MECHANICAL PROPERTIES OF BAMBOO (*BAMBU*SA VULGARIS*)

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ABSTRACT:

This research project investigated the tensile, bending and compressive strength of a species of bamboo called *Bambusa vulgaris*. The density of the *B.* vulgaris was found to be 500kg/m\(^3\) (oven dry). The tensile strength was 94.3MPa with nodes and 117.8MPa without nodes. The compressive strength was 49.9MPa with nodes and 56.7MPa without nodes, bending strength was 107.0MPa with nodes and 137.7MPa without nodes and Modulus of Elasticity in tension was 3002.2MPa with nodes and 3594.0MPa without nodes. Modulus of Elasticity in compression was 10,405.3MPa without nodes and 7,268.1MPa with nodes. The nodes were found to have a significant effect in lowering the tensile and bending strength of bamboo. The compressive strength was not affected by the presence or absence of nodes.

**Keywords**: Mechanical Properties, *bambusa vulgaris*, strength

1.0 INTRODUCTION

Wood is only a renewable resource if the annual supply of wood products can keep up with the demand for them. This has not been the case in Kenya because trees are being cut down much faster than they can replace themselves (Ondimu and Gumbe, 1997 and Hankins, 1987).
The forested area in Kenya has, therefore, been on the decline. While this is largely attributed to clearing for agriculture, fuel-wood, and paper manufacture, many trees are cut each year for use in the building and furniture industry. Wood is a commonly used building material because of its reasonable cost, ease of working, attractive appearance, insulation properties, and adequate life if protected from moisture and insects (Bengtsson and Whitaker, 1988).

Due to these desirable characteristics, it is likely that wood will continue to be exploited for construction. The construction industry has tended to draw timber from just a few species (Ondimu and Gumbe, 1997) the depletion of primary forests by excessive harvesting of useful plants threatens the gene resource (Zhang and Cao, 1995 and Kigomo, 1988)

To reduce pressure upon the forest resources and utilize them rationally, a systematic conservation strategy and more scientific efforts are needed urgently (Zhang and Cao, 1995). Hankins (1987) says that the standing stock must be constant to ensure sustainable yield.to ease pressure on forests; Agroforestry must be practiced with greater intensity (Christianity et al, 1997). Secondly, this can be achieved by obtaining timber from many different trees so as not to deplete individual species (Ondimu and Gumbe, 1997). Another course of action may be to encourage the use of timber from early maturing trees.

One source of wood which meets the criteria is bamboo. The fast growth rate of bamboo is well known and many varieties are available that are suitable for semi-arid and humid conditions (Dhanarajan et al, 1990). It has a short growing period of 6-8 years (Bengtsson and Whitaker, 1988) as compared to most hardwoods and softwoods which take up to 35 years to mature (Kaigarula, 1987 and Brown 1978).

Bamboo is the fastest growing plant on earth. It grows one third faster than the fastest growing tree and some species have been reported to grow more than one meter in a single day (Environmental Bamboo Foundation, 1999).

This research exercise sought to determine as accurately as possible the properties that are important for design using B. vulgaris. It is hoped that when these properties are published, designers will have at least one more properly defined and codified construction material from which to choose, which also meets the objective of sustainable use of forest resources.

The broad objective of this study was to determine the mechanical properties of bamboo (B. vulgaris). The specific objectives were;

1. To determine the following properties of B. Vulgaris:
   - Density
   - Tensile strength
   - Compressive strength
   - Bending strength
   - Modulus of elasticity
2. To compare the values of the above parameters with those of other bamboo species
3. To evaluate the effect of nodes on tensile, compressive and bending strength
2.0 LITERATURE REVIEW

Physical and mechanical properties of bamboo have been investigated by several researchers including: growth and anatomy, thermal expansion, moisture content, density, chemistry, compressive strength, dynamic visco-elasticity, bending strength, shear strength and tensile strength. The relationship between these properties has also been investigated (Janssen, 1991). Table 2.1 gives examples of the equations used to estimate the moisture content and density of bamboo in different conditions.

