*ISSN (E): 2959-3921*
*(P): 2959-393X*
**DOI:** *https://doi.org/10.59122/164CFC16*
*Ethiopian International Journal of Engineering and Technology (EIJET)*
*Volume 2, Issue 2, 2024*


# ANALYZING MECHANICAL PROPERTY AND THE CORRESPONDING POWER OUTPUT OF BAMBOO PLANT FOR THE CONSTRUCTION OF VERTICAL AXIS WIND TURBINE BLADE

Elias Alemu[1*] and Degnet Abose[2]

*[1, 2]Arba Minch Institute of Technology, Arba Minch University, Ethiopia*

**Corresponding Author's Email: eli_alemu@yahoo.com*

## Abstract

*Ethiopia has the largest bamboo plant coverage in Africa and has the third-largest wind power potential in Africa. These two factors inspired us to conduct this research. Use of Bamboo plant in Ethiopia is limited to a few common utilizations such as for furniture and civil construction. These applications resulted from less understanding of mechanical properties of the plant. Hence, this study aimed to determine the mechanical properties of bamboo, particularly tensile and fatigue strength. Mechanical properties were analyzed on lowland (Oxytenantheria abyssinica) and highland (Yushania alpina) untreated bamboo. Tensile test specimens were prepared from both species, and the test was conducted with calibrated universal testing machines (UTM). The expected outcome was to decide whether or not bamboo plant mechanical properties qualify for the construction of small-scale wind turbine blades. A total of 30 tensile specimens were prepared to conduct the test. Fatigue stress was calculated using the relationship between the tensile stress as various literatures revealed that fatigue strength equals 40 % to 60 % of the tensile stress. Experimental test output shows that lowland bamboo tensile strength is 178.1 Mpa while the corresponding fatigue strength is 71.24 Mpa. For highland bamboo, the tensile and the fatigue stresses are 122 Mpa and 48.8 Mpa respectively. This result confirmed that lowland bamboo has better strength compared to highland bamboo. This is because lowland bamboo is denser in fiber or microstructure than highland bamboo. This ensures that lowland bamboo has a larger load-bearing capacity. Fatigue stress (cyclic load) is the predominant stress for the failure of a structure when an intermittent load is subjected to the specific structure even if the exerted stress is below the yield stress of the component. Findings ensured that the bamboo plant has adequate strength for the construction of small-scale wind turbine blade production. In Ethiopia, the estimated wind power potential is nearly one Gigawatt, and the installed capacity is only 404 MW. Small-scale wind turbine installation was not offered sufficient attention. Integrating these two potential resources (bamboo as raw material and wind resources) will enhance and contribute to small-scale energy production.*

**Keywords:** ***Highland bamboo, Lowland bamboo, Fatigue Strength, Tensile Strength***

***Received***: *August 2024;* ***Revised:*** *16 November 2024;* ***Accepted:*** *28 October 2024;* ***Published:*** *24 December 2024*

*Corresponding author-* ***Elias Alemu***

# I. INTRODUCTION

Ethiopian Standard Agency article ES-ES 6416:2021 defined Bamboo as: "tropical or semitropical grass having a tree-like character, usually hollow culms growing tall, enclosing lignin and having absence of secondary growth [1]. More than 1500 species of bamboo plants have been found worldwide [2]. In Ethiopia, two types of bamboo species are known as lowland (Oxytenantheria Abyssinia) and highland (Yushania alpina) [3]. In Ethiopia, lowland bamboo (nearly solid) and highland bamboo (hollow) cover nearly 1.4 million hectares [3, 4].

Lowland bamboo commonly grows in a warm and humid environment. This promotes rapid growth of the bamboo and in turn, it allows dense microstructures or fibers of the bamboo with cell thickness microstructure: For example, lowland bamboo in the Benishangul Gumuz region. On the other hand, highland bamboo grows in cooler and highland altitude environments. This permits slow growth of the cell wall with higher thickness as compared to lowland bamboo. This ensures that the structure has a higher thickness which carries more load than the thinner one. Therefore, bamboo growing in the lowland has better density which implies lowland bamboo has better mechanical properties than highland bamboo. In addition, it was observed from the experimental outcome, and it was compared with other plants [4].

