^3}{4 d' b h^3} \qquad (3.5)$$

Where: Emi = modulus of elasticity in ($\frac{N}{mm^2}$)

P’= load at which the load and the deflection are linear in (N)

d’= is the deflection at which the load and the deflection are linear in (mm) b = width of the specimen in (mm)

d = depth of the specimen in (mm)

l = span of the specimen in (mm)

3.2.5 Compression parallel to the grain Test

Specimen preparation, size and designation

Compression parallel to the grain Specimens were prepared to sizes of 20 x 20 x 60mm each. While doing the experiment, each specimen was placed on the testing machine with its length parallel to the direction of the load.

Table 3-2: specimen designation for compression test

No.	Specimen name	Specimen designation
1	T-comp-B-1	Ted(Cupressus L.) specimen prepared from bottom part of the tree specimen number 1 out of 15
2	B-comp-B-2	B'zaf (Eucalyptus G.) prepared specimen from bottom part of the tree, specimen number 2 out of 15 specimen

Compression parallel to the grain Test set up

The same machine that have used to determine bending strength is used to determine the compression parallel to the grain strength and the rate of loading was 0.01 mm/sec. Compression parallel to the grain represents the maximum stress sustained by the specimen parallel-to-grain. Specimen having a ratio of length to least dimension of less than or equal to 3 have been used for the experiment. The specimens were placed in such a way that the load will be truly centric load. The load was then applied until failure occurred, the load at failure being 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). The ultimate compressive strength was calculated from Equation 3.6.

The idea of performing compression parallel to the grain test was to compare the value with the analytic values which will be derived from the formula given in EN-338(2009).

Figure 3-2: Test set up for Compression parallel to the grain test

Compression parallel to the grain formula

The following formula was used to determine the compressive strength after getting the maximum crushing load from the test. [8, 9].

$$F_{c,0} = \frac{F_{max}}{A} \quad (3.6)$$

Where: $F_{c,0}$ = Compression parallel to the grain

F_{max} = the maximum load

A = area of the specimen

3.2.6 Other derived mechanical property

Characteristic values of other mechanical properties at 12% moisture content such as tensile strengths parallel and perpendicular to grain, shear modulus, compressive strength parallel and perpendicular to grain and other stiffness properties of the timbers were determined using equations from Annex A of EN 338 (2009) based on the bending strength and modulus of elasticity result which were found from the experiments.

1. Tensile strengths parallel to grain

The tensile strength parallel to grain represents the maximum tensile stress sustained in direction parallel to grain.

The characteristic values of tensile strength parallel to grain ($f_{t,0,k}$) is calculated using the equation,

$$f_{t,0,k} = 0.6f_{m,k} \qquad (3.7)$$

Where, $f_{m,k}$ is bending strength

2. Tensile strengths perpendicular to grain

Tensile strength perpendicular to grain value is taken for hard wood and soft wood separately. Tensile strength perpendicular to grain is considered to be constant (0.6N/mm^2 for Hardwood and 0.4N/mm^2 for softwood) for the purpose of grading [5]

3. Compressive strengths parallel to grain

The Compressive strengths parallel to grain represents the maximum compression stress sustained in direction perpendicular to grain.

$$f_{c,0,k} = 5(f_{m,k})^{0.45} \qquad (3.8)$$

Where $f_{m,k}$ is bending strength

4. Compressive strengths perpendicular to grain

The Compressive strengths perpendicular to grain represents the maximum compression stress sustained in direction perpendicular to grain.

$$f_{c,90,k} = 0.007\rho_k \qquad (3.9)$$

Where ρ_k is characteristics density

5. The characteristic values of mean modulus of elasticity parallel to grain ($E_{0,0.05}$)

The characteristic values of mean modulus of elasticity parallel to grain ($E_{0,0.05}$) was computed from the following equations;

$$E_{0,0.05} = 0.67E_{0,mean} \text{ for soft wood} \qquad (3.10)$$

$$E_{0,0.05} = 0.84E_{0,mean} \text{ for hard wood} \qquad (3.11)$$

6. The characteristic values of mean modulus of elasticity perpendicular to grain ($E_{90,\ mean}$)

The characteristic values of mean modulus of elasticity perpendicular to grain ($E_{90,\ mean}$) for the timbers were computed from the following equations;

$$E_{90,\ mean} = E_{0,\ mean}/30 \quad \text{for soft wood} \qquad (3.12)$$

$$E_{90,\ mean} = E_{0,\ mean}/15 \quad \text{for hard wood} \qquad (3.13)$$

7. The characteristic values of mean shear modulus ($G_{,mean}$)

The characteristic values of mean shear modulus (G_{mean}) is computed from equation

$$G_{,mean} = E_{0,mean}/16 \qquad (3.14)$$

3.3 Specimen preparation process

Step-1. Determine the number of trees to prepare the samples.
EN-384-2004 under article 7.1 state that for small clear data, the number of specimens in a sample shall be at least 40 taken from at least five trees. So I cut five trees at different location randomly for the two species each, a total of 10 trees were cut. And I decide to prepare a small clear specimen of 45 for each species. Care was given in order not to cut young trees, So DBH (diameter at burst height) more than 22 cm was checked.

Step-2. After the trees are cut, a portion from them which has a diameter less than 12 cm was cut and removed because this part will not be comfortable to work with sawn machine. After that a measurement of length was done and the measured length was divided in to 3 to get the bottom, the middle and the top part.

Step-3. Determining the age of the trees .This was estimated by using the number of the ring of the tree, finally the age of the trees were 7 and 15 for Eucalyptus and Cupressus L. respectively.

Step-4.Final sample preparation steps
The samples were transported for the final preparation of the test specimen and for performing all the necessary tests to Ethiopian wood technology research center. The tress

which arrived at Ethiopian wood research center on 24/03/12E.C. has passed in to the following steps. The steps are shown in appendix B-1 part.

Step-4-A. **Ripping the trees logs in to lumbers:** This steps is all about ripping the trees log to extract the lumber with the thickness of 3.5 cm. The number of lumber extracted is different for each logs. This is because the thickness of each tree logs is different. The number of lumber extracted from each tree logs is presented in table 3.3 and 3.4 for the two species respectively.

Table 3-3: tree log name and number of lumber extracted for Cupersus lusitanica

No.	**Tree log name**	**Number of lumber extracted**
1	A tree log which is found from Yefrenji-Ted bottom part of tree -1	3
2	A tree log which is found from Yefrenji-Ted middle part of tree -1	2
3	A tree log which is found from Yefrenji-Ted top part of tree -1	4
4	A tree log which is found from Yefrenji-Ted bottom part of tree -2	4
5	A tree log which is found from Yefrenji-Ted middle part of tree -2	3
6	A tree log which is found from Yefrenji-Ted top part of tree -2	3
7	A tree log which is found from Yefrenji-Ted bottom part of tree -3	3
8	A tree log which is found from Yefrenji-Ted middle part of tree -3	3
9	A tree log which is found from Yefrenji-Top part of tree -3	2
10	A tree log which is found from Yefrenji-Ted bottom part of tree -4	3
11	A tree log which is found from Yefrenji-Ted middle part of tree -4	2
12	A tree log which is found from Yefrenji-Ted top part of tree -4	2`
13	A tree log which is found from Yefrenji-Ted bottom part of tree -5	3
14	A tree log which is found from Yefrenji-Ted middle part of tree -5	3
15	A tree log which is found from Yefrenji-Ted top part of tree -5	2

Table 3-4: tree log name and number of lumber extracted for Eucalyptus globulus

No.	Tree log name	Number of lumber extracted
1	A tree log which is found from Nechi-B'zaf bottom part of tree -1	3
2	A tree log which is found from Nechi-B'zaf middle part of tree -1	2
3	A tree log which is found from Nechi-B'zaf top part of tree -1	2
4	A tree log which is found from Nechi-B'zaf bottom part of tree -2	3
5	A tree log which is found from Nechi-B'zaf middle part of tree -2	2
6	A tree log which is found from Nechi-B'zaf toppart of tree -2	2
7	A tree log which is found from Nechi-B'zaf bottom part of tree -3	2
8	A tree log which is found from Nechi-B'zaf middle part of tree -3	2
9	A tree log which is found from Nechi-B'zaf top part of tree -3	2
10	A tree log which is found from Nechi-B'zaf bottom part of tree -4	2
11	A tree log which is found from Nechi-B'zaf middle part of tree -4	2
12	A tree log which is found from Nechi-B'zaf top part of tree -4	2
13	A tree log which is found from Nechi-B'zaf bottom part of tree -5	1
14	A tree log which is found from Nechi-B'zaf middle part of tree -5	3
15	A tree log which is found from Nechi-B'zaf top part of tree -5	3

Step-4-B. **Ripping the lumbers in to battens**

The lumbers then were split in to batten of size 3.5*3.5 cm. The final size of the batten is 2 *2 cm.