Table 2.1: Physical Properties of Bamboo

<table>
<thead>
<tr>
<th>Physical property</th>
<th>Equation</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content</td>
<td>( M.C. = 94.5 - 12.7H + 1.6H^2 - 0.088H^3 )</td>
<td>Janssen (1991)</td>
</tr>
<tr>
<td>Density (function of position)</td>
<td>( \rho = 596 + 15H + 0.4H^2 )</td>
<td>Fangchun (1981)</td>
</tr>
<tr>
<td>Density (function of age)</td>
<td>( \rho = 435 + 11A - 0.155A^2 )</td>
<td>Fangchun (1981)</td>
</tr>
</tbody>
</table>

Where:
- \( H \) = any value between 0 and 10 derived by dividing the length of the culm into ten equal parts in which 0 means bottom and 10 means top.
- \( M.C. \) = Moisture content
- \( \rho \) = density (kg/m\(^3\))
- \( A \) = age (years)

Factors Affecting Tensile Strength of bamboo include: Mass per Volume, age of the culm, position along the stem and the presence of nodes. Researchers have developed equations to explain these relationships such as the examples given in Table 2.2.

Table 2.2: Effect of Density on Tensile Strength

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>RELATIONSHIP WITH STRENGTH</th>
<th>TENSILE STRENGTH</th>
<th>AUTHOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density for small samples (0.004-0.025mm(^2) X-sectional area)</td>
<td>( \sigma = 0.76\rho + 2.25 \times 10^{-3}E - 131 )</td>
<td>McLaughlin (2009)</td>
<td></td>
</tr>
<tr>
<td>Density for large samples (10-100mm(^2) X-sectional area), Density for all samples</td>
<td>( \sigma = 0.25\rho + 2.14 \times 10^{-3}E - 443 )</td>
<td>McLaughlin (2009)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \sigma = 0.307\rho )</td>
<td>Fangchun (1981)</td>
<td></td>
</tr>
</tbody>
</table>

Where:
- \( \sigma \) = ultimate tensile strength (MPa)
- \( P \) = mass per volume of the bamboo (kg/m\(^3\))
- \( E \) = Young’s Modulus (MPa)
Apart from the determination of the compressive strength of the various bamboo species, many researchers have considered the influence of several factors on compressive strength such as moisture content, density, age, position along the culm and seasoning as presented in Table 2.3.

Table 2.3: Factors Affecting Compressive Strength

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>RELATIONSHIP WITH COMPRESSIVE STRENGTH</th>
<th>AUTHOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content</td>
<td>$\sigma = 56.56 + \frac{130}{M.C.}$</td>
<td>Fangchun (1981)</td>
</tr>
<tr>
<td>Density (Green condition)</td>
<td>$\sigma = 0.003\rho^{1.5}$</td>
<td>Sekhar et al (1992)</td>
</tr>
<tr>
<td>Density (Dry condition)</td>
<td>$\sigma = 0.0089\rho^{1.33}$</td>
<td>Sekhar et al (1992)</td>
</tr>
<tr>
<td>Density (All conditions)</td>
<td>$\sigma = 0.107\rho$</td>
<td>Fangchun (1981)</td>
</tr>
<tr>
<td>Age</td>
<td>$\sigma = 44.4 + 13.1A + 1.83A^2$</td>
<td>Fangchun (1981)</td>
</tr>
</tbody>
</table>

3.0. THEORETICAL CONSIDERATIONS

3.1. STRESS

Stress is the basic parameter from which strength is determined. Consider the small cube below to be a point on which stress acts in all directions, idealized in the rectangular Cartesian coordinate system in three dimensions (Chung, 1988):

If a small area $\Delta A$ is taken in a plane and a force $\Delta P$ is the internal force acting on it activated from the load $P$, then the unit stress acting at this point is defined as (Chung, 1988):

$$\sigma = \lim_{\Delta A \to 0} \frac{\Delta P}{\Delta A} = \frac{dP}{dA} \quad \ldots \ (3.1)$$

