JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
STRUCTURAL ENGINEERING STREAM

A Comparative study on the Structural Performance of Bamboo and Eucalyptus Scaffolding

By

Shiferaw Negatu

Thesis submitted to the School of Graduate Studies of Jimma Institute of Technology, in partial fulfillment of the requirement of the Degree of Master of Science in Civil Engineering (Structural Engineering)

Date: July 2024

Jimma, Ethiopia

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Co-Advisor: Eng. Abebechi Deme (MSc.)

Date: July 2024

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DECLARATION

This thesis entitled “A Comparative study on Structural Performance of Bamboo and Eucalyptus Scaffolding” is my original work and has not been presented for a degree in any other university.

Shiferaw Nrgatu _	………………………….	………………………..
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ABSTRACT

Scaffolding is primarily constructed to provide workers with access to various exposed areas for carrying out construction and maintenance activities. In the modern construction sector of our country, In Ethiopia, the use of bamboo scaffolding is not used compared to eucalyptus scaffolding and steel scaffolding. However, bamboo is an abundant and sustainable alternative material, making it a viable option for scaffolding in Ethiopia. Eucalyptus tree products are commonly used for temporary support in concrete construction scaffolding. Whereas Bamboo plant is limited use in scaffolding, bamboo plants are more abundantly found in southwest Ethiopia, particularly in the Masha areas. A study was conducted in specific areas of Masha area to examine the physical and mechanical properties of bamboo and eucalyptus materials.The study involved testing of compressive strength, bending strength, modules of elasticity, moisture content and dry density on typical bamboo and eucalyptus members and also comparing the structural performance of bamboo and eucalyptus scaffolding. The test results showed that Masha bamboo scaffolds have a higher structural adequacy than eucalyptus scaffolds, with an axial load resistance of 34.42 KN for bamboo and 22.24 KN for eucalyptus. Indicating that Masha bamboo culm of structural performances are 35.38% stronger than eucalyptus culm. Additionally, the characteristic compression strength value of Masha bamboo materials is 54.44Mpa, whereas for eucalyptus materials it is 30.57Mpa, indicating that Masha bamboo materials are 43.9% stronger than eucalyptus materials. In conclusion, the study suggests that Masha Bamboo can effectively replace eucalyptus tree scaffolding.

Key words: ***Bamboo, Eucalyptus, Culm***

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ACRONYMS

ASTM……………. American Society for Testing Materials

CSSR…………….. Construction site safety regulation

EBCS …………..... Ethiopian Building Code Standard

EEFRI…………… Ethiopian Environment and Forest Research Institute

ESA …………….. Ethiopian Standard Agency

ES ……..……….. European standard

INBAR…..……. International Bamboo and Rattan Organization

ISO…………….International Organization for Standardization

UTM …………Universal Testing Machine

CHAPTER ONE

1. INTRODUCTION

1.1. Background of Study

Scaffolding means any temporarily provided structure on or form which persons perform works in connection with operation or works to which the construction site apply, and any temporary provided structure which enables persons to obtain access to or which enables materials to be taken to any place at which such work is performed.

The local construction industry exploits industrial products and natural indigenous natural resources like eucalyptus for scaffolding activities. Eucalyptus is a natural resource harvested to meet society demand for scaffolding purposes. The decline in resource of eucalyptus through deforestation has a negative impact on the environment and reducing the demand of eucalyptus for construction through other alternative is necessary. The need to identify an alternative material which is sustainable, environmentally friendly and widely available promotes conservation of dwindling eucalyptus resources locally. One species that is natural resource is bamboo, using it as a construction material can reduce the pressure on use of local eucalyptus.

Bamboo is fast growing woody grass and natural resource, used for construction extensively for many centuries by people all over the world. It also has a long history of usefulness in the field of scaffolding construction, particularly in Asian countries. The properties of bamboo such as resilience, shape and strength make it an ideal material for scaffolding purposes (Chung & Yu, 2002). However, it is not a popular scaffolding material in Ethiopia and its application has been limited to traditional household use.

Ethiopia is one of the largest bamboo resources in Africa, belonging to two main indigenous species Yushania alpina (highland bamboo) comprising 20% of the bamboo resource and Oxytenanthera abyssinica (lowland bamboo) constituting 80% of the Ethiopia's bamboo resources In addition, the Ethiopian Environment and Forest Research Institute (EEFRI), International Bamboo and Rattan Organization (INBAR) and other development agencies have introduced more than 40 bamboo species. Hence, Yushania alpina (highland bamboo) plants are more abundantly found in southwest Ethiopia, particularly in the Masha area

In general, it is believed that the mechanical properties of bamboo are likely to be at least similar, if not superior, to those of timber. Furthermore, as bamboo grows very fast and usually takes three to six years to harvest, depending on the species and the plantation, there is a growing global interest in developing bamboo as a substitute for timber in the construction. Now a day's safety and cost-effectiveness is the predominant role of scaffolding on the type of materials in building construction.

The physical and mechanical properties of bamboo make it an exceptional economic resource for a wide range of uses. Bamboo has high strength, low weight and easily worked using simple tools. This characteristic can be attributed to its hollow stem and nodes.

This research explores Masha bamboo (South west Ethiopia) as scaffold material and assess the physical and mechanical properties of bamboo and eucalyptus materials. In view of this, the comparison of bamboo and eucalyptus materials is to ensure adequate utilization of scaffolding systems and to promote the alternative materials to be used on scaffolding. It gives the opportunity to compare and adapt the basic design data of the mechanical properties of both materials. It also allows researchers to examine the variation of physical properties in a specific area.

1.2. Statement of the Problem

A major constraint to the development of structural bamboo as a modern construction material is the lack of design standards for both mechanical properties and structural adequacy (Chung & Yu, 2002) . An attempt to study the scaffolding system by collecting responses from developers, contractors, and suppliers could give better insight and recommendations on its local application.

A construction project should be designed with safety in mind; this approach makes it possible to eliminate or minimize work hazards. There are challenges to the development of structural bamboo due to a lack of design standards for both mechanical and structural properties. Proper planning and design of the methods of construction are key to creating a safe environment for workers, contractors, and the public alike.

The Code of practice for bamboo scaffolding safety (Labour Department, 2017) had stated that the safe scaffold and its erection, alteration, and dismantling for all different stages of construction should be designed and planned well beforehand. The strength and stability of the scaffold throughout all stages of scaffolding should be ensured, and a realistic assessment of the loading at all work stages should be made while it is an inadequate scaffold design in standard Ethiopian building codes of practice.

The main problem with scaffolding is buckling due to its slenderness. Buckling is the failure when there is uncontrolled lateral displacement of columns at which no additional load can be supported, especially under compressive stress. In order to promote the effective use of structural bamboo, it is essential to provide basic design data on mechanical properties. Design rules against various modes of failure should be in accordance with modern design philosophy.

The structural adequacies of both scaffolding materials are governed by specific areas of resources, and the effectiveness of using both materials depends on physical properties. Among many physical properties that affect the strength characteristics of structural timber, moisture content, density, slope of grain, and defects are considered the most important ones.

1.3. Research Question

- ✓ What are the physical and mechanical properties of bamboo materials in the Masha area?
- ✓ What are the physical and mechanical properties of eucalyptus materials?
- ✓ What is the difference between structural performance of bamboo & eucalyptus column?

1.4. Objective

1.4.1. General objective

The main objective of this study was to compare the structural performance of bamboo and eucalyptus scaffolding.

1.4.2. Specific Objective

- ✓ To determine the physical and mechanical properties of bamboo materials in the Masha area.
- ✓ To determine the physical and mechanical properties of eucalyptus materials.
- ✓ To compare the structural performance of bamboo and eucalyptus scaffolding column.

1.5. Significance of the research

This research's significance is to compare bamboo and eucalyptus scaffolding materials for local experience and knowledge on the application of particular species in deciding the species. By conducting laboratory tests to know the physical and mechanical properties of the two materials located in Masha area (south west Ethiopia), as well as to know the characteristic strength of both materials, the design companies and construction sectors will have a better understanding of alternative scaffold materials

1.6. Scope and limitation of the study

1.6.1. Scope of the study

The study covers the evaluation of the physical properties such as dry density, moisture content and cross-sectional area and mechanical properties such as compressive strength, bending strength and modules of elasticity of the Masha bamboo and eucalyptus materials and to compare the structural performance of bamboo and eucalyptus scaffolding culm.

1.6.2. Limitation of the study

- ✓ Connection test of bamboo and eucalyptus scaffolding is not considered.
- ✓ Long culm of bending test is not considered
- ✓ 3D Modeling of bamboo and eucalyptus scaffolding

CHAPTER TWO

2. LITERATURE REVIEW

2.1. General

"Scaffold" refers to any temporary structure on or from which people perform work in connection with operations or works to which the construction site safety regulations (CSSR) apply, as well as any temporary structure that allows a person to gain access to or transport materials to any location where such work is performed, and includes any lifting appliance or a structure used merely to support such an appliance or to support other plant or equipment (Labour Department, 2017)For many decades, there has been an increasing interest in the use of bamboo scaffolds, mostly in developing countries, over the standardized tubular steel scaffolds in building construction. However, there are different advantages or disadvantages associated with the use of the two materials. The constructors and other stakeholders in the building industry are mostly interested in executing the safest and most economical building projects. In general, it is believed that the mechanical properties of bamboo are likely to be at least similar, if not superior, to those of timber. Furthermore, as bamboo grows very fast and usually takes three to six years to harvest, depending on the species and the plantation, there is a growing global interest in developing bamboo as a substitute for timber in construction. However, a major constraint to the development of structural bamboo as a modern construction material is the lack of design standards on both mechanical properties and structural adequacy (Zhou, Tian, Liu, & Zhang, 2021)

2.2. Types of scaffolding system

Some typical scaffolding configurations, such as single-row bamboo scaffolding system, double-row bamboo scaffolding system, truss-out bamboo scaffolding system, cantilever type bamboo scaffolding system, and scaffolding system for slope works. These bamboo scaffolding systems will be designed following the Code of Practice for Bamboo Scaffolding. (Labour Department, 2017) The following are the most common types of scaffolding system:-Single-row bamboo scaffolding are constructed nowadays only for the provision of access, whilst double-row scaffolding, which can provide a secure working platform, are normally constructed for construction purposes Figure 2.1 illustrates the use double layer scaffolds of Eucalyptus and Figure 2.2 illustrates the use double layer scaffolds of Bamboo

Figure 2-1 double layered eucalyptus scaffold- Teppi construction site-author

Figure 2-2 Double layered bamboo scaffold (Chan & Chung, 2002)

2.2.1. Diameter of scaffold minimum requirement

According to code of practice for bamboo scaffolding safety had stated that, The effective diameter of scaffolding on bamboo member standards (vertical members) and ledgers (horizontal members) used should not be less than 40mm.(Labour Department, 2017)

Technical report No. 23 (Design of bamboo scaffolds) had explained that, In south east Asia,in particular, in Hong Kong and the southern china both Kao Jue and Mao Jue are commonly used in bamboo scaffolds. Kao Jue is a structural bamboo with a typical external diameter ranging from about 50 mm at the bottom to 30 mm at the top of a member over a typical length of 6 m. The wall thickness may range from 5 mm in low quality Kao Jue to 10 mm in high quality Kao Jue. They are used extensively as posts, standards (vertical members) and ledgers (horizontal members) in bamboo scaffolds. (Chan & Chung, 2002) . Hence for selection of external diameter on comparing physical and mechanical properties of bamboo and eucalyptus scaffolding culm used above 40mm.

2.3. Connection

In general, all connections in bamboo scaffolds are made up of plastic strips by hand, and they are considered simple connections in design. Both the strength and the stiffness of the connections depend primarily on the workmanship of scaffolding practitioners. It is important to ensure that all the connections in bamboo scaffolds are strong and reliable in both dry and wet conditions over prolonged periods The basic characteristic resistance for each fastening (or knot) in both ledger-to-post connections and post-to-post connections may be taken at 1.10 kN, and this may be conservatively applied to all connections between members of Kao Jue and Mao Jue (Chung & Yu, 2002)

2.4. Physical properties of Bamboo & Eucalyptus materials

Physical properties such as basic density, moisture content, wall thickness, and culm diameter are important properties that determine the utilization of bamboo in construction and for structural purposes. These physical properties were studied. The study revealed that the four-year-old culms had lower moisture content than the two and three-year-old bamboo culms. Moisture content and shrinkage in wall thickness at different age groups were significantly different for Ethiopian highland bamboo (*Yushania alpine).* (Gebremariam, 2018)

The physical and mechanical characterization of the wood species Planchonella tachycardia was performed to evaluate the possibility of estimating physical and mechanical properties as a function of apparent density, rigidity properties as a function of the respective strength properties, as well as evaluating the relationships between the strength properties and comparing them with the arranged relationships in the Brazilian standard. (Aquino, 2021)

As natural non-homogeneous organic materials, large variations of physical properties along the length of bamboo culms are apparent: external and internal diameters, dry density and moisture content.

2.5. Mechanical properties of Bamboo & Eucalyptus materials

African highland bamboo (Arundinaria alpine) is one of the most important bamboo species in Ethiopia, but few studies have been done on its properties and value-added utilization. In this study, some main physical-mechanical properties of A. alpine were tested and analyzed and compared with those of Moso bamboo (Phyllostachys pubescens). The results showed that A. alpine had a small taper, higher wall thickness, lower basic density, and higher shrinkage, and the tangential modulus of elasticity in static bending was higher than that of Moso bamboo, while compressive strength parallel to the grain, tangential bending strength, and shearing strength parallel to the grain were lower. It has been determined that A. alpine can be used in construction and bamboo-based panel processes. (Li, Zheng, Tao, & Yang, 2010)

Further investigation of the influence of moisture and density on the mechanical properties is needed to provide a foundation from which to develop design characterization factors for engineered bamboo. Additional testing of full-scale specimens would also elucidate any effects in comparison to small clear specimens, as well as allow further comparison to timber and provide an additional step forward towards construction (Sharma, 2015)

The mechanical properties of Moso bamboo have a significant an isotropic characteristic, especially for the parallel-to-grain tensile properties, bending properties. Performances of parallel-to-grain compressive strength, tensile strength and bending strength are significantly better than Performances of perpendicular-to-grain mechanical properties. Moso bamboo is an ideal renewable green building material with the advantages of high strength, high stiffness and high ratio of strength to weight. The density of Moso bamboo gradually increases along the height of the bamboo stem. The parallel-to-grain compressive resistance, parallel-to-grain tensile resistance, parallel-to-grain shear resistance, parallel-to-grain bending resistance, and perpendicular-to-grain compressive resistances of internode are positively correlated with the density. In contrast, the perpendicular-to-grain compressive resistance of node and perpendicular-to-grain tensile resistance are negatively correlated with the density. There is a strong correlation between mechanical properties and the density of Moso bamboo, which can be fitted and used to predict the mechanical properties of Moso bamboo. The conversion parameters of the mechanical properties are derived from the relationship between mechanical properties and density of Moso bamboo. Those parameters can provide references for the performance evaluation of bamboo materials and the prediction of mechanical properties of bamboo in actual engineering (Zhou, Tian, Liu, & Zhang, 2021)

Eucalyptus globulus Labill stands out as one of the hardwood species produced in Europe with prominent mechanical properties that are undergoing interest in extending added value. To determine the main mechanical properties of E. globulus from small clear specimens provides experimental results on the ultimate capacity and modules of elasticity considering different stresses: tension, parallel, and perpendicular to the grain (radial and tangential directions), shear and longitudinal static bending (Jorge, Majano-Majano, Lara-Bocanegra, & Guilta, 2020)

2.5.1. Modulus of Elasticity in Bending

The test procedure of timber specimen shall be loaded in third point bending over a span of 18 times the nominal depth. If the test equipment does not permit these conditions to be achieved exactly, then the distance between the inner load points shall be increased by an amount not greater than 1 times the nominal depth, and the span and specimen length shall be increased by an amount not greater than three times the nominal depth, while maintaining the symmetry of the test. The specimen shall be supported on rollers and a fixed knife edge reaction or by other devices which achieve an acceptable free support condition (EBCS-5, 1995)

2.5.2. Empirical design

The empirical design criteria provide a baseline for structural engineers to begin designing bamboo structures. These calculations allow engineers to produce a proposal before conducting formal testing on the specified bamboo species. The empirical design criteria do not replace or neglect the significance of quantitative mechanical properties determined from testing because without these properties,

The empirical design criteria for bamboo strength require the density of the species analyzed (Janssen, 2000) . The equations below pertain to air-dried bamboo in compression (C), bending (B), shear (V), modulus of elasticity (E), slenderness (λ), and deflection (δ). These equations relate to the density (ρ in kg/m^3) and safety factor (Ω) for allowable stresses ($MPa=N/mm^2$). These equations are used when the mechanical properties are unknown.

