Density, Porosity and Dimensional Changes of naturally – Grown *Bambusa vulgaris*

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Abstract
Density, porosity and volumetric changes of *Bambusa vulgaris* Shrad. ex. JC Wendl were evaluated in this study. Culms aged two, three and four were harvested from bamboo groove growing naturally on the Federal University of Technology, Akure Campus. Samples were collected at 10 %, 50 % and 90 % sampling height which represented the base, middle and top portions of the culm. Culm density, porosity, shrinkage and swelling characteristics were determined according to standard procedures. The mean density values were 755 kg/m^3, 877 kg/m^3, and 782 kg/m^3. For ages two, three and four years, respectively. The mean porosities were 42.6 %, 29.44 % and 36.86 % for ages two, three and four years respectively. The mean shrinkage in the longitudinal directions were 0.88 %, 0.94 % and 0.9%. The mean radial shrinkage values were 7.69 %, 5.21 % and 5.60 % while the mean tangential shrinkage were 15.17 %, 8.80 % and 10.72 % for ages two, three and four years, respectively. The mean swelling values in the longitudinal directions were 0.46 %, 0.46 % and 0.63 %, the mean radial swelling values were 5.62 %, 6.27 % and 5.17 % while the mean tangential swelling values were 7.24 %, 10.21 % and 9.46 % also for ages two, three and four years, respectively. The mean volumetric shrinkage values were 22.24 %, 14.34 % and 16.50 % while the mean volumetric swelling values were 20.88 %, 28.63 % and 30.47 % for the two, three and four year old Bamboo, respectively. There were no significant variations in the density and porosity along the culm length. However, significant variation existed among the three ages classes. The shrinkage characteristics were similar along the length of the culm for all the orthogonal directions. Among the different ages, significant variations existed with exception of longitudinal shrinkage. The swelling behaviour was similar for all the three age series from the base to the top portion of the culm.

Keywords: *Bambusa vulgaris*; Physical properties; Density; Porosity; Swelling; Shrinkage

Introduction

Timber resources in Nigeria are dwindling in availability as a result of the continuous and uncontrolled use of forest resources. As a result, there is more pressure on both the economic and less utilized wood species today. This has led to over exploitation of the existing forest resources and contributed to the decrease in timber resources. The use of Bamboo to supplement domestic application of timber is an efficient way to reduce this increasing pressure on the traditional timber species (Kokutse et al. 2013). With the current advancement in the application of bamboo in modern era, there is high potential for development of bamboo industries in Nigeria. Demonstrations have been made on utilization of bamboo for glue laminated products (Ogunsanwo and Terziev, 2010; Aina *et al*., 2012; Olajide *et al*., 2013; and Ogunsanwo *et al.* 2015). All these products were made with little documented information on the properties of the bamboo. Restrictions in processing and utilization of bamboo are often related to unsuitable properties (Liese 1987). Properties to a high degree will influence its quality and hence its utilization as close substitute to wood. Physical properties are very important as they affect the dimensional stability and the strength of materials. As with wood, the suitability of any bamboo species is also dependent upon its properties. With the advent of industrial utilization of bamboo in Nigeria, a comprehensive knowledge of the properties such as the physical properties is necessary to facilitate its use in the forestry industrial sector as additional or alternative raw materials for these industries.

Like wood, ageing of bamboo culm influences its properties and consequently its processing and utilization (Chauhan, 2000). Generally, most of its properties decreases from the top portion to the bottom while the specific gravity increases along the culm from the bottom to the top (Kabir *et al.* 1996). Both the radial and tangential shrinkage usually decrease with the height of the culm owing to higher number of vascular bundles at the top. Older bamboos were found to shrink and split less than younger ones (Abd. Latif *et al*., 1995; Ahmad, 2000) whereas, immature culms are prone to excessive splitting and shrinkage. Bamboo, like wood is hygroscopic in nature, It adsorbs and desorbs moisture until it is in equilibrium with the moisture content (MC) of the surrounding. Bamboo will start to shrink right at the beginning of seasoning. This characteristic is in contrast to wood that shrinks or swells only below the fibre saturation point (FSP).