Figure 3-3: Naming the battens after ripping the lumber

Step-4-C-Kiln drying process

Since the samples have initial moisture content greater than 80%, drying of samples were necessary. There are two ways of drying. The first one is air drying and the second one is kiln drying. In this research the second one is used.

Table 3-5: main difference of natural seasoning and artificial seasoning

No.	Characteristics	Natural seasoning	Artificial seasoning
1	Control on drying	Not perfect	Perfect
2	Economy	Less coasty	Expensive
3	Supervision	Ordinary supervision	Skilled supervision
4	Time of seasoning	More than 6 month	4-5 days

The sample has been removed from kiln after 16 and 17 days of duration for cuperessus lusitanica and Eucalyptus globulus respectively.

The first step was to know initial moisture content of the specimen for the two species separately. In order to know the initial moisture content a controlling specimen were chosen randomly. And the initial moisture content of the samples was 80.97% and 57.73% for Cupressus Lusitanica and Eucalyptus globulus respectively.

Kiln drying process controlling

After this the drying process can be controlled because we have the initial moisture content and controlling specimens. And then the controlling specimens will be removed from the kiln at regular interval of 12 hours and their current moisture content will be calculated after taking the weight of the controlling specimens. So the samples were removed when Cupressus Lusitanica gain 16.84% moisture content and Eucalyptus globulus gain 17.03% moisture content. Moisture content while in the kiln were controlled by the following formulas and the process is shown in appendix B-2.

$$AODW= (IWAS*100)/IMC+100) \quad (3.15)$$

$$CMC= (CW-AODW)/ (AODW+100) \quad (3.16)$$

Where, AODW = analytic oven dry weight

CMC = current moisture content

IWAS = control section initial weight

CW = current weigh (measurement taken at regular interval which is 24 hours)

Step 4-D: reducing the size of the battens to 2*2 cm, this was done on three stage.

A. Reduce to 33*33 mm size form 35*35 mm size
B. Reduce to 26.5*26.5 mm size after step –A
C. Reduce to 20*20 mm size after step-B

The sample size was checked by caliper to make sure the final size is attained. After this A cutting was done for bending and modulus of elasticity test, 15 from bottom, 15 from middle and 15 for the top part specimens. And After this with the same procedure, 15 from the bottom15 from middle and 15 from top, a total of 45 samples of 2*2*6 cm for compression parallel to the grain test was prepared. All the samples which have been prepared for bending, modulus of elasticity and compression parallel to the grain tests contain heart and sap and was labeled after that.

CHAPTER 4 RESULTS AND DISSCUSSION

4.1 Experimental results

4.1.1 Introduction

In this section the result of, density, moisture content bending capacity test and modulus of elasticity test result of the two species are presented. It also contains test result for compression parallel to the grain test result.

For modulus of elasticity test, while doing the test for each specimen, there was a load increment reading part on the testing machine and mounted deflection reader. After that load versus deflection were plotted.

Derivation of Basic stress and characteristics strength values

Originally the mean and basic stress values were obtained from the statically analysis of the test results from small clear specimens. The basic stress is the stress which could safely be permanently sustained by timber. Many samples of a particular species would be tasted. Because of the uniformity of the samples, statically analysis is possible. [10]

Standard deviation

Standard deviation tells the researcher how spread out the responses are. It tells whether the spread of a data is concentrated around the mean or scattered far. Standard deviation generally does not indicate ’right/wrong’ or ‘better/worse’. It only describe the distribution in the relation to the mean.

But finally, I calculated for all the experiments a coefficient of variation, which were calculated by dividing the standard deviation by the mean. For all experiments including, density. Moisture content, Bending and Modulus of elasticity, the coefficient of variation were lower than one.

For approximate answer, after calculating coefficient of variation: as a rule of thumb, A CV which is equal or greater than one indicate a relatively high variation and while a CV which is equal or lower than one can be considered low.[11]

4.1.2 Density and Moisture content test result

4.1.2.1 Density test result

From the experiment the characteristic density, mean density and standard deviation of the samples of the two species were determined. Density test were conducted on 45 specimen for each species by measuring the mass at test for each test specimen.

The detail calculation of density for each specimen for the two species are included in the appendix-A-1 andA-2, the values are the density of the specimens at the time of the test. Density was calculated by using equation 3.1.After calculating mean and standard deviation for densities for the two species separately, calculation of characteristics density by using, mean value, standard deviation, and Eq.3.2 was done.

Then after, Calculation of density adjustment factor was done. Since timber density is different at different moisture content and our interest is to know the density at 12% moisture content equivalent, I calculated the adjustment factor by using EN-384(2004). This values are 1.00338 and 1.01416 for cupressus L and Eucalyptus g. respectively as shown in the Appendix-A-1 and A-2. Finally use this value to get at 12 % moisture content adjusted equivalent density.

Table 4-1: summery of density test result for specimen prepared for bending and modulus of elasticity test

	Species Name	
	Cupressus L.	Eucalyptus G.
Mean Density(kg/m^3)	501.75	651.61
Standard deviation	23.3	32.563
Characteristics density (kg/m^3)	460	597.879
12% M.C adjusted characteristics density	461.5611	606.345

4.1.2.2 Moisture content at experimental test, test result

From the experiment the moisture content at the test and standard deviation of the samples of the two species were determined. Moisture content test were conducted on 45 specimen for each species by measuring the mass at test for each test specimen. Each specimen result is shown in the appendix A-3 and A-4. The following procedure were followed to calculate the moisture content. The calculation of moisture content was done by using equation number 3.3.

Table 4-2: summery of moisture content result for specimen prepared for bending and modulus of elasticity test

Timber species	Mean moisture content	Standard deviation
Cupressus Lustanica	11.324	1.37527
Eucalyptus globulus	9.168	0.96925

4.1.3 Bending and Modulus of elasticity test result

4.1.3.1 Bending capacity test result

From the experiment the ultimate load carrying capacity and types of failure were recorded. Bending test were conducted on 45 specimen for each species by three point loading test. In the experimental test failure in most of the specimen occurred at the middle position. Few number of the test specimen failed by splitting in the two part. The result for the two species is shown in the appendix A-5 and A-6.