**Bamboo has the following amazing properties:**

- It ranks first in absorbing a large amount of carbon dioxide and expelling out a large amount of oxygen, Bamboo is a crucial element in the balance of oxygen and carbon dioxide in the atmosphere. Bamboo releases 35% more oxygen than an equivalent stand of trees**.** Because of this, planting bamboo is a great way of reducing carbon footprint and helping fight global warming.
- It has excellent mechanical properties compared to other wooden plants.
- It has a fast-growing nature, growing 47.6 inches (1.2 meters) in 24 hours.

Research was conducted on locally available bamboo focusing on tensile, bending, and compressive stress by neglecting fatigue strength [5],[6]. The reason is that the common application of bamboo is for the construction of houses and furniture. In these situations, structures are naturally subjected to static loads. However, one can manufacture a component that is subjected

**Received**: August 2024; **Revised:** 16 November 2024; **Accepted:** 28 October 2024; **Published:** 24 December 2024
Corresponding author- **Elias Alemu**

ISSN (E): 2959-3921
(P): 2959-393X
DOI: https://doi.org/10.59122/164CFC16
Ethiopian International Journal of Engineering and Technology (EIJET)
Volume 2, Issue 2, 2024


to variable or intermittent loads such as wind turbine blades. In this case, it is essential to conduct and analyze the fatigue strength of the bamboo to determine its load and carrying capacity.

Bamboo in this report implies chemically untreated or not reinforced composite bamboo or not a single (bundle fiber), it is just natural bamboo. Locally available bamboo plant tests were conducted by considering its natural cylindrical geometry as specimens, without modifying shapes (Fig. 1).

The bamboo plant samples aged 3 to 4 years were collected from three different regions of the country, Benishangul Gumuz region (Assosa), Sidama Region (Arbegona), and Southern region (Chencha). This research work is specifically focused on preparing a standard tensile specimen as shown in Fig. 2 and conducting a tensile test followed by the corresponding fatigue stress using the two-stress relationship.

The middle culm of the bamboo was selected since it has a relatively better tensile strength as compared with the bottom and top part of the stem [7].

Specimens were prepared by splitting the bamboo into pieces and several numbers specimens were manufactured. The rough external surface of each of the specimens was smoothed by filing or rubbing with the help of various tools like file, sandpaper, or other similar tools. These specimens were not treated by chemical substances such as boric acid, hydrochloric acid varnish, and so on, which is common in treated bamboo.

(A) Highland bamboo from Chencha

(B) Highland bamboo from Arbegona

(C) lowland bamboo from Assosa

Fig. 1.: Collected sample (highland) photo of bamboo–location Arbegona

**Received**: August 2024; **Revised:** 16 November 2024; **Accepted:** 28 October 2024; **Published:** 24 December 2024
Corresponding author- **Elias Alemu**

Most research works supported by experimental tests and analysis were focused on the tensile, compressive, and bending stress of bamboo, even by considering the natural bamboo shape as a specimen. This ensures that tests did not consider how bamboo structures respond when it is subjected to impact or fluctuating loads. For example, if a structure is subjected to such types of loads, it will fail with a stess magnitude even below the yielding stress [8]. As a result, the component failure is early before the expected lifetime. This ensured that the effect of the corresponding fatigue test was neglected.

## II. MATERIALS AND METHODS

### A. Introduction

The two species of bamboo were collected from different regions of Ethiopia which are potential sites such as Benishagul Gumuz (Assosa), Sidama Region (Arbegona), and Southern Region (Chencha). After preparing the standard tensile specimens, tests were performed using a Calibrated Universal Tensile Testing Machine at Addis Ababa Science and Technology University. Subsequently, data are systematically recorded and organized - scientifically for further analysis. Experimental test results were supported by graphs and tables to explore research outcomes.

### B. Materials

***1) Sample Preparation*:** 30 (thirty) Tensile test specimens were prepared with standard shapes and dimensions as noted in an international standard on ISO 22156 and [9],[10]. This standard recommends the suitable range of size and shape of the specimens for the tensile test of bamboo as indicated in Fig 2.