Bamboo like all wood-based materials is affected by the amount of water present. Bamboo composites are normally used for structural products rather than in raw form. As with many other building materials, bamboo displays variability in its physical properties. Shrinkage and swelling are two important physical properties. These properties can result in warping, checking, splitting, loosening of tool handles, gaps in strip flooring, or performance problems. These are setbacks to the usefulness of bamboo products. In processing and utilizing bamboo, an understanding of the patterns of variation in properties is important. Knowledge of its shrinkage and swelling behaviour is important as they affect its properties. Thus, in order to satisfactorily use bamboo as a raw material for structural application or as composite material, its physical characteristics must be studied. With proper understanding of the hygroscopic behaviour, dimensional instability problems associated with bamboo can be avoided or reduced from impacting the final end product. Therefore, the objectives of this work were to evaluate the density of *B. vulgaris*, its porosity and dimensional changes at different ages and along the culm height.

Materials and Methods

Selection and Preparation of samples

Culms that were two, three and four years old were harvested from bamboo grooves growing naturally on campus of the Federal University of Technology, Akure, Nigeria. The ages of the culms within the clump were determined by taken note of the colour of the culm and presence of algae on the culm; the colour of bamboo culms relates to the ages of the culm. The colour of one year old culms was normally bright green and the surfaces of the culms were thinly pruinose. As the culms age from 2 to 3 and to 4 years, their green colour was seen with yellowish patches indicating that they are turning yellowish gradually with age. From age 4 onwards, the colour of the culms were seen turning to yellow and fungi and mosses were seen appearing on the culms surface. Age 5 had turned completely to golden or yellow colour and with a lot of cracks and splits on the culm surfaces, therefore age 5 was not included in the study as deterioration sets in from age 4 onward. The position of the culms within the clump whether inside or outside of the clump; the ones inside the clump were the oldest while the newly emerging culms were seen growing at the periphery of the clump and the sound given on knocking on the culm; the ones with deep sound were young ones owing to the high moisture content while the ones with light sound were the old ones owing to low moisture within them.

Three (3) culms from each age class were harvested. The culms were carefully marked and labelled according to ages for easy identification and from base to the top portion along the culm length. Experimental specimens were sampled at 10%, 50% and 90% of the merchantable height to represent the base, middle and top positions of the bamboo culm. The samples were obtained from clear and uniform grained culms that contained no obvious flaws such as splits, checks and cross grains.

Properties Determination

The physical properties examined are the density, shrinkage, swelling and porosity. The culm density was determined following ASTM D 2395-93 (ASTM 1993) but with slight modification in the dimension of the samples. The specimen dimension was 20mm x 60mm x actual thickness, the bamboo's natural thickness which varies from the base to the top of the culm did not reach the standard thickness of 20mm that is specified by the standard. Therefore, the

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bamboo was tested based on the measured thickness. Specimens for the basic density were taken from the internodes of the 10%, 50% and 90% portions. Ten (10) samples were taken for measurement, the bamboo skin was removed using hand spoke. Culm porosity was determined following ASTM D 2395-93 (ASTM 1993).

The culm density was calculated using the formula:

---- Equation 1

The porosity was calculated using the formula:

..........Equation 2

where: 1 = is the total volume of wood; g/g_0 = fractional volume of solid wood substance; g = bulk density and g_0 = specific gravity of wood substance which is put at (1.5) (FPL 2010).

Bamboo shrinks and swells similar to wood. Therefore, the standard method of testing small clear specimens of timber ASTM D 143-94 (ASTM 1994) was used. The shrinkage and swelling of each culm according to age, location along the culm length and the three orthogonal directions (longitudinal, radial and tangential) were measured. The shrinkage of the samples was measured from green to oven dry condition while swelling was measured from oven dry state to water swollen state. The following formula were used to calculate the various dimensional changes:

Radial Variation:

---------- Equation 3

Where, R_t is the radial shrinkage or swelling, r_o is the initial radial dimension, r_t is the final radial dimension

Tangential variation:

---------------Equation 4

Where, t_o is the initial tangential thickness, t_t is the final tangential thickness at the moment of measurement

Longitudinal variation:

--------------------Equation 5

Where, l_o is the initial longitudinal dimension, l_t is the final longitudinal dimension.

Statistical Analysis

All statistical analyses were carried out using SPSS version 17. Factorial experiment in Completely Randomised Design was used to determine significant differences among means. Duncan Multiple Range Test (DMRT) was used for mean separation.

