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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 propoerties of the culm in relation to some physical parameters that affect structural performance of biological materials. Literatures have 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 was 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 bambusa vulgaris culm. Analysis showed 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 44.84N/mm^2 for green specimen. 36.5N/mm^2 for sundried and 61.12N/mm^2 for the ambient-temperature dried. The average flexural stress was 32.57N/mm^2 for green samples, 35.17N/mm^2 for oven-dried, 36.45N mm^2 for ambient temperature dried. The modulus of elasticity was fairly constant along the length of each culm and hovers around 2.5 x 10^{4}N/mm^2 for green samples and 3.0 x 10^{4}N/mm^2 for green samples and 3.0 x10^{4}N/mm^2 for cured 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 schools 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 (Narayama, Abdul and Rahman, 1962). Egyptian [illegible] oo (Youssef, 1976) and Pennsylvania bamboo ([illegible] ang 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. Wu 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 study 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 bond with the concrete. Datyle (1976) identified bamboo structural forms, which do not depend on bond and can function satisfactorily inspite of poor dimensional stability and low elastic modulus. Janssen ([illegible] 83, 1988) formulated design standard for determining the allowable stress for bamboo by arriving 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 specie of bamboo of structural values is the bambusa vulgaris and little research efforts have been made towards its standardisation as an engineering material. Omojola and Omoyosi (1976) studied the potential of bambusa vulgaris as a structural engineering material for use in farm structures. They concluded that bamboo obeys Hooke's law for small strain and that the node is a source of weakness to bamboo., Nwa (1978) explored the use of bamboo as a drainage material and concluded that it could be used effectively as field drainage. Lucas and Ogedengbe (1987) studied the shrinkage characteristics of bamboo and found that bamboo clumps shrink mainly in the radial direction and that there was no measurable shrinkage in longitudinal direction. Olateju (1993) investigated the use of bambusa vulgaris (BaVu) splints as reinforcement in terracrete and concluded that the splints performs better as reinforcement than when the whole culm is used.

Standardisation of [illegible] application of bamboo as an engineering material is realisable only when design [illegible] are [illegible]

effect of some physical and anatomic conditions [illegible] the variation of strength along the length of the culm. The strength properties of bamboo like wood, would depend on the moisture content, anatomy of the plant, position of the specimen on the plant, specific gravity and age. The object of this study is to present additional experimental information based on investigation of the influence of plant anatomy and mode of seasoning on the compressive and flexural strength of bamboo culm.

MATERIALS AND METHODS

The primary material used in the experiment was bambusa vulgaris culm, the most widely available specie of bamboo of structural value in Nigeria. Bamboo clumps were procured from a single large clump in the vicinity of Obafemi Awolowo University, Ile-Ife. Clumps selected were those having well grown and developed side branches and fairly straight with external culm diameter and internodes 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 specimens [illegible] ij.

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 1000C 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 lightening 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 [illegible] load touched the bamboo specimen when the testing machine was switched on (figure 1).

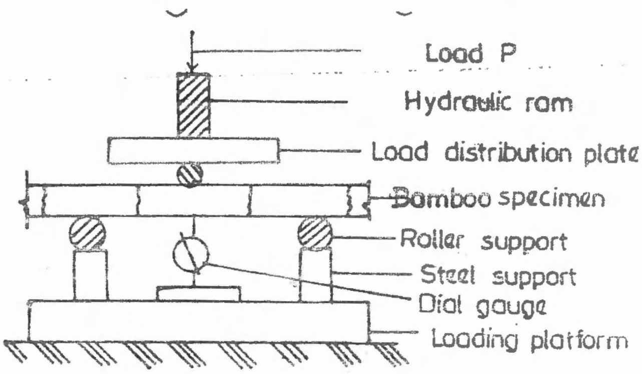


Fig.1: Principle of one points flexural loading

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 6300mm 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 600mm above ground level, the average section modulus was 31.76 x 10^3mm^3 and this decreased to [illegible] height of 6300mm 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 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 600mm above ground level, the average section modulus was 31.76 x 10^3mm^3 and this decreased to 4.69 x 10^4mm^3 at the height of 6300mm above ground level (Fig.2). The average density for the specimens was 1,365.5Kg/m^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 (Lucas and Ogendengbe, 1987). The ranges of moistures content on dry basis for the cured samples were from 10.75 to 11.20% for oven-dried, 11.35 to 11.85% for sundried and 11.45 to 12.10% for ambient temperature dried. The corresponding average dry density were 734g/m^3, 741kg/m^3 and745kg/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 that there were significant differences in the means of the moisture content and density of the over-dried samples when compared with sundried and ambient temperature dried samples. However, there were no significant differences in the means of the moisture content and density of the sundried samples when compared with the ambient temperature dried.

