Test and Characterization of Tensile Strength of Oxytenanthera Abyssinica and Yushania Alpina Bamboos

Fentahun Ayu Muche and Yonas Mitiku Degu(✉)

Faculty of Mechanical and Industrial Engineering,
Bahir Dar Institute of Technology, Bahir Dar University, Bahir Dar, Ethiopia
fentahunayu30@gmail.com, yonasm@bdu.edu.et

Abstract. Bamboo has a long and well-established tradition as a building material throughout the world. Bamboo has various applications such as, for furniture, bicycle structure, unmanned air vehicle structure. Despite the fact that Ethiopia has abundance bamboo, till now the tensile strength of both Oxytenanthera abyssinica (solid) and Yushania Alpina (hollow) bamboo was not studied sufficiently. This research focuses on tensile strength testing and characterization of solid and hollow bamboo found in Amhara region at Jawi and Awi district through standard test procedures. The specimens were prepared and tested according to ISO standard. The tensile strength of specimens were tested and characterized with respect to its species, age and culm position. The test result showed that tensile strength of solid and hollow bamboo without node, increases from bottom to top. Hollow and solid bamboo specimens without node had greater tensile strength than specimens with node. Besides solid bamboo without node had superior average tensile strength (ranges between 211.5 MPa to 260.2 MPa) than hollow bamboo without node (179.7 MPa to 246.1 MPa). Irrespective of the age, specious, with node and without node the lowest strength showed on the bottom portion of the specimens. The test specimen results demonstrated as the age increases from year two to four, the bottom strength increased consistently. To use bamboo for structural and related purpose it is recommended to take the bottom portion strength than the average or the highest strength for safe design.

Keywords: Hollow bamboo · Solid bamboo · Oxytenanthera abyssinica and Yushania Alpina bamboo culm · Tensile strength

1 Introduction

The mechanical properties of materials are the most important parameters for structural design. It relates the relationship between a material's responses to the applied load [1]. Tensile test is frequently used parameter to evaluate the mechanical properties of materials. Tensile strength property is one of the most prominent measuring criteria in the design of engineering structures and in the developing new product suit to the specified application [2].

F. A. Zimale et al. (Eds.): ICAST 2018, LNICST 274, pp. 160–169, 2019.
https://doi.org/10.1007/978-3-030-15357-1_13

Bamboo has a long and well established tradition as a building material throughout the world's tropical and sub-tropical regions [3]. It is a naturally occurring composite material consisting of cellulose fibers. It has a maximum tensile strength and flexural strength because of its fibers placed along its length [4]. Bamboo grows mostly in tropical and subtropical areas ranging from sea level to mountain peaks, with a few species reaching into temperate areas [5]. Bamboo is a light weight, flexible, sustainable, eco-friendly, green material and its use, shall be advocated in building construction for sustainable development [6].

Currently, the use of bamboo is well known by craftsman. Unlike other countries, bamboo utilization in Ethiopia has been customary and mainly limited to construction, fencing, handicraft, furniture, water container, baskets, firewood, house utensils, various art-facts, and walking sticks. The study of the mechanical property of bamboo is very important for the industrialization of the material [7]. Although tensile strength of Ethiopian bamboo with node and without node along the grain direction was tested by students for their partial fulfillments of the Bachelor of Science degree, the test procedure was not following the standard test method [8].

The tensile strength of Indian bamboo various species with node and without node was tested. The sample was prepared from four year old green bamboo (*Dendrocalamus strictus*) and the test was done on different region of bamboo. The test result proves that tensile strength increases with height and also increases from inner to outer section [9]. The curved portions of the bamboo split at the end were filled with sand and high strength epoxy resin to prevent the failures of the sample at the grip part. Another research on various species of Indian bamboo and the result shows that bamboo with node has less strength than without node [3].

For the proper utilization of bamboo in structural application the tensile strength characteristic must be known well. Till now the actual tensile strength of Ethiopian bamboo was not studied sufficiently. Hence the objective of this research is to test and characterize the tensile strength of Oxytenanthera abyssinica and Yushania Alpina specious bamboo found in Amhara region at Jawi and Awi district.

