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The Influence of Anatomy and Mode of Seasoning on the Strength Properties of Bamboo

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Standardization of the application of bamboo as material of construction requires indepth knowledge of the geometrical and mechanical properties of the culm in relation to some physical parameters that affect structural performance of biological materials. Literature has concentrated mostly on the application of bamboo as reinforcement in low modulus concrete while treating many other factors affecting its structural performance as constant. An investigation therefore conducted to determine the influence of some parameters such as culm girth, moisture content and mode of seasoning on variations of strength along the length of bamboo vulgaris culm. Analysis shows that the girth of matured culm tapers linearly from the ground level to the tip. The green moisture content decreased along the length of the culm while the density was relatively constant. Seasoning was found to increase the strength of bamboo and strength depended on the mode of seasoning. The average compressive stress was 44.84 N/mm² for green specimen, 36.5 N/mm² for sun-dried and 61.12 N/mm² for the ambient-temperature dried. The average flexural stress was 32.57 N/mm² for green samples, 35.17 N/mm² for oven-dried, 36.45 N/mm² for ambient temperature dried. The modulus of elasticity was fairly constant along the length of each culm and hovered around 2.5 x 10⁶ N/mm² for green samples and 3.0 x 10⁶ N/mm² for the ambient-temperature dried samples. It was concluded that the strength of dried bamboo depended on the mode of seasoning and the ambient temperature is the best mode of seasoning bamboo for improved strength.

INTRODUCTION

Bamboo plays an essential role in the daily life of millions of people in both the developed and developing countries. It has been used for centuries for various purposes ranging from consumption of the young shoots as food, to the application matured clumps as prop for formwork in building construction and as reinforcement in low-cost housing. Scientific applications of bamboo species as material of construction in low-cost housing projects have been subject of research focus world-wide since mid-twentieth century in a drive towards standardisation. Glenn (1950) investigated the mechanical properties of bamboo in tension, compression and flexure. He conducted tests on rectangular and tee beam specimen by varying the percentage of bamboo reinforcement and strength of concrete. Mebra, Uppal and Chadda (1951) investigated the water absorption and volume change of bamboo. Mentzinger and Plourde (1966) carried out tension and bond test in untreated, varnish treated and sealer treated bamboo. Francis and Paul (1966) suggested the procedure for selecting and preparing bamboo as reinforcement. Cox and Guymayer (1969) performed tests to determine the tensile strength, bond strength, coefficient of thermal expansion and flexural strength of bamboo under sustained load. They then investigated the properties of bamboo reinforced concrete by varying the type, volume and treatment of bamboo culm.
Separate studies on Indian-bamboo (Narayana, Abdul and Rahman, 1962), Egyptian bamboo (Youssef, 1976) and Pennsylvania bamboo (Fang and Fay, 1978) showed that bamboo culm is capable of absorbing between 20 to 40% water in the first 14 hours when soaked in water. Wang and Wang (1976) concluded that the inner fibre of bamboo is by far more sensitive to water absorption than the outside fibre. In two separate studies of sulphur treated bamboo poles (Fang et al., 1976) and sulphur treated bamboo rods for structural reinforcement of concrete (Fang and Mehta, 1978), it was shown that treated bamboo were less sensitive to water absorption than the untreated ones. It was further observed that non-treated bamboo had strong and tight bonds with the concrete. Dayle (1976) identified bamboo structural forms, which do not depend on board and can function satisfactorily inside of prior dimensional stability and low elastic modulus. Janssen (1983, 1988) formulated a design standard for determining the allowable stress for bamboo by treating at the ratio shown in Table 1 between the density of dry and wet bamboo and their compressive flexural and shearing strengths.

In Nigeria, the most widely available species of bamboo of structural value is the bambusa vulgaris culm, the most widely available species of bamboo of structural value in Nigeria. Bamboo lengths were procured from a single location of the Obafemi Awolowo University, Ilu-Ife. Clumps selected were those having well grown and developed side branches and fairly straight with external culm diameter in the range of 60mm and 300mm respectively. This was to ensure that test specimens were matured clumps.

A total of 32 culm lengths each nine metres long were cut at a height of 600mm above ground level, carefully trimmed to remove the bud outgrowth and transported to the Faculty of Environmental Design and Management laboratory of the University for processing. Twenty-four culm lengths were finally selected for the experiment and were divided into groups C and F of 12 culm lengths each. Group C corresponds to where compressive test specimen were to be taken while group F was for flexural test specimen. Each group was later divided into four sections of three culm lengths per section. The sections relate to the modes of seasoning and control which were oven-drying, sun-drying, ambient temperature drying and green (control). Twenty 300mm long compressive test specimen were taken from each culm length in group C while ten 600mm long flexural test specimen were taken from each culm length in group F. A total of 60 specimens were tested in each section of the compressive test while 30 specimens were tested in each section of the flexural test. All specimens were with nodes occurring at approximately 150mm from either ends and were taken serially from the bottom of each culm length to the top. The compressive test specimen were conditioned 48 hours while the flexural test specimen
Where $k$ denotes the mode of seasoning ($k = 1, 2, 3, 4$ represents oven-drying, sun-drying, ambient-temperature drying and green specimen respectively).