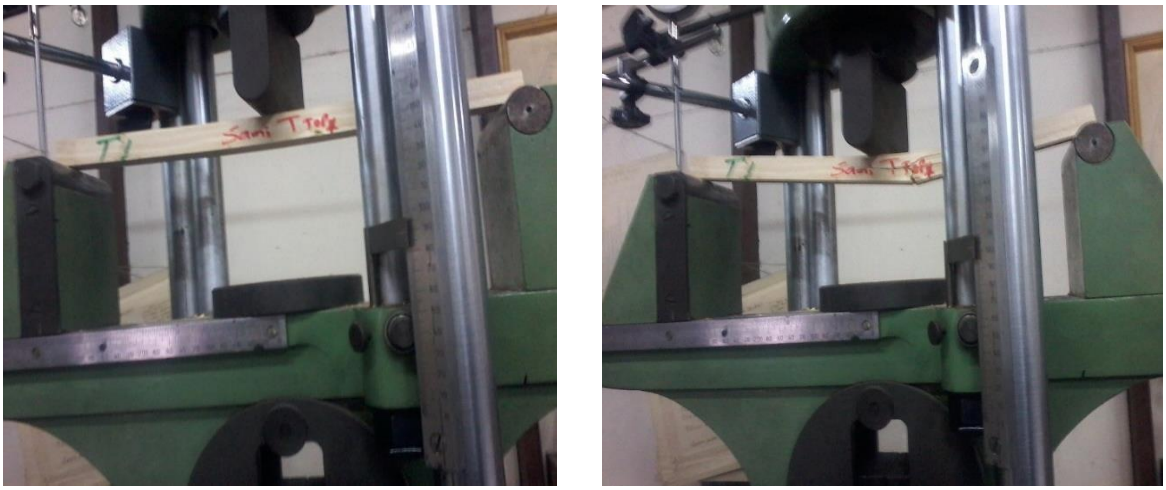

Figure 4-1: Specimen before and after test

The following figures show the prepared specimens before and after the experiment. For cuprusses L. top part specimen and for Eucalyptus G. middle part specimen are presented for illustration purpose.

Figure 4-2: Cupressus l. top specimens before and after the experiment

Figure 4-3: Eucalyptus g. middle samples before and after the experiment

Table 4-3: summery of mean bending stress for the two species

Timber species	Mean Bending Stress (N/mm^2)	Standard deviation
Cupressus Lustanica	97.965	8.55
Eucalyptus globulus	124.53	12.469

4.1.3.2 Modulus of elasticity test result

The analysis is done from the result of the same specimen that were used for bending stress. From the test Load vs. deflection for all the specimen was drawn. And identification of linear point for the load and deflection was identified. This is shown in figure 4.4 for TB1.

The procedure used to calculate the values in tables 4.4 and the values in the appendix-A- 7 and A-8 are the followings,

By applying the load, each 1mm deflection was recorded by deflection reader gauge and for each one millimeter deflection, the load in newton result was shown by the machine. And the P' value and d' are found after drawing the load versus deflection diagram. This points are the point where the relation between load and deflection is linear. After this point the relation is not linear.

Note in the equation 3.4 and 3.5, there is a parameter L which designate the length.as shown above length is 380 mm. But we do not use this value in the equation directly rather we subtract the length that rest on the support and use clear length. By subtracting 10 mm for each side, the length that will be used in the equation is 360 mm.

For instance for TB1 the graph of load vs. deflection is presented in figure 4.4 and the experiments result presented in table 4.4. In order to find the maximum load, we can find its value by comparing the values under load column of table 4.4.

After drawing the load vs. deflection diagram, the graph has some part which the relation between the load and deflection is linear as shown in figure 4.4.

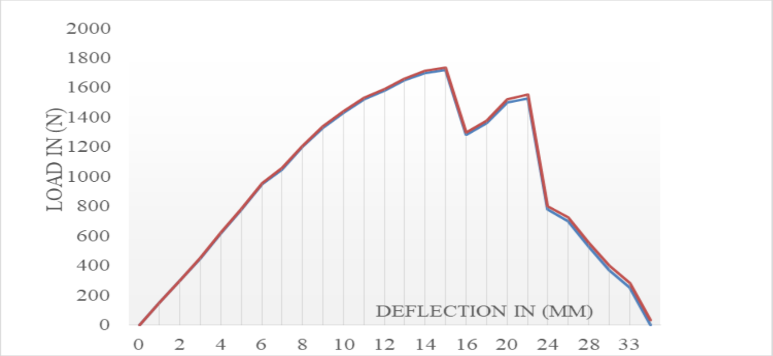

Figure 4-4: Load vs. deflection diagram for Cupressus lustanica tree bottom sample (TB1)

Table 4-4: Cupressus lustanica tree bottom sample-1(TB1) test result

TB1				
Dimension			**Load(N)**	**Deflection(mm)**
D(mm)	**W(mm)**	**L(mm)**		
20	20	380	0	0
20	20	380	150	1
20	20	380	300	2
20	20	380	450	3
20	20	380	620	4
20	20	380	780	5
20	20	380	950	6
20	20	380	1050	7
20	20	380	1200	8
20	20	380	1330	9
20	20	380	1430	10
20	20	380	1520	11
20	20	380	1580	12
20	20	380	1650	13
20	20	380	1700	14
20	20	380	1720	15
20	20	380	1280	16
20	20	380	1360	18
20	20	380	1500	20
20	20	380	1530	22
20	20	380	780	24
20	20	380	700	27
20	20	380	530	28
20	20	380	370	30
20	20	380	250	33
20	20	380	0	34

After performing the analysis for modulus of elasticity, the following values were obtained by using equation 3.5.

Table 4-5: modulus of elasticity values

Timber species	Mean modulus of elasticity (N/mm^2)	Standard deviation
Cupressus Lustanica	9598.52	1523.181
Eucalyptus globulus	12309.45	1493.531

4.1.4 Compression parallel to the grain test result

Since the strength is dependent on the moisture content both the result and moisture content at the time of the test are presented. This values are annexed on appendix A-11 up to A-12. The following procedure was followed to calculate the compressive strength,

By performing compressive test parallel to the grain, one can have the maximum crushing load from the machine. Then calculate compressive strength by using equation 3.6. After this Calculating of mean and standard deviation for each species were done.

Since result is dependent on moisture content determine the moisture content at the time of the test. The moisture content at the time of testing was 10.511% and 8.753% for Cupressus L. and Eucalyptus g. respectively.

Table 4-6: compression parallel to the grain values

Timber species	Mean Compressive parallel to the grain (N/mm^2)	Standard deviation
Cupressus Lustanica	48.72	4.518
Eucalyptus globulus	54.108	4.36

4.2 Discussion

4.2.1 Derivation of Basic stress and characteristics strength values

4.2.1.1 Basic bending strength parallel to the grain

Basic bending strength parallel to the grain for the species were determined using the following formula by using the failure stress, [7, 10]

$$f_{B,\,PAR}=\frac{(fm-2.33*\delta)}{2.25} \tag{4.1}$$

Where $f_{B,\,PAR}$ = basic bending strength parallel to the grain,

fm = mean value of the failure stress

δ = standard deviation and

Note: 2.25 is a correction factor. This correction factor is applied for specimen dimension, rate of loading and duration of loading error.

But EN-384-(2004) state that for the experiment made on clear specimen the value found by the above equation must be multiplied by 0.9. These are one of the basic values that will be used to the grading and determination of other parameters.

Table 4-7: basic bending values

Timber species	Basic Bending stress value (N/mm^2)	Basic Bending stress value after multiplying by 0.9 (N/mm^2)
Cupressus Lustanica	34.7	31.23
Eucalyptus globulus	42.434	38.2

4.2.1.2 Modulus of Elasticity value

The values in table 4.8 for the species is calculated by the following formula, [7, and 10]

$$E_{N}=E_{,\,Mean}-\frac{2.33\delta}{\sqrt{N}} \tag{4.2}$$

Where E mean = mean value for modulus of elasticity from the tests,

N = number of specimen tested,

δ = standard deviation

Remark: These are one of the basic values that will be used to the grading and determination of other parameters.