2 Materials and Methods

2.1 Materials

Bamboo: Bamboos of age two, three and four were used; the ages of bamboo was selected based on the availability and farmers recommendation from their rich experience in using and planting. Bamboo is mostly used for different applications from the age of two to four. It is mainly characterized by two parts: the main stem above ground called the culm and the underground part called rhizome.

Bamboo Culm: The main stem of a bamboo is a culm, which is the supportive structure of the branches and leaves and contains the main vascular system for the transport of water, nutrients, and food; the culm diameter decrease from bottom to top. The hollow bamboo is larger in diameter compared to the solid bamboo. Figure 1 shows the culm of hollow and solid bamboo.

a) Yushania alpina bamboo culm b) Oxytenanthera abyssinica bamboo culm

Fig. 1. Culms of bamboo [www.allchile.net]

Study Area: The specimens were prepared from the two species of bamboo found in Ethiopian, Amhara region, outskirt of Jawi (solid bamboo) and Awi zone (hollow bamboo). The two areas were selected for the study due to the abundance availability of bamboo. Solid bamboo is also known as lowland bamboo (Oxytenanthera abyssinica) and it is distributed to Amhara region which is found at Awi zone around Jawi. Hollow bamboo is also known as highland bamboo (Yushania Alpina) which is found at Awi zone around Injibara town.

Node: The jointed segments of the bamboo plant and the area between nodes are called an internode. The nodes of a bamboo are always solid, and the internodes of most bamboos are hollow [11].

Tools and Machines:

- Hand and measuring tools like saw, knife, digital vernier caliper and tape meter were used for sample preparation.
- Universal testing machine: microcomputer controlled UTM YF (Zhejiang Tugong PN0206000031 WAW- 1000B) was used to test the tensile strength of bamboo specimens. The capacity of the machine is 1000 kN at load rating of 0.05 kN/s.

2.2 Methods

The research was carried out based on:

1. *Reviewing prior works:* Searching for different works about mechanical properties and testing techniques of bamboo was the primary task of the research. Here, testing method, specimen preparation from bamboo and other related works were reviewed.
2. *Sample preparation:* Among different standards for wood-based materials, the tensile test was carried out according to ISO/TR 22157-2: 2004 (E) [10]. This standard recommended the suitable size of the specimens for tensile test of bamboo. As bamboo is an anisotropic material, the properties will be varied from the bottom to the top positions. Specimens from the three positions (bottom, middle and top) were taken to check the variation of the properties of bamboo along its length. The three positions were given according to their order from the root to the tip leaves. Figure 2 shows the standard dimension of bamboo specimen for tensile test.

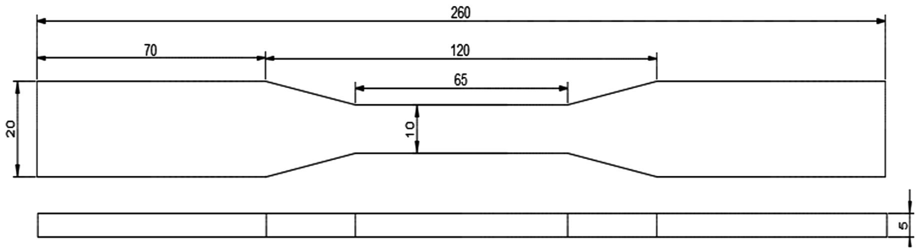


Fig. 2. Standard specimen dimensions for tensile test [dimensions are given in mm]

2.3 Experiment Design

The number of specimens can be determined by the principles of factorial design and fractional factorial design [12]. The mechanical properties of bamboo are dependent on its age, species and culm position. The experiment was done based on these three factors for both solid and hollow bamboo. Here the number of repetitions was determined by the principle of fractional factorial design for the three factors. The equation is given by:

$$\text{Number of specimens a single test} = \frac{2^n}{2} \tag{1}$$

Where: n is the number of factors

$$\text{Number of specimens for a single test} = \frac{2^3}{2} = 4$$

Four specimens were prepared for each position of specimens without node and with node. The total specimens prepared from solid and hollow bamboo were 144.

