

Morphological Variation of Strength In Solid Timber Beam Using Volume Integration Method

Ezeagu, C. A and Eluemunoh O.O

Department of Civil Engineering, Nnamdi Azikiwe University Awka, Anambra State, Nigeria

ABSTRACT: The work verifies the morphological variation of strength in various sizes of solid timber beam in order to ascertain their respective volumetric strength mode at the three (3) perpendicular directions. In this work, a mathematical tool known as Volume Integral was adopted to analyze the volumetric strength mode of timber in mutually perpendicular axes of three (3) batches (A, B & C) having five (5) different sizes of solid timber beam respectively and thereafter, morphological values generated were used in determination of ultimate bending strength assuming Ekki *lophira alata*, as the timber specie. The result of the analysis showed that increase in timber morphology increases the volumetric strength mode. Also that the maximum volumetric strength for all the sizes of the solid timber beam analyzed occurred at the tangential axis which is perpendicular to the grain direction and tangent to the growth ring (x-direction) followed by the volumetric strength of the radial axis which is also perpendicular to the grain direction and normal to the growth ring (z-direction). While the least volumetric strength occurred at the longitudinal axis which is parallel to the grain direction (y-direction). This is because solid timber beam has its highest and weakest volumetric strength zone at the tangential and longitudinal directions respectively and the strength varies from specie to specie. Furthermore, it was discovered that Volume Integral ($\int_V Fdv = \int_{x_1}^{x_2} \int_{y_1}^{y_2} \int_{z_1}^{z_2} Fdzdydx$) is a good mathematical tool to analyze the morphological variation of volumetric strength mode in structural timber beam because it shows the respective volumetric strength behavior at the respective principle axes (tangential, longitudinal and radial directions respectively) of the timber member.

Keywords: Morphology, Strength, Timber, Beam, Principal Axes

Introduction: Timber is one of the oldest and best-known structural materials and one of the few renewable natural resources. Timber is a desirable material for construction because it requires less energy to produce a usable end product than other materials such as concrete and steel. Timber is also extremely versatile. Because wood has a wide range of physical and mechanical properties, species can be selected on the basis of how well they fit the requirements for a particular product. The ability of wood to resist loads depends on a number of factors, including the type, direction, and duration of loading; ambient conditions of moisture content and temperature; and the presence or absence of defects such as knots and splits (Green D.W. 2001). In the past, the strength of a timber member was determined from the “clear-wood” strength (Hansson, 2001). The commercial timber however, does not have the same properties as clear wood at all. But nowadays, the strength capacity is determined from direct testing of structural timber.

A comprehensive knowledge of the structure of wood, its chemical and physical behavior, and the causes of variability, as they affect its utilization form the basis of present and potential utilization of wood (Panshin and de Zeeuw, 1999). According to Farmer (1990), timber, like all other materials of construction, has the ability to resist applied or external forces. In practice, timber is frequently subjected to a combination of stresses (compressive, bending tensile and shearing), although one usually predominates. Farmer (1990), expressly explained that many other factors have to be considered as well in the selection of species for a particular purpose, but in general, there are few instances where the choice does not depend to some degree upon one or more of its mechanical properties. Hence, a basic knowledge of the strength properties of timber is essential, if it is to be used efficiently. The strength properties largely determine the fitness of wood for structural building purposes and there is hardly a single use of wood that does not depend at least to some degree on one or more of its strength properties (Kollmann and Cote, 2000). Haygreen and Bowyer (1996) pointed out that wood that is relatively strong with respect to a strength property may rank lower in a different property. They also stated that strength properties are designed almost exclusively to obtain data for predicting the performance of wood during service. For it is this data that will aid a forester who is selecting a “superior tree” for genetic breeding, a wood technologist developing a new product, and a design engineer encountering environmental condition.

Statement of Problem: The volumetric nature of wood is natural, wood structure grows in rings and the annual ring represents the fibrous strength development of the wood. Due to fibrous nature of timber its strength responds differently in its different directions. Therefore, there is need to ascertain the volumetric integral approach in the analysis of strength variation of timber.

Aims and Objectives of the Work:

The aim of this work is to verify the morphological variation of strength in solid timber beam using volume integral.

The specific objectives of this study are as follows:

- I. To ascertain the volumetric strength variation of the three axes of a solid timber beam which will help in its utilization as an engineering material.
- II. To determine how Volume Integral approach can be used in the analysis of the volumetric strength of solid timber beams.
- III. To verify how the volumetric strength vary in the three (3) principal directions namely, tangential, longitudinal and radial directions.
- IV. To compare the volumes of the strength generated.