$C=0.094\rho$ …………………………………………………………………………….. (2.1)

$B=0.14\rho$ ……………………………………………………………………………… (2.2)

$V=0.021\rho$ ……………………………………………………………………………… (2.3)

$E=24\rho$ …………………………………………………………………………………… (2.4)

$\delta max= l/300$ ……………………………………………………………………………… (2.5)

To determined compression, bending, and shear stresses are the primary stresses a bamboo member experiences in application. (Myers, 2013)

2.6. Characteristic strength of Bamboo and Eucalyptus materials

Testing standards have been developed locally in different countries, but since 2001, the International Organization for Standardization (ISO), with the cooperation of the International Network for Bamboo and Rattan (INBAR), assigned the Technical Committee ISO/TC 165 to develop an international standard for the determination of physical and mechanical properties of bamboo: ISO/DIS-22,157 (ISO, 2004a) . This standard is focused only on pole bamboo culms and it is used to obtain data to establish characteristic strength values for allowable stresses according to the ASD method. (Correal, 2020)

Table 2.1 illustrates the proposed characteristic strengths for any bamboo species normalized to Service Class 1 or 2. Only detailed published test data is available for Colombian-grown Guadua angustifolia Kunth – this is based on NSR G-12 (AIS, 2010) and Lozano (2010).
For a detailed design, testing would normally need to be undertaken to validate the values below. However, they are intended to be conservative, so for simple structures (low rise, low occupancy, and low stress), depending on local regulations, it may be possible to use these design values without any testing. Where bamboo is sourced from a single consistent source, a large amount of testing is undertaken, and testing and selection are rigorous, it is possible that better characteristic strengths can be achieved (Kaminski; et.al., 2016)

Table 2-1 Characteristic strengths, fi,k,

	Flexure (*fm,k*)	Shear (*fv,k*)	Tension parallel to	Compression parallel to
Colombian grown *Guadua*	35-50	3-5	40	20
For scheme design, all species	30	2	40	20
C24 softwood	24	2.5	14	22

For design of dry*, mature** bamboo, free of visual defects (splits, decay etc.) and assuming a 10min test load (N/mm2) (Kaminski; et.al., 2016)

* at 12% moisture content.

** Within ‘mature’ age range for that particular species – normally 3-5 year

The modulus of elasticity of bamboo is significant because it indicates bamboo’s flexibility and behavior. The modulus of elasticity helps predict the culms change in length based on axial loading in tension or compression, and the modulus of elasticity is used to determine member deflection. The modulus of elasticity for tested bamboo species ranges from 2113-22000 MPa (Sharma, 2015) INBAR conducted a study which found that the modulus of elasticity for air-dried bamboo can be estimated as twenty-four times the bamboo density, E=24ρ (Janssen, 2000)

It proposes a range of typical modulus of elasticity E at 12% and 19% moisture content. The lower values of the 5th percentile should be used for Euler buckling checks based on NSR G-12 (AIS, 2010).

Table 2-2.Typical moduli of elasticity E for bamboo

Moisture content (%)	Average modulus E0.5 (N/mm2)	5th percentile modulus E0.05 (N/mm2)
12	10,000-17000	7500-13,000
19	8500-15,000	6700-8000

2.7. Structural performance of Bamboo and Eucalyptus scaffolds

Based on the experimental investigation of thirty-nine original bamboo columns, parametric analyses were conducted to investigate the influence of the diameter–thickness ratio, cross-sectional area, and slenderness ratio on the axial compression behavior of original bamboo columns. The test results indicate that the failure modes of the columns are substantially affected by the slenderness ratio and diameter–thickness ratio (Nie, Wei, Huang, & Dong, 2021)

2.7.1. Column buckling of bamboo and eucalyptus scaffolds

Column buckling is a critical limit state for bamboo and eucalyptus scaffolds, often leading to their overall collapse. The proposed design method follows closely to the column buckling methods of other constructional materials: Such as structural steel as given in the European steel code (Euro code 3) (Silva, Simões, Rui, & Helena, 2000).and structural timber as given in the European timber code (Euro code 5) (Porteous, 2013)

The variations of physical properties along the length of bamboo and eucalyptus members such as external and internal diameters are apparent. Thus, the non-prismatic effect is significant in the column buckling analysis, and this may be readily achieved by incorporating a non-prismatic parameter, α to the elastic Euler buckling load of the bamboo and eucalyptus member. The non-prismatic parameter α is a function of the change of the second moment of area along member length, and it may be evaluated through the minimum energy method.

Based on the experimental investigation, the test results indicate that the failure modes of the columns are substantially affected by the slenderness ratio and diameter–thickness ratio (Nie, Wei, Huang, & Dong, 2021)

CHAPTER THREE

3. METHODOLGY

3.1. Study Area

The study area of Bamboo material sample collection from Masha area, southwest Ethiopia and eucalyptus material from Teppi town

3.2. Study design

The study design of bamboo and eucalyptus materials is conducted on the variation of compressive strength against a number of physical properties along the length of culm in air dry condition. The physical test in this study includes; external diameter D, cross-sectional area A, mass by volume (density ρ), and moisture content (m.c.) All the physical properties of the test specimens are measured before and after the compression tests as necessary.

3.3. Study variable

3.3.1. Independent variable

The independent variable of this study was;

- ✓ Length
- ✓ Cross-sectional area

3.3.2. Dependent variable

The dependent variable of this study was;

- ✓ Compressive strength
- ✓ Bending strength
- ✓ Modulus of elasticity
- ✓ Dry density
- ✓ Moisture content

3.4. Selection and sample preparation

Six bamboo and eucalyptus culms were selected from different matured clumps with different sizes and free from any defects in the standing condition. The age of all bamboo culms is between 3-4 years. Immediately after selection, the bamboo is marked as Bamboo (B) and eucalyptus (E) followed by culm and position number. The height of the culms felled range from 6 meters to 7 meters. A length of 0.70 meters from bottom of the culms and top part at the edge are cut. After that, a 4.5 meter culm is prepared and each culm marked into three parts as bottom (B), middle (M) and top (T) at a distance of about 1.5 m above the bottom as shown in Figure 3-1. The test specimens are prepared with a diameter ranging from 70mm to 50mm .A number of test specimens were cut out from the bamboo inter node culms, each marked with a label indicating its position. Such as: Bamboo, culm one, Bottom part (B1B), Middle part (B1M), Top part (B1T) and eucalyptus sample are the same procedure by using Eucalyptus, culm one, Bottom part (E1B), Middle part (E1M), Top (E1T) Finally for compressive strength and physical properties of bamboo and eucalyptus test are used 60 pieces from two culm and for bending strength test are used twelve pieces from four culm

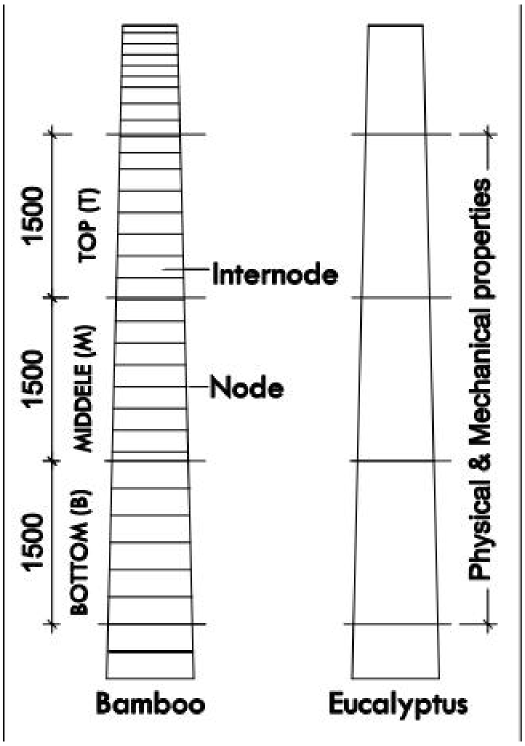

Figure 3-1 Sampling location

Figure 3-2 Sample preparation (Bamboo Masha area & Eucalyptus Teppi area)

3.5. Moisture content

As natural organic material, the mechanical property of bamboo and eucalyptus material is largely depends on moisture content. The sample for moisture content is prepared after each compression test.

The moisture content m.c. of each test piece is calculated as the loss in mass, expressed as a percentage of the oven dry mass, according to the equation below:

Moisture content, percent (m.c)

$$\mathrm{m.c} = \frac{(\mathrm{mi} - \mathrm{mo})}{\mathrm{mo}} 100 \ldots\ldots\ldots\ldots (3.1)$$

Where

mi= initial mass of the test specimen, in Kg; and

mo = oven dry mass, in Kg.

The arithmetic mean of the results obtained from the individual test pieces is reported as the mean value for the moisture content of the test pieces.

3.6. Basic mass per volume or Density

The mass by volume is calculated by dividing the oven dry mass by the volume of the specimens. Here the mass is taken as the oven-dry mass and only the volume is taken by measurement of its dimensions at the natural moisture content of the specimen. The calculation of mass by volume is calculated as follows

Mass per volume, (ρ) in kg/m^3

$$\rho = \left(\frac{\mathrm{mo}}{\mathrm{Vg}}\right) 10\hat{}9 \ldots\ldots\ldots\ldots (3.2)$$

Where

mo = oven dry mass, in Kg. and

Vg= green volume, in mm^3

Figure 3-3 Oven dry specimen (Mizan - Teppi University Lab. test)

3.7. Compressive Strength Parallel to Grain

Compression test is carried out as per the procedure outlined on ISO 22157-1. The test is performed parallel-to-the-axis of specimens made from bamboo culms without node. Specimens are taken from the bottom part, middle part and top part of each culm. These specimens are marked indicating the location from the bottom of the culm. The length of the specimen is taken as 100mm as shown in Figure 3.4

Figure 3-4 Compression test sample

For this study, Controls Automatic Compression testing machine with model 50-C36V is used to determine the compressive strength of bamboo culms. The load is applied at an average rate of 0.01mm/sec (1N/mm2/s).The specimen placed so that the center off the movable head is vertically above the center of the cross section of the specimen. Then the final reading of the maximum load, at which the specimen fails, is recorded as shown in Figure 3.5.

Figure 3-5 Compression test specimen (Mizan-Teppi University Lab test)

The maximum compressive strength (fc, ult), in N/mm^2, shall be determined as follows:

$$fc, ult = \frac{P}{A} \text{..} (3.3)$$

Bamboo

$$A = \frac{\pi}{4}[D^2 - (D - 2t)^2] \text{..} (3.4)$$

Eucalyptus

$$A = \frac{\pi}{4}[D^2] \text{..} (3.5)$$

Where

P = maximum load, in N;

A= area of cross-section of test specimen, in mm^2

D= external diameter, in mm, and

t = wall thickness, in mm

3.7.1. Characteristic strength value

Material property is represented by a 5percentile property, estimated from test results, obtained as in ES-6416-2021 published by (Ethiopian Standard Agency, 2021) , with confidence that it represents the population. This is called the characteristic value. It can be obtained with this formula

$$f, k = f, 0.05 \left(1 - \frac{2.7 \frac{s}{m}}{\sqrt{n}} \right) \text{..} (3.6)$$

$f, 0.05 = (m - 1.645\ )$ ………………………… ……………………… …………………(3.7)

Where,

f, k = is the characteristic value

$f, 0.05$ = is the 5percentile from the test data;

m = is the mean value from the test data;

s= is the standard deviation from the test data;

n= is the number of tests (at least 10).

3.8. Bending Strength

A three-point bending test is conducted as per the procedure outlined on ISO 22157-1. This test ensures a region of constant moment and is performed to determine bending capacity, load versus vertical deflection curve and the nominal modulus of elasticity of the culm

The ultimate strength (fb, ul) in static bending, in N/mm^2, is given by the formula

$$fb, ul = \left[\frac{1}{6I}\left(F\, L\frac{D}{2}\right)\right] \quad (3.8)$$

Where

F = maximum load, in N; and

L = effective span, in mm

The modulus of elasticity (Young's modulus) , *E,* in N/mm2, is given by the formula

Bamboo

$$E = \frac{23\ \Delta F\ L^3}{1296\ \Delta\delta\ I} \quad (3.9)$$

Eucalyptus

$$E = \frac{3\ \Delta F\ L^3}{4\pi\ \Delta\delta\ \ Deq^4} \quad (3.10)$$

Where

ΔF= the difference between upper and lower limit load, in N

Δδ= the deflection change at the middle span between upper and lower limit load, in mm

Deq= equivalent diameter, in mm

The length of the specimen culms (L_{total}=500mm) and a total of 12 Bamboo specimens and 12 Eucalyptus specimens are tested as shown figure 3.6 and figure 3.7

Figure 3-6 Bending test sample

Figure 3-7 Bending test specimen (Addis Ababa science and Technology University)

3.9. Axial load resistance

As natural non-homogeneous organic materials, large variations of physical properties along the length of bamboo members such as external and internal diameters are apparent. Thus, the non-prismatic effect is significant in the column buckling analysis, and this may be readily achieved by incorporating a non-prismatic parameter, α , to the elastic Euler buckling load of the bamboo member. The non-prismatic parameter α is a function of the change of the second moment of area along member length, and it may be evaluated through the minimum energy method. (Chung & Yu, 2002)

The elastic critical buckling strength of column ($f_{c,r}$), in N/mm^2, is given by:

$$f_{c,r} = \alpha \frac{\pi^2 * E_{b,d}}{{\lambda_1}^2} \qquad (3.12)$$

Where the non-prismatic parameter, α, is the minimum root of the following cubic function