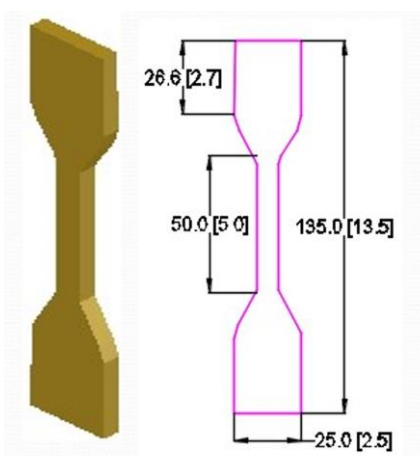


Fig.2.: *Tensile test specimens* with thickness = 4mm

**Received**: August 2024; **Revised:** 16 November 2024; **Accepted:** 28 October 2024; **Published:** 24 December 2024
Corresponding author- **Elias Alemu**

***2) Specimen Preparation steps:*** To obtain accurate and irreproducible results, specimens were carefully prepared. Naturally, bamboo plants have different fiber distributions throughout their structure. For instance, its density or thickness increases as we go from the interior to the external surface. In addition, its mechanical property varies from the bottom to the top part of the culm. These factors were taken into account during the specimen preparation.

The following procedures were implemented for both species step-by-step to prepare the specimens.

***a) Selection of Bamboo Culm:*** Bamboo culminating ages 3 to 4 years were selected. Too young culms have less strength while the aged ones also reduce their strength by propagating and cracking during testing.

***b) Cleaning the Bamboo Culm:*** Remove outer sheath (covering): The outermost shell of the bamboo cover was removed to expose smooth surfaces. In addition, file or remove any branches, knots, nodes, and surface imperfections.

***c) Cutting the Bamboo culm:*** cutting should be along the longitudinal cross-section of the fibers parallel to the applied load's direction. From the cylindrical bamboo culm, a rectangular cross-section was cut out with appropriate length and thickness. The length of the specimen should be sufficient to accommodate the elongation and failure length.

***d) Shaping the Specimen***: using an appropriate tool sandpaper or file, rub off the surface of the specimen to avoid any irregularities or roughness. Finally, the required shape of the specimen was cut out according to the dimensions given in Fig 1.2. Uneven surfaces are cases of stress concentration which mislead the accuracy of the results. The length of the specimens' thickness should be uniform throughout and consistent to overcome uneven load distribution.

***e) locating the grip region.*** During the griping of the specimen on the tensile testing machine, we have to control premature failure or slippage. So that the ends of the specimens were flattened and free from any notching.

***f) Mark the gauge length:*** the portion of the specimens between the gripping surfaces where the elongation of the specimens was measured. Here the gauge length is 50 mm,

***g) Check Uniformity:*** Finally, before conducting the test, such as dimensions, surface finish, straightness, and uniformity were checked to proceed to the next test setup.

***Received***: *August 2024;* ***Revised:*** *16 November 2024;* ***Accepted:*** *28 October 2024;* ***Published:*** *24 December 2024*
*Corresponding author-* ***Elias Alemu***

### *C. Equipment*

The experiment was conducted using the universal tensile testing machine, typically named as "WOW 100S Computer Controlled Electromechanical Universal Testing Machine". This UTM including its equipment was calibrated by conducting all significant tests, while outputs are recognized within the ISO ranges. In addition, the result generated during the experiment is partly included in this paper.

### *D. Test Procedures*

The tensile test was managed by considering some of the important steps listed below.

The specimen was gripped properly between the jaws of the machine at the marked points.

- Tighten the jaws slowly and firmly.
- Ensured that the specimen was aligned between the top and the bottom jaws. This helps us to avoid any transversal loads on the specimens.
- Start the machine with a constant load rate. In our test, the speed rate of the machine was adjusted to 0.01 mm/s [9],[11].

Five best and most feasible reproducible test results were selected as indicated in this report. The rest of them have almost similar trend output and few of them show inaccurate output as a result of error during sample preparation and fixing on the UTM.

## III. RESULTS

Finally, tensile test results of two highland bamboos (Chencha and Arbegona) and three lowland bamboos from Assossa tensile are presented. Moreover, selected test result data have a similar trend compared with other bamboo or fiberglass experimental outcomes.