The unit stress is decomposed into two components:

1. Normal stress – Normal to the plane of reference

To completely specify the stresses at a point, it is necessary to specify the stresses at the point on 3 mutually perpendicular planes passing through the point. For each plane it is possible to specify one normal stress and two shear stresses. This yields a total of nine stresses at a point. If the three mutually perpendicular planes are perpendicular to the $x$, $y$ and
coordinate axes, and then the complete specification of the stress at a point is $\sigma_{ij}$ (Timoshenko and Goodier, 1983). Where:

$$\sigma_{ij} = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{bmatrix} \quad \text{… (3.2)}$$

the first subscript denotes the normal to the plane under consideration and the second subscript designates the direction of the stress. Thus $\sigma_{12}$ denotes shearing stress acting on the plane perpendicular to the x-axis and the stress acts on the y-axis.

Normal stresses are therefore, $\sigma_{11}$, $\sigma_{22}$ and $\sigma_{33}$ while the rest are shear stresses. Hence, the necessary and sufficient condition for state of pure shear exists when:

$$\sigma_{ii} = 0 \quad \text{… (3.3)}$$

If there are no stresses (or negligible stress) acting in Z direction, but there are stresses acting in X and Y directions, the state of stress is called plane stress. Hence,

$$\sigma_{13} = \sigma_{23} = \sigma_{33} = 0 \quad \text{… (3.4)}$$

In unidirectional stress, the action is in one direction only, say X-direction. Hence (Mase, 1970):

$$\sigma_{ij} = \begin{bmatrix} \sigma_{11} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} = \sigma_{11} = \frac{P}{A} \quad \text{… (3.6)}$$

This is the stress determined in this project sine testing machines for stress(strength) determination only give values of stress in one direction (unidirectional) at a time. Hence to give all the nine parameters required to fully define the state of stress in all directions, the orientation of the material must be changed on the machine to suit the various directions.

### 3.2. STRAIN

When an elemental body is deformed, the unit elongation or strain at a point on the element is $U_{ij}$ in the X-direction and $V_{ij}$ and $W_{ij}$ in the Y and Z directions respectively. The shearing stresses are: $\frac{1}{2}(V_{ij} + U_{ij})$, $\frac{1}{2}(V_{ij} + W_{ij})$, and $\frac{1}{2}(U_{ij} + W_{ij})$. Hence the complete specification of strain at a point is $\varepsilon_{ij}$ (Timoshenko, 1983).

Where:

$$\varepsilon_{ij} = \begin{bmatrix} \varepsilon_{11} & \varepsilon_{12} & \varepsilon_{13} \\ \varepsilon_{21} & \varepsilon_{22} & \varepsilon_{23} \\ \varepsilon_{31} & \varepsilon_{32} & \varepsilon_{33} \end{bmatrix} \quad \text{… (3.8)}$$

The first subscript (i) denotes the normal to the plane under consideration and the second subscript (j) designates the direction of the strain. Thus $\varepsilon_{12}$ denotes shearing strain acting on the plane perpendicular to the x-axis and the strain acts in the y-axis.

Equation 3.5 can be reduced in the same manner to obtain unidirectional strain. Thus:
\[ \varepsilon_{ij} = \varepsilon_x = \frac{(l_i - l_0)}{l_0} \quad \ldots (3.9) \]

In the x-direction. This is the strain determined in this research project for bamboo in tension.

### 3.3. HOOKE’S LAW

Hooke’s law applies when stress is linearly proportional to strain. The generalized Hooke's law for small strain in linear elasticity is (Chung, 1988):

\[ \sigma_{ij} = C_{ijkl} \varepsilon_{km} \quad \ldots (3.10) \]

Where:

- \( \varepsilon_{km} \) = Cauchy’s infinitesimal strain tensor
- \( \sigma_{ij} \) = the stress tensor
- \( C_{ijkl} \) = the stiffness tensor and it describes the elastic moduli of materials.