$g(\alpha) = c_3\alpha^3 + c_2\alpha^2 + c_1\alpha + c_0$

Where

$c_3 = -0.2880$

$c_2 = 2.016(2 + \rho)$

$c_1 = -(14.11 + 14.11\rho + 3.098\rho^2)$

$c_0 = 10.37 + 15.55\rho + 7.047\rho^2 + 0.932\rho^3$

$\rho = \frac{I_1 - I_2}{I_1}$

If the value of ρ lies between 0 and 3, the value of α may be evaluated approximately as follows:

$\alpha = 1.005 + 0.4751\,\rho - 0.011\rho^2$ where α lies between 1.00 and 2.35

The compressive strength of column $f_{c,d}$ is given by:

$$f_{c,d} = \frac{f_{c,k}}{\delta_m} \qquad (3.13)$$

Where

$f_{c,k}$ = characteristic value, in N/mm^2 and

δ_m = Partial safety factor

The compressive buckling strength of column $f_{cc,d}$ is thus given by:

$$f_{cc,d} = \frac{f_{c,r} * f_{c,d}}{\phi + (\phi^2 - f_{c,r} * f_{c,d})^{1/2}} \qquad (3.15)$$

Where

$\phi = \frac{f_{c,d} + (1 + \eta) f_{c,r}}{2}$

Petty factor, $\eta = 0.001a\,(\lambda_1 - \lambda_0)$

Where

a = Robertson constant

Limiting slenderness ratio, $\lambda_0 = 0.2\pi\sqrt{\frac{E_{b,d}}{f_{c,d}}}$………………………………………….. (3.16)

A non-dimensional column buckling curve may be plotted using the following two non-dimensional quantities:

Modified slenderness ratio, $\lambda^{'} = \sqrt{\frac{f_{c,d}}{f_{c,r}}}$……………………… ………………………… (3.16)

Strength reduction factor, $\psi_c^{'} = \frac{f_{cc,d}}{f_{c,d}}$ ………… ……………………. . ……………… (3.17)

Axial load resistance, $p = f_{cc,d} * A$………… ……………………. . . ……………… (3.18)

Where

A= area of cross section member, in mm^2

CHAPTER FOUR

4. RESULTS AND DISCUSSION

In this section the result of experimental tests on bamboo and eucalyptus culms are reported and discussed. Initially, the changes observed on diameter, wall, moisture content and dry density varied along the sections from bottom to top are reported. Following, the compressive strength is studied against moisture content of saturated bamboo and eucalyptus culm specimens. The compression test conducted on sixty samples and bending tests conducted on twelve samples of bamboo and eucalyptus culms were conducted. The compressive tests are carried out with Universal Testing machine and bending test are carried out with Electro Mechanical Machine. The experimental results are illustrated here using a representative set of specimen data. A complete set of experimental test results are presented in the Appendix A and B.

4.1. Result of physical properties

Reporting of the primary study results are organized into three sections. First, the diameter changes observed along the culm length of both materials are discussed and illustrated. Next, moisture content data of the culms along the culm length are observed. Finally mass by volume changes is discussed.

4.1.1. Diameter

The selected samples of bamboo and eucalyptus minimum diameter size are above 40mm.because of the effective diameter of scaffolding on bamboo member standards (vertical members) and ledgers (horizontal members) used should not be less than 40mm had stated by.(Labour Department, 2017)

Table 4-1 External diameter result of Bamboo and eucalyptus culm

No	Materials	External Diameter result		
		Maximum	Minimum	Mean
1	Bamboo specimen	74.75	54.75	64.66
2	Eucalyptus specimen	61.25	49.75	55.54

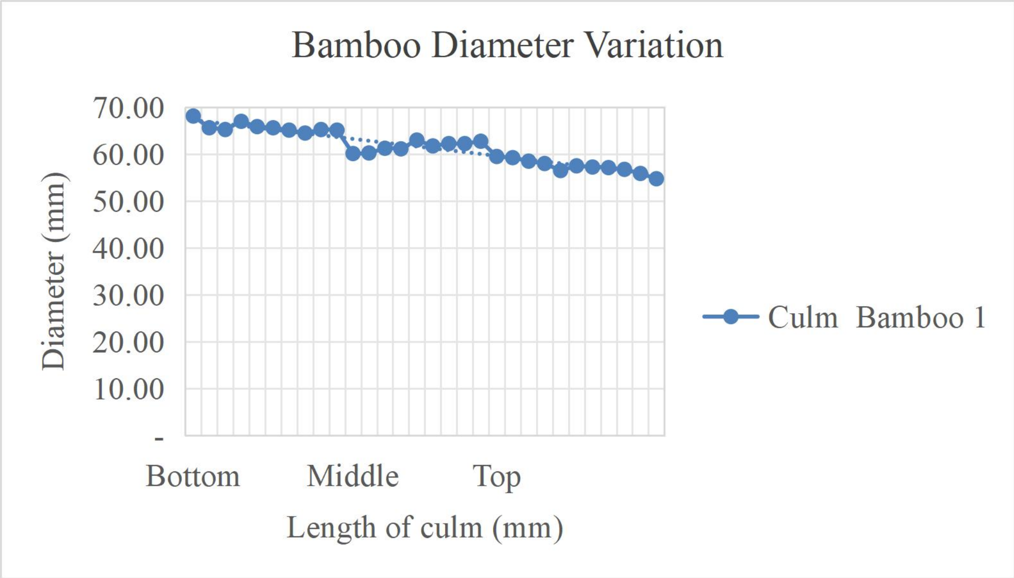

Figure 4-1 Variation of bamboo external cross sectional diameter

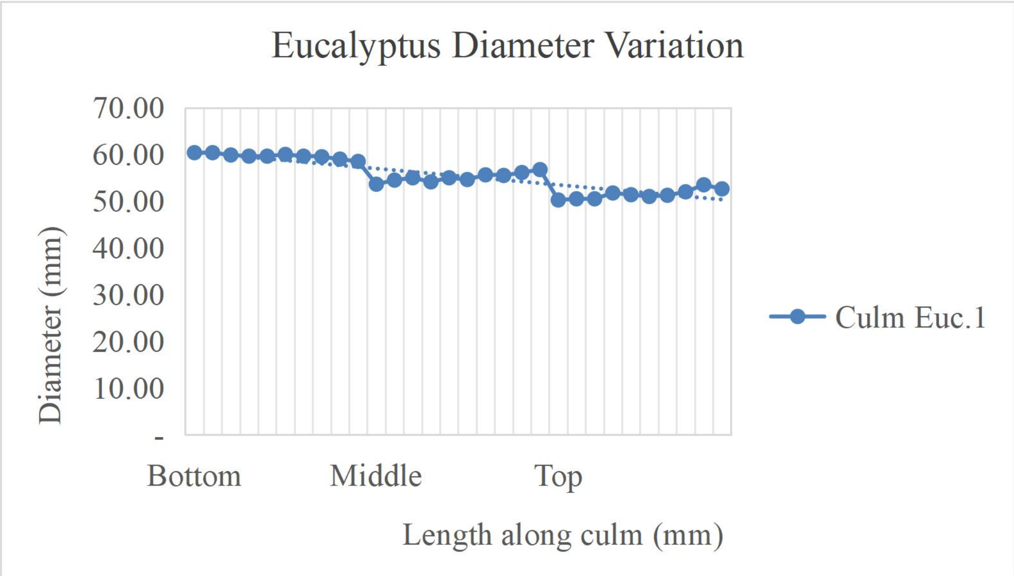

Figure 4-2 Variation of eucalyptus external cross sectional diameter

The external diameter of Masha bamboo and eucalyptus decreases from bottom to top of culm. For bamboo, the external diameter decreases from an average diameter of 75mm at bottom to average diameter of 54mm at upper part of the culm and for eucalyptus, the external diameter decreases from an average diameter of 62mm at bottom to average diameter of 50mm at upper part of the culm

As a result, the average diameter of bamboo is 64.66 mm and eucalyptus is 55.54 mm. While, both materials diameter is a large variation along the whole member length. Because of this reason, it changed cross sectional area. Therefore, both materials using designing purpose had determined the non-prismatic factor (α) through the minimum energy method recommended by researcher (Chung & Yu, 2002)

4.1.2. Moisture content

The moisture content of bamboo and eucalyptus are the important factor as all mechanical and physical properties are functions of it. Also, the duration of bamboo may depend upon the moisture content because of its high water soluble nutrient content and can be attached by fungi and borer insects.

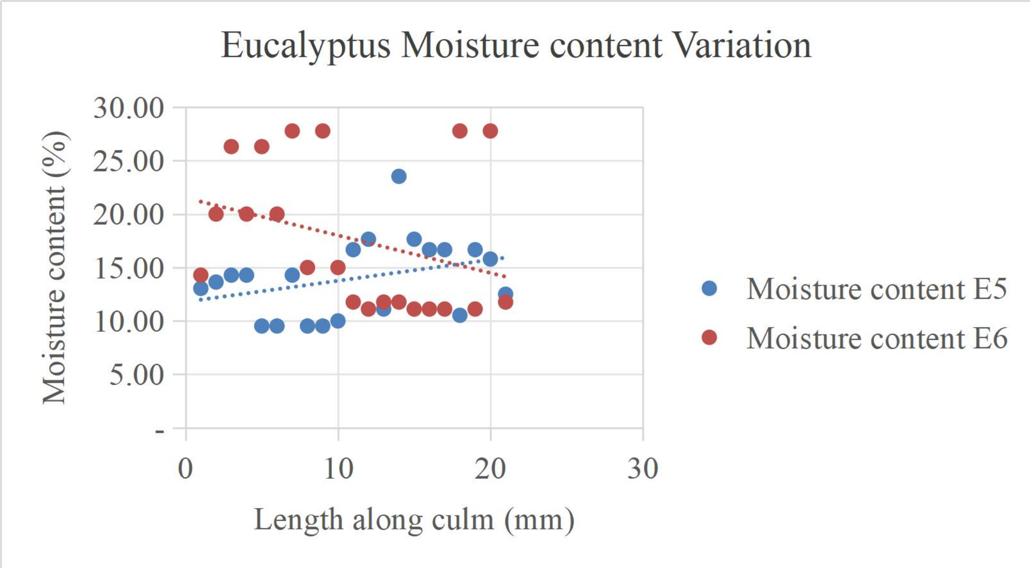

Figure 4-3 Variation of eucalyptus moisture content

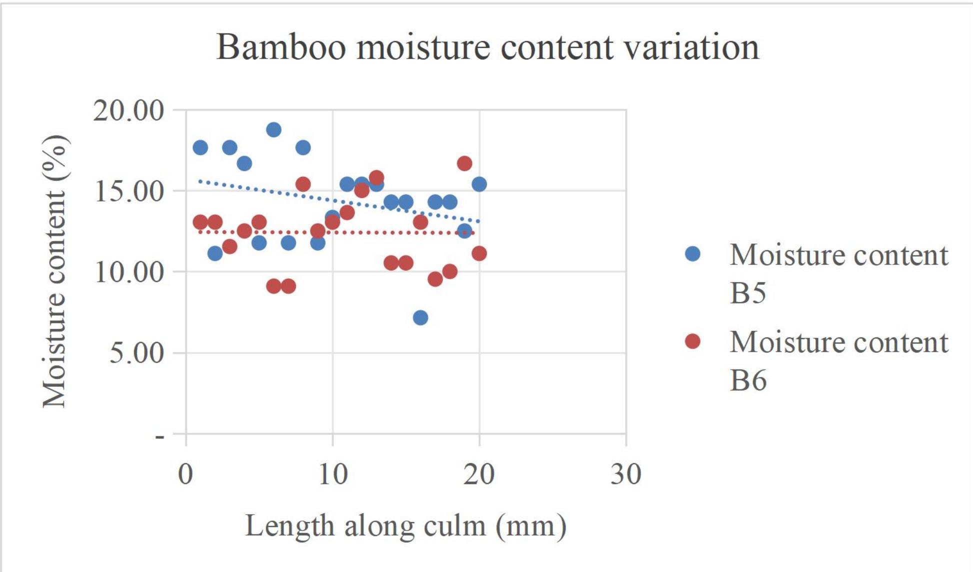

Figure 4-4 Variation of eucalyptus moisture content

As presented in Figure 4.3 and 4.4 the trend of moisture content along the height of eucalyptus and bamboo culm are not constant along the length of culm. It is not strictly decreasing as other physical properties but slightly decreasing. 95% of moisture content of bamboo range is 9-18% and eucalyptus moisture range is 8-26%. As a result, moisture content of bamboo specimen mean value is 13.35 % and eucalyptus specimen is 14.94 %

4.1.3. Dry density

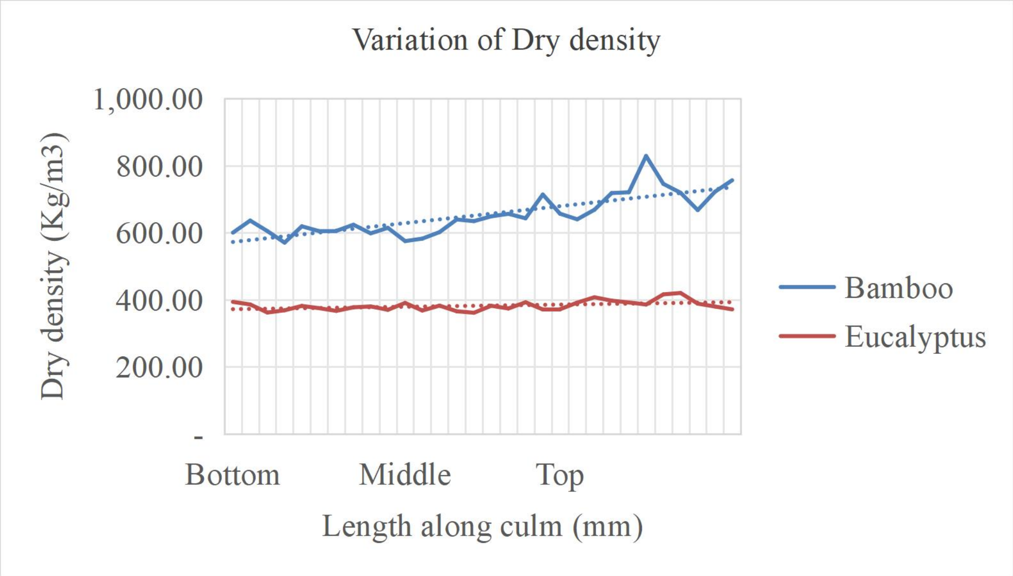

Figure 4-5 Dry density variation of bamboo & eucalyptus culm

The trend of mass by volume (dry density) of bamboo decreases from the top portion to the bottom. While, dry density of eucalyptus almost equal from the top portion to the bottom as shown in Figure 4.5

The dry density range of bamboo is 916.90 Kg/m3 to 570.42 Kg/m3 and eucalyptus is 420.45 Kg/m3 to 326.68 Kg/m3. The mean value of bamboo dry density is 722.03 Kg/m3 and eucalyptus is 371.94 Kg/m3. As a result, the characteristic strength value of dry density for design input on Masha bamboo is 555.45Kg/m3 and eucalyptus is 334.30Kg/m3