2.4 Sample Preparation and Testing Procedure

Two types of bamboo were collected from the two areas. The average total lengths of hollow bamboo culm and solid bamboo were found 10 m and 5 m respectively. The culms of hollow and solid bamboo were left in open air until it dries and ready for the sample preparation.

The general procedures used for sample preparation were (depicted Fig. 3):-

1. Cut the bamboo culm from farming site and leave in open space until it gets dries.
2. Remove 1 m from the bottom and then measure again 2.4 m and cut, which is the required portion for the test.
3. Divide the 2.4 m into three equal length (0.8 m each)
4. Split the hollow bamboo prepared in step 3 into four and the solid into two.
5. Plain the bamboo pices until the curved shape become flat.
6. Measure 0.26 m and cut from 0.8 m length from all positions for both with node and without a node.

Fig. 3. Steps of specimen preparation for tensile test [Photo by the authors]

7. Mark to get the bone shape on the prepared specimens according to the standard dimension (refer Fig. 2).
8. Remove the unwanted portion of the sample to get the bon shaped sample.
9. Glued wood at both ends and faces of the specimens for proper gripping during testing.
10. Shaping the sample by sandpaper to obtain the required smooth finished specimen.

After specimens were prepared, the test was performed using universal testing machine which has a sensor connected to the computer. The test results were stored on the computer for each run; after the test was completed the stored data were retrieved for further analysis. The test was done based on the following steps:

1. Specimens gripped by both jaws of the machine at the marked gage length.
2. Run the machine.
3. Save the test files to the appropriate location.
4. Repeat these steps until finishing all the specimens.

The specimens prepared before and after the test are shown in Figs. 4 and 5 respectively.

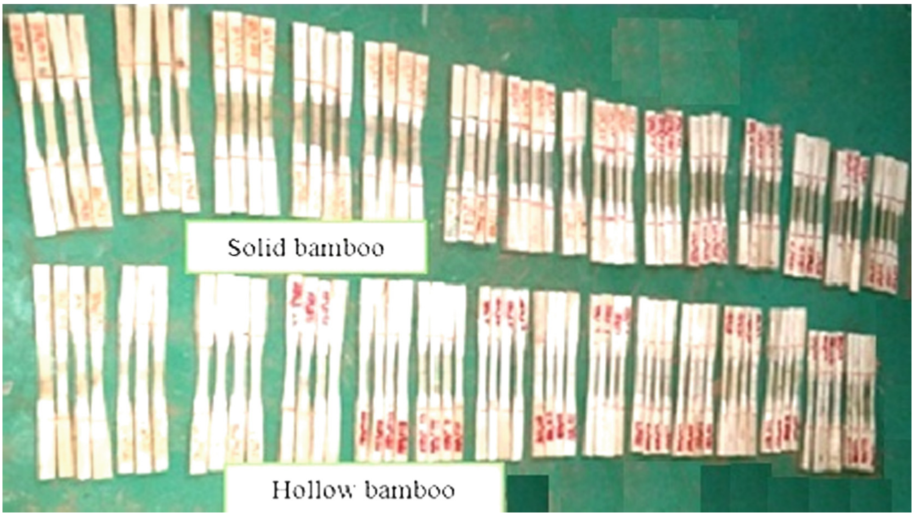
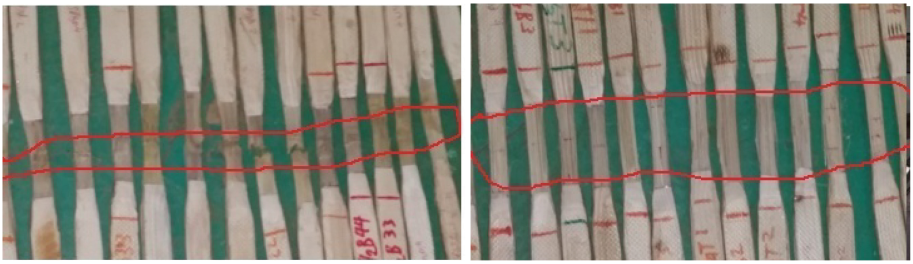


Fig. 4. Specimens prepared for tensile test [Photo by the authors]



a) Explosive failure b) Brittle failure

Fig. 5. Mode of failure of specimens during tensile test [Photo by the authors]

3 Results and Discussion

3.1 Results

The tensile strength of bamboo specimens with node and without node was tested with respect to the type of species, culm position and age. The results obtained during the test are presented from Figs. 6, 7, 8 and 9.