(a) Lowland (solid) - Assosa (b) Highland (hollow) - Arbegona (c) Highland (hollow) -Chencha

Fig. 3: Specimens before the test was conducted

***Received**: August 2024; **Revised:** 16 November 2024; **Accepted:** 28 October 2024; **Published:** 24 December 2024*

*Corresponding author- **Elias Alemu***

ISSN (E): 2959-3921 Ethiopian International Journal of Engineering and Technology (EIJET)
(P): 2959-393X Volume 2, Issue 2, 2024
DOI: https://doi.org/10.59122/164CFC16 

a b

Fig. 4: a) Conducting of the tensile testing (a) and the corresponding fractured specimens (b)

*A.* Result of the experimental Test

Results are tabulated in Table 1 which represents the stress vs. Strain test output of lowland bamboo and its corresponding graph of stress-strain diagram is indicated in Fig. 4. Similarly, table 2 and Fig 5 represent the highland bamboo of Arbegona.

Data are too large (1 to 1165) to include in the table, hence only a part of it is presented. Others are omitted by broken lines in the table, but in the graph, data are incorporated.

Table 1: tensile test result of 01 lowland bamboo (stress in MPA).

| No | Stress | Strain | No | Stress | Strain |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 20 | 25.7 | 0.304 |
| 2 | 0 | 0.004 | | | |
| 3 | 0 | 0.02 | | | |
| 4 | 23.85 | 0.036 | | | |
| 5 | 24 | 0.052 | | | |
| 6 | 24.2 | 0.07 | 1154 | 177.95 | 7.69 |
| 7 | 24.4 | 0.086 | 1155 | 178.05 | 7.71 |
| 8 | 24.55 | 0.104 | 1156 | 178.1 | 7.732 |
| 9 | 24.75 | 0.12 | 1157 | 178.05 | 7.762 |
| 10 | 24.95 | 0.136 | 1158 | 177.95 | 7.802 |
| 11 | 25.15 | 0.154 | 1159 | 177.8 | 7.85 |
| 12 | 25.35 | 0.17 | 1160 | 177.6 | 7.906 |
| 13 | 25.45 | 0.188 | 1161 | 177.3 | 7.972 |

**Received**: August 2024; **Revised:** 16 November 2024; **Accepted:** 28 October 2024; **Published:** 24 December 2024
Corresponding author- **Elias Alemu**

| | | | | | |
|---|---|---|---|---|---|
| 14 | 25.55 | 0.204 | 1162 | 176.75 | 8.06 |
| 15 | 25.55 | 0.22 | 1163 | 174.95 | 8.186 |
| 16 | 25.6 | 0.238 | 1164 | 141.8 | 8.504 |
| 17 | 25.6 | 0.254 | 1165 | 102.65 | 9.124 |
| 18 | 25.65 | 0.27 | | | |
| 19 | 25.7 | 0.288 | | | |