4.2. Compression test

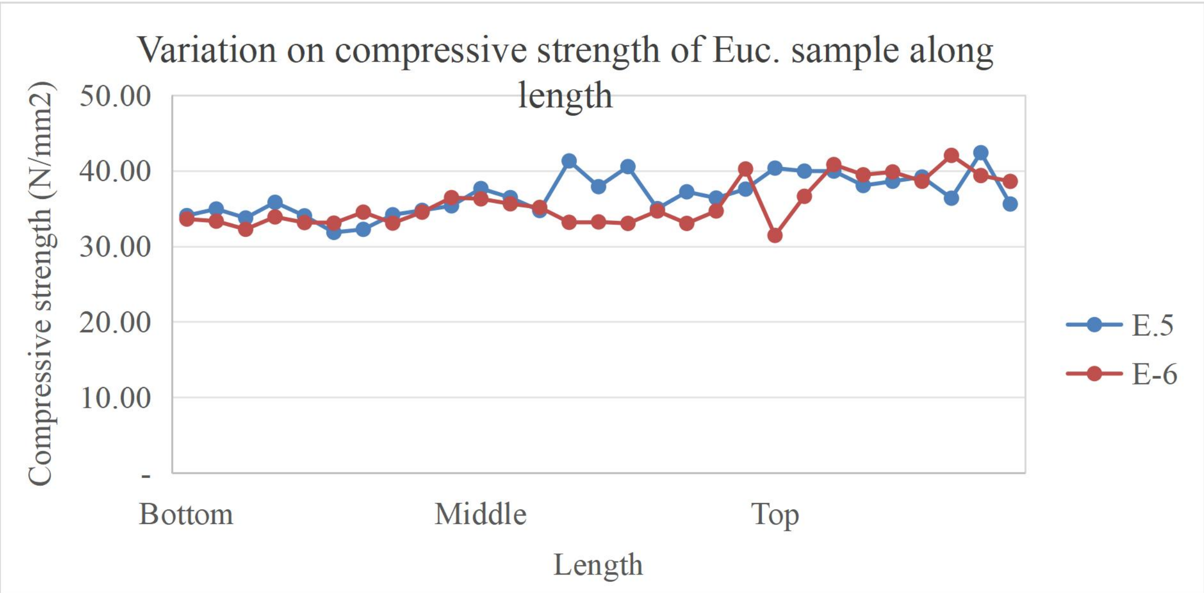

Figure 4-6 Variation of bamboo compressive strength

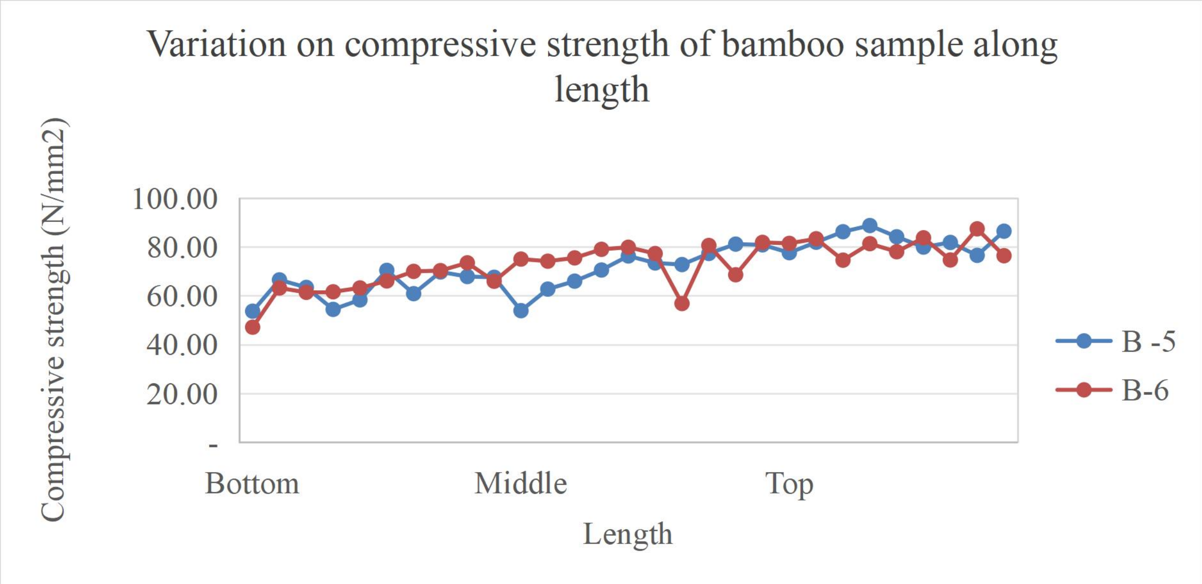

Figure 4-7 Variation of eucalyptus compressive strength

Table 4-3 Compressive strength value of bamboo & Eucalyptus

Compressive strength						
No	Materials	Test Result of Compressive strength (N/mm2)				
		Maximum	Minimum	Mean	Chara. value at fifth %	chara. strength value
1	Bamboo Result	88.73	47.11	72.74	**57.05**	**54.44**
2	Eucalyptus Result	42.38	31.43	36.13	**31.43**	**30.57**

The compressive stress (fc, ult) variation of bamboo and eucalyptus are presented in Figure 4.6 and 4.7. the lowest recorded compressive stress at the bottom of bamboo column one and two are 58 and 62 Mpa and the highest recorded compressive stress at the top of the culm are 89 and 85 Mpa and also the lowest recorded compressive stress at the bottom of eucalyptus column one and two are 34 and 32 Mpa and the highest recorded compressive stress at the top of the culm are 40 and 42 Mpa

The reason for increase of compressive strength along the length of culm is attributed to decrease in cross section area and increase in number of fibers to the upper part of the culm. Hence the top portion of bamboo and eucalyptus has the highest compressive stress and the bottom of culm has the lowest compressive stress.

From the results obtained as shown in Table 4.3, the compressive strength of Masha bamboo mean value is 72.74 Mpa and characteristic strength value determined as 54.44Mpa. Whereas, eucalyptus mean value is 36.13 Mpa and characteristic strength value determined as 30.57Mp

4.3. Bending test and modules of elasticity

Table 4-4 Bending Strength and Modulus of Elasticity of bamboo & eucalyptus

No.	Sample Material	Bending strength(Mpa) from Test result			Modules of Elasticity(Mpa) from Test result		
		Maximum	Minimum	Average	Maximum	Minimum	Mean
1	Bamboo	19.52	11.08	13.24	2,172.02	772.11	1,548.76
2	Eucalyptus	82.33	49.49	64.55	2,328.75	921.43	1,469.24

The bending strength data of twelve different bamboos and eucalyptus culms sample of Masha area is presented in Table 4.3 that Short culm of bamboo had a significant effect on the pure bending strength. According to the study by (Myers, 2013) had bending strength of a bamboo member can be determined by the span and Shear governs for short members as a result, 500mm length of bamboo bending strength on average value is 13.24 Mpa and modulus of elasticity is 1,548.76 Mpa and also eucalyptus bending strength on average value is 64.55 Mpa and modulus of elasticity is 1,469.24 Mpa.

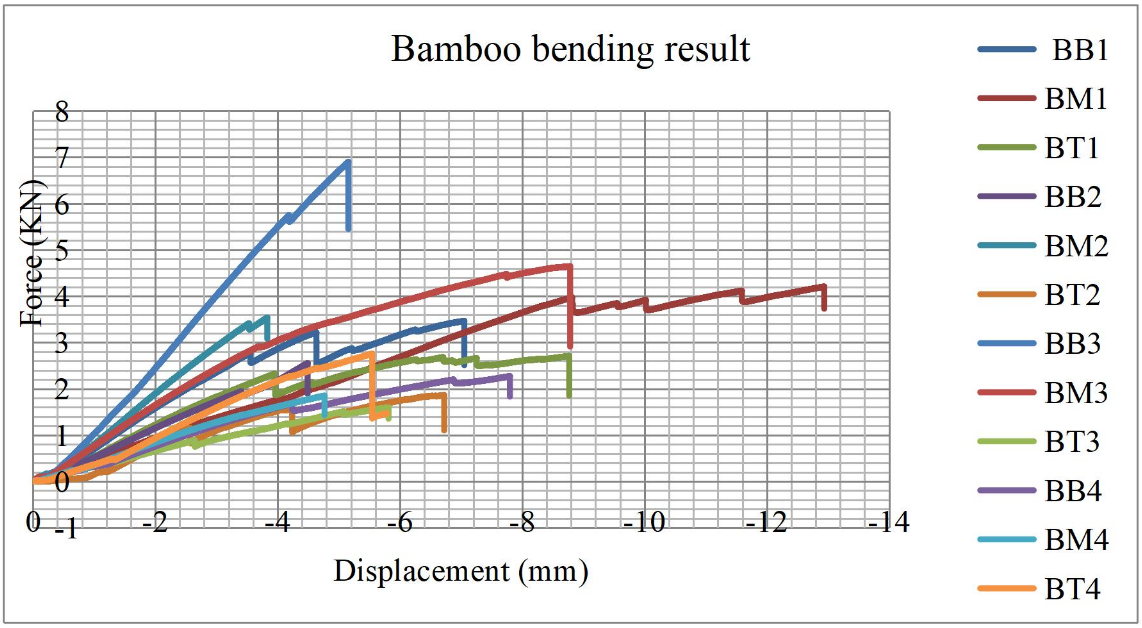

Figure 4-8 Bamboo load-deflection diagram

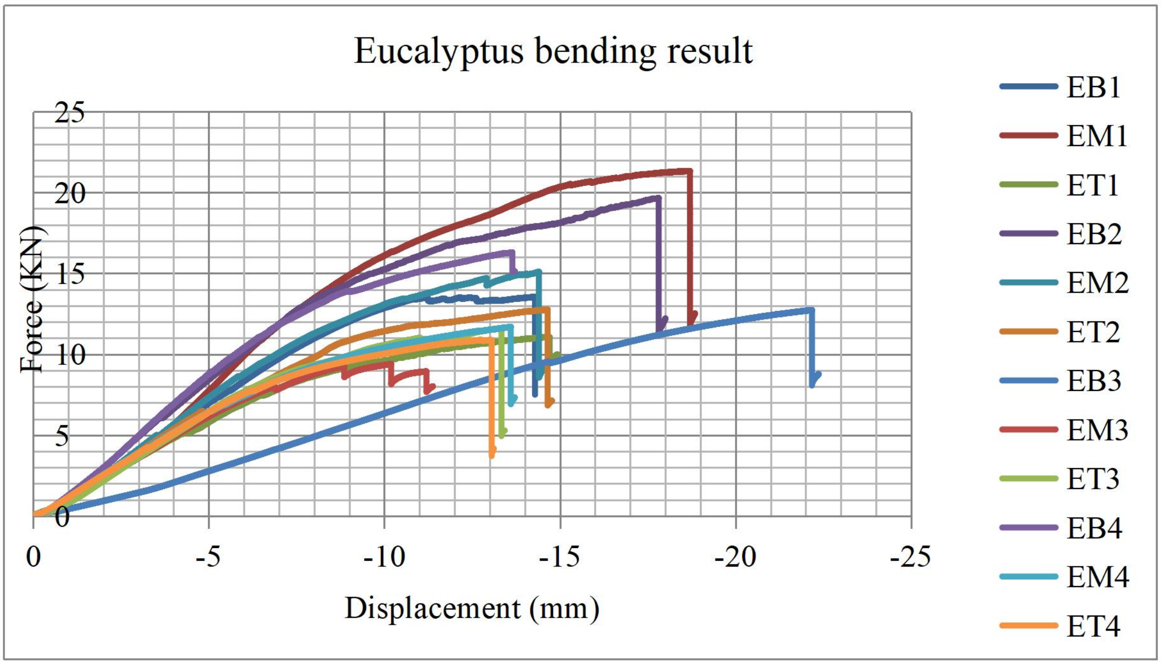

Figure 4-9 Eucalyptus load-deflection diagram

Deflection at the middle of the span shall be noted by means of computer of load increments and deflection, at the time of failure and crack development at maximum level, thus test result of bamboo mean value on failure load is 3.20KN and eucalyptus mean value on failure load is 13.84KN, A load-deflection diagram are plotting as shown in Fig 4.8 and Fig 4.9

Table 4-6 Summaries of physical and mechanical properties of Bamboo

Description	No.	Maximum	Minimum	Average	Standard deviation	Chara. value at fifth percentile	Characteristic strength value
External diameter , D (mm)	60	74.75	54.75	64.66	4.89	56.61	55.11
Internal diameter , d (mm)	60	58.00	44.75	51.45	3.67	45.41	44.29
Wall thickness , t (mm)	60	8.63	4.88	6.60	0.94	5.06	4.81
Cross-sectional area, A (mm2)	60	1,791.74	781.08	1,212.33	237.34	821.90	765.82
Dry density, ρ (Kg/m3)	60	916.90	570.42	722.03	86.54	579.67	555.45
Moisture content, mc (%)	60	18.75	7.14	13.35	3.05	8.34	7.67
Compresive strength, fc (N/mm2)	60	88.73	47.11	72.74	9.54	57.05	54.44
Bending strength , fb (N/mm2)	12	19.52	11.08	13.24	2.18	9.66	8.42
Modules of elasticity, Eb (N/mm2	12	2,172.02	772.11	1,548.76	396.07	897.22	718.38

Table 4-7 Summaries of physical and mechanical properties of Eucalyptus

Description	No.	Maximum	Minimum	Average	Standard deviation	Chara. value at fifth percentile	Characteristic strength value
External diameter , D (mm)	60	61.25	49.75	55.54	3.36	50.01	48.96
Cross-sectional area, A (mm2)	60	2,946.47	1,943.91	2,431.72	293.19	1,949.43	1,867.50
Dry density, ρ (Kg/m3)	60	420.45	326.68	371.94	19.16	340.41	334.30
Moisture content, mc (%)	60	27.78	9.52	14.94	5.05	6.64	5.86
Compresive strength, fc (N/mm2)	60	42.38	31.43	36.13	2.86	31.43	30.57
Bending strength , fb (N/mm2)	12	82.33	49.49	64.55	11.88	45.01	38.55
Modules of elasticity, Eb (N/mm2	12	2,328.75	921.43	1,469.24	370.76	859.34	690.32

Finally summaries of physical and mechanical properties of bamboo and eucalyptus materials are shown on Table 4.6 and Table 4.7 to compere test result

4.4. Axial load resistance of scaffolding

A design method had proposed by (Chan & Chung, 2002) This proposed design method follows closely to the column buckling methods of other constructional material and it adopts the use of a Perry Robertson interaction formula to allow for the effects of both geometrical and material initial imperfections. In general, both the Perry factor and the Robertson coefficient may be chosen in such a way to fit a column buckling curve rationally into the relevant test data of columns with different cross-sections under different axes of buckling.

Table 4-8 Summary of empirical design strength result

Summary of Mechanical properties from Empirical test result					
No	Mechanical Properties	Bamboo		Eucalyptus	
1	Dry density	555.45	Kg/m3	334.30	Kg/m3
2	Compression Strength	52.21	Mpa	31.42	Mpa
3	Bending Strength	77.76	Mpa	46.80	Mpa
4	Shear strength	11.66	Mpa	7.02	Mpa
5	Modules of Elasticity	13,330.89	Mpa	8,023.18	Mpa

The empirical design criteria for bamboo strength related to the density of the species by (Janssen 2000).had explained to analyzed the equations in compression (C), bending (B), shear (V), modulus of elasticity (E), when the mechanical properties are unknown.