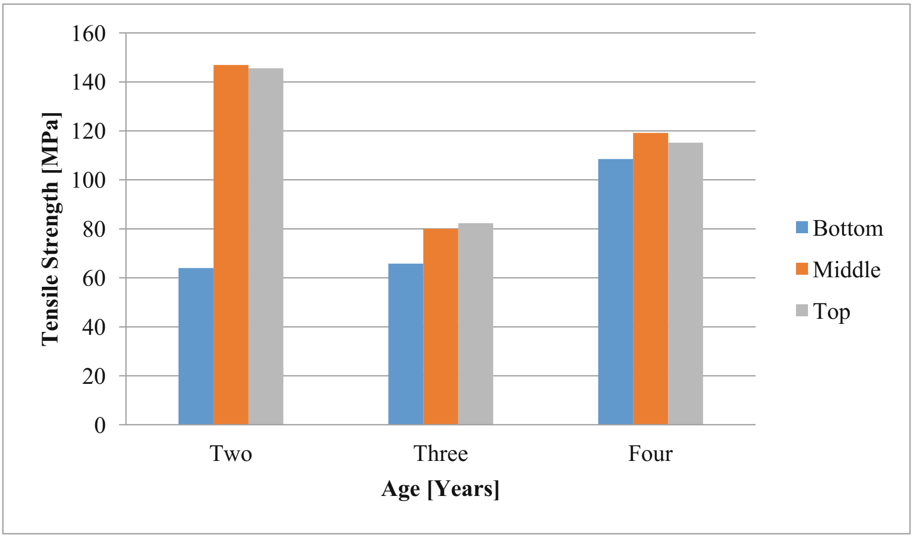


Fig. 6. Tensile strength of hollow bamboo specimens with node vs age and culm position

3.2 Discussion

The tensile strength test result with respect to position and age of both solid and hollow bamboo are plotted from Figs. 6, 7, 8 and 9. Specimens of both types of species without node have higher tensile strength than specimens of with node. Due to the fact

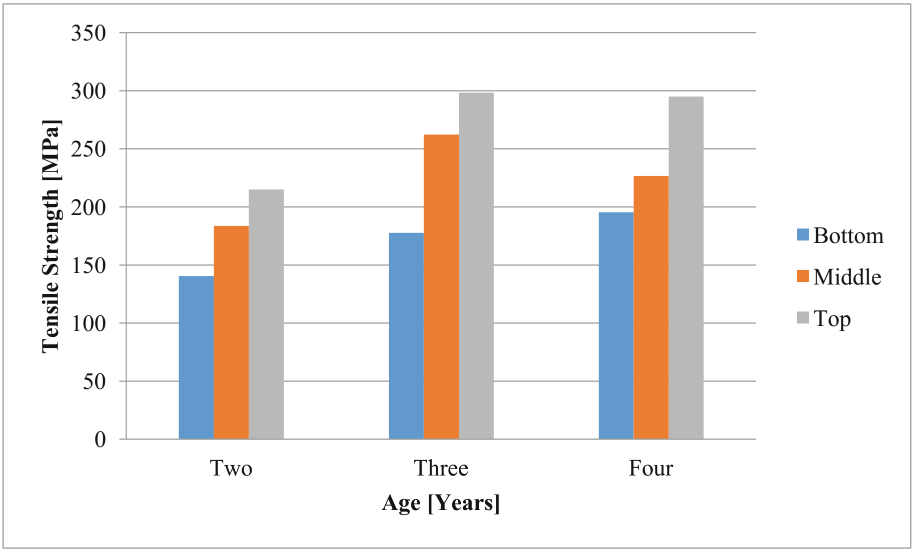


Fig. 7. Tensile strength of hollow bamboo specimens without node vs age and culm position