Table 4-8: basic modulus of elasticity values

Timber species	Basic Modulus of Elasticity(N/mm^2)	Basic Modulus of Elasticity after multiplying by 0.9 (N/mm^2)
Cupressus Lustanica	9371	8433.9
Eucalyptus globulus	12087	10878

4.2.1.3 Basic compression parallel to the grain values

The basic values were computed by using the following equations, [7]

$$C_{B,\ PAR}=\frac{(cm-2.33*\delta)}{1.4} \qquad (4.3)$$

Where: $C_{B,\ PAR}$ = basic value for compression parallel to the grain from the test

cm =value for compression parallel to the grain from the tests,

δ = standard deviation

Table 4-9: basic compression parallel to the grain values

Timber species	Basic Compression stress value (N/mm^2)	Basic Compression stress value after multiplying by 0.9 (N/mm^2)
Cupressus Lustanica	27.277	24.55
Eucalyptus globulus	31.384	28.24

4.2.2 Adjusting values to 12% moisture content equivalent

Since the test is not done at 12 moisture content, do the values need adjustment to 12 % moisture content equivalent, which is the standard that the grading table is made at is one of the critical questions. EN-384(2004) gives adjustment factors. So the adjustment is done by using the following equation and adjustment factors in table 4.10.

$$F_{12}=F_W\ (1+\alpha\ (W-12) \qquad (4.4)$$

Where, F_{12} = failure stress at 12% moisture content,

W = moisture content at the time of testing.

α =correction factor given in the following tables

F_W = the failure stress at the moisture content at the time the testing

Table 4-10: adjustment factor for moisture content variation

State of stress	α (for all wood species)	References
Bending strength	No adjustment	EN-384(2004)
Modulus of elasticity	0.02	EN-384(2004)
Density	0.005	EN-384(2004)
Compression parallel to the grain	0.03	EN-384(2004)

Table 4-11: adjusted values for moisture content variation

Timber species	12 % moisture content adjusted modulus of elasticity values(N/mm^2)	12 % moisture content adjusted compression parallel to the grain values(N/mm^2)
Cupressus Lustanica	8321	23.5
Eucalyptus globulus	10295	25.73

4.2.3 Other derived mechanical properties

The following are calculated values based on the formulas which are listed in chapter three starting from Eq. 3.7 Up to Eq.3.14.The equation from 3.7 up to 3.14 are based on characteristic bending strength, modulus of elasticity and density values.

The derived mechanical properties include tensile strength parallel to the grain and perpendicular to the grain, compression strength parallel and perpendicular to the grain, shear strength, modulus of elasticity parallel and perpendicular to the grain, mean shear modulus and mean density. Their values are presented in table 4.12 in the following page.

Table 4-12: other derived mechanical property

	Timber Species	
Other Mechanical properties	cupressus L.	Eucalyptus G.
Tensile strengths parallel to grain t, 0, k,(N/mm^2)	18.738	22.914
Tensile strengths perpendicular to grain t,90, k,(N/mm^2)	0.4	0.6
Compression strengths parallel to grain t, 0, k,(N/mm^2)	23.524879	25.7541577
Compression strengths perpendicular to grain t,90, k,(N/mm^2)	3.2309277	9.095175
Shear strength,	3.1382503	4
5th percentile values of MOE parallel to grain (E0, 0.05) ,(KN/mm^2)	5.57507	8.6478
Mean modulus of elasticity perpendicular to grain (E90, mean),(KN/mm^2)	0.2773667	0.686333333
Mean shear modulus (G,mean),(KN/mm^3)	0.5200625	0.6434375
Mean density(Kg/m^3)	553.87332	727.614

4.2.4 Comparing experimental values with analytical

4.2.4.1 Comparing the compression parallel to the grain found from the test and by the formula from EN-338(2009)

As shown on table 4.13 the two result, the one found from the experiment and the one found from analytic one by the formula from EN-338(2009) which is based on characteristic bending strength, are almost the same.

Table 4-13: result of comparing the compression parallel to the grain found from the test and by the formula from EN-338(2009), result found from appendix A-11 and A-12

Timber species	Basic Compression stress value (N/mm^2) found from experiment	Basic Compression stress value from analytic analysis (N/mm^2)
Cupressus Lustanica	23.50019	23.525
Eucalyptus globulus	25.738	25.754

4.2.4.2 Comparing the bending strength found from the test at two different moisture content for Eucalyptus G.

The idea is in EN-384(2004), there are adjustment factor for the conversion of results which are done at different moisture content to change to 12% moisture content equivalent. One of the article stated there say there need no adjustment factor for bending strength. As shown on table 4.14 the two result found from at two different moisture content prove the above statement for the Eucalyptus G. But the investigation was not done Cupressus Lusitanica.

Table 4-14: mean bending strength tested at two different moisture content result found from appendix A-9 and A-10.

Mean bending strength	**Mean bending value found from experiment done at 9.17% M.C.(N/mm^2)**	**Mean bending value found from experiment done at 8.09% M.C.(N/mm^2)**
Eucalyptus globulus	124.53	124.46

4.2.5 Grading

The whole idea of the work that have been up to now is to grade the two species based on EN-338(2009).

4.2.5.1 Criteria for grading

EN-338(2009) gives the following criteria that will be used for grading under clause 6.2.2 (Allocation to a strength class),

A timber population may be assigned to a strength class if its characteristics values of bending strength and density equal or exceed the value for that strength class given in Table -1,and its characteristic mean modulus of elasticity in bending equal or exceed 95% of the value for that strength class given in Table-1[15]

4.2.5.2 Grading criteria values

Table 4-15: grading criteria values

Grading criteria value	**Timber species**	
	Cupressus L.	Eucalyptus G.
Characteristic bending strength(N/mm^2)	31.23	38.19
Characteristic density(kg/M^2)	461.5611	606.345
Characteristic modulus of elasticity(N/mm^2)	8321	10295

4.2.5.3 Possible strength classes

4.2.5.3.1 Possible strength classes for cupressus lusitanica

So from the criteria mentioned above and the analysis, the best class for this species which is found from Gullele botanic garden (GBG) is soft wood and the grade is **c-16**. Even if the bending strength and density values are higher, the characteristics mean modulus of elasticity 95% match perfectly for c-16 class. Comparing values were taken from table 4.16.

4.2.5.3.2 Possible strength classes for Eucalyptus globulus

So from the criteria mentioned above and the analysis, the best class for this specie which is found from Gullele botanic garden (GBG) is hard wood and the grade is **D-24**.The bending strength, density values and the characteristics mean modulus of elasticity 95% match perfectly for D-24 class. Comparing values were taken from table 4.16.

Table 4-16: values taken from EN-338(2009)

Values taken from EN-338(2009)	**Timber class**	
	C-16	D-24
Characteristic bending strength(N/mm^2)	16	24
Characteristic density(kg/M^3)	310	485
Characteristic modulus of elasticity(N/mm^2)	8000	10000

CHAPTER 5 CONCLUSIONAND RECOMMENDATION

5.1 Conclusion

We need to know Ethiopian timbers properties to effective utilization of timber resources. In order to do this characterizing and grading timbers is important. From the experiments and the analysis of characterization and grading of the two selected species, the following conclusion can be drawn:

1. The strength class for cupressus lusitanica is C-16

2. The strength class for Eucalyptus globulus is D-24

3. The formulas which are given in EN-338(2009) to determine other mechanical properties which are based on bending strength, modulus of elasticity and density values are correct.

4. The adjustment factor given in EN-384(2004) for changing results based on moisture content for bending strength for hard wood is correct.

5.2 Recommendation

In order to increase the usage of timber in the construction industry, the following recommendations are put forward by the author:

1. Since timber property is different as the place where the timber grow, the same specie but that grow in other part of the country other than Gullele botanic garden (GBG), must be investigated

2. Since the timber property is affected by its age at the time of cutting, investigating the property at other ages can be investigated.

3. Factors given in EN-384(2004) other than stated above must be investigated.

4. The whole thesis is done from the result which are found from small clear specimen, but EN-408 recommend to do structural size specimen tests. It is good to perform structural size test and compare the two result.