Results and Discussion

Variation in Culm Density

The density was found to vary with age and position along the culm length. The density varied from 709.63 kg/m^3 to 937.95 kg/m^3 and increased from the basal portion of the culm to the top (Table 2). The ANOVA results in Table 1 showed that there was no significant variation in culm density along the culm length as well as among the three age classes. The interaction of age and culm portion was also not significantly. However, DMRT result (Table 2) showed that there was no significant variation in culm density along the culm length but significant variations existed among the three age classes. The results from previous works (Liese 1986 & 1998; Espiloy 1987; Abd. Latif 1993; Abd Latif and Liese 2002; Ahmad and Kamke 2005; Malanit et al. 2008) supported the findings of this work. According to these authors, Bamboo density has a close relationship with vascular bundles and ground tissues percentages. The reason for higher basic density at the top portion could be attributed to the presence of higher proportion of fibrous tissue and higher frequency of vascular bundles at the top of the culm (Liese 1998; Janssen 1981; Espiloy 1987 and Widjaja and Risyad 1987; Razak et al. 2010) as well as maturation process that starts from the lower internodes to the upper internodes (Itoh 1990). Variation in density showed an increase from ages 2 to 3 with slight decrease at age 4. This may be due to the cell wall thickening during maturation of the culm from 1 to 3 years which leads to an increase in basic density of the culm material (Alvin and Murphy 1988; Jamaludin et al. 1992; Abd. Latif 1993; Espiloy 1994; Sattar et al. 1994; Razak et al. 2007 & 2010*)*. The increase in density is dramatic during the first two years but becomes more gradual during the third year and stabilized thereafter as also reported by Abd Latif et al. (1996) and Bath (2003). The starch deposition and lignification process also increases with age (Razak et al. 2010). Alvin and Murphy (1988) and Razak et al. (2007) got similar findings for *Gigantochloa scortechinii* and *Sinobamboo tootsik.* The variation in the density of *B. vulgaris* is similar to the findings of Espiloy (1987), Liese (1986), Santhoshkumar and Bhat (2014). Since there were significant differences in the density of the three age classes and along the culm length, its selection to serve a particular end use will be affected by age and culm portion.

Table 1: ANOVA for density and porosity

Properties	Source of variation	df	F-value
Density (kg/m^3)	Age	2	3.189 ns
	Portion	2	0.667 ns
	Age*Portion	4	0.473 ns
Porosity (%)	Age	2	4.391 *
	Portion	2	0.917 ns
	Age*Portion	4	0.179 ns

***** = significant at ($p \leq 0.05$); ns = not significant ($p \leq 0.05$)***

Table 2: Result of DMRT for Influence of age and culm portion on the Density and Porosity

Source of Variation	Level	Density (kg/m^3)	Porosity (%)
Age (Years)	2	755.22^c	42.60^a
	3	877.23^a	29.44^c
	4	782.21^{ab}	36.86^{ab}
Portion	Base	772.70^a	39.10^a
	Middle	811.82^a	36.69^a
	Top	830.11^a	33.11^a

Means with the same letter vertically are not significantly different ($p \leq 0.05$)

Variation in Porosity of *B. vulgaris*

According to the ANOVA result in Table 1, the pattern of variation in the culm porosity showed that only age had significant influence on the culm porosity while culm portion and interaction of the age and culm portion had no significant influence on the culm porosity. However, the results of mean separation further showed that the pattern of variation in the culm porosity was similar to that of culm density. There was no significant variation in the culm porosity along the culm length but significant variation existed among the three age classes (Table 2). The porosity of *B. vulgaris* from all the three age classes decreased from the base to the top (Table 1). This result was not similar to that of Fokwa et al. (2012).

They reported that the porosity of *Arundinaria alpine* increased from bottom to the top which they attributed to the variability in the structure and concentration of the fibres along the culm length and the fact that the fibres along the culm length do not have the same structure. In this study the age and portion with the highest density seemed to have the lowest porosity and vice versa. This shows that there is a kind of relationship of density with porosity of the culm. Permeability of bamboo is mainly affected by the anatomical characteristics and this influences moisture movement and hence its treat-ability (Sattar 1990). Therefore, since bamboos are generally prone to attacks from bio-deteriorating agents. The high porosity of *B. vulgaris* (especially that of the basal portion 39.10 %) is an advantage in the preservative treatment of the culms to impart durability probity against bio-deteriorating agents as the cells will more readily absorb preservative chemicals.