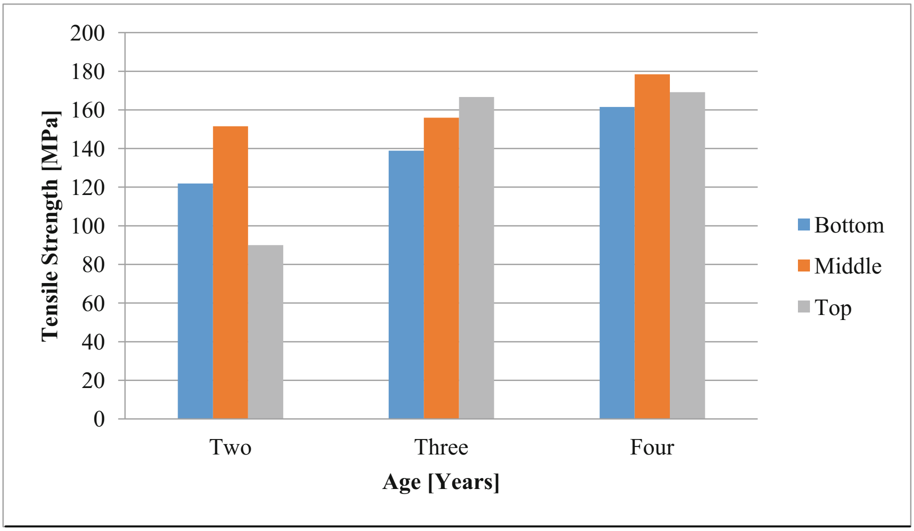


Fig. 8. Tensile strength of solid bamboo specimens with node vs age and culm position

that fiber around the node is discontinuous so it will cause to have lower tensile strength for specimens with node.

The test result demonstrates that the tensile strength of solid and hollow bamboo increases as their ages increased except hollow bamboo with node demonstrate unpredictable behavior in the middle and top portion. The tensile strength of solid

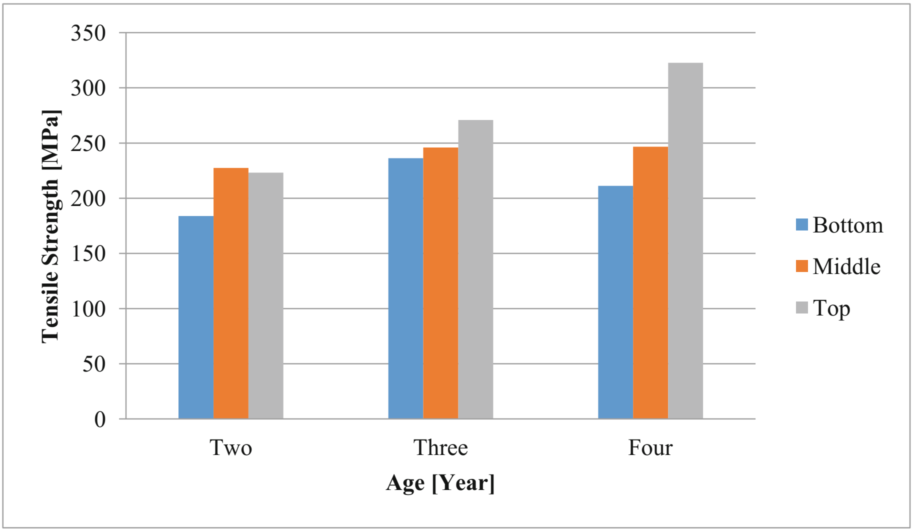


Fig. 9. Tensile strength of solid bamboo specimens without node vs age and culm position

bamboo is directly related to its age for both with and without nodes. As the age of sold bamboo increases from year two, three and four its average tensile strength is also increased from 211.5 MPa, 251 MPa and 260.2 MPa respectively for specimens without node; and from 121.1 MPa, 153.9 MPa and 169.7 MPa respectively for the specimens with nodes.

In the case of hollow bamboo without node registered higher average tensile strength at year three which is 246.1 MPa and followed by year four and two 239 MPa and 179.9 MPa respectively. Hollow bamboo with node got higher average tensile strength at year two followed by four and three 118.8 MPa, 114.3 MPa and 76.0 MPa respectively.