To determined compression, bending, and shear stresses are the primary stresses a bamboo member experiences in application (Myers, 2013).Therefore from test result of density to get the primary stress of bamboo and eucalyptus as shown Table 4.8

The calculation of axial load resistance for bamboo and eucalyptus scaffolding is based on Bamboo Scaffolds in Building Construction proceedings no.8 international network for bamboo and rattan (INBAR). (Chung & Yu, 2002)

AXIAL LOAD RESISTANCE OF BAMBOO POST						
Design data						
	Moisture content		13.35	%		
	$E_{b,d} =$		13,330.89	N/mm2		
	$f_{c,d} =$		52.21	N/mm2		
Member length	L=	1000	mm			
Effective length factor	K=	1				
Effective length	Le=	1000	mm			
		Cross section 1		Cross section 2		
External diameter	$D_{e,1}$=	74.75	mm	$D_{e,2}$=	54.75	mm
Internal diameter	$D_{i,1}$=	58.00	mm	$D_{i,2}$=	44.75	mm
Cross sectional area	$A_1 = \frac{\pi}{4}(D_{e,1}{}^2 - D_{i,1}{}^2)$			$A_2 = \frac{\pi}{4}(D_{e,2}{}^2 - D_{i,2}{}^2)$		
	$A_1 =$	1,746	mm2	$A_2 =$	781	mm2
Second moment area	$I_1 = \frac{\pi}{64}(D_{e,1}{}^4 - D_{i,1}{}^4)$			$I_2 = \frac{\pi}{64}(D_{e,2}{}^4 - D_{i,2}{}^4)$		
	$I_1 =$	977,053	mm4	$I_2 =$	244,216	mm4
Radius of gyration	$r_{y,1} = \sqrt{\frac{I_1}{A_1}}$			$r_{y,2} = \sqrt{\frac{I_2}{A_2}}$		
	$r_{y,1} =$	23.65	mm	$r_{y,2} =$	17.68	mm
Slenderness ratio of section	$\lambda_1 = \frac{Le}{r_{y,1}}$					
	$\lambda_1 =$	42.28				
Ratio of section change	$\rho = \frac{I_1 - I_2}{I_1}$					
	ρ=	-0.750				

if the value of ρ lies between 0 and 3, the value of α evaluated as follow

Non-prismatic parameter	$\alpha = 1.005 + 0.4751\,\rho - 0.011\rho^2$ where α lies between 1.00 and 2.35			
	α=	**0.65**		
Young's modules against bending	$E_{b,d} =$	13330.891		Ɣm=1
Design compressive strength	$f_{c,d} =$	35		Ɣm=1.5
Elastic critical buckling strength	$f_{c,r} = \alpha \dfrac{\pi^2 * E_{b,d}}{\lambda_1^{\,2}}$			
	$f_{c,r} =$	47.7	N/mm2	
Column Buckling Curve				
Robertson constant	a=	15		
Limiting slenderness	$\lambda_0 = 0.2\pi\sqrt{\dfrac{E_{b,d}}{f_{c,d}}}$			
	$\lambda_0 =$	12.30		
Petty factor	$\eta = 0.001a\,(\lambda_1 - \lambda_0)$			
	η=	0.45		
	$\phi = \dfrac{f_{c,d} + (1+\eta)f_{c,r}}{2}$			
	ϕ=	51.98	N/mm2	
Design compressive strength against column buckling	$f_{cc,d} = \dfrac{f_{c,r} * f_{c,d}}{\phi + (\phi^2 - f_{c,r} * f_{c,d})^{1/2}}$			
	$f_{cc,d} =$	19.7	N/mm2	
Modified slenderness	$\lambda' = \sqrt{\dfrac{f_{c,d}}{f_{c,r}}}$			
	$\lambda' =$	0.85		
Modified strength	$\psi_c{}' = \dfrac{f_{cc,d}}{f_{c,d}}$			
	$\psi_c{}' =$	0.57		
Axial Load Resistance	$p = f_{cc,d} * A$			
	p =	**34.42 KN**		

AXIAL LOAD RESISTANCE OF EUCALYPTUS POST

Design data						
	Moisture content		14.94	%		
	$E_{b,d} =$		8,023.18	N/mm2		
	$f_{c,d} =$		31.42	N/mm2		
Member length	L=	1000	mm			
Effective length factor	K=	1				
Effective length	Le=	1000	mm			
		Cross section 1			Cross section 2	
External diameter	$D_{e,1}$=	61.25	mm	$D_{e,2}$=	49.75	mm
Internal diameter	$D_{i,1}$=	-	mm	$D_{i,2}$=	-	mm
Cross sectional area	$A_1 = \frac{\pi}{4}(D_{e,1}{}^2 - D_{i,1}{}^2)$			$A_2 = \frac{\pi}{4}(D_{e,2}{}^2 - D_{i,2}{}^2)$		
	$A_1 =$	2,946	mm2	$A_2 =$	1,944	mm2
Second moment area	$I_1 = \frac{\pi}{64}(D_{e,1}{}^4 - D_{i,1}{}^4)$			$I_2 = \frac{\pi}{64}(D_{e,2}{}^4 - D_{i,2}{}^4)$		
	$I_1 =$	690,867	mm4	$I_2 =$	300,706	mm4
Radius of gyration	$r_{y,1} = \sqrt{\frac{I_1}{A_1}}$			$r_{y,2} = \sqrt{\frac{I_2}{A_2}}$		
	$r_{y,1} =$	15.31	mm	$r_{y,2} =$	12.44	mm
Slenderness ratio of section	$\lambda_1 = \frac{Le}{r_{y,1}}$					
	$\lambda_1 =$	65.31				
Ratio of section change	$\rho = \frac{I_1 - I_2}{I_1}$					
	ρ=	-0.565				

if the value of ρ lies between 0 and 3, the value of α evaluated as follow

Non-prismatic parameter	$\alpha = 1.005 + 0.4751\rho - 0.011\rho^2$ where α lies between 1.00 and 2.35					
	α=	**0.74**				
Young's modules against bending	$E_{b,d} =$	8023.176		ϒm=1		
Design compressive strength	$f_{c,d} =$	21		ϒm=1.5		

Elastic critical buckling strength	$f_{c,r} = \alpha \frac{\pi^2 * E_{b,d}}{\lambda_1{}^2}$		
	$f_{c,r} =$	**13.7**	N/mm2
Column Buckling Curve			
Robertson constant	a=	15	
Limiting slenderness	$\lambda_0 = 0.2\pi \sqrt{\frac{E_{b,d}}{f_{c,d}}}$		
	$\lambda_0 =$	12.30	
Petty factor	$\eta = 0.001a\,(\lambda_1 - \lambda_0)$		
	η=	0.80	
	$\phi = \frac{f_{c,d} + (1+\eta) f_{c,r}}{2}$		
	ϕ=	22.75	N/mm2
Design compressive strength against column buckling	$f_{cc,d} = \frac{f_{c,r} * f_{c,d}}{\phi + (\phi^2 - f_{c,r} * f_{c,d})^{1/2}}$		
	$f_{cc,d} =$	7.5	N/mm2
Modified slenderness	$\lambda' = \sqrt{\frac{f_{c,d}}{f_{c,r}}}$		
	$\lambda' =$	1.24	
Modified strength	$\psi_c{}' = \frac{f_{cc,d}}{f_{c,d}}$		
	$\psi_c{}' =$	0.36	
Axial Load Resistance	$p = f_{cc,d} * A$		
	p =	**22.24**	**KN**

As a result, the comparison of axial load resistance of bamboo and eucalyptus culm are from test result of the mean value moisture content and empirical value of compressive strength and modules of elasticity Hence the result of comparing on structural performance of bamboo scaffolding is 34.42 KN and eucalyptus scaffolding is 22.24 KN

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The research was conducted to assess the practicality of the Ethiopian highland bamboo from Masha area (southwest Ethiopia) for comparing as scaffolding material with eucalyptus material. From the experiments conducted and design output there are several conclusions that can be derived from this study:

1) Considering the benefits of abundance, rapid renewable and good mechanical properties, bamboo has a great potential and an alternative scaffolding material that can add to the local construction resource of eucalyptus material. However, absence of design procedures and standards have affected acceptance of bamboo scaffolding to choice in the construction industry.
2) From total sample test of 95% on the moisture content about Masha bamboo range is 9-18% and mean value of moisture content is 13.35 %.
3) From total sample test of 95% on the moisture content about eucalyptus range is 8-26% and mean value of moisture content is 14.94 %.
4) The dry density ranges of Masha bamboos are 916.90 Kg/m3 to 570.42 Kg/m3 and mean value is 722.03 Kg/m3. Dry density has a strong correlation with mechanical properties of those materials. Hence the characteristic strength value of dry density for design input on Masha bamboo is 555.45Kg/m3.
5) The dry density ranges of eucalyptus are 420.45 Kg/m3 to 326.68 Kg/m3 and mean value is 371.94 Kg/m3. and also the characteristic strength value of dry density is 334.30Kg/m3.
6) The compressive strength of Masha bamboo material of mean value is 72.74 Mpa and eucalyptus material of mean value is 36.13 Mpa.
7) The characteristic strength on compressive strength value of Masha bamboo materials is 54.44Mpa, whereas for eucalyptus materials is 30.57Mpa indicating that Masha bamboo materials are 43.9% stronger than eucalyptus materials.
8) For short culm of bamboo bending strength on average value is 13.24 Mpa and modulus of elasticity is 1,548.76 Mpa. Whereas eucalyptus bending strength on average value is 64.55 Mpa and modulus of elasticity is 1,469.24 Mpa.
9) The empirical design criteria by using characteristic strength value of dry density for Masha bamboo bending stress calculation is 77.76 Mpa and modules of elasticity is

13.3Gpa. Whereas eucalyptus bending stress calculation is 46.80 Mpa and modules of elasticity is 8 Gpa.

10) The axial load resistance of Masha bamboo culm is 34.42 KN and eucalyptus culm is 22.24 KN. Hence comparing on structural performance of bamboo scaffolding is 35.38% stronger than eucalyptus scaffolding. hence the mechanical performance of Masha bamboo scaffold has been found adequate for use as an alternative scaffolding material.

5.2. Recommendation

In the future, researchers can conduct additional tests beyond just the axial strength structural performance. For example, they can compare the shear strength of Bamboo and Eucalyptus scaffolding. Furthermore, they can also conduct more structural modeling and cost comparisons through market assessment, considering connection methods and the flexibility of reuse mechanisms.

The ISO standards provide a foundation from which to design with bamboo, but they need to be updated and expanded to reflect the growing research on test methods and material characterization.

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Appendix A

Experimental test result of physical and mechanical properties of bamboo and eucalyptus material have listed below

Table A1: Before and after measurement oven dry mass of bamboo

No	Sample code No	BEFORE OVEN DRY										Force (KN)	After oven dry
		Length (mm)	BOTTOM				TOP						
			External Diameter (mm)		thickness (mm)		External Diameter (mm)		thickness (mm)				
			D1	D2	t1	t2	D1	D2	t1	t2			Mass (Kg)
1	B5B01	95	69	68	8.5	9	67.5	68	7	7		80	0.085
2	B5B02	99	62	66	8.5	9	66	68.5	7	7		95	0.09
3	B5B03	99	68	64	7	8	64	65	7.5	9		90	0.085
4	B5B04	101	68	68	9	9	67	65	8	8		85	0.09
5	B5B05	97	64	68	8	8	63.5	68	7.5	7.5		82.5	0.085
6	B5B06	98	68	63	7.5	7	63.5	68	7.5	7.5		95	0.08
7	B5B07	100.5	64.5	66.5	7.5	8	63	66.5	8	7.5		85	0.085
8	B5B08	100	64	65	7.5	8	64	65	7.5	7.5		95	0.085
9	B5B09	101.5	63	67	8	8	63	68	8	7		95	0.085
10	B5B10	97	67.5	63	7	7	67.5	62.5	6.5	7		85	0.075
11	B5M01	101.5	63	57	6	7	63.5	57	6.5	7		60	0.065
12	B5M02	100	63	57	6	7	63	58	6.5	7		70	0.065
13	B5M03	95	64	58.5	6	7	64	58.5	6.5	7		75	0.065
14	B5M04	96.5	64	58.5	7	6	63	59	6.5	7		80	0.07
15	B5M05	99	62	68	6	7	63	59	6	6		85	0.07
16	B5M06	99	64	59	6	7	64	60	6	6		80	0.07
17	B5M07	97	64	60	6	7	64	61	6	6		80	0.07
18	B5M08	99	64	61	6	6	64	60	7	6		85	0.07
19	B5M09	101	64	62	7	6	64	61	6	6		90	0.08
20	B5T01	100	58.5	61	6	6	61	57.5	6	5.5		80	0.065
21	B5T02	97	57.5	61	5.5	6	57.5	61	5.5	6		75	0.06
22	B5T03	98	57	60	5.5	5.5	57	60	5	6		75	0.06
23	B5T04	96	59	58	5	5.5	57	58	5.5	5		75	0.06
24	B5T05	98.5	55.5	57.5	5.5	6	56	57	4.5	5		75	0.06
25	B5T06	98	59.5	56.5	5.5	6	55.5	58.5	4.5	5		72.5	0.07
26	B5T07	99.5	55	60	5	5	55	59	5.5	6		70	0.065
27	B5T08	97.5	59.5	54.5	5	5	55	59.5	5.5	5.5		70	0.06
28	B5T09	97	54.5	59	5	5.5	54	59.5	5	5.5		65	0.055
29	B5T10	97.5	58	54	5	4.5	54.5	57	5	5		67.5	0.055
30	B5T11	101.5	54.5	56	5	4.5	53.5	55	5.5	5		65	0.06

31	B6B01	97.5	69	74	7	7	69	74	7.5	8	70	0.115
32	B6B02	99	69	73	7	8	69	73	9	8	100	0.115
33	B6B03	98	72	76	9	8	77	74	9	8.5	110	0.13
34	B6B04	99	72	76	8	9	72	76	8	8	105	0.12
35	B6B05	100	71	75	8	8	70	75	7	8	100	0.115
36	B6B06	97	71	74	7	8	69	73	7	8	100	0.11
37	B6B07	98.5	68	72	7.5	7.5	68	72	7	7	100	0.11
38	B6B08	99	74	74	7.5	7.5	72	74	8	8	112.5	0.13
39	B6B09	103	71	73	7	7.5	71	73	7	8	110	0.12
40	B6B10	103	71	73	7	7.5	69	73	7	7	95	0.115
41	B6M01	100	64.5	64.5	7.5	7.5	66.5	65.5	8.5	7.5	105	0.11
42	B6M02	98	72	66	6	7	66.5	72.5	7	6	95	0.1
43	B6M03	98	64	71.5	6.5	6	65	72	7	6.5	95	0.095
44	B6M04	98	65	70	6.5	6	64	71	6.5	6	95	0.095
45	B6M05	98.5	68	62	6.5	6	68.5	62.5	6.5	6	92.5	0.095
46	B6M06	102	67	70	6.5	6	68.5	70	6.5	6	95	0.115
47	B6M07	98.5	68	70	6.5	6	67	71	6.5	6	70	0.105
48	B6M08	98.5	65.5	70	6	6.5	69	67	6.5	6	97.5	0.1
49	B6M09	98.5	65.5	69	6	6.5	64	68.5	6	6	80	0.09
50	B6M10	98	63	67	6	6.5	68	63.5	6.5	6	95	0.09
51	B6T01	98.5	65.5	69	6	6.5	64	68.5	6	6	95	0.1
52	B6T02	98	63	67	6	6	68	63.5	6.5	6	95	0.09
53	B6T03	98	63	67	6	6	68	63.5	6.5	6	85	0.09
54	B6T04	97	64	62	6.5	6.5	63.5	61	6	6	90	0.08
55	B6T05	100	64	62	6.5	6	64	61	6	6	85	0.08
56	B6T06	102	68	62	6.5	6.5	67	63	6.5	6.5	100	0.1
57	B6T07	99	62	67	6.5	6	68	60	6.5	6	85	0.09
58	B6T08	98	64	62	6	6.5	63.5	61	6	6	95	0.085
59	B6T09	97	64	62	6	5.5	63.5	61	6	6	80	0.08
60	B6T10	100	64	62	5.5	5.5	64	61	5.5	6	80	0.075