For an anisotropic body with material properties that are different in all directions at a point, with no planes of symmetry and whose properties are functions of orientation at a point in the body (Gumbe, 1993) \( C_{ijkl} \) has a total of 81 constants. That is \( d^n = 3^4 = 81 \), with \( d \) = number of dimensions, \( n \) = orders of tensor. Hence for anisotropic materials (Chung, 1988),

\[
C_{ijkl} =
\begin{bmatrix}
C_{1111} & C_{1122} & C_{1133} & 0 & 0 & 0 \\
C_{2222} & C_{2233} & 0 & 0 & 0 & 0 \\
C_{3333} & 0 & 0 & 0 & 0 & 0 \\
C_{1212} & 0 & 0 & C_{2323} & 0 & 0 \\
C_{1313} & 0 & 0 & 0 & C_{3113} & 0 \\
\end{bmatrix}
\ldots (3.11)
\]

Twelve constants (nine are independent) are needed to describe the elastic behavior of wood: three moduli of elasticity, (E), three moduli of rigidity, (G), and six Poisson’s ratios, (\( \nu \)) (USDA, 1987). Hence for wood (Chung, 1988),

\[
\begin{bmatrix}
\gamma_{11} \\
\gamma_{22} \\
\gamma_{33} \\
\gamma_{12} \\
\gamma_{23} \\
\gamma_{31} \\
\end{bmatrix}
= \frac{1}{C_{ijkl}}
\begin{bmatrix}
\sigma_{11} \\
\sigma_{22} \\
\sigma_{33} \\
\sigma_{12} \\
\sigma_{23} \\
\sigma_{31} \\
\end{bmatrix}
\ldots (3.13)
\]

The moduli of elasticity and Poisson’s ratios are related by the expression of the form (USDA, 1987),

\[
\frac{\nu_{ij}}{E_i} = \frac{v_{ij}}{E_i}, i \neq j; i, j = L, R, T \quad \ldots (3.14)
\]

The three moduli of elasticity denoted by \( E_L \), \( E_R \) and \( E_T \) are, respectively moduli along longitudinal, radial and tangential axes of wood. The three moduli of rigidity are denoted by \( G_{LR} \), \( G_{LT} \), \( G_{RT} \) are the elastic constants in the LR, LT and RT planes, respectively. For example, \( G_{LR} \) is the modulus of rigidity based on shear strain on LR plane, and shear stresses in the LT and RT planes. The six Poisson’s ratios are denoted by \( \nu_{LR}, \nu_{RL}, \nu_{LT}, \nu_{TL}, \nu_{RT}, \nu_{TR} \). The first letter of the subscript refers to the direction of the applied stress and the second letter refers to the direction of the lateral deformation. For example, \( \nu_{LR} \) is the Poisson’s
ratio for deformation along the radial axis caused by stress along the longitudinal axis (USDA, 1987).

3.4. FACTORS AFFECTING MECHANICAL PROPERTIES OF WOOD

During tests to determine mechanical properties of timber the following factors are recorded together with the strength parameters to make such experiments reproducible: moisture content, density, temperature and time under load.

When moisture decreases below the fiber saturation point, it begins to affect the mechanical properties of wood. Decrease in moisture content increases the strength of wood since the cell walls become more compact. Cell walls are compacted because, with loss of moisture, the mass of wood substance contained in a certain volume increase (Tsoumis, 1991).

Given any mechanical property at standard values of moisture content, it is possible to predict the values of that property at any moisture content using equation 3.7 (USDA, 1987)

\[ P_x = P_{12} \left( \frac{P_{12}}{P_g} \right) \text{Exp}\left( \frac{12-M}{M_p-12} \right) \]  … (3.15)

Where:

- \( P_x \) = mechanical property at a given moisture content, for example, tensile strength at 8% m.c.
- \( P_{12} \) = property at 12% m.c.
- \( P_g \) = property value in green condition
- \( M \) = m.c. at which property is desired
- \( M_p \) = Moisture content at the intersection of a horizontal line representing the strength of greenwood and an inclined line representing the logarithm of strength-m.c. relationship for dry wood. It is usually taken to be 25%m.c.