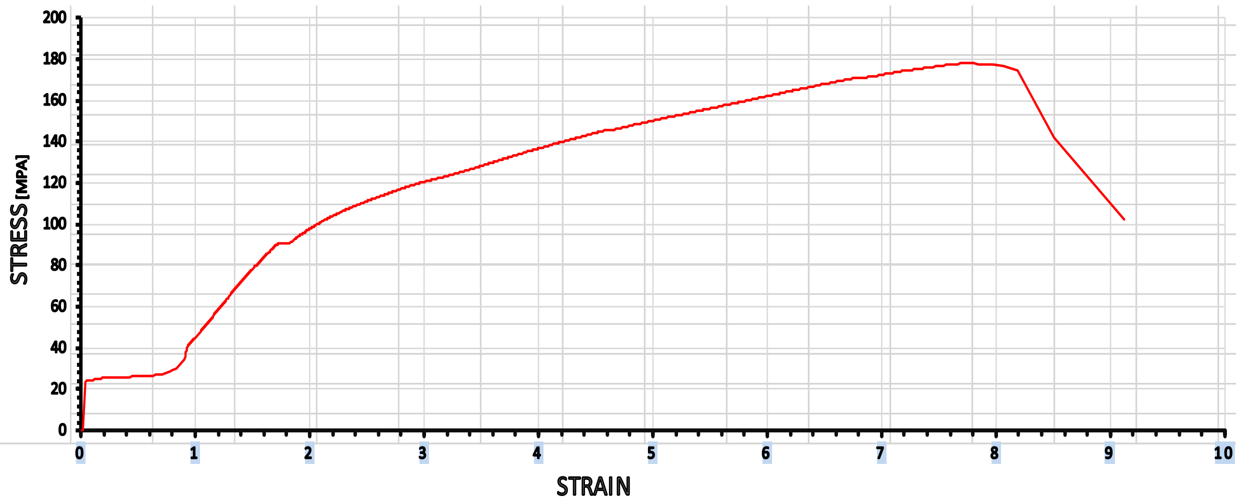


Fig. 5.: Stress-Strain diagram of 01 Lowland Bamboo (Benishangul Region - Assosa)

Table 2: Tensile test result of 02 highland bamboo *(Arbegona).* Data ranges from 1 to 659

| No | Stress | Strain | No | Stress | Strain |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 637 | 121 | 3.49 |
| 2 | 0 | 0 | 638 | 121.1 | 3.498 |
| 3 | 0 | 0.016 | 639 | 121.2 | 3.506 |
| 4 | 24.25 | 0.034 | 640 | 121.3 | 3.514 |
| 5 | 24.35 | 0.05 | 641 | 121.4 | 3.522 |
| 6 | 24.5 | 0.066 | 642 | 121.5 | 3.53 |
| 7 | 24.6 | 0.084 | 643 | 121.7 | 3.54 |
| 8 | 24.75 | 0.1 | 644 | 121.8 | 3.548 |
| 9 | 24.85 | 0.116 | 645 | 121.9 | 3.556 |
| 10 | 24.95 | 0.134 | 646 | 122 | 3.564 |

***Received***: August 2024; ***Revised:*** 16 November 2024; ***Accepted:*** 28 October 2024; ***Published:*** 24 December 2024
*Corresponding author- **Elias Alemu***

| | | | | | |
|---|---|---|---|---|---|
| 11 | 25.05 | 0.15 | 647 | 122 | 3.574 |
| 12 | 25.15 | 0.168 | 648 | 121.8 | 3.59 |
| 13 | 25.2 | 0.184 | 649 | 121.7 | 3.614 |
| 14 | 25.15 | 0.2 | 650 | 121.6 | 3.634 |
| 15 | 25.15 | 0.218 | 651 | 121.4 | 3.652 |
| 16 | 25.15 | 0.234 | 652 | 121.3 | 3.672 |
| 17 | 25.1 | 0.252 | 653 | 121.2 | 3.692 |
| 18 | 25.05 | 0.268 | 654 | 121 | 3.712 |
| 19 | 25 | 0.284 | 655 | 102.2 | 3.754 |
| 20 | 25 | 0.302 | 656 | 95.65 | 3.878 |
| 21 | 25 | 0.318 | 657 | 99.2 | 4.008 |
| | | | 658 | 98.2 | 4.126 |
| | | | 659 | 95.23 | 4.24 |