Table A2: Before and after measurement oven dry mass of eucalyptus

No	Sample code No	BEFORE OVEN DRY						Force (KN)	After oven dry Mass (Kg)
		Mass (Kg)	Length (mm)	BOTTOM Diameter		TOP Diameter			
				D1	D2	D1	D2		
1	E5B01	0.13	102	67	56	56.5	62	97.5	0.115
2	E5B02	0.125	99.5	57	65	63	56.5	100	0.11
3	E5B03	0.12	103	63.5	56.5	63.5	56	95	0.105
4	E5B04	0.12	102	63	56	55	64.5	100	0.105
5	E5B05	0.115	98.5	62.5	57	56.5	62.5	95	0.105
6	E5B06	0.115	99	57	62	57	64	90	0.105

7	E5B07	0.12	102.5	63	57	56.5	62	90	0.105
8	E5B08	0.115	100	62	56	61	59	95	0.105
9	E5B09	0.115	101	60	56	64	56	95	0.105
10	E5B10	0.11	100.5	61	56	55	62	95	0.1
11	E5M01	0.105	102	52	54	57.5	51	85	0.09
12	E5M02	0.1	99	50	57	57.5	53.5	85	0.085
13	E5M03	0.1	99	57	53	58	52	82.5	0.09
14	E5M04	0.105	101	57	51.5	57	51	95	0.085
15	E5M05	0.1	99	58	53	52	57	90	0.085
16	E5M06	0.105	100.5	52.5	57	52.5	56.5	95	0.09
17	E5M07	0.105	99	52.5	59	57	54	85	0.09
18	E5M08	0.105	100	52	58	52	60	90	0.095
19	E5M09	0.105	98	52.5	59	54	59	90	0.09
20	E5M10	0.11	101	60	53	61	53	95	0.095
21	E5T01	0.09	103	55	45	47	54	80	0.08
22	E5T02	0.09	98	48	53	48	53	80	0.08
23	E5T03	0.09	100.5	54	47	49	52	80	0.08
24	E5T04	0.09	97	49	55	48	55	80	0.08
25	E5T05	0.09	100	49.5	54.5	50	51.5	80	0.08
26	E5T06	0.095	100	50	49	50	55	80	0.085
27	E5T07	0.095	98	49	53	50	53	75	0.085
28	E5T08	0.095	103	49	55	50	54	90	0.085
29	E5T09	0.095	99.5	50	57	50	57	80	0.085
30	E5T10	0.09	99	57	49	49.5	55	80	0.08
31	E6B01	0.12	100	55.5	61	61	62	90	0.105
32	E6B02	0.12	98	58	57	64	61	95	0.1
33	E6B03	0.12	102	64	58	63	56	95	0.095
34	E6B04	0.12	100	64	59	64	58	95	0.1
35	E6B05	0.12	99	64	57	63	55	95	0.095
36	E6B06	0.12	100	57	63	63.5	55	92.5	0.1
37	E6B07	0.115	100	55.5	62	55	63	90	0.09
38	E6B08	0.115	101	55.5	58	59	58	90	0.1
39	E6B09	0.115	100	55.5	62	55	63	90	0.09
40	E6B10	0.115	101	55.5	58	59	58	90	0.1
41	E6M01	0.095	103	51.5	56.5	54	56	85	0.085
42	E6M02	0.1	98.5	56	51.5	56	55	85	0.09
43	E6M03	0.095	100.5	55.5	53	54	58	85	0.085
44	E6M04	0.095	98.5	58	54.5	54.5	55	85	0.085
45	E6M05	0.1	100	59	56.5	59	54	85	0.09
46	E6M06	0.1	99.5	54	58.5	55	54	80	0.09
47	E6M07	0.1	98	59	56.5	59	54.5	85	0.09
48	E6M08	0.115	100.5	57	55	57	54.5	85	0.09
49	E6M09	0.1	98	59	56.5	59	54.5	85	0.09

50	E6M10	0.115	100.5	57	55	57	54.5	85	0.09
51	E6T01	0.095	102	57	51	50.5	55	90	0.085
52	E6T02	0.09	99	51	56.5	56	49.5	70	0.08
53	E6T03	0.09	100	50	53	51	57	80	0.08
54	E6T04	0.09	99.5	52	50	49.5	54.5	85	0.08
55	E6T05	0.09	101.5	54	51	54.5	50	85	0.075
56	E6T06	0.085	100	48.5	54	55	51	85	0.075
57	E6T07	0.085	100	53.5	50	51	51	80	0.075
58	E6T08	0.09	100.5	52	50	50	51	85	0.08
59	E6T09	0.085	97	50	53	51	49.5	80	0.075
60	E6T10	0.085	102	47	51	51.5	49.5	75	0.075

Table A3: dry density Test Output of Bamboo culm

No	Sample code No	Length (mm)	Average External diameter (mm)	Average wall thickness (mm)	Area (mm2)	Volume (mm3)	Oven dry mass (Kg)	Density (Kg/m3)
		L	Dext	t	A	Vg	mo	ρ
1	B5B01	95	68.13	7.88	1,490.59	141,605.82	0.085	600.26
2	B5B02	99	65.63	7.88	1,428.74	141,445.01	0.09	636.29
3	B5B03	99	65.25	7.88	1,419.46	140,526.53	0.085	604.87
4	B5B04	101	67.00	8.50	1,562.16	157,777.85	0.09	570.42
5	B5B05	97	65.88	7.75	1,415.19	137,273.36	0.085	619.20
6	B5B06	98	65.63	7.38	1,349.61	132,261.64	0.08	604.86
7	B5B07	100.5	65.13	7.75	1,396.93	140,391.35	0.085	605.45
8	B5B08	100	64.50	7.63	1,362.42	136,242.04	0.085	623.89
9	B5B09	101.5	65.25	7.75	1,399.97	142,097.18	0.085	598.18
10	B5B10	97	65.13	6.88	1,258.11	122,036.64	0.075	614.57
11	B5M01	101.5	60.13	6.63	1,113.50	113,020.07	0.065	575.12
12	B5M02	100	60.25	6.63	1,116.10	111,609.99	0.065	582.39
13	B5M03	95	61.25	6.63	1,136.91	108,006.73	0.065	601.81
14	B5M04	96.5	61.13	6.63	1,134.31	109,461.04	0.07	639.50
15	B5M05	99	63.00	6.25	1,114.28	110,314.08	0.07	634.55
16	B5M06	99	61.75	6.25	1,089.74	107,884.26	0.07	648.84
17	B5M07	97	62.25	6.25	1,099.56	106,657.07	0.07	656.31
18	B5M08	99	62.25	6.25	1,099.56	108,856.19	0.07	643.05
19	B5M09	101	62.75	6.25	1,109.37	112,046.87	0.08	713.99
20	B5T01	100	59.50	5.88	989.75	98,974.89	0.065	656.73
21	B5T02	97	59.25	5.75	966.43	93,743.95	0.06	640.04
22	B5T03	98	58.50	5.50	915.77	89,745.88	0.06	668.55
23	B5T04	96	58.00	5.25	870.02	83,522.38	0.06	718.37

24	B5T05	98.5	56.50	5.25	845.28	83,260.55	0.06	720.63
25	B5T06	98	57.50	5.25	861.78	84,454.26	0.07	828.85
26	B5T07	99.5	57.25	5.38	875.96	87,158.46	0.065	745.77
27	B5T08	97.5	57.13	5.25	855.59	83,420.33	0.06	719.25
28	B5T09	97	56.75	5.25	849.41	82,392.59	0.055	667.54
29	B5T10	97.5	55.88	4.88	781.08	76,155.15	0.055	722.21
30	B5T11	101.5	54.75	5.00	781.47	79,319.32	0.06	756.44
31	B6B01	97.5	71.50	7.38	1,485.73	144,858.47	0.115	793.88
32	B6B02	99	71.00	8.00	1,583.36	156,752.91	0.115	733.64
33	B6B03	98	74.75	8.63	1,791.74	175,590.39	0.13	740.36
34	B6B04	99	74.00	8.25	1,704.12	168,707.65	0.12	711.29
35	B6B05	100	72.75	7.75	1,582.58	158,257.73	0.115	726.66
36	B6B06	97	71.75	7.50	1,513.85	146,843.93	0.11	749.09
37	B6B07	98.5	70.00	7.25	1,429.23	140,778.99	0.11	781.37
38	B6B08	99	73.50	7.75	1,600.84	158,482.94	0.13	820.28
39	B6B09	103	72.00	7.38	1,497.31	154,223.19	0.12	778.09
40	B6B10	103	71.50	7.13	1,440.96	148,418.90	0.115	774.83
41	B6M01	100	65.25	7.75	1,399.97	139,997.22	0.11	785.73
42	B6M02	98	69.25	6.50	1,281.38	125,574.96	0.1	796.34
43	B6M03	98	68.13	6.50	1,258.40	123,323.61	0.095	770.33
44	B6M04	98	67.50	6.25	1,202.64	117,858.81	0.095	806.05
45	B6M05	98.5	65.25	6.25	1,158.46	114,108.54	0.095	832.54
46	B6M06	102	68.88	6.25	1,229.64	125,423.18	0.115	916.90
47	B6M07	98.5	69.00	6.25	1,232.09	121,361.20	0.105	865.19
48	B6M08	98.5	67.88	6.25	1,210.00	119,185.40	0.1	839.03
49	B6M09	98.5	66.75	6.13	1,166.56	114,906.33	0.09	783.25
50	B6M10	98	65.38	6.25	1,160.92	113,769.83	0.09	791.07
51	B6T01	98.5	66.75	6.13	1,166.56	114,906.33	0.1	870.27
52	B6T02	98	65.38	6.13	1,140.10	111,730.15	0.09	805.51
53	B6T03	98	65.38	6.13	1,140.10	111,730.15	0.09	805.51
54	B6T04	97	62.63	6.25	1,106.92	107,371.29	0.08	745.08
55	B6T05	100	62.75	6.13	1,089.59	108,959.27	0.08	734.22
56	B6T06	102	65.00	6.50	1,194.59	121,848.24	0.1	820.69
57	B6T07	99	64.25	6.25	1,138.83	112,743.91	0.09	798.27
58	B6T08	98	62.63	6.13	1,087.19	106,544.37	0.085	797.79
59	B6T09	97	62.63	5.88	1,047.43	101,600.38	0.08	787.40
60	B6T10	100	62.75	5.63	1,009.48	100,948.21	0.075	742.96

Table A4: dry density Test Output of Eucalyptus culm

No	Sample code No	Average External diameter (mm)	Area (mm2)	Volume (mm3)	Oven dry mass (Kg)	Density (Kg/m3)
		D ext	A	Vg	mo	ρ
1	E5B01	60.38	2,862.89	292,014.45	0.115	393.82
2	E5B02	60.38	2,862.89	284,857.23	0.11	386.16
3	E5B03	59.88	2,815.66	290,013.46	0.105	362.05
4	E5B04	59.63	2,792.20	284,804.49	0.105	368.67
5	E5B05	59.63	2,792.20	275,031.79	0.105	381.77
6	E5B06	60.00	2,827.43	279,915.91	0.105	375.11
7	E5B07	59.63	2,792.20	286,200.59	0.105	366.88
8	E5B08	59.50	2,780.51	278,050.58	0.105	377.63
9	E5B09	59.00	2,733.97	276,131.07	0.105	380.25
10	E5B10	58.50	2,687.83	270,126.80	0.1	370.20
11	E5M01	53.63	2,258.52	230,369.33	0.09	390.68
12	E5M02	54.50	2,332.83	230,950.06	0.085	368.04
13	E5M03	55.00	2,375.83	235,207.11	0.09	382.64
14	E5M04	54.13	2,300.84	232,384.46	0.085	365.77
15	E5M05	55.00	2,375.83	235,207.11	0.085	361.38
16	E5M06	54.63	2,343.54	235,525.99	0.09	382.12
17	E5M07	55.63	2,430.13	240,583.10	0.09	374.09
18	E5M08	55.50	2,419.22	241,922.27	0.095	392.69
19	E5M09	56.13	2,474.02	242,453.62	0.09	371.21
20	E5M10	56.75	2,529.42	255,471.81	0.095	371.86
21	E5T01	50.25	1,983.18	204,267.48	0.08	391.64
22	E5T02	50.50	2,002.96	196,290.24	0.08	407.56
23	E5T03	50.50	2,002.96	201,297.65	0.08	397.42
24	E5T04	51.75	2,103.35	204,024.50	0.08	392.11
25	E5T05	51.38	2,072.97	207,297.25	0.08	385.92
26	E5T06	51.00	2,042.82	204,282.06	0.085	416.09
27	E5T07	51.25	2,062.90	202,163.94	0.085	420.45
28	E5T08	52.00	2,123.72	218,742.81	0.085	388.58
29	E5T09	53.50	2,248.01	223,676.59	0.085	380.01
30	E5T10	52.63	2,175.07	215,332.36	0.08	371.52
31	E6B01	59.88	2,815.66	281,566.47	0.105	372.91
32	E6B02	60.00	2,827.43	277,088.47	0.1	360.90
33	E6B03	60.25	2,851.04	290,806.53	0.095	326.68
34	E6B04	61.25	2,946.47	294,647.03	0.1	339.39
35	E6B05	59.75	2,803.92	277,588.13	0.095	342.23

36	E6B06	59.63	2,792.20	279,220.09	0.1	358.14
37	E6B07	58.88	2,722.40	272,239.87	0.09	330.59
38	E6B08	57.63	2,608.03	263,410.53	0.1	379.64
39	E6B09	58.88	2,722.40	272,239.87	0.09	330.59
40	E6B10	57.63	2,608.03	263,410.53	0.1	379.64
41	E6M01	54.50	2,332.83	240,281.38	0.085	353.75
42	E6M02	54.63	2,343.54	230,838.91	0.09	389.88
43	E6M03	55.13	2,386.64	239,857.41	0.085	354.38
44	E6M04	55.50	2,419.22	238,293.44	0.085	356.70
45	E6M05	57.13	2,562.96	256,296.28	0.09	351.16
46	E6M06	55.38	2,408.34	239,629.59	0.09	375.58
47	E6M07	57.25	2,574.19	252,270.77	0.09	356.76
48	E6M08	55.88	2,452.03	246,428.55	0.09	365.22
49	E6M09	57.25	2,574.19	252,270.77	0.09	356.76
50	E6M10	55.88	2,452.03	246,428.55	0.09	365.22
51	E6T01	53.38	2,237.51	228,226.37	0.085	372.44
52	E6T02	53.25	2,227.05	220,477.51	0.08	362.85
53	E6T03	52.75	2,185.42	218,541.95	0.08	366.06
54	E6T04	51.50	2,083.07	207,265.69	0.08	385.98
55	E6T05	52.38	2,154.46	218,677.45	0.075	342.97
56	E6T06	52.13	2,133.94	213,393.91	0.075	351.46
57	E6T07	51.38	2,072.97	207,297.25	0.075	361.80
58	E6T08	50.75	2,022.84	203,295.63	0.08	393.52
59	E6T09	50.88	2,032.82	197,183.45	0.075	380.36
60	E6T10	49.75	1,943.91	198,278.77	0.075	378.26