The result of the compressive test showed a decrease in the ultimate compression load from the bottom to the tip of the culm for the seasoned and unseasoned samples (Fig.4). The range of the ultimate compressive load for the fresh culm between the height of 600mm and 6300mm above ground level was 100.65KN to 41.15KN. The range for the oven-dried samples was 105.40KN to 48.45KN. For sundried and ambient temperature specimen the range was 110.50KN to 50.15KN and 112.75KN to 52.15KN respectively. The average ultimate load for the green specimen was 67.29KN, 72.70KN for the oven-dried, 74.2KN for the sundried and 75.34KN for the ambient temperature dried.

The compressive stress correspondingly decreased from the bottom of the culm to the tip. The average compressive stress for the green culm was 44.84N/mm^3, 56.51 N/mm^3 for the oven-dried, 60.14N/mm^2 for the sundried and 61.12N/mm^2 for the ambient temperature dried (Table 2). The modulus of elasticity in compression was obtained by dividing the product of the load at failure and the gauge length by the product of the cross-sectional area and the axial shortening ($E=Pl/A\Delta$). Table 3 showed that the average modulus of elasticity for the fresh specimen was 2.8x10^4N/mm^2. This result is different, significantly from those of the cured samples, which were 3.15x104N/mm2, 3.42x104N/mm2 and 3.47x104Nmm2 for the oven-dried, sundried, and the ambient temperature dried respectively. The lower modulus of elasticity of the green samples could be attributed to lower failure load, higher cross-sectional area (no shrinkage) higher axial shortening and more moisture content than the cured samples.

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 4 85KN and the corresponding values for the cured specimens were: 5.62KN, 5.75KN and 5.96KN for the oven-dried, sundried and ambient-temperature dried specimens respectively. The corresponding average bending stress were 32.57N/mm^2 for the green specimens. 35.17N/mm^2 for the oven-dried, 36.45N/mm^2 for the sundried and 38.25N/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 $E= PL^3/48dI$

Where P is the failure 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 The strength results showed that curing significantly increased the strength of bamboo clumps. Oven-dried clumps were however significantly weaker in compression and flexure than the sundried and the ambient temperature dried clumps. There was no significant difference in the strength of clumps cured under the sun and those cured under ambient temperature except that ambient-temperature dried specimen had slightly higher strength. The differences in the strength of the green clumps and those cured in various modes may be attributed to the following reasons:

1. The strength of biological materials is affected by their moisture content thus high strength is associated with low moisture content for forest products (Cave, 1975).
2. The lower strength of oven-dried bamboo culm specimens in comparison with the sundried and the ambient-temperature dried, was as a result of fast rate of moisture extraction from the material by gamma radiation which led to greater fibre-shrinkage. According to Frey-Wyssling (1968) gamma radiation often result in discontinuity in fibre length causing decrease in strength.
3. There is a slower extraction of water from the fibres of samples dried in the sun. Sun-drying involves simultaneous activities of both short and long wave radiation with changes in temperature and relative humidity. 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.
4. 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.

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

CONCLUSION

The result of this investigation revealed the following:

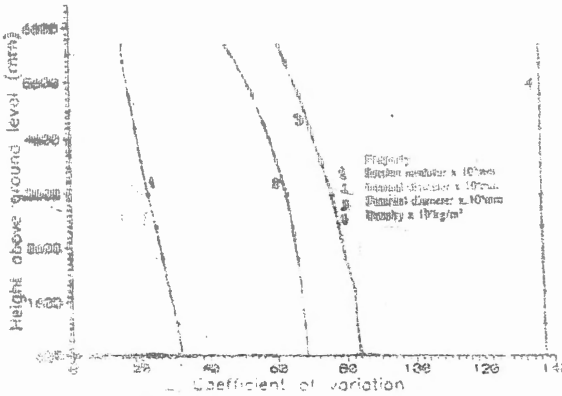
i) The girth of bamboo culm tapers linearly along its length from the bottom to the top hence it cannot be analysed as a prismatic element in structural applications.

ii) 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.