4.0 MATERIALS AND METHODS

4.1 MATERIAL SELECTION AND SAMPLING

The materials used in research project were bamboo of the species *Bambusa Vulgaris*. The number of samples required was 120 (40 for each of the three strength parameters under study). Hence each of the identified stalks was numbered from No. 1 – No. 220. Random numbers were then generated from a calculator to select the required 120 stalks. From the selected 120 culms, 24 culms were randomly selected for the abstraction of samples for the determination of density and moisture content determination, the selected culms were put back among the rest for use in the determination of strength properties.

The 120 stalks were then divided into three groups by randomly assigning the numbers 1,2,3 to each sample. The forty samples obtained in each group were used in the determination of tensile, compressive and bending strength respectively. The diameter of the bamboo stalks used ranged from 4cm to 6cm. The actual diameters were used to obtain the areas used to calculate the strength parameters specified in the tables in Appendix 3. The heights from which the samples were obtained were limited to 6m from the bottom of the stalk.

4.2 MATERIALS DRYING

The bamboos were then air-dried (naturally dried) for six weeks when they attained a moisture content of 10.8%. Subsequent measurements of the moisture content in the next two weeks gave similar values to those obtained earlier, indicating that the stalks had reached equilibrium with the atmospheric conditions. Since ambient temperature and relative humidity were in the range of 17°C to 23°C and 63% to 67% respectively, the mode of moisture reduction was in
agreement with BS 373: 1979 for control of moisture content.

**4.3 EXPERIMENTS**

Several experiments were carried out to determine the various mechanical properties of *B. Vulgaris*. The properties investigated included density, tensile strength, compressive strength and bending strength.

**4.3.1 MATERIALS TESTING**

The material testing procedures are well defined in existing standards and Table 4.1 outlines the various standards that were used for different tests.

*Table 4.1. Standards Used for Different Tests*

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>STANDARD</th>
<th>RELEVANT FORMULAE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength</td>
<td>KS02 – 982: part 5: (1990), (BS 373, 1957), (BS 5820, 1979)</td>
<td>( A = 20X )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( F_t = \frac{F_{\text{max}}}{A} )</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>KS 02 – 982: part 3 (1990), (BS 373, 1957), (BS 5820, 1979)</td>
<td>( A = \pi \left[ \frac{d_e^2}{2} - \frac{d_i^2}{2} \right] )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( F_c = \frac{F_{\text{max}}}{A} )</td>
</tr>
<tr>
<td></td>
<td>(BS 5820, 1979)</td>
<td>( I = \frac{bh^3}{12} ), ( Z = \frac{I}{c} )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( F_b = \frac{1}{2} \frac{F_{\text{max}}}{Z} )</td>
</tr>
</tbody>
</table>

Where:
- \( F_t \) = tension strength (MPa) 3 sf.
- \( F_{\text{max}} \) = maximum load (N)
- \( A \) = cross-sectional area (mm²)
- \( D_e \) = external diameter (mm)
- \( D_i \) = internal diameter (mm)
- \( A \) = cross-sectional area (mm²)
- \( F_c \) = compressive strength (N/mm²)
- \( F_{\text{max}} \) = maximum load (N)
- \( F_b \) = bending strength (MPa)
- \( B \) = width of the timber (mm)
- \( H \) = height of cross-section of timber (mm)
- \( L \) = length of specimen (mm)
- \( I \) = second moment of area (mm⁴)
- \( C \) = maximum height from neutral axis to point of load application = \( h/2 \) (mm)
- \( Z \) = section modulus (mm³)
- \( F_{\text{max}} \) = maximum load at failure (N)
- \( F_b \) = bending strength (MPa)

The Torsee Universal Tensile Machine type AMU – 5 – DE shown in Fig. 4.4 was used in the determination of the tensile, compressive and bending strength.