5. Other species grading and characteristic must be done to Know Ethiopian timbers properties.

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APPENDIX A

- Appendix-A-1. Density for cupressus Lusitanica of which prepared for bending strength and modulus of elasticity test
- Appendix A-2. Density for Eucalyptus globulus of which prepared for bending strength and modulus of elasticity test
- Appendix A-3 Moisture content for cupressus lusitanica of which prepared for bending strength and modulus of elasticity test
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Appendix-A-1. Density for cupressus Lusitanica of which prepared for bending strength and modulus of elasticity test

Name	width(mm)	Depth(mm)	Length(mm)	Mass at test in gram	Volume in m^3	Density in kg/m^3
Tb1	20	20	380	86	0.000152	565.7894737
Tb2	20	20	380	76	0.000152	500
Tb3	20	20	380	82	0.000152	539.4736842
Tb4	20	20	380	79	0.000152	519.7368421
Tb5	20	20	380	72	0.000152	473.6842105
Tb6	20	20	380	81	0.000152	532.8947368
Tb7	20	20	380	78	0.000152	513.1578947
Tb8	20	20	380	71	0.000152	467.1052632
Tb9	20	20	380	81	0.000152	532.8947368
Tb10	20	20	380	77	0.000152	506.5789474
Tb11	20	20	380	79	0.000152	519.7368421
Tb12	20	20	380	74	0.000152	486.8421053
Tb13	20	20	380	78	0.000152	513.1578947
Tb14	20	20	380	79	0.000152	519.7368421
Tb15	20	20	380	73	0.000152	480.2631579
Tm1	20	20	380	74	0.000152	486.8421053
Tm2	20	20	380	78	0.000152	513.1578947
Tm3	20	20	380	68	0.000152	447.3684211
Tm4	20	20	380	73	0.000152	480.2631579
Tm5	20	20	380	75	0.000152	493.4210526
Tm6	20	20	380	73	0.000152	480.2631579
Tm7	20	20	380	78	0.000152	513.1578947
Tm8	20	20	380	75	0.000152	493.4210526
Tm9	20	20	380	69	0.000152	453.9473684
Tm10	20	20	380	74	0.000152	486.8421053
Tm11	20	20	380	76	0.000152	500

Appendix-A-1. Density for cupressus Lusitanica continued…

Tm12	20	20	380	74	0.000152	486.8421053
Tm13	20	20	380	76	0.000152	500
Tm14	20	20	380	75	0.000152	493.4210526
Tm15	20	20	380	77	0.000152	506.5789474
Tt1	20	20	380	78	0.000152	513.1578947
Tt2	20	20	380	78	0.000152	513.1578947
Tt3	20	20	380	77	0.000152	506.5789474
Tt4	20	20	380	76	0.000152	500
Tt5	20	20	380	74	0.000152	486.8421053
Tt6	20	20	380	68	0.000152	447.3684211
Tt7	20	20	380	80	0.000152	526.3157895
Tt8	20	20	380	72	0.000152	473.6842105
Tt9	20	20	380	77	0.000152	506.5789474
Tt10	20	20	380	78	0.000152	513.1578947
Tt11	20	20	380	74	0.000152	486.8421053
Tt12	20	20	380	80	0.000152	526.3157895
Tt13	20	20	380	82	0.000152	539.4736842
Tt14	20	20	380	74	0.000152	486.8421053
Tt15	20	20	380	83	0.000152	546.0526316
					Mean density	501.754386
					Stand. Deviation	25.30194142
					Pk (characteristic density)	460.0061826
					Adjustment factor for 12% M.C	1.003380277
					Pk adjusted	461.5611311

Appendix A-2. Density for Eucalyptus globulus of which prepared for bending strength and modulus of elastcitiy test

Name	width(mm)	Depth(mm)	Length(mm)	Mass at test in gram	Volume in m^3	Density in kg/ m^3
Bb1	20	20	380	100	0.000152	657.8947368
Bb2	20	20	380	89	0.000152	585.5263158
Bb3	20	20	380	100	0.000152	657.8947368
Bb4	20	20	380	98	0.000152	644.7368421
Bb5	20	20	380	100	0.000152	657.8947368
Bb6	20	20	380	97	0.000152	638.1578947
Bb7	20	20	380	99	0.000152	651.3157895
Bb8	20	20	380	110	0.000152	723.6842105
Bb9	20	20	380	102	0.000152	671.0526316
Bb10	20	20	380	96	0.000152	631.5789474
Bb11	20	20	380	96	0.000152	631.5789474
Bb12	20	20	380	109	0.000152	717.1052632
Bb13	20	20	380	98	0.000152	644.7368421
Bb14	20	20	380	96	0.000152	631.5789474
Bb15	20	20	380	98	0.000152	644.7368421
Bm1	20	20	380	92	0.000152	605.2631579
Bm2	20	20	380	94	0.000152	618.4210526
Bm3	20	20	380	102	0.000152	671.0526316
Bm4	20	20	380	96	0.000152	631.5789474
Bm5	20	20	380	94	0.000152	618.4210526
Bm6	20	20	380	104	0.000152	684.2105263
Bm7	20	20	380	105	0.000152	690.7894737
Bm8	20	20	380	103	0.000152	677.6315789

Appendix A-2. Density for Eucalyptus globulus continued……….

Bm9	20	20	380	93	0.000152	611.8421053
Bm10	20	20	380	97	0.000152	638.1578947
Bm11	20	20	380	95	0.000152	625
Bm12	20	20	380	93	0.000152	611.8421053
Bm13	20	20	380	94	0.000152	618.4210526
Bm14	20	20	380	94	0.000152	618.4210526
Bm15	20	20	380	102	0.000152	671.0526316
Bt1	20	20	380	93	0.000152	611.8421053
Bt2	20	20	380	103	0.000152	677.6315789
Bt3	20	20	380	102	0.000152	671.0526316
Bt4	20	20	380	104	0.000152	684.2105263
Bt5	20	20	380	101	0.000152	664.4736842
Bt6	20	20	380	101	0.000152	664.4736842
Bt7	20	20	380	108	0.000152	710.5263158
Bt8	20	20	380	93	0.000152	611.8421053
Bt9	20	20	380	102	0.000152	671.0526316
Bt10	20	20	380	98	0.000152	644.7368421
Bt11	20	20	380	97	0.000152	638.1578947
Bt12	20	20	380	94	0.000152	618.4210526
Bt13	20	20	380	103	0.000152	677.6315789
Bt14	20	20	380	105	0.000152	690.7894737
Bt15	20	20	380	107	0.000152	703.9473684
					Mean density	651.6081871
					Stand. Deviation	32.56278548
					pk(characteristic density)	597.8795911
					Adjustment factor for 12% M.C	1.014158902
					Pk adjusted	606.3449096

Appendix A-3 Moisture content for cupressus lusitanica of which prepared for bending strength and modulus of elasticity test

Name	Initial mass in gram(m1)	first round in gm	Second round in gm	Final mass in gram(m2)	M.C%
Tb1	86	79	78	78	10.25641026
Tb2	76	69	68	68	11.76470588
Tb3	82	74	73	73	12.32876712
Tb4	79	72	71	71	11.26760563
Tb5	72	66	65	65	10.76923077
Tb6	81	73	72	70	15.71428571
Tb7	78	71	70	70	11.42857143
Tb8	71	64	63	63	12.6984127
Tb9	81	72	71	71	14.08450704
Tb10	77	69	68	68	13.23529412
Tb11	79	71	70	70	12.85714286
Tb12	74	68	67	67	10.44776119
Tb13	78	71	70	70	11.42857143
Tb14	79	72	71	71	11.26760563
Tb15	73	68	67	67	8.955223881
Tm1	74	68	67	67	10.44776119
Tm2	78	71	70	70	11.42857143
Tm3	68	62	61	61	11.47540984
Tm4	73	66	65	65	12.30769231
Tm5	75	69	68	68	10.29411765
Tm6	73	66	65	65	12.30769231
Tm7	78	71	70	70	11.42857143
Tm8	75	68	67	67	11.94029851
Tm9	69	63	62	62	11.29032258