$i$ is the serial number of culm length in a particular section ($i = 1, 2, 3$).

$j$ is the position of the specimen along a culm length ($j = 1, 2, ....$).

The external and internal diameters of each final specimen were measured with vernier callipers after which they were weighed and their moisture content determined. Specimen for ambient-temperature seasoning were left to dry under room temperature inside the laboratory for a period of four months and those for sun-drying were spread outside the laboratory for three months. Putting specimen inside the oven for 24 hours at a temperature of 100°C seasoned the oven-drying samples.

Specimens were tested as soon as their seasoning period was over. The green specimens were tested immediately after preparation. This was followed by the oven-dried specimens and later the sundried and ambient-temperature dried specimens. The compression specimens were carefully subjected to compression load one after the other using ELE compression testing machine. Each sample was positioned such that the bottom part rest on the bottom platen of the machine while the top platen fixed the specimen in upright position. This ensured that compression stress was evenly distributed parallel to the grain of the specimen. A specimen was loaded by clockwise tightening of the loading valve. The black pointer on the scale then carried along with it the red pointer at the point the specimen started to experience compressive stress. Immediately the material failed, the black pointer moved back to the zero point leaving the red pointer to be read.

The flexural test was performed using Avery Universal testing machine. Here, two strong planks were used as loading platforms. The base platform which is longer had size 55 x 12 x 1.2cm while the upper platform had size 25 x 12 x 1.5cm. Two steel supports were fixed into the base platform and close to each of the ends. Similar steel loading was fixed to the upper platform for one-point loading. The 600mm long bamboo specimens were placed on the base platform one after the other. The upper platform was then fixed in position. As the specimen was subjected to load touched the bamboo specimen when the testing machine was switched on (figure 1).

![Fig. 1: Principle of one-point flexural loading](image)

**RESULTS AND DISCUSSION**

Studies on the girth of fresh culm showed that bamboo tapers gently from the bottom to the tip. The average variation of the external diameter of bamboo clumps studied between the height of 600mm to 630mm above ground level is shown in Figure 2. The variation of the external diameter showed a gentle trend amounting to an average change of 0.5mm between successive internodes. At 600mm above ground level, the average external diameter of the clumps was 83.62mm and the average internal diameter was 68.37mm. These decreased to 77.82mm and 64.32mm respectively at the height of 3000mm above ground level. At 630mm above ground level, the external and internal diameter further decreased to 60.37mm and 45.41mm respectively. This girth variation gave an average culm thickness of 13.75mm for the specimens studied. From a structural point of view therefore, bamboo culm is more of tapered structural elements rather than linear prismatic element.

The maximum flexural stress a structural member can be subjected to is a function of the section modulus. Figure 2 also showed that the section of bamboo culm decreases along the length of the culm from the bottom to the tip. For the culm lengths studied, the section modulus decreased approximately linearly. At 500mm above ground level, the average section modulus was 31.76 $10^3$ $mm^4$ and this decreased to $10.32$ $10^3$ $mm^4$.
height or diameter above ground level, the external and internal diameter further decreased to 69.37 mm and 45.41 mm respectively. This girth variation gave an average culm thickness of 13.75 mm for the specimens studied. From structural point of view therefore, bamboo culm is more of tapered structural elements rather than linear prismatic element.

The maximum flexural stress a structural member can be subjected to is a function of the section modulus. Figure 1 also showed that the section of bamboo culm decreases along the length of the culm from the bottom to the tip. For the culm length studied, the section modulus decreased approximately linearly. At 600 mm above ground level, the average section modulus was 31.76 x 10^3 mm^4 and this decreased to 4.69 x 10^3 mm^4 at the height of 6300 mm above ground level (Fig.2). The average density for the specimen was 1.345 g/cm^3. This figure could be used to estimate the weight of fresh bamboo culm since density does not vary substantially along the length of the culm. The green moisture content of the specimens ranged from 150% at the bottom to 127% at the tip. This showed that bambusa vulgaris culm holds substantial water and is responsible for its large radial shrinkage when seasoned. Similar view has been expressed by some other authors (Liese, 1986) and (Doem and Ogendengbe, 1987). The ranges of moisture content and dry basis for the cured samples were from 10.75 to 11.29% for oven-dried, 11.35 to 11.83% for sun-dried and 11.45 to 12.10% for ambient temperature dried. The corresponding average dry density were 734 g/m^3, 741 g/m^3 and 748 g/m^3. Statistical t-test were performed at 5% level of significance to know whether the means of the moisture content on one hand and the means of the density on the other hand differ significantly from the curing method to the other. The results showed at there were significant differences in the means of the moisture content and density of the over-dried samples when compared with sun-dried and ambient temperature dried samples. However, there were no significant differences in the means of the moisture content and density of the sun-dried samples when compared with the ambient temperature dried.