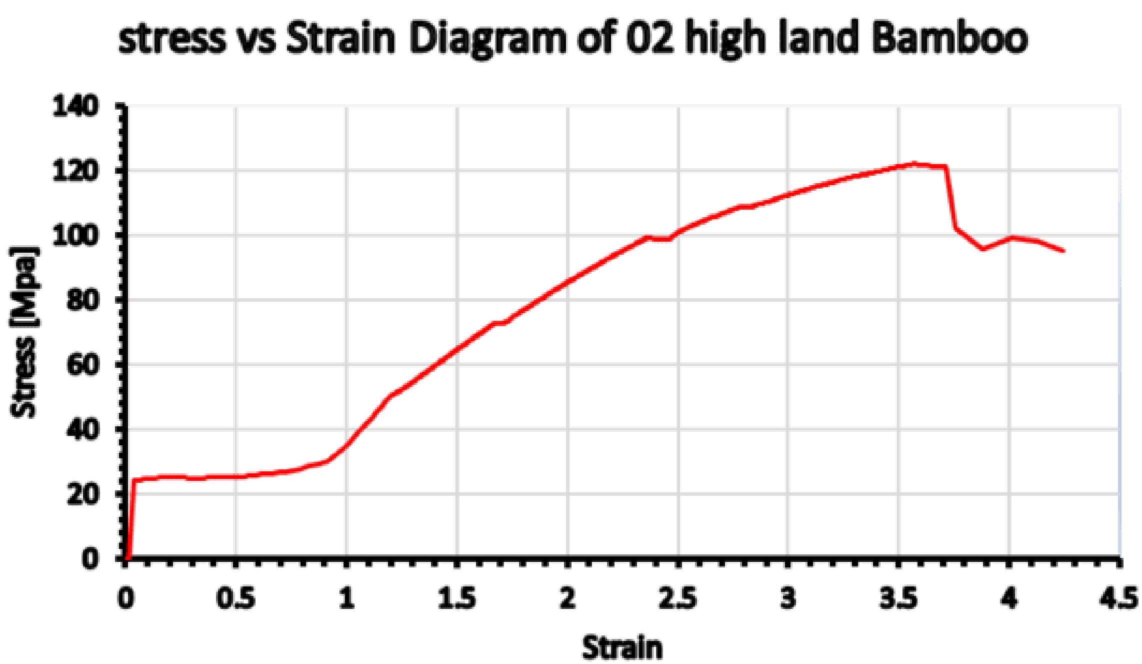


Fig.6.: Stress vs Strain Diagram of 02 Highland Bamboo (Sidama Region -Arbegona)

**Received**: August 2024; **Revised:** 16 November 2024; **Accepted:** 28 October 2024; **Published:** 24 December 2024
Corresponding author- **Elias Alemu**

ISSN (E): 2959-3921 Ethiopian International Journal of Engineering and Technology (EIJET)
(P): 2959-393X Volume 2, Issue 2, 2024
DOI: https://doi.org/10.59122/164CFC16 

## IV. DISCUSSION

As shown in the stress-strain diagram the yield and ultimate stress are nearly at the same point. There is no significant clear point to distinguish them. In addition, the Fatigue life of the structure is highly dependent on the surface roughness of the material. If the roughness is high the fatigue life of the material decreases and vice versa [12].

From the experiment, we observed that sample 01 lowland (solid bamboo) has the maximum load carrying capacity = 7.124 KN, with the corresponding yielding strength ($\sigma_y$) = 178.1 Mpa. As a result, the fatigue stress is 40% of the tensile stress which is 71.24 Mpa & Modulus of elasticity = 6 Gpa.

### *A. Sample 01 Lowland Bamboo (Assosa)*

At the beginning of the tensile test, the stress-strain diagram shows that (Table 1 and Fig. 4) strain is very limited and has less response to elongation, however, stress is increasing significantly. From the origin of the graph, the yielding stress is nearly, close to 25Mpa and strain to 0.154, here also both the parameters have a direct relationship and satisfy Hooke’s Law.

Between the stresses 25 Mpa and 40 Mpa, the stress-strain is not in a proportional limit; however, the strain is increasing significantly than the previous trend.

Yin as the test continued, the previous observation from the graph shifted considerably. The strain or elongation increased significantly, even with small increments in stress. This relationship is continuous up to the point where cracking is propagating nearly, and stresses and strain are equal to 178.1Mpa and 0.55 respectively.

Finally, the specimen completely failed at stress and strain nearly 102.65 Mpa and 7.732 respectively.

### *B. Sample 02 highland bamboo (Arbegona).*

This trend is also similar to the lowland of bamboo with a basic difference of the proportionality and failure point as it is observed in the stress and strain diagram.

At the beginning of the test, the specimen is less responsive to elongation as stress is increasing significantly. Table 2 and Fig. 5 indicate stress 0 Mpa and strain 0. Stress increases up to the yielding stress nearly equal to 24.25 Mpa and strain is 0.034. In this range, both stress and strain have a direct relationship which satisfies Hooke’s law as well.