Variation in Shrinkage Characteristics of *B. vulgaris*

Bamboo, like wood, changes dimension when it loses moisture. However, unlike wood, its dimension starts to change as soon as it starts to loose moisture (Razak et al. 2006). Similarly, the dimensional shrinkage of bamboo varies in different orthogonal directions as found in wood. The mean longitudinal, radial, tangential and volumetric shrinkage varies from 0.82 % - 1.00 %, 5.21 % - 7.69 %, 8.80 % - 15.17 % and 14.34 % - 22.24 %, respectively (Table 3). There was no significant difference in the longitudinal and radial shrinkage among the three age classes and culm portion according to the ANOVA result (Table 3). Interactions of age and culm portion were also not significant for the shrinkage properties in the three orthogonal directions. However, age had significant influence on the tangential and volumetric shrinkage. The DMRT however showed there were significant variations in the radial, tangential and volumetric shrinkage of *B. vulgaris* among the three age classes but that of longitudinal shrinkage was not significant.

Along the culm length, from the base to the top, no significant variation existed in all the three orthogonal directions and volumetric shrinkage Although, radial and tangential shrinkage decreases with the height of the culm owing to a higher number of vascular bundles in the top portion (Liese 1998). This is contrary to the findings of this work where longitudinal, tangential and volumetric shrinkage increased from the base to the top while radial shrinkage decreases from the base to top. This could be attributed to the individual characteristics of the bamboo. Longitudinal shrinkage increased from age 2 to 3 and later start decreasing at age 4 while radial, tangential and volumetric shrinkages decreased from age 2 to 3 and later increased at age 4 (Table 4). This trend is similar to the observation of Wahab et al. (2012). The range of radial (5.21 – 7.69 %) tangential (8.80 % – 15.17 %) and volumetric shrinkage (14.34 % - 22.24 %) of *B. vulgaris* under study falls in the same range of values reported for *Gigantochloea scortechinii*, *G. brang*, *G. wrayi* and *G. levis* (Wahab et al. 2012). In comparison to some locally used timber species, volumetric shrinkage of *B. vulgaris* is almost similar to that of *Strombosia pustulata* (19.7 %), Azadirachta *indica* (19.12 %), *Streculia rhinopetala* (20.9 %), *Eribroma oblonga* (18.3 %) and *Lophira alata* (19.8 %) (Ghelmeziu 1981) but higher than *Terminalia superba* (10.1 %), *Khaya ivorensis* (9.11 %), *Triplochyton scleroxylon* (9.7 %), *Mansonia altissima* (10.3 %), *Afzelia africana* (9.8 %) and *Ceiba pentandra* (10.40 %) (Akpan, 2007).

Bamboo lacks radially oriented cells and growth rings like wood, therefore, its dimensional movement is expected to be similar in the two directions. The result of this work showed that tangential shrinkages from all the age classes and portion of the culm are more than the radial shrinkages while that of longitudinal shrinkages were negligible. Vo (2007), Pham (2009) and Ho (2011) got similar results for *Bambusa stenostachya*, *Dendrocalamus asper* and *Thyrsostachys siamensis* respectively. Wahab et al. (2012) had similar result for *Gigantochloa. scortechinii.* Malanit et al. (2008) and Liese (1985) reported tangential shrinkage to be about one-half as much in radial and much less along the longitudinal direction. However, the results are contrary to the findings of Lee et al. (1994), for *Phylostachys pubescens*. They observed the greatest shrinkage in the radial direction, which was about twice as great as shrinkage in the tangential direction while longitudinal shrinkage was negligible. Generally, when compared with wood species, *B. vulgaris* had almost similar dimensional stability. This is a favourable property for its use as raw material for composite products.

Table 3: ANOVA for Shrinkage characteristics of *B. vulgaris*

Properties	Source of variation	df	F-value
Longitudinal shrinkage	Age	2	0.199 ns
	Portion	2	1.766 ns
	Age*Portion	4	1.429 ns
Radial shrinkage	Age	2	3.139 ns
	Portion	2	1.089 ns
	Age*Portion	4	0.632 ns
Tangential shrinkage	Age	2	5.592 *
	Portion	2	0.704 ns
	Age*Portion	4	1.817 ns
Volumetric shrinkage	Age	2	5.348 *
	Portion	2	0.094 ns
	Age*Portion	4	1.473 ns

***** = significant at ($p \leq 0.05$); ns = not significant ($p \leq 0.05$)***

Table 4: Result of DMRT for Influence of age and culm portion on the shrinkage *of B. vulgaris*

Source of Variation	Level	Longitudinal shrinkage (%)	Radial shrinkage (%)	Tangential shrinkage (%)	Volumetric shrinkage (%)
Age	2	0.88[a]	7.69[a]	15.17[a]	22.24[a]
	3	0.94[a]	5.21[c]	8.80[b]	14.34[b]
	4	0.90[a]	5.60[ab]	10.72[b]	16.50[b]
Portion	Base	0.82[a]	7.03[a]	10.40[a]	17.29[a]
	Middle	0.89[a]	5.96[a]	11.58[a]	17.48[a]
	Top	1.00[a]	5.50[a]	12.72[a]	18.31[a]