Among all specimens the top position 86.1% specimens' scores higher strength value followed by 13.9% middle portions. Solid bamboo without node 66.67% behave as top portion having higher tensile strength and followed by the middle portion 33.33% Hollow bamboo without node 100% behave as top portion having higher tensile strength and followed by the middle and bottom. Hollow bamboo with node demonstrates random pattern with respect to the culm position. The failures of bamboo with node are different from that of bamboo without a node. As it is shown in Fig. 5 bamboo with node failed in a brittle manner and the failure of culm without node is in an explosive manner.

For conservative design the lowest strength could be taken as the ultimate tensile strength of the whole portion of the bamboo. Irrespective of the age the lowest strength for the hollow and solid bamboo recorded at the bottom portion. It had also a trend of as the age increases the lowest strength of both bamboo increases consistently.

4 Conclusions

Solid bamboo specimens were having higher tensile strength than hollow bamboo specimens with respect to tensile load. The maximum tensile strength of solid bamboo without node specimens for year two, three and four were found 227.5 MPa, 270.9 MPa and 322.7 MPa respectively, at the top portion except year two which is in the middle portion. The maximum tensile strength of hollow bamboo without node specimens were found at the top portion 215.0 MPa, 298.4 MPa and 295.0 MPa at year two, three and four respectively. The lowest tensile strength of hollow bamboo without node specimens were registered at the bottom portion 140.5 MPa, 177.7 MPa and 195.4 MPa at year two, three and four respectively.

The average tensile strength without node of hollow bamboo ranges between 179.7 MPa to 246.1 MPa and solid bamboo ranges between 211.5.0 MPa to 260.2 MPa.

The lowest tensile strength of solid bamboo without node specimens were registered at the bottom portion 183.8 MPa, 236.3 MPa and 211.2 MPa at year two, three and four respectively. The lowest tensile strength of hollow bamboo without node specimens were registered at the bottom portion 140.5 MPa, 177.7 MPa and 195.4 MPa at year two, three and four respectively.

Solid and hollow bamboo specimens without node showing higher tensile strength than bamboo with node. It can also be concluded that bamboo with node having unpredictable behavior of tensile strength, than bamboo without node. To know the unpredictable behavior the microstructure study has to be conducted before testing of the specimens. In addition tensile strength of bamboo with respect to cultivation soil type and environmental conditions need to be studied.

References

1. Scott, M.J.: Material testing lab, engineering innovation section A last modified 4 July 2011, Johns Hopkins University (2011)
2. Favilla, S.: Tensile testing laboratory date of lab exercise, 28 January 2010
3. Bhonde, D., Nagarnaik, P.B., Parbat, D.K., Waghe, U.P.: Physical and mechanical properties of bamboo. Int. J. Sci. Eng. Res. **5**(1) (2014)
4. Soyoye, F.R.: The influence of age and location on selected physical and mechanical properties of bamboo. Int. J. Res. Agric. For. **1**(1), 44–54 (2014)
5. Kassahun, E.: Ecological aspects and resource management of bamboo forest in Ethiopia. Swedish University of Agricultural Sciences, Uppsala (2003)
6. Bhondea, D., Nagarnaik, P.B., Parbatc, D.K., Waghed, U.P.: Experimental analysis of bending stresses in bamboo reinforced concrete beam. In: Proceedings of 3rd International Conference on Recent Trends in Engineering and Technology (ICRTET 2014). Elsevier (2014)
7. Kindu, Y.M.: Status of bamboo resource development, utilization and research in Ethiopia. Ethiop. J. Nat. Resour. **1**, 79–98 (2010)
8. Dereje, D.A.: Testing, determination and characterization of bamboo. Bahir Dar Institute of Technology, Mechanical Engineering Program, BSc. thesis (2016)
9. Verma, V.C.: Tensile strength analysis of bamboo and layered laminate bamboo composites. Int. J. Eng. Res. Appl. (IJERA) **2**(2), 1253–1264 (2012)

10. ISO/TR, 2.-2, Determination of physical and mechanical properties of bamboo part 2 laboratory manual (2004)
11. David, F.: The Book of Bamboo. Library of Congress Cataloging in Publication of Data, San Francisco (1984)
12. Montgomery, D.C.: Design and Analysis of Experiments, 5th edn. Toronto (2001)