The compressive stress corresponding to failure load of the green culm between the height of 600 mm and 6300 mm above ground level was 100.65 KN to 41.15 KN. The range for the oven-dried samples was 105.40 KN to 48.45 KN. For sun-dried and ambient temperature specimen the range was 110.50 KN to 50.15 KN and 112.75 KN to 52.15 KN respectively. The average ultimate load for the green specimen was 67.25 KN, 72.70 KN for the oven-dried, 74.2 KN for the sun-dried and 75.34 KN for the ambient temperature dried.

In the flexural test, all specimens did not go through significant deflection before splitting failure started at the point of application of the load and spread to the two ends. The failure load appeared to depend on the cross-sectional area of the specimen being tested. Table 3 showed that the average failure load for the green specimen was 483 KN and the corresponding values for the cured specimens were 5.62 KN, 5.75 KN and 5.96 KN for the oven-dried, sun-dried, and ambient-temperature dried specimens respectively. The corresponding average bending stress were 32.57 KN/mm^2 for the green specimen, 35.17 KN/mm^2 for the oven-dried, 36.45 KN/mm^2 for the sun-dried and 38.25 KN/mm^2 for the ambient temperature dried.

For a simple supported beam with concentrated load at the middle, the modulus of elasticity, E, is given by

\[ E = \frac{Pl^3}{48bh^3} \]
Where $F$ is the failure load
\[ F = \frac{P \times d}{L} \]
\[ P \] is the applied load
\[ L \] is the gauge length
\[ d \] is the deflection and
\[ I \] is the second moment of area

The result of the computation indicated that the average modulus of elasticity in bending for the green specimens was $2.24 \times 10^4 \text{N/mm}^2$ and for the cured specimens, it was $2.70 \times 10^4 \text{N/mm}^2$, $2.85 \text{N/mm}^2$ and $3.08 \text{N/mm}^2$ for the oven-dried, sundried and ambient temperature dried samples respectively (Table 3.).

CONCLUSION
The result of this investigation revealed the following:

1) The girth of bamboo culm tapers linearly along its length from the bottom to the top; hence it cannot be analysed as a prismatic element in structural applications.

2) As a result of tapering, the density and load carrying capacity of bamboo reduces along the length of the culm from the ground level to the tip.

3) Seasoning increased the strength of bamboo and this varied with the mode of seasoning.

4) Ambient-temperature seasoning improved the strength capacity of bamboo over sundried and oven-dried mode of seasoning. However, the strength of bamboo seasoned by ambient temperature and the one seasoned by sun-drying were not significantly different.

5) The modulus of elasticity of bamboo culm is relatively constant throughout the length of a culm and it hovers around $3.08 \times 10^4 \text{N/mm}^2$ for sundried and ambient temperature dried bamboo.

As a result of tapering, the density and load carrying capacity of bamboo reduces along the length of the culm from the ground level to the tip. Hence fibre-shrinkage is less in sun-drying than in oven-drying and this led to improved strength of the sundried samples over the oven-dried samples.

Ambient-temperature drying involves only long wave radiation with fluctuating effects of temperature and relative humidity. Thus the rate of moisture extraction from saturated fibre is slowest and quite gradual. This led to improved strength over the over-dried and the sundried samples.
Table 1: The Ratio between the Density (Kg/m³) and the Allowable Stress (N/mm²) of Bamboo

<table>
<thead>
<tr>
<th>Mode of Seasoning</th>
<th>Compressive Stress (no buckling)</th>
<th>Bending</th>
<th>Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>0.011</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td>Oven-dried</td>
<td>0.013</td>
<td>0.020</td>
<td>0.003</td>
</tr>
<tr>
<td>Sun-dried</td>
<td>0.003</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Compressive Stress and Modulus of Elasticity of Bamboo at Various Modes of Seasoning

<table>
<thead>
<tr>
<th>Mode of Seasoning</th>
<th>Compressive Stress N/mm²</th>
<th>Modulus of Elasticity x 10⁴ N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green (unseasoned)</td>
<td>44.84</td>
<td>2.80</td>
</tr>
<tr>
<td>Oven-dried</td>
<td>56.53</td>
<td>3.15</td>
</tr>
<tr>
<td>Sun-dried</td>
<td>60.14</td>
<td>3.42</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>61.12</td>
<td>3.47</td>
</tr>
</tbody>
</table>

Fig. 3: Variation of Ultimate Compressive Load along the Length of Bamboo Culm

Fig. 4: Variation of Ultimate Flexural Load along the Length of Bamboo Culm
Table 3: Flexural Stress and Modulus of Elasticity for Various Modes of Seasoning

<table>
<thead>
<tr>
<th></th>
<th>Flexural Stress (N/mm²)</th>
<th>Modulus of Elasticity x 10⁶ N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green (unseasoned)</td>
<td>32.57</td>
<td>2.24</td>
</tr>
<tr>
<td>Oven-dried</td>
<td>35.17</td>
<td>2.70</td>
</tr>
<tr>
<td>Sun-dried</td>
<td>36.45</td>
<td>2.85</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>38.25</td>
<td>3.08</td>
</tr>
</tbody>
</table>

REFERENCES