Means with the same letter vertically are not significantly different (p≤ 0.05)

Variation in Swelling Characteristics of *B. vulgaris*

The dimensional stability behaviour shown by bamboo occurs in timber as well. This behaviour occurs in timber because the orientation of most of the microfibrils (S2 layer) is aligned parallel to the longitudinal axis. The explanation of this behaviour can also be applied to bamboo. Like wood, the dimensional shrinkage of bamboo varies in different orthotropic directions. The mean longitudinal, radial, tangential and volumetric swelling varies from 0.42 % - 0.68 %, 4.64 % - 6.27 %, 7.24 % - 10.21 % and 20.88 % - 30.53 % respectively (Table 5). The ANOVA result revealed that age and culm portion had no influence on all the swelling properties except the longitudinal swelling. Contrary to the result of the shrinkage properties, the result of mean separation showed that there was no significant variation in the radial, tangential and volumetric swelling among the three age classes and along the culm length. Only longitudinal swelling showed significant variation among the three age classes (Table 6). The swelling result is consistent with the dimensional stability of some bamboo species such as *Dendrocalamus strictus* (Ahmad, 2000) and *Bambusa blumeana* (Toralde et al., 2013). When compared to some hard wood species such as *Celtis mildbraedii* (11.36 %), *Khaya ivorensis* (10.46 %), *Meliceae excelsa* (10.12 %), *Afzelia africana* (7.5 %) and *Triplocyton scleroxylon* (6.44 %) (Jamala et al., 2013); 8.71 % for *Gmelina arborea* (Owoyemi et al,. 2015), the swelling properties of *B. vulgaris* is high. The explanation for this behaviour is that bamboo has a different anatomical structure compared to timber. The tangential swellings were more than radial swellings for all ages and portion of the culm. The volumetric swellings were relatively high (20.88 % – 30.53 %). Moreover, both the shrinkage and swelling in the longitudinal direction have small values compared to the radial and tangential directions, therefore were negligible. In this study, there was no significant variation in the swelling of both old and young bamboo. This is contrary to the findings of Ahmad (2000) who reported that older bamboo (3-year-old) is more dimensionally stabled compared to the young ones (1-year-old).

Table 5: ANOVA for swelling characteristics of *B. vulgaris*

Properties	Source of variation	df	F-value
Longitudinal swelling (%)	Age	2	2.205 ns
	Portion	2	4.266 *
	Age*Portion	4	2.993 *
Radial swelling (%)	Age	2	0.419 ns
	Portion	2	1.118 ns
	Age*Portion	4	1.020 ns
Tangential swelling (%)	Age	2	2.608 ns
	Portion	2	0.041 ns
	Age*Portion	4	0.751 ns
Volumetric swelling (%)	Age	2	0.482 ns
	Portion	2	0.337 ns
	Age*Portion	4	1.281 ns

***** = significant at ($p \leq 0.05$); ns = not significant ($p \leq 0.05$)***

Table 6: Result of DMRT for Influence of age and culm portion on the swelling *of B. vulgaris*

Source of variation	Level	Longitudinal swelling (%)	Radial swelling (%)	Tangential swelling (%)	Volumetric swelling (%)
Age	2	0.46[a]	5.17[a]	7.24[a]	20.88[a]
	3	0.46[a]	5.62[a]	9.46[a]	28.63[a]
	4	0.63[a]	6.27[a]	10.21[a]	30.47[a]
Portion	Base	0.46[a]	6.17[a]	8.88[a]	27.36[a]
	Middle	0.42[a]	6.24[a]	8.83[a]	22.10[a]
	Top	0.68[a]	4.64[a]	9.19[a]	30.53[a]

Means with the same letter vertically are not significantly different ($p \leq 0.05$)

Conclusion and recommendations

The physical properties of *B. vulgaris* were observed to vary significantly among ages and along the culm length. The optimum culm density was attained at age 3. The shrinkage characteristics were comparable to most durable wood species and the swelling characteristics were higher than most durable wood species. With the knowledge of hygroscopic behaviour, dimensional instability problems associated with bamboo can be minimised through efficient seasoning of the culms and utilization of bamboo in area with little or no wetting as well as chemical or thermal modification of bamboo samples prior utilization.

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