AppendixA-3 Moisture content for cupressus lusitanica continued……………

Tm10	74	67	66	66	12.12121212
Tm11	76	69	68	68	11.76470588
Tm12	74	68	67	67	10.44776119
Tm13	76	70	69	69	10.14492754
Tm14	75	69	68	68	10.29411765
Tm15	77	71	70	70	10
Tt1	78	70	69	69	13.04347826
Tt2	78	70	69	69	13.04347826
Tt3	77	70	69	69	11.5942029
Tt4	76	70	69	69	10.14492754
Tt5	74	70	68	68	8.823529412
Tt6	68	63	62	62	9.677419355
Tt7	80	72	71	71	12.67605634
Tt8	72	66	65	65	10.76923077
Tt9	77	71	70	70	10
Tt10	78	71	70	70	11.42857143
Tt11	74	68	67	67	10.44776119
Tt12	80	74	73	73	9.589041096
Tt13	82	75	74	74	10.81081081
Tt14	74	67	66	66	12.12121212
Tt15	83	77	76	76	9.210526316
				Mean moisture content %	11.32394451
				Standard deviation	1.375270508

Appendix A-4 Moisture content for Eucalyptus globulus of which prepared for bending strength and modulus of elasticity

Name	Initial mass in gram(m1)	first round mass in gm.	Second round mass in gm.	Final mass in gram(m2)	M.C%
Bb1	100	93	92	92	8.695652174
Bb2	89	83	82	82	8.536585366
Bb3	100	92	91	91	9.89010989
Bb4	98	91	90	90	8.888888889
Bb5	100	92	91	91	9.89010989
Bb6	97	90	89	89	8.988764045
Bb7	99	92	91	91	8.791208791
Bb8	110	102	100	100	10
Bb9	102	94	93	93	9.677419355
Bb10	96	88	87	87	10.34482759
Bb11	96	90	89	89	7.865168539
Bb12	109	101	100	100	9
Bb13	98	88	87	87	12.64367816
Bb14	96	88	87	87	10.34482759
Bb15	98	89	88	88	11.36363636
Bm1	92	86	85	85	8.235294118
Bm2	94	87	86	86	9.302325581
Bm3	102	94	93	93	9.677419355
Bm4	96	89	88	88	9.090909091
Bm5	94	87	86	86	9.302325581
Bm6	104	96	95	95	9.473684211
Bm7	105	98	97	97	8.24742268
Bm8	103	94	93	93	10.75268817
Bm9	93	86	85	85	9.411764706

Appendix A-4 Moisture content for Eucalyptus globulus continued……….

Bm10	97	90	89	89	8.988764045
Bm11	95	88	87	87	9.195402299
Bm12	93	86	85	85	9.411764706
Bm13	94	87	86	86	9.302325581
Bm14	94	87	86	86	9.302325581
Bm15	102	96	95	95	7.368421053
Bt1	93	87	86	86	8.139534884
Bt2	103	95	94	94	9.574468085
Bt3	102	95	94	94	8.510638298
Bt4	104	96	95	95	9.473684211
Bt5	101	94	93	93	8.602150538
Bt6	101	94	93	93	8.602150538
Bt7	108	101	100	100	8
Bt8	93	86	85	85	9.411764706
Bt9	102	96	95	95	7.368421053
Bt10	98	91	90	90	8.888888889
Bt11	97	90	89	89	8.988764045
Bt12	94	88	87	87	8.045977011
Bt13	103	96	95	95	8.421052632
Bt14	105	97	96	96	9.375
Bt15	107	99	98	98	9.183673469
				Mean Moisture content%	9.168219595
				Standard deviation	0.969253865

Appendix A-5 Bending Strength test result for cupressus lusitanica

Name	D(mm)	H(mm)	L(mm)	P'(N)	D	P max(N)	Bending strength (N/mm^2)
Tb1	20	20	380	950	6	1720	116.1
Tb2	20	20	380	730	5	1590	107.325
Tb3	20	20	380	800	7	1400	94.5
Tb4	20	20	380	1030	7	1480	99.9
Tb5	20	20	380	420	4	1190	80.325
Tb6	20	20	380	770	5	1580	106.65
Tb7	20	20	380	620	4	1440	97.2
Tb8	20	20	380	390	4	1330	89.775
Tb9	20	20	380	455	3	1490	100.575
Tb10	20	20	380	390	3	1290	87.075
Tb11	20	20	380	450	3	1500	101.25
Tb12	20	20	380	410	3	1380	93.15
Tb13	20	20	380	385	3	1430	96.525
Tb14	20	20	380	380	3	1520	102.6
Tb15	20	20	380	530	5	1430	96.525
Tm1	20	20	380	950	6	1720	116.1
Tm2	20	20	380	720	5	1590	107.325
Tm3	20	20	380	590	5	1400	94.5
Tm4	20	20	380	900	6	1480	99.9
Tm5	20	20	380	320	3	1190	80.325
Tm6	20	20	380	320	2	1580	106.65
Tm7	20	20	380	620	4	1440	97.2
Tm8	20	20	380	390	4	1330	89.775

Appendix A-5 Bending strength test result for cupressus lusitanica continued…

Tm9	20	20	380	580	4	1490	100.575
Tm10	20	20	380	360	3	1290	87.075
Tm11	20	20	380	450	3	1500	101.25
Tm12	20	20	380	360	3	1380	93.15
Tm13	20	20	380	460	4	1430	96.525
Tm14	20	20	380	620	5	1520	102.6
Tm15	20	20	380	410	4	1430	96.525
Tt1	20	20	380	780	5	1720	116.1
Tt2	20	20	380	550	4	1590	107.325
Tt3	20	20	380	320	3	1400	94.5
Tt4	20	20	380	900	6	1480	99.9
Tt5	20	20	380	220	2	1190	80.325
Tt6	20	20	380	320	2	1580	106.65
Tt7	20	20	380	620	4	1440	97.2
Tt8	20	20	380	390	4	1330	89.775
Tt9	20	20	380	150	1	1490	100.575
Tt10	20	20	380	630	5	1290	87.075
Tt11	20	20	380	450	3	1500	101.25
Tt12	20	20	380	950	8	1380	93.15
Tt13	20	20	380	840	8	1430	96.525
Tt14	20	20	380	620	5	1520	102.6
Tt15	20	20	380	530	5	1430	96.525
						Mean bending strength	97.965
						Standard deviation	8.547362033

Appendix A-6 Bending strength test result for Eucalyptus globulus

Name	D(mm)	H(mm)	L(mm)	P'(N)	D(mm)	P max(N)	Bending strength(N/mm^2)
Bb1	20	20	380	730	6	1780	120.15
Bb2	20	20	380	1000	8	1450	97.875
Bb3	20	20	380	1100	8	1720	116.1
Bb4	20	20	380	250	2	1680	113.4
Bb5	20	20	380	1110	6	1810	122.175
Bb6	20	20	380	1230	7	1890	127.575
Bb7	20	20	380	930	7	1910	128.925
Bb8	20	20	380	750	4	2170	146.475
Bb9	20	20	380	830	5	1910	128.925
Bb10	20	20	380	700	4	1750	118.125
Bb11	20	20	380	1350	8	1920	129.6
Bb12	20	20	380	1350	8	2190	147.825
Bb13	20	20	380	970	6	1730	116.775
Bb14	20	20	380	530	3	1510	101.925
Bb15	20	20	380	1180	7	1770	119.475
Bm1	20	20	380	1020	6	1870	126.225
Bm2	20	20	380	1030	7	1800	121.5
Bm3	20	20	380	1110	6	1810	122.175
Bm4	20	20	380	910	6	1830	123.525
Bm5	20	20	380	1160	7	2010	135.675
Bm6	20	20	380	1150	6	2150	145.125
Bm7	20	20	380	1270	7	2200	148.5
Bm8	20	20	380	1020	6	1620	109.35
Bm9	20	20	380	1100	7	1830	123.525