Table A5: Moisture Content Output of Bamboo culm

No	Sample code No	Initial mass (Kg)	Oven dry mass (Kg)	Moisture content (%)
		mi	mo	m.c
1	B5B01	0.1	0.085	17.65
2	B5B02	0.1	0.09	11.11
3	B5B03	0.1	0.085	17.65
4	B5B04	0.105	0.09	16.67
5	B5B05	0.095	0.085	11.76
6	B5B06	0.095	0.08	18.75
7	B5B07	0.095	0.085	11.76
8	B5B08	0.1	0.085	17.65

9	B5B09	0.095	0.085	11.76
10	B5B10	0.085	0.075	13.33
11	B5M01	0.075	0.065	15.38
12	B5M02	0.075	0.065	15.38
13	B5M03	0.075	0.065	15.38
14	B5M04	0.08	0.07	14.29
15	B5M05	0.08	0.07	14.29
16	B5M06	0.075	0.07	7.14
17	B5M07	0.08	0.07	14.29
18	B5M08	0.08	0.07	14.29
19	B5M09	0.09	0.08	12.50
20	B5T01	0.075	0.065	15.38
21	B5T02	0.07	0.06	16.67
22	B5T03	0.07	0.06	16.67
23	B5T04	0.065	0.06	8.33
24	B5T05	0.07	0.06	16.67
25	B5T06	0.08	0.07	14.29
26	B5T07	0.07	0.065	7.69
27	B5T08	0.065	0.06	8.33
28	B5T09	0.065	0.055	18.18
29	B5T10	0.065	0.055	18.18
30	B5T11	0.065	0.06	8.33
31	B6B01	0.13	0.115	13.04
32	B6B02	0.13	0.115	13.04
33	B6B03	0.145	0.13	11.54
34	B6B04	0.135	0.12	12.50
35	B6B05	0.13	0.115	13.04
36	B6B06	0.12	0.11	9.09
37	B6B07	0.12	0.11	9.09
38	B6B08	0.15	0.13	15.38
39	B6B09	0.135	0.12	12.50
40	B6B10	0.13	0.115	13.04
41	B6M01	0.125	0.11	13.64
42	B6M02	0.115	0.1	15.00
43	B6M03	0.11	0.095	15.79
44	B6M04	0.105	0.095	10.53
45	B6M05	0.105	0.095	10.53
46	B6M06	0.13	0.115	13.04
47	B6M07	0.115	0.105	9.52
48	B6M08	0.11	0.1	10.00
49	B6M09	0.105	0.09	16.67
50	B6M10	0.1	0.09	11.11

51	B6T01	0.11	0.1	10.00
52	B6T02	0.1	0.09	11.11
53	B6T03	0.1	0.09	11.11
54	B6T04	0.095	0.08	18.75
55	B6T05	0.095	0.08	18.75
56	B6T06	0.115	0.1	15.00
57	B6T07	0.1	0.09	11.11
58	B6T08	0.095	0.085	11.76
59	B6T09	0.09	0.08	12.50
60	B6T10	0.085	0.075	13.33

Table A6: Moisture Content Output of Eucalyptus culm

No	Sample code No	Initial mass (Kg)	Oven dry mass (Kg)	Moisture content (%)
		mi	mo	m.c
1	B5B01	0.1	0.085	17.65
2	B5B02	0.1	0.09	11.11
3	B5B03	0.1	0.085	17.65
4	B5B04	0.105	0.09	16.67
5	B5B05	0.095	0.085	11.76
6	B5B06	0.095	0.08	18.75
7	B5B07	0.095	0.085	11.76
8	B5B08	0.1	0.085	17.65
9	B5B09	0.095	0.085	11.76
10	B5B10	0.085	0.075	13.33
11	B5M01	0.075	0.065	15.38
12	B5M02	0.075	0.065	15.38
13	B5M03	0.075	0.065	15.38
14	B5M04	0.08	0.07	14.29
15	B5M05	0.08	0.07	14.29
16	B5M06	0.075	0.07	7.14
17	B5M07	0.08	0.07	14.29
18	B5M08	0.08	0.07	14.29
19	B5M09	0.09	0.08	12.50
20	B5T01	0.075	0.065	15.38
21	B5T02	0.07	0.06	16.67
22	B5T03	0.07	0.06	16.67
23	B5T04	0.065	0.06	8.33

24	B5T05	0.07	0.06	16.67
25	B5T06	0.08	0.07	14.29
26	B5T07	0.07	0.065	7.69
27	B5T08	0.065	0.06	8.33
28	B5T09	0.065	0.055	18.18
29	B5T10	0.065	0.055	18.18
30	B5T11	0.065	0.06	8.33
31	B6B01	0.13	0.115	13.04
32	B6B02	0.13	0.115	13.04
33	B6B03	0.145	0.13	11.54
34	B6B04	0.135	0.12	12.50
35	B6B05	0.13	0.115	13.04
36	B6B06	0.12	0.11	9.09
37	B6B07	0.12	0.11	9.09
38	B6B08	0.15	0.13	15.38
39	B6B09	0.135	0.12	12.50
40	B6B10	0.13	0.115	13.04
41	B6M01	0.125	0.11	13.64
42	B6M02	0.115	0.1	15.00
43	B6M03	0.11	0.095	15.79
44	B6M04	0.105	0.095	10.53
45	B6M05	0.105	0.095	10.53
46	B6M06	0.13	0.115	13.04
47	B6M07	0.115	0.105	9.52
48	B6M08	0.11	0.1	10.00
49	B6M09	0.105	0.09	16.67
50	B6M10	0.1	0.09	11.11
51	B6T01	0.11	0.1	10.00
52	B6T02	0.1	0.09	11.11
53	B6T03	0.1	0.09	11.11
54	B6T04	0.095	0.08	18.75
55	B6T05	0.095	0.08	18.75
56	B6T06	0.115	0.1	15.00
57	B6T07	0.1	0.09	11.11
58	B6T08	0.095	0.085	11.76
59	B6T09	0.09	0.08	12.50
60	B6T10	0.085	0.075	13.33

Table A7: Compressive force Test Output of Bamboo culm

No	Sample code No	Average External diameter (mm)	Average wall thickness (mm)	Area (mm2)	Force (KN)	Compressive strength (N/mm2)
		D ext	t	A	p	fc,ult
1	B5B01	68.13	7.88	1,490.59	80	53.67
2	B5B02	65.63	7.88	1,428.74	95	66.49
3	B5B03	65.25	7.88	1,419.46	90	63.40
4	B5B04	67.00	8.50	1,562.16	85	54.41
5	B5B05	65.88	7.75	1,415.19	82.5	58.30
6	B5B06	65.63	7.38	1,349.61	95	70.39
7	B5B07	65.13	7.75	1,396.93	85	60.85
8	B5B08	64.50	7.63	1,362.42	95	69.73
9	B5B09	65.25	7.75	1,399.97	95	67.86
10	B5B10	65.13	6.88	1,258.11	85	67.56
11	B5M01	60.13	6.63	1,113.50	60	53.88
12	B5M02	60.25	6.63	1,116.10	70	62.72
13	B5M03	61.25	6.63	1,136.91	75	65.97
14	B5M04	61.13	6.63	1,134.31	80	70.53
15	B5M05	63.00	6.25	1,114.28	85	76.28
16	B5M06	61.75	6.25	1,089.74	80	73.41
17	B5M07	62.25	6.25	1,099.56	80	72.76
18	B5M08	62.25	6.25	1,099.56	85	77.30
19	B5M09	62.75	6.25	1,109.37	90	81.13
20	B5T01	59.50	5.88	989.75	80	80.83
21	B5T02	59.25	5.75	966.43	75	77.61
22	B5T03	58.50	5.50	915.77	75	81.90
23	B5T04	58.00	5.25	870.02	75	86.20
24	B5T05	56.50	5.25	845.28	75	88.73
25	B5T06	57.50	5.25	861.78	72.5	84.13
26	B5T07	57.25	5.38	875.96	70	79.91
27	B5T08	57.13	5.25	855.59	70	81.81
28	B5T09	56.75	5.25	849.41	65	76.52
29	B5T10	55.88	4.88	781.08	67.5	86.42
30	B5T11	54.75	5.00	781.47	65	83.18
31	B6B01	71.50	7.38	1,485.73	70	47.11
32	B6B02	71.00	8.00	1,583.36	100	63.16
33	B6B03	74.75	8.63	1,791.74	110	61.39
34	B6B04	74.00	8.25	1,704.12	105	61.62
35	B6B05	72.75	7.75	1,582.58	100	63.19

36	B6B06	71.75	7.50	1,513.85	100	66.06
37	B6B07	70.00	7.25	1,429.23	100	69.97
38	B6B08	73.50	7.75	1,600.84	112.5	70.28
39	B6B09	72.00	7.38	1,497.31	110	73.46
40	B6B10	71.50	7.13	1,440.96	95	65.93
41	B6M01	65.25	7.75	1,399.97	105	75.00
42	B6M02	69.25	6.50	1,281.38	95	74.14
43	B6M03	68.13	6.50	1,258.40	95	75.49
44	B6M04	67.50	6.25	1,202.64	95	78.99
45	B6M05	65.25	6.25	1,158.46	92.5	79.85
46	B6M06	68.88	6.25	1,229.64	95	77.26
47	B6M07	69.00	6.25	1,232.09	70	56.81
48	B6M08	67.88	6.25	1,210.00	97.5	80.58
49	B6M09	66.75	6.13	1,166.56	80	68.58
50	B6M10	65.38	6.25	1,160.92	95	81.83
51	B6T01	66.75	6.13	1,166.56	95	81.44
52	B6T02	65.38	6.13	1,140.10	95	83.33
53	B6T03	65.38	6.13	1,140.10	85	74.55
54	B6T04	62.63	6.25	1,106.92	90	81.31
55	B6T05	62.75	6.13	1,089.59	85	78.01
56	B6T06	65.00	6.50	1,194.59	100	83.71
57	B6T07	64.25	6.25	1,138.83	85	74.64
58	B6T08	62.63	6.13	1,087.19	95	87.38
59	B6T09	62.63	5.88	1,047.43	80	76.38
60	B6T10	62.75	5.63	1,009.48	80	79.25

Table A8: Compressive force Test Output of Eucalyptus culm

No	Sample code No	Average External diameter (mm)	Area (mm2)	Force (KN)	Compressive strength (N/mm2)
		D_{ext}	A	p	fc,ult
1	E5B01	60.38	2,862.89	97.5	34.06
2	E5B02	60.38	2,862.89	100	34.93
3	E5B03	59.88	2,815.66	95	33.74
4	E5B04	59.63	2,792.20	100	35.81
5	E5B05	59.63	2,792.20	95	34.02
6	E5B06	60.00	2,827.43	90	31.83
7	E5B07	59.63	2,792.20	90	32.23
8	E5B08	59.50	2,780.51	95	34.17

9	E5B09	59.00	2,733.97	95	34.75
10	E5B10	58.50	2,687.83	95	35.34
11	E5M01	53.63	2,258.52	85	37.64
12	E5M02	54.50	2,332.83	85	36.44
13	E5M03	55.00	2,375.83	82.5	34.72
14	E5M04	54.13	2,300.84	95	41.29
15	E5M05	55.00	2,375.83	90	37.88
16	E5M06	54.63	2,343.54	95	40.54
17	E5M07	55.63	2,430.13	85	34.98
18	E5M08	55.50	2,419.22	90	37.20
19	E5M09	56.13	2,474.02	90	36.38
20	E5M10	56.75	2,529.42	95	37.56
21	E5T01	50.25	1,983.18	80	40.34
22	E5T02	50.50	2,002.96	80	39.94
23	E5T03	50.50	2,002.96	80	39.94
24	E5T04	51.75	2,103.35	80	38.03
25	E5T05	51.38	2,072.97	80	38.59
26	E5T06	51.00	2,042.82	80	39.16
27	E5T07	51.25	2,062.90	75	36.36
28	E5T08	52.00	2,123.72	90	42.38
29	E5T09	53.50	2,248.01	80	35.59
30	E5T10	52.63	2,175.07	80	36.78
31	E6B01	59.88	2,815.66	90	31.96
32	E6B02	60.00	2,827.43	95	33.60
33	E6B03	60.25	2,851.04	95	33.32
34	E6B04	61.25	2,946.47	95	32.24
35	E6B05	59.75	2,803.92	95	33.88
36	E6B06	59.63	2,792.20	92.5	33.13
37	E6B07	58.88	2,722.40	90	33.06
38	E6B08	57.63	2,608.03	90	34.51
39	E6B09	58.88	2,722.40	90	33.06
40	E6B10	57.63	2,608.03	90	34.51
41	E6M01	54.50	2,332.83	85	36.44
42	E6M02	54.63	2,343.54	85	36.27
43	E6M03	55.13	2,386.64	85	35.61
44	E6M04	55.50	2,419.22	85	35.14
45	E6M05	57.13	2,562.96	85	33.16
46	E6M06	55.38	2,408.34	80	33.22
47	E6M07	57.25	2,574.19	85	33.02
48	E6M08	55.88	2,452.03	85	34.67
49	E6M09	57.25	2,574.19	85	33.02
50	E6M10	55.88	2,452.03	85	34.67

51	E6T01	53.38	2,237.51	90	40.22
52	E6T02	53.25	2,227.05	70	31.43
53	E6T03	52.75	2,185.42	80	36.61
54	E6T04	51.50	2,083.07	85	40.81
55	E6T05	52.38	2,154.46	85	39.45
56	E6T06	52.13	2,133.94	85	39.83
57	E6T07	51.38	2,072.97	80	38.59
58	E6T08	50.75	2,022.84	85	42.02
59	E6T09	50.88	2,032.82	80	39.35
60	E6T10	49.75	1,943.91	75	38.58