***Received***: August 2024; ***Revised:*** 16 November 2024; ***Accepted:*** 28 October 2024; ***Published:*** 24 December 2024
*Corresponding author- **Elias Alemu***

ISSN (E): 2959-3921
(P): 2959-393X
DOI: https://doi.org/10.59122/164CFC16
Ethiopian International Journal of Engineering and Technology (EIJET)
Volume 2, Issue 2, 2024


Between the stresses 24.25 Mpa and 47.35 Mpa, the stress-strain is not in a proportional limit; however, the strain is increasing significantly than the previous values.

As the test continued, above the stress 47.35 Mpa and strain 1.16, both are in a proportional relationship. Cracking started to propagate near the stress equal to 121.4 Mpa and strain 3.652. Finally, the specimen completely failed at stress and strain at nearly 95.23 Mpa and 4.24 respectively.

Experimental Test result of the Tensile test and the corresponding Fatigue strength of bamboo specimens are given in the table below.

Table 3: Summary of the entire test result of low and highland bamboo

| No | Types of samples | Location | Max.Tensile load (KN) | Yield strength (σy) Mpa | Fatigue Strength = 40% *(σy) Mpa | Modulus of Elasticity (Gpa) |
|---|---|---|---|---|---|---|
| 1 | 01 lowland | Assosa | 7.124 | 178.1 | 71.24 | 6 |
| 2 | 02 lowland | | 5.99 | 150 | 60 | 5 |
| 3 | 03 lowland | Assosa | 4.586 | 114.65 | 45.86 | 4 |
| 4 | 01 highland | Chencha | 4.846 | 121 | 48.4 | 4 |
| 5 | 02 highland | Arbegona | 4.866 | 122 | 48.8 | 5 |

## V. CONCLUSION

The specimens are free of any chemical treatment. If we apply such retting, certainly the strength of the bamboo increases [13]. The experimental data ensured that lowland bamboo (*Oxytenanthera abyssinica*) has better mechanical properties as compared to highland bamboo (*Yushania Alpina*). For example, 01 lowland bamboo has a fatigue stress equal to 71.24 Mpa, while sample 02 highland bamboo has a fatigue strength of 48.8 Mpa.

Finally, this study ensured that both species of bamboo which are locally available in Ethiopia qualify for the manufacturing of various components. For example, highland bamboo is the fittest to manufacture a component when it is subjected to a fluctuating load up to a fatigue stress equal to or less than 48.4 Mpa. Similarly, the lowland bamboo can be applicable for manufacturing a component when subjected to stress up to 71.24Mpa.

**Received**: August 2024; **Revised:** 16 November 2024; **Accepted:** 28 October 2024; **Published:** 24 December 2024
Corresponding author- **Elias Alemu**

Conversely, when subjected to a uniform load (continuous stress), bamboo structures can withstand higher stress levels, reaching 178.1 MPa for lowland and 122 MPa for highland varieties. The mechanical properties of bamboo are influenced by various factors, including species, culm position, age, and environmental conditions.

Lowland bamboo, typically grown in warm, humid climates, exhibits rapid growth, leading to denser microstructures and thicker cell walls. This is exemplified by lowland bamboo found in the Benishangul Gumuz region. In contrast, highland bamboo, cultivated in cooler, high-altitude environments, experiences slower growth and develops thinner cell walls compared to lowland bamboo [14] [15].

This ensures that the structure with a higher thickness carries more load than the thinner one. Therefore, as was observed from the experimental outcome, lowland bamboo has better mechanical properties than highland bamboo.

To sum up, experimental test data revealed that lowland bamboo available in Benishangul Gumuz regional state (like the Asosa zone) has better mechanical properties than highland bamboo (Chencha or Arbegona). Wind turbine blades are frequently subjected to intermittent or fluctuating wind loads. This leads to fatigue failure. For example, as an alternative material bamboo is applicable for the construction of small-scale wind turbines that generate electric power up to 6 kW. Hence, bamboo can be utilized for other lightweight components such as aerospace and piping systems when they are subjected to repeated loads.

The present study focused on the characterization of the mechanical properties of natural bamboo. Future studies can expand this research work on treated, hybrid, or composite bamboo materials and compare their output.