**5. RESULTS AND DISCUSSION**

**5.1. INTRODUCTION**

Table 5.1 is a summary of the results obtained. The table gives the results of the various tests performed in the project, in terms of mean, standard deviation (S.D) and coefficient of variation (C.V).
**Table 5.1: Summary of All Results**

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>MEAN</th>
<th>S.D</th>
<th>C.V.(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content</td>
<td>Dry basis</td>
<td>10.76%</td>
<td>1.35</td>
</tr>
<tr>
<td>Density</td>
<td>Oven basis</td>
<td>590kg/m(^3)</td>
<td>0.10</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>With nodes</td>
<td>49.89 MPa</td>
<td>8.93</td>
</tr>
<tr>
<td></td>
<td>Without nodes</td>
<td>51.68 MPa</td>
<td>7.95</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>With nodes</td>
<td>94.3 MPa</td>
<td>19.10</td>
</tr>
<tr>
<td></td>
<td>Without nodes</td>
<td>117.9 MPa</td>
<td>9.70</td>
</tr>
<tr>
<td>Bending strength</td>
<td>With nodes</td>
<td>107.0 MPa</td>
<td>21.50</td>
</tr>
<tr>
<td></td>
<td>Without nodes</td>
<td>137.7 MPa</td>
<td>15.30</td>
</tr>
<tr>
<td>MOE*(tensile)</td>
<td>With nodes</td>
<td>3002.2 MPa</td>
<td>567.30</td>
</tr>
<tr>
<td></td>
<td>Without nodes</td>
<td>3594.0 MPa</td>
<td>649.80</td>
</tr>
<tr>
<td>MOE*(compressive)</td>
<td>With nodes</td>
<td>7268.1 MPa</td>
<td>2889.20</td>
</tr>
<tr>
<td></td>
<td>Without nodes</td>
<td>10405.3 MPa</td>
<td>3525.5</td>
</tr>
</tbody>
</table>

MOE* is Modulus of Elasticity

**5.2 DENSITY**

Before the commencement of tests to determine the various strength parameters, it was necessary to determine the moisture content of the air-dried bamboo. It was found that the M.C was 10.76%. This particular experiment confirmed that the bamboo culms to be used in the determination of strength properties were below 12% moisture content as stipulated by the standards. These values are useful in correcting the strength values obtained in this particular research project to the required strength at 12% moisture content. The determination of the density of bamboo culms used was also performed before the start of the experiments to determine strength properties. It was found that the density was 590kg/m\(^3\). It was necessary to find out the density of the particular bamboos used in this project in recognition of the fact that density has a great influence on mechanical properties of wood.

In the research papers presented in Janssen (1991) the values of density range from 500 – 700kg/m\(^3\). The values of densities obtained for *B. Vulgaris* in this project falls within this range. From this result alone, it is possible to deduce that, holding all factors the
same, the strength parameters obtained in this project will be similar to those of other bamboo species on the strength of the fact that density has a major influence on strength. This is because the density of the bamboo is a property of the wood material in it.

5.3 COMPRESSIVE STRENGTH

Fig 5.1 is the frequency diagram of results obtained in the compressive strength test. The frequency curve was drawn using the data contained in Figure 3.1. Janssen (1991) and U.N (1972) report that the values of compressive strength from past research work on bamboo in general falls within the range of 30 – 90 MPa. The results obtained in this project, that is, 49.89MPa and 51.68MPa for nodes and without nodes respectively, fall within this range. Statistical analysis reveals that there is no significant difference between the compressive strength of specimens with nodes and those without nodes. Hence, the presence or absence of nodes was found not to have any effect on the compressive strength as per this experiment. This is supported by the frequency curves in Figure 5.1 in which peaks of the nodes and the internode are on the same vertical line, indicating similar values of compressive strength. The Figures 5.2 and 5.3 compare whole specimens with specimens which have not yielded.