Table A9: Bending strength and modules of elasticity Test Output of bamboo culm

Test result of Bamboo member								
No	Sample code No	Clear span	Average External diameter (mm)	Max. Force	slope	Moment of Inertia	Bending strength	Modules of elasticity
		L (mm)	D (mm)	P (KN)	s(%)	I(mm4)	fb(N/mm2)	E(N/mm2)
1	B1B	450	70.09	3.467	0.5829	7.87E+05	11.58	1,198.07
2	B1M	450	70.27	4.207	0.3867	8.10E+05	13.69	772.11
3	B1T	450	62.27	2.708	0.3953	4.46E+05	14.17	1,432.36
4	B2B	450	61.99	2.55	0.558	5.35E+05	11.08	1,687.39
5	B2M	450	71.08	3.54	0.9468	8.49E+05	11.11	1,802.48
6	B2T	450	57.04	1.86	0.3065	3.11E+05	12.79	1,593.37
7	B3B	450	74.40	6.901	1.3251	9.87E+05	19.52	2,172.02
8	B3M	450	74.10	4.645	0.6263	9.69E+05	13.32	1,044.86
9	B3T	450	55.80	1.594	0.2946	2.87E+05	11.63	1,661.45
10	B4B	450	60.01	2.273	0.3322	3.97E+05	12.88	1,353.37
11	B4M	450	57.04	1.849	0.4073	3.11E+05	12.71	2,117.39
12	B4T	450	62.32	2.756	0.4843	4.47E+05	14.39	1,750.19
Maximum Value			74.40	6.90	1.33	9.87E+05	19.52	2,172.02
Minimum Value			55.80	1.59	0.29	2.87E+05	11.08	772.11
Mean			64.70	**3.20**	**0.55**	**5.95E+05**	**13.24**	**1,548.76**

Table A10: Bending strength and modules of elasticity Test Output of eucalyptus culm

Eucalyptus Test Result								
No	Sample code No	Clear span	Average External diameter (mm)	Maximum Force	slope	Moment of Inertia	Bending strength	Modules of elasticity
		L (mm)	D (mm)	P (KN)	s(%)	I(mm4)	fb(N/mm2)	E(N/mm2)
1	E1B	450	58.67	13.541	0.5897	5.82E+05	51.22	1,082.72
2	E1M	450	58.35	21.324	0.6791	5.69E+05	82.00	1,274.44
3	E1T	450	54.53	11.063	0.5897	4.34E+05	52.14	1,451.43
4	E2B	450	58.51	19.654	0.6488	5.75E+05	74.98	1,204.72
5	E2M	450	61.54	15.096	0.6073	7.04E+05	49.49	921.43
6	E2T	450	51.03	12.758	0.5218	3.33E+05	73.34	1,673.98
7	E3B	450	56.20	12.733	0.6128	4.90E+05	54.81	1,336.83
8	E3M	450	50.53	9.401	0.5	3.20E+05	55.67	1,668.48
9	E3T	450	48.93	11.614	0.5144	2.81E+05	75.74	1,952.31
10	E4B	450	58.01	16.291	0.7102	5.56E+05	63.77	1,364.80
11	E4M	450	53.26	11.698	0.5071	3.95E+05	59.15	1,371.00
12	E4T	450	46.57	10.885	0.5035	2.31E+05	82.33	2,328.75
Maximum Value			61.54	21.32	0.71	7.04E+05	82.33	2,328.75
Minimum Value			46.57	9.40	0.50	2.31E+05	49.49	921.43
Mean			54.68	**13.84**	**0.58**	**4.56E+05**	**64.55**	**1,469.24**

Appendix B

Force verses deflection output sample of bamboo and eucalyptus material from Electro mechanical machine as shown below

Table B1: Bamboo culm output sample

Test Date 2022/7/2
Operator SHIFERAW
Lo (mm) 450
Sample ID BB1
Fail Load (kN)3.47
Comp. Str.(MPa) 10.91
Fsc (kN) /
Rsc (MPa) /
Fpc (kN) 2.51
Rpc (MPa) 8
Ftc (kN) /
Rtc (MPa) /
YM (GPa) 0.13
-----------Curve----------

Time	Load	Elong	Disp	Stress	Strain	Width	
0	0.001	0.00070		-0.004	0.002	0.001	0.000
0	0.000	0.00070		-0.004	0.000	0.001	0.000
.001	0.001	0.00080		-0.005	0.002	0.002	0.000
.002	0.001	0.00100		-0.005	0.002	0.002	0.000
.003	0.001	0.00120		-0.005	0.002	0.002	0.000
.005	0.002	0.00150		-0.005	0.005	0.003	0.000
.006	0.002	0.00170		-0.005	0.005	0.003	0.000
.007	0.001	0.00180		-0.006	0.002	0.004	0.000
.008	0.002	0.00200		-0.006	0.005	0.004	0.000
.009	0.002	0.00220		-0.006	0.005	0.004	0.000
.01	0.002	0.00240		-0.006	0.007	0.005	0.000
.01	0.002	0.00240		-0.006	0.007	0.005	0.000
.011	0.003	0.00250		-0.007	0.009	0.005	0.000
.012	0.002	0.00270		-0.007	0.005	0.005	0.000
.014	0.002	0.00300		-0.007	0.007	0.006	0.000
.015	0.002	0.00320		-0.007	0.007	0.006	0.000
.016	0.002	0.00340		-0.007	0.007	0.007	0.000
.017	0.003	0.00360		-0.008	0.009	0.007	0.000
.018	0.002	0.00370		-0.008	0.005	0.007	0.000
.019	0.002	0.00390		-0.008	0.007	0.008	0.000
.02	0.002	0.00410		-0.008	0.007	0.008	0.000
.02	0.003	0.00410		-0.008	0.009	0.008	0.000
.021	0.002	0.00420		-0.009	0.007	0.008	0.000
.022	0.003	0.00440		-0.009	0.009	0.009	0.000
.024	0.004	0.00470		-0.009	0.012	0.009	0.000
.025	0.003	0.00490		-0.009	0.009	0.010	0.000
.026	0.004	0.00510		-0.009	0.012	0.010	0.000
.027	0.004	0.00530		-0.010	0.012	0.011	0.000
.028	0.004	0.00540		-0.010	0.012	0.011	0.000

.029	0.003	0.00560	-0.010	0.009	0.011	0.000
.029	0.004	0.00560	-0.010	0.012	0.011	0.000
.03	0.004	0.00580	-0.010	0.012	0.012	0.000
.031	0.004	0.00590	-0.011	0.014	0.012	0.000
.032	0.004	0.00610	-0.011	0.012	0.012	0.000
.034	0.004	0.00640	-0.011	0.012	0.013	0.000
.035	0.004	0.00660	-0.011	0.012	0.013	0.000
.036	0.005	0.00680	-0.011	0.016	0.014	0.000
.037	0.005	0.00700	-0.011	0.016	0.014	0.000
.038	0.005	0.00710	-0.012	0.016	0.014	0.000
.039	0.004	0.00730	-0.012	0.014	0.015	0.000
.039	0.006	0.00730	-0.012	0.019	0.015	0.000
.04	0.005	0.00750	-0.012	0.016	0.015	0.000
.041	0.006	0.00760	-0.012	0.019	0.015	0.000
.043	0.006	0.00800	-0.013	0.019	0.016	0.000
.044	0.005	0.00810	-0.013	0.016	0.016	0.000
.045	0.005	0.00830	-0.013	0.016	0.017	0.000
.046	0.005	0.00850	-0.013	0.016	0.017	0.000
.047	0.006	0.00870	-0.013	0.019	0.017	0.000
.048	0.006	0.00880	-0.013	0.019	0.018	0.000
.048	0.006	0.00880	-0.014	0.019	0.018	0.000
.049	0.007	0.00900	-0.014	0.021	0.018	0.000
.05	0.007	0.00920	-0.014	0.021	0.018	0.000
.051	0.005	0.00930	-0.014	0.016	0.019	0.000
.053	0.007	0.00970	-0.014	0.021	0.019	0.000
.054	0.007	0.00980	-0.014	0.023	0.020	0.000
.055	0.007	0.01000	-0.015	0.023	0.020	0.000
.056	0.006	0.01020	-0.015	0.019	0.020	0.000
.057	0.007	0.01030	-0.015	0.021	0.021	0.000
.058	0.007	0.01050	-0.015	0.023	0.021	0.000
.058	0.007	0.01050	-0.015	0.023	0.021	0.000
.059	0.007	0.01070	-0.015	0.021	0.021	0.000
.06	0.007	0.01090	-0.016	0.023	0.022	0.000
.062	0.007	0.01120	-0.016	0.023	0.022	0.000
.063	0.007	0.01140	-0.016	0.023	0.023	0.000
.064	0.007	0.01150	-0.016	0.023	0.023	0.000
.065	0.008	0.01170	-0.016	0.025	0.023	0.000
.066	0.008	0.01190	-0.016	0.025	0.024	0.000
.067	0.008	0.01200	-0.017	0.025	0.024	0.000
.068	0.008	0.01220	-0.017	0.025	0.024	0.000
.068	0.010	0.01220	-0.017	0.030	0.024	0.000
.069	0.008	0.01240	-0.017	0.025	0.025	0.000
.07	0.009	0.01250	-0.017	0.028	0.025	0.000
.072	0.010	0.01290	-0.017	0.032	0.026	0.000
.073	0.010	0.01310	-0.018	0.032	0.026	0.000
.074	0.009	0.01320	-0.018	0.028	0.026	0.000
.075	0.010	0.01340	-0.018	0.030	0.027	0.000

Table B2: Eucalyptus culm test output sample

Test Date	2022/7/2
Operator	SHIFERAW
Lo(mm)	450
Sample ID	EB1
Fail Load (kN)	13.54
Comp. Str.(MPa)	42.58
Fsc (kN)	/
Rsc (MPa)	/
Fpc (kN)	7.50
Rpc (MPa)	24
Ftc (kN)	/
Rtc (MPa)	/
YM (GPa)	0.12

-----------Curve----------

Time	Load	Elong	Disp	Stress	Strain	Width	
0	0.001	0.00670		-0.006	0.002	0.013	0.000
0	0.004	0.00670		-0.011	0.014	0.013	0.000
0	0.004	0.00670		-0.012	0.014	0.013	0.000
.002	0.004	0.00730		-0.012	0.014	0.015	0.000
.003	0.004	0.00770		-0.012	0.012	0.015	0.000
.004	0.006	0.00800		-0.013	0.019	0.016	0.000
.005	0.006	0.00830		-0.013	0.019	0.017	0.000
.005	0.005	0.00830		-0.014	0.016	0.017	0.000
.007	0.005	0.00900		-0.014	0.016	0.018	0.000
.007	0.006	0.00900		-0.014	0.019	0.018	0.000
.009	0.006	0.00970		-0.015	0.019	0.019	0.000
.009	0.005	0.00970		-0.015	0.016	0.019	0.000
.011	0.007	0.01040		-0.016	0.021	0.021	0.000
.012	0.005	0.01070		-0.016	0.016	0.021	0.000
.013	0.007	0.01100		-0.016	0.023	0.022	0.000
.014	0.007	0.01140		-0.017	0.023	0.023	0.000
.015	0.007	0.01170		-0.017	0.023	0.023	0.000
.016	0.008	0.01200		-0.017	0.025	0.024	0.000
.016	0.007	0.01200		-0.018	0.023	0.024	0.000
.018	0.008	0.01270		-0.018	0.025	0.025	0.000
.018	0.008	0.01270		-0.019	0.025	0.025	0.000
.02	0.008	0.01340		-0.019	0.025	0.027	0.000
.02	0.008	0.01340		-0.019	0.025	0.027	0.000
.022	0.009	0.01410		-0.020	0.028	0.028	0.000
.023	0.010	0.01440		-0.020	0.030	0.029	0.000
.024	0.009	0.01470		-0.020	0.028	0.029	0.000
.025	0.010	0.01510		-0.021	0.030	0.030	0.000
.025	0.010	0.01510		-0.021	0.032	0.030	0.000
.027	0.010	0.01570		-0.022	0.032	0.031	0.000
.027	0.010	0.01570		-0.022	0.032	0.031	0.000
.029	0.010	0.01640		-0.022	0.032	0.033	0.000
.029	0.011	0.01640		-0.023	0.035	0.033	0.000
.031	0.011	0.01710		-0.023	0.035	0.034	0.000
.032	0.012	0.01740		-0.023	0.037	0.035	0.000

.033	0.012	0.01770	-0.024	0.037	0.035	0.000
.034	0.012	0.01810	-0.024	0.037	0.036	0.000
.034	0.012	0.01810	-0.024	0.037	0.036	0.000
.036	0.013	0.01880	-0.025	0.039	0.038	0.000
.036	0.013	0.01880	-0.025	0.039	0.038	0.000
.038	0.013	0.01940	-0.026	0.039	0.039	0.000
.038	0.013	0.01940	-0.026	0.042	0.039	0.000
.04	0.013	0.02010	-0.026	0.042	0.040	0.000
.041	0.013	0.02040	-0.027	0.042	0.041	0.000
.042	0.014	0.02080	-0.027	0.044	0.042	0.000
.043	0.014	0.02110	-0.027	0.044	0.042	0.000
.044	0.014	0.02140	-0.028	0.044	0.043	0.000
.045	0.014	0.02180	-0.028	0.044	0.044	0.000
.045	0.015	0.02180	-0.028	0.046	0.044	0.000
.047	0.015	0.02240	-0.029	0.046	0.045	0.000
.047	0.014	0.02240	-0.029	0.044	0.045	0.000
.049	0.015	0.02310	-0.029	0.046	0.046	0.000
.049	0.015	0.02310	-0.030	0.049	0.046	0.000
.051	0.015	0.02380	-0.030	0.046	0.048	0.000
.052	0.015	0.02410	-0.030	0.049	0.048	0.000
.053	0.015	0.02450	-0.031	0.046	0.049	0.000
.054	0.015	0.02480	-0.031	0.049	0.050	0.000
.054	0.016	0.02480	-0.032	0.051	0.050	0.000
.056	0.015	0.02550	-0.032	0.049	0.051	0.000
.056	0.017	0.02550	-0.032	0.053	0.051	0.000
.058	0.017	0.02610	-0.033	0.053	0.052	0.000
.058	0.016	0.02610	-0.033	0.051	0.052	0.000
.06	0.017	0.02680	-0.033	0.053	0.054	0.000
.061	0.017	0.02710	-0.034	0.053	0.054	0.000
.062	0.016	0.02750	-0.034	0.051	0.055	0.000
.063	0.018	0.02780	-0.034	0.056	0.056	0.000
.063	0.018	0.02780	-0.035	0.056	0.056	0.000
.065	0.018	0.02850	-0.035	0.056	0.057	0.000
.065	0.016	0.02850	-0.035	0.051	0.057	0.000
.067	0.018	0.02920	-0.036	0.056	0.058	0.000
.067	0.018	0.02920	-0.036	0.058	0.058	0.000
.069	0.018	0.02980	-0.036	0.058	0.060	0.000
.07	0.018	0.03020	-0.037	0.056	0.060	0.000
.071	0.019	0.03050	-0.037	0.060	0.061	0.000
.072	0.018	0.03080	-0.037	0.058	0.062	0.000
.072	0.019	0.03080	-0.038	0.060	0.062	0.000
.074	0.019	0.03150	-0.038	0.060	0.063	0.000
.074	0.020	0.03150	-0.038	0.063	0.063	0.000
.076	0.020	0.03220	-0.038	0.063	0.064	0.000
.076	0.018	0.03220	-0.039	0.058	0.064	0.000
.078	0.019	0.03280	-0.039	0.060	0.066	0.000
.078	0.021	0.03280	-0.039	0.065	0.066	0.000
.08	0.020	0.03350	-0.040	0.063	0.067	0.000
.081	0.021	0.03380	-0.040	0.067	0.068	0.000
.082	0.021	0.03420	-0.040	0.067	0.068	0.000