Appendix A-6 Bending strength test result for Eucalyptus globulus continued……

Bm10	20	20	380	1020	6	1890	127.575
Bm11	20	20	380	1170	7	1770	119.475
Bm12	20	20	380	1150	8	1590	107.325
Bm13	20	20	380	980	6	1680	113.4
Bm14	20	20	380	750	5	1660	112.05
Bm15	20	20	380	1330	7	1970	132.975
Bt1	20	20	380	850	5	1740	117.45
Bt2	20	20	380	1230	7	1940	130.95
Bt3	20	20	380	940	5	2060	139.05
Bt4	20	20	380	1100	6	2040	137.7
Bt5	20	20	380	340	2	1860	125.55
Bt6	20	20	380	1050	5	1860	125.55
Bt7	20	20	380	1250	7	1850	124.875
Bt8	20	20	380	920	6	1450	97.875
Bt9	20	20	380	1350	7	2110	142.425
Bt10	20	20	380	1520	9	1820	122.85
Bt11	20	20	380	1130	6	1870	126.225
Bt12	20	20	380	980	6	1770	119.475
Bt13	20	20	380	1180	6	1960	132.3
Bt14	20	20	380	1250	6	2140	144.45
Bt15	20	20	380	1200	7	1680	113.4
						Mean bending strength	124.53
						Standard deviation	12.46934491

Appendix A-7 Modulus of Elasticity test result for cupressus lusitanica

Name	D(mm)	H(mm)	L(mm)	P'(N)	D(mm)	P max(N)	MOE(N/mm^2)
Tb1	20	20	380	950	6	1720	11542.5
Tb2	20	20	380	730	5	1590	10643.4
Tb3	20	20	380	800	7	1400	8331.428571
Tb4	20	20	380	1030	7	1480	10726.71429
Tb5	20	20	380	420	4	1190	7654.5
Tb6	20	20	380	770	5	1580	11226.6
Tb7	20	20	380	620	4	1440	11299.5
Tb8	20	20	380	390	4	1330	7107.75
Tb9	20	20	380	455	3	1490	11056.5
Tb10	20	20	380	390	3	1290	9477
Tb11	20	20	380	450	3	1500	10935
Tb12	20	20	380	410	3	1380	9963
Tb13	20	20	380	385	3	1430	9355.5
Tb14	20	20	380	380	3	1520	9234
Tb15	20	20	380	530	5	1430	7727.4
Tm1	20	20	380	950	6	1720	11542.5
Tm2	20	20	380	720	5	1590	10497.6
Tm3	20	20	380	590	5	1400	8602.2
Tm4	20	20	380	900	6	1480	10935
Tm5	20	20	380	320	3	1190	7776
Tm6	20	20	380	320	2	1580	11664
Tm7	20	20	380	620	4	1440	11299.5
Tm8	20	20	380	390	4	1330	7107.75
Tm9	20	20	380	580	4	1490	10570.5

Appendix A-7 Modulus of Elasticity test result for cupressus lusitanica continued……

Tm10	20	20	380	360	3	1290	8748
Tm11	20	20	380	450	3	1500	10935
Tm12	20	20	380	360	3	1380	8748
Tm13	20	20	380	460	4	1430	8383.5
Tm14	20	20	380	620	5	1520	9039.6
Tm15	20	20	380	410	4	1430	7472.25
Tt1	20	20	380	780	5	1720	11372.4
Tt2	20	20	380	550	4	1590	10023.75
Tt3	20	20	380	320	3	1400	7776
Tt4	20	20	380	900	6	1480	10935
Tt5	20	20	380	220	2	1190	8019
Tt6	20	20	380	320	2	1580	11664
Tt7	20	20	380	620	4	1440	11299.5
Tt8	20	20	380	390	4	1330	7107.75
Tt9	20	20	380	150	1	1490	10935
Tt10	20	20	380	630	5	1290	9185.4
Tt11	20	20	380	450	3	1500	10935
Tt12	20	20	380	950	8	1380	8656.875
Tt13	20	20	380	840	8	1430	7654.5
Tt14	20	20	380	620	5	1520	9039.6
Tt15	20	20	380	530	5	1430	7727.4
						Mean MOE	9598.519286
						Standard deviation	1523.180727

Appendix A-8 Modulus of Elasticity test result for Eucalyptus globulus

Name	D(mm)	H(mm)	L(mm)	P'(N)	D(mm)	P max(N)	MOE(N/mm^2)
Bb1	20	20	380	730	6	1780	8869.5
Bb2	20	20	380	1000	8	1450	9112.5
Bb3	20	20	380	1100	8	1720	10023.75
Bb4	20	20	380	250	2	1680	9112.5
Bb5	20	20	380	1110	6	1810	13486.5
Bb6	20	20	380	1230	7	1890	12809.57143
Bb7	20	20	380	930	7	1910	9685.285714
Bb8	20	20	380	750	4	2170	13668.75
Bb9	20	20	380	830	5	1910	12101.4
Bb10	20	20	380	700	4	1750	12757.5
Bb11	20	20	380	1350	8	1920	12301.875
Bb12	20	20	380	1350	8	2190	12301.875
Bb13	20	20	380	970	6	1730	11785.5
Bb14	20	20	380	530	3	1510	12879
Bb15	20	20	380	1180	7	1770	12288.85714
Bm1	20	20	380	1020	6	1870	12393
Bm2	20	20	380	1030	7	1800	10726.71429
Bm3	20	20	380	1110	6	1810	13486.5
Bm4	20	20	380	910	6	1830	11056.5
Bm5	20	20	380	1160	7	2010	12080.57143
Bm6	20	20	380	1150	6	2150	13972.5
Bm7	20	20	380	1270	7	2200	13226.14286
Bm8	20	20	380	1020	6	1620	12393
Bm9	20	20	380	1100	7	1830	11455.71429

Appendix A-8 Modulus of Elasticity test result for Eucalyptus globulus continued……..

Bm10	20	20	380	1020	6	1890	12393
Bm11	20	20	380	1170	7	1770	12184.71429
Bm12	20	20	380	1150	8	1590	10479.375
Bm13	20	20	380	980	6	1680	11907
Bm14	20	20	380	750	5	1660	10935
Bm15	20	20	380	1330	7	1970	13851
Bt1	20	20	380	850	5	1740	12393
Bt2	20	20	380	1230	7	1940	12809.57143
Bt3	20	20	380	940	5	2060	13705.2
Bt4	20	20	380	1100	6	2040	13365
Bt5	20	20	380	340	2	1860	12393
Bt6	20	20	380	1050	5	1860	15309
Bt7	20	20	380	1250	7	1850	13017.85714
Bt8	20	20	380	920	6	1450	11178
Bt9	20	20	380	1350	7	2110	14059.28571
Bt10	20	20	380	1520	9	1820	12312
Bt11	20	20	380	1130	6	1870	13729.5
Bt12	20	20	380	980	6	1770	11907
Bt13	20	20	380	1180	6	1960	14337
Bt14	20	20	380	1250	6	2140	15187.5
Bt15	20	20	380	1200	7	1680	12497.14286
						Mean MOE	12309.44786
						Standard deviation	1493.531318

Appendix A-9 Bending test result at different moisture content for Eucalyptus globule

Note: Tests carried out to check Moisture adjustment factor for bending in EN-384(2004) and the number of specimen prepared was 15, 5 from bottom, 5 from middle and 5 from top part of the tree. And the test was carried only for Eucalyptus globule

Name	D(mm)	H(mm)	L(mm)	P'(N)	D	P max	MOR
B'azaf-bott-1	20	20	300	1500	7	2010	105.525
B'azaf-bott-2	20	20	300	1850	7	2500	131.25
B'azaf-bott-3	20	20	300	1350	4	2310	121.275
B'azaf-bott-4	20	20	300	1320	5	1920	100.8
B'azaf-bott-5	20	20	300	1600	6	2450	128.625
B'azaf-midd-1	20	20	300	1950	6	2340	122.85
B'azaf-midd-2	20	20	300	1430	5	2250	118.125
B'azaf-midd-3	20	20	300	1830	5	2720	142.8
B'azaf-midd-4	20	20	300	1720	6	2560	134.4
B'azaf-midd-5	20	20	300	1480	5	2320	121.8
B'azaf-top-1	20	20	300	1500	5	2360	123.9
B'azaf-top-2	20	20	300	1520	5	2460	129.15
B'azaf-top-3	20	20	300	1900	6	2410	126.525
B'azaf-top-4	20	20	300	1670	6	2200	115.5
B'azaf-top-5	20	20	300	2090	7	2750	144.375
						Mean bending strength	124.46
						Standard deviation	11.8934