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

iv) 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.

v) The modulus of elasticity of bamboo culm is relatively constant throughout the length of a culm and it hovers around $3.00 \times 10^4 N/mm^2$ for sundried and ambient temperature dried bamboo.



Variation of Section Properties and Density along the length of Bamboo Culm

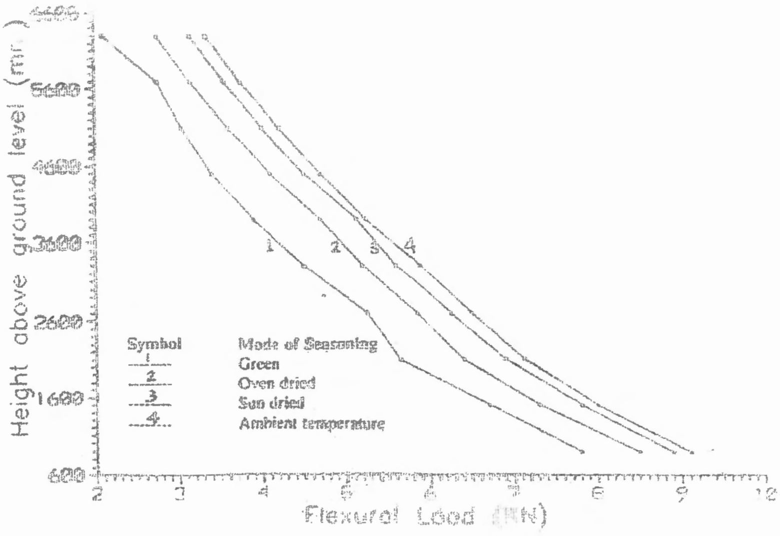


Fig. 4: Variation of Ultimate Flexural Load along the Length of Bamboo Culm

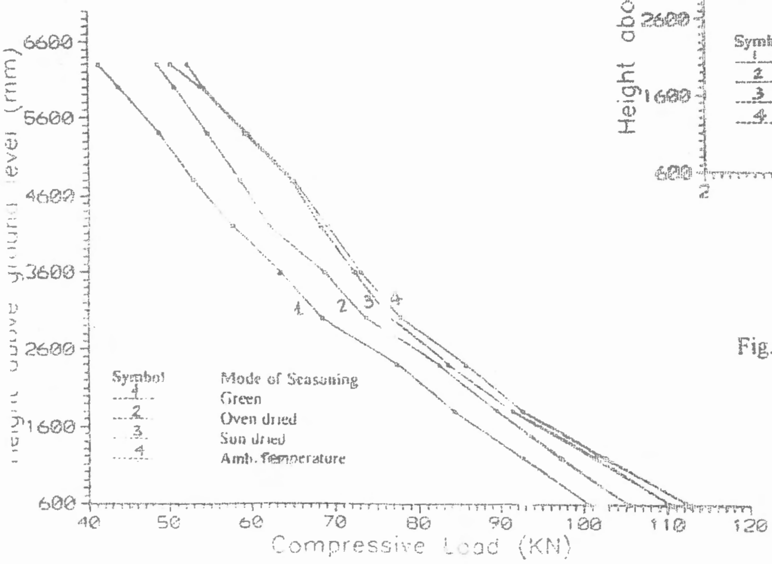


Fig. 3: Variation of Ultimate Compressive Load along the Length of Bamboo Culm

Table 1: The Ratio between the Density (Kg/m³)and the Allowable Stress (N/mm²) of Bamboo

	Compression (no buckling)	Bending	Shear
Dry Bamboo	0.013	0.020	0.003
Green Bamboo	0.011	0.015	-

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

	Compressive Stress N/mm²	Modulus of Elasticity x 10^4 N/mm²
Green (unseasoned)	44.84	2.80
Oven-dried	56.53	3.15
Sun-dried	60.14	3.42
Ambient temperature	61.12	3.47

Table 3: Flexural Stress and Modulus of Elasticity for Various Modes of Seasoning

	Flexural Stress (N/mm^2)	Modulus of Elasticity $\times 10^4$ N/mm^2
Green (unseasoned)	32.57	2.24
Oven-dried	35.17	2.70
Sun-dried	36.45	2.85
Ambient temperature	38.25	3.08

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