## VI. RECOMMENDATIONS

1. Extending the research by conducting tests on bamboo plants from different locations other than those listed in this report.
2. Extending the research by conducting additional fatigue tests which strongly confirm results.
3. Extending the research by polishing or using the chemical treatment on the external surface of the bamboo and analyzing the output of the study.

***Received**: August 2024; **Revised:** 16 November 2024; **Accepted:** 28 October 2024; **Published:** 24 December 2024*
*Corresponding author- **Elias Alemu***

4. Extend the research for the Heat as the Heat Treatment also has a valuable impact on its strength.
5. Take into consideration that during tensile or fatigue testing, care should be given to avoid any external stress such as tightening of the specimen.

## REFERENCES

[1]. Ethiopian Standards Agency, *Design of Bamboo Structures*, 1st ed., 2021.

[2]. Bamboo: Origin, Habitat, Distributions and Global Prospective. Available: https://www.researchgate.net/publication/354206084.

[3]. United Nations Industrial Development Organization, *Bamboo Cultivation Manual: Guideline for Cultivating Ethiopian Highland Bamboo*.

[4]. Interesting Facts About Bamboo. Available: https://lewisbamboo.com/pages/interesting-facts-about-bamboo.

[5]. S. Woubshet and D. Addissie, *Investigation on Mechanical Properties and Suitability of Highland Bamboo (Yushania Alpina) for Use in Structural Truss Members*.

[6]. F. A. Muche and Y. M. Degu, "Experimental Investigation of Bending Strength of Oxytenanthera Abyssinica and Yushania Alpina Bamboos," Faculty of Mechanical and Industrial Engineering, Bahir Dar Institute of Technology, Bahir Dar University, Bahir Dar, Ethiopia.

[7]. S. Woubshet and D. Addissie, "Investigation on Mechanical Properties and Suitability of Highland Bamboo (Yushania Alpina) for Use in Structural Truss Members," *Science Development*, vol. 2, no. 2, pp. 23-29, 2021. doi: 10.11648/j.scidev.20210202.11.

[8]. Design Of Machine Element. Available: https://madeesay.in.

[9]. ISO/TR, *Determination of Physical and Mechanical Properties of Bamboo Part 2: Laboratory Manual*, 2004.

[10]. ISO/TR 22157-1, *Bamboo - Determination of Physical and Mechanical Properties - Part 1: Requirement*, 2004, pp. 1–8.

[11]. Bureau Of Indian Standards, *Indian Standard Method of Tests for Bamboo*, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002, 2008.

***Received***: *August 2024;* ***Revised:*** *16 November 2024;* ***Accepted:*** *28 October 2024;* ***Published:*** *24 December 2024*
*Corresponding author-* ***Elias Alemu***

***ISSN** (E): 2959-3921*
*(P): 2959-393X*
***DOI:** [https://doi.org/10.59122/164CFC16](https://doi.org/10.59122/164CFC16)*
*Ethiopian International Journal of Engineering and Technology (EIJET)*
*Volume 2, Issue 2, 2024*


[12]. W.L. Xiao, H.B. Chen, and Y. Yin, "Effects of Surface Roughness on the Fatigue Life of Alloy Steel," Department of Modern Mechanics, University of Science and Technology of China, Hefei, Anhui 230026, China.

[13]. H. Chen, H. Cheng, G. Wang, et al., "Tensile Properties of Bamboo in Different Sizes," *Journal of Wood Science*, vol. 61, pp. 552-561, 2015.

[14]. Kidane, B., Mekonnen, Z., Getahun, A. et al., "Highland bamboo value chains development to enhance local livelihoods in Southern Ethiopia." *J Innov Entrep 13,* 50 (2024). https://doi.org/10.1186/s13731-024-00406-3

[15]. H. Huang and K.F. Chung, "Mechanical Properties of Bamboo as a Structural Material," *Journal of Materials Science*, vol. 43, no. 3, pp. 1069-1076, 2008.

***Received**: August 2024; **Revised:** 16 November 2024; **Accepted:** 28 October 2024; **Published:** 24 December 2024*
*Corresponding author- **Elias Alemu***