Appendix A-10 Second round moisture content result for Eucalyptus globulus for bending test

Name	Initial mass in gm.	first round in gm.	Second round in gm.	Final mass in gm.	M.C%
B'azaf-bott-1	77	76	73	73	5.47945
B'azaf-bott-2	79	76	73.2	73.2	7.9235
B'azaf-bott-3	79	75	72.2	72.2	9.41828
B'azaf-bott-4	76	74	70.4	70.4	7.95455
B'azaf-bott-5	78	75	72.3	72.3	7.88382
B'azaf-midd-1	81	77	74.7	74.7	8.43373
B'azaf-midd-2	72	68	66.3	66.3	8.59729
B'azaf-midd-3	87	83	81	81	7.40741
B'azaf-midd-4	76	73	70.3	70.3	8.10811
B'azaf-midd-5	72	70	65	65	10.7692
B'azaf-top-1	80	73	74.2	74.2	7.81671
B'azaf-top-2	74	72	69	69	7.24638
B'azaf-top-3	85	83	78.3	78.3	8.55683
B'azaf-top-4	75	73	69.3	69.3	8.22511
B'azaf-top-5	82	80	76.2	76.2	7.61155
				Mean moisture content	8.09546
				Standard deviation	1.09359

Appendix A-11.Compression parallel to the grain experimental result for cupressus lusitanica

Name	D(mm)	H(mm)	L(mm)	P max(N)	Comp(N/mm^2)
T-comp-B-1	20	20	60	19,200	48
T-comp-B-2	20	20	60	18,540	46.35
T-comp-B-3	20	20	60	18,000	45
T-comp-B-4	20	20	60	17,600	44
T-comp-B-5	20	20	60	17,900	44.75
T-comp-B-6	20	20	60	24,300	60.75
T-comp-B-7	20	20	60	17,500	43.75
T-comp-B-8	20	20	60	23,200	58
T-comp-B-9	20	20	60	18,800	47
T-comp-B-10	20	20	60	18,700	46.75
T-comp-B-11	20	20	60	20,400	51
T-comp-B-12	20	20	60	20,100	50.25
T-comp-B-13	20	20	60	21,500	53.75
T-comp-B-14	20	20	60	20,100	50.25
T-comp-B-15	20	20	60	20,500	51.25
T-comp-M-1	20	20	60	17,450	43.625
T-comp-M-2	20	20	60	17,900	44.75
T-comp-M-3	20	20	60	19,100	47.75
T-comp-M-4	20	20	60	18,200	45.5
T-comp-M-5	20	20	60	19,300	48.25
T-comp-M-6	20	20	60	18,600	46.5
T-comp-M-7	20	20	60	17,500	43.75
T-comp-M-8	20	20	60	17,300	43.25
T-comp-M-9	20	20	60	19,500	48.75

Appendix A-11.Compression parallel to the grain result for cupressus lusitanica continued……

T-comp-M-10	20	20	60	20,200	50.5
T-comp-M-11	20	20	60	20,300	50.75
T-comp-M-12	20	20	60	18,700	46.75
T-comp-M-13	20	20	60	17,600	44
T-comp-M-14	20	20	60	16,550	41.375
T-comp-M-15	20	20	60	17,900	44.75
T-comp-T-1	20	20	60	21,400	53.5
T-comp-T-2	20	20	60	21,150	52.875
T-comp-T-3	20	20	60	19,300	48.25
T-comp-T-4	20	20	60	18,500	46.25
T-comp-T-5	20	20	60	23,800	59.5
T-comp-T-6	20	20	60	22,200	55.5
T-comp-T-7	20	20	60	18,300	45.75
T-comp-T-8	20	20	60	19,900	49.75
T-comp-T-9	20	20	60	17,000	42.5
T-comp-T-10	20	20	60	21,600	54
T-comp-T-11	20	20	60	20,400	51
T-comp-T-12	20	20	60	19,750	49.375
T-comp-T-13	20	20	60	19,250	48.125
T-comp-T-14	20	20	60	20,500	51.25
T-comp-T-15	20	20	60	21,400	53.5
				Mean compressive strength	48.71611111
				standard deviation	4.518205457

Appendix A-12 Compression parallel to the grain experimental result for Eucalyptus G.

Name	D(mm)	H(mm)	L(mm)	P max(N)	Comp(N/mm^2)
B-comp-B-1	20	20	60	20,300	50.75
B-comp-B-2	20	20	60	21,200	53
B-comp-B-3	20	20	60	20,700	51.75
B-comp-B-4	20	20	60	19,100	47.75
B-comp-B-5	20	20	60	20,000	50
B-comp-B-6	20	20	60	19,900	49.75
B-comp-B-7	20	20	60	19,600	49
B-comp-B-8	20	20	60	20,800	52
B-comp-B-9	20	20	60	18,800	47
B-comp-B-10	20	20	60	22,500	56.25
B-comp-B-11	20	20	60	21,800	54.5
B-comp-B-12	20	20	60	20,150	50.375
B-comp-B-13	20	20	60	21,750	54.375
B-comp-B-14	20	20	60	19,500	48.75
B-comp-B-15	20	20	60	17,500	43.75
B-comp-M1	20	20	60	20,050	50.125
B-comp-M2	20	20	60	20,150	50.375
B-comp-M3	20	20	60	23,450	58.625
B-comp-M4	20	20	60	20,200	50.5
B-comp-M5	20	20	60	23,300	58.25
B-comp-M6	20	20	60	24,400	61
B-comp-M7	20	20	60	22,600	56.5
B-comp-M8	20	20	60	22,500	56.25
B-comp-M9	20	20	60	18,500	46.25

Appendix A-12 Compression parallel to the grain experimental result for Eucalyptus G continued…….

B-comp-M10	20	20	60	20,600	51.5
B-comp-M11	20	20	60	21,600	54
B-comp-M12	20	20	60	24,650	61.625
B-comp-M13	20	20	60	24,650	61.625
B-comp-M14	20	20	60	22,600	56.5
B-comp-M15	20	20	60	21,650	54.125
B-comp-T-1	20	20	60	22,650	56.625
B-comp-T-2	20	20	60	24,400	61
B-comp-T-3	20	20	60	23,200	58
B-comp-T-4	20	20	60	22,100	55.25
B-comp-T-5	20	20	60	21,300	53.25
B-comp-T-6	20	20	60	23,300	58.25
B-comp-T-7	20	20	60	22500	56.25
B-comp-T-8	20	20	60	22,600	56.5
B-comp-T-9	20	20	60	24,100	60.25
B-comp-T-10	20	20	60	21,700	54.25
B-comp-T-11	20	20	60	22,100	55.25
B-comp-T-12	20	20	60	23,900	59.75
B-comp-T-13	20	20	60	21,800	54.5
B-comp-T-14	20	20	60	20,900	52.25
B-comp-T-15	20	20	60	22,900	57.25
				Mean compression strength	54.10833333
				Standard deviation	4.365379032

Appendix-B

Appendix B-1 specimen preparing process

Figure B.1 Ripping the tree logs into lumbers

Figure B.2 Naming the lumber extracted from the tree loge by ripping

Figure B.3 Ripping the battens from the lumber

Appendix B-1 specimen preparing process continued…….


Figure B.4 Reducing the size of battens


Figure B.5 Measuring and cutting of final specimens

Appendix B-2 Initial moisture content determining samples before entering kiln & preparing the battens to the kiln drying process