![Fig. 5.1 Frequency Curve for Compressive Strength](image)
The practical application of these results is that, during compression, the loads may be applied at any point as long as they do not exceed the values indicated for the nodes and the appropriate slenderness ratios. The most common application of compression members is in columns. It is possible to use bamboo for this application as long as the area and slenderness ratios are adequate. Since, the node does not affect compressive strength, this means that the multiplicity of nodes (more than one node) along the culm will not affect the overall strength of a bamboo member in compression.

5.4 TENSILE STRENGTH

The following results were obtained in the tensile strength test: 94.30MPa with nodes and 117.90MPa without nodes as presented in Table 5.1. The values obtained for tensile strength at the node obtained in this project were slightly lower than those obtained in the earlier experiments presented in Janssen (1991) which range from 100–200 MPa. However, the value of tensile strength for specimens without nodes still falls within this range. This difference may be explained in the context of different ages, growth conditions and species of bamboo used.

The statistical analysis revealed that there was a significant difference in strengths between specimens with nodes and those without nodes. This means that the internode of bamboo culms is stronger in tension than the node. This can be supported by the fact that in the experiments, all the specimens with nodes failed at the node in tension. The fact that the peak of the tensile frequency curve (Fig. 5.4) of the node is to the left of the tensile strength frequency curve of the internode also shows that the bamboo is stronger in the internode.

Again, the statistical result can be attributed to the distribution of fibers along the bamboo culm. Hence failure occurred at the node because of the absence of fibers which indicates a weakness in tension. This is because fibers are responsible for reinforcing the bamboo in tension.

Theoretically, the presence of more or less nodes along the stem of a bamboo member in tension will not change the tensile strength. This is because failure occurs at the weakest point along the length. Hence if there is more than one node along the stem, failure will most definitely occur at the weakest node.
5.5 BENDING STRENGTH

The frequency curve in Figure 5.6

These values of bending strength obtained in the bending strength test, that is, 107.00MPa and 137.70MPa with and without nodes respectively, tally with those obtained for the other bamboo species used in the past research and presented in Janssen (1991) where the range is between 90-150MPa.

The nodes were shown in the statistical analysis to have a significant effect on the bending strength of bamboo. In the actual bending strength test, all the specimens with nodes failed at the node, which indicates an obvious weakness at the node. This failure at the node can be explained by the absence of fibers at the node, which would have resisted bending.
Fig. 5.7. Failure in Bending

When there is more than one node, failure is likely to occur at the nodes closest to the loading. As such, the loading with bending forces (of beams) must be designed to avoid the node. It would be helpful for designers using bamboo beams to use more than one bamboo pole and have nodes on different poles featuring at different positions along the poles.

5.6 MODULUS OF ELASTICITY

The modulus of elasticity was determined in both the tensile and compressive tests. The values of Modulus of Elasticity obtained from the compressive strength test (10,405.3MPa and 7,268.1MPa) are much higher than those obtained from the tensile strength (3,002.2MPa and 3,594.0MPa) the values from the tensile strength test are much lower than the values expected for the Modulus of Elasticity of bamboo.

This may be explained by the fact that when subjected to tensile forces, wood tends to fail by shearing. Hence, the elongation is much longer than expected and this decreases the value of the Young’s Modulus. Therefore, the values obtained from the compressive test can be considered to be more accurate than those obtained from tensile strength test.

6.0 CONCLUSIONS

a) The following strength parameters were obtained from the study
1. The mass per unit volume of bamboo was found to be 590kg/mm³.
2. Tensile strength of the bamboo at the nodes was found to be 94.30MPA while the internode was found to have a strength of 117.90MPa.
3. Compressive strength of bamboo was obtained as 49.89MPa and 51.68MPa at the internode.
4. The bending strength test yielded 107.00MPa at the node and 137.70MPa at the internode.
5. The Modulus of Elasticity from the compression strength test was 10,405.3MPa at the internode and 7,268.1MPa at the node.

b) The mechanical properties of Bambusa Vulgaris compares very well with those of other species of bamboo.

c) The effect of nodes has been shown in this project to be significant in tension and in bending, but has no influence over the compressive strength. Hence the node is the weakest point in this bamboo during tension and bending.
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