Scope of the Work: For the purpose of this work, a mathematical tool called Volume Integral was adopted to analyze the volumetric strength of timber in mutually perpendicular axes of three (3) batches (A, B & C) having five (5) different sizes of solid timber beam respectively. The batches analyzed were as follows:

Table 1.1: Showing five (5) different sizes of timber dimension in different directions both in millimeter and in inches – Batch A

Batch A

S/N	Timber dimension at the mutually perpendicular axes (mm)			Timber dimension at the mutually perpendicular axes (inches)		
	<i>i(x)</i> Tangential direction	<i>j(y)</i> Longitudinal direction	<i>k(z)</i> Radial direction	<i>i(x)</i> Tangential direction	<i>j(y)</i> Longitudinal direction	<i>k(z)</i> Radial direction
1.	25	100	25	1	4	1
2.	30	100	30	1.2	4	1.2
3.	35	100	35	1.4	4	1.4
4.	40	100	40	1.6	4	1.6
5.	45	100	45	1.8	4	1.8

Table 1.2: Showing five (5) different sizes of timber dimension in different directions both in millimeter and in inches – Batch B

BATCH B

S/N	Timber dimension at the mutually perpendicular axes (mm)			Timber dimension at the mutually perpendicular axes (inches)		
	<i>i(x)</i> Tangential direction	<i>j(y)</i> Longitudinal direction	<i>k(z)</i> Radial direction	<i>i(x)</i> Tangential direction	<i>j(y)</i> Longitudinal direction	<i>k(z)</i> Radial direction
1.	50	200	50	2	8	2
2.	55	200	55	2.2	8	2.2
3.	60	200	60	2.4	8	2.4
4.	65	200	65	2.6	8	2.6
5.	70	200	70	2.8	8	2.8

Table 1.3: Showing five (5) different sizes of timber dimension in different directions both in millimeter and in inches – Batch C

BATCH C

S/N	Timber dimension at the mutually perpendicular axes (mm)			Timber dimension at the mutually perpendicular axes (inches)		
	<i>i(x)</i> Tangential direction	<i>j(y)</i> Longitudinal direction	<i>k(z)</i> Radial direction	<i>i(x)</i> Tangential direction	<i>j(y)</i> Longitudinal direction	<i>k(z)</i> Radial direction
1.	75	300	75	3	12	3
2.	80	300	80	3.2	12	3.2
3.	85	300	85	3.4	12	3.4
4.	90	300	90	3.5	12	3.5
5.	100	300	100	4	12	4

Note: All are fibrous solid timber beam

Literature Review

1. Variation and Causes of Variation in Wood Properties: The comprehensive knowledge of the structure of wood, its chemical and physical behavior and the causes of its variability as they affect its utilization form the basis of present and potential utilization of wood (Adjaye, 2012). He further explained that wood is an inherently variable material owing to its origin as a product of metabolism and its properties are subject to wide variations culminating from the physiology of tree or its genetic constitution and environmental influences affecting its growth condition. Adjaye (2012), also pointed out that differences in structure and hence performance occur not only between different species growing in different environment but also between different parts of a single tree. The variations in properties of wood occur principally between species, within a single species in a geographical area, in a single tree, in the stem in the radial direction, in tangential and in the longitudinal directions (Adjaye, 2012). Haygreen and Bowyer (1996) stressed that strength varies widely within and among species. Within any species there is a considerable variation in clear wood strength properties, which corresponds to the variation in density and to the density – relationship for that property. Panshin and de Zeeuw (1999) again revealed that the variability of wood characteristics within individual trees is fundamentally influenced by changes in the cambium as it ages, genetic controls that govern form and growth of the tree and environmental influences such as seasonal or geographical conditions or nutrient supply. These may give rise to modifications of the basic patterns for variance of wood. They mentioned for example that variation in the amount of cell wall substance in wood are the results of changes in cell morphology (length, diameter and wall thickness) and changes in the proportionate volumes of different cell types with position in the tree, although additional modifications arise from the presence of extractives and also from the influence of growth rate . Nevertheless, it is difficult to ascribe this variability of wood characteristics to a single factor or even to a combination of factors affecting tree growth. This is because of the interactive influence of these factors. Adjaye (2012) has noted that variability in wood is one of its characteristic deficiencies as a structural material. Structural differences do occur not only between different species of timber but also between different parts in a single tree (Carmicheal, 200). Within a tree trunk, there are systematic patterns of variation in cell length, cell wall thickness, and angle of grain Adjaye (2012). Panshin and DeZeeuw (1999) also reported that, horizontal variation exist in wood structure from the pith to the bark and a vertical variation from the base to the crown. At any height level, and from the pith to the bark, there is a general variation in structural characteristics. The parenchyma cells in any zone after some time lose their living protoplasm and the vessels and tracheids cease their conductive function, wood then function as a supporting tissue as these changes take place. In the development stages, from juvenile to maturity, changes are observed under normal conditions of growth of the tree. Wood from different parts of a tree is noted to show differences in density (Jane, 2005). Furthermore, Ezeagu, C.A. & Nwokoye, D.N. (2009) in their work state that the draw back to the use of wood as structural material is its variability which is itemized as follows: Variability in different trees, Variability in pieces derived from different

parts of the same tree, Colour, Knotty or clear, Growth rings may differ in width, Grain and texture variation, Difference in density, hardness and toughness etc. They also state that variation in timber may be inherent, individual variation – due to its age (time of the tree formation).

2. Variation of Elastic Properties of Timber within the Stem: The structure of the wood cells formed by the tree varies during its growing process over the years, namely because of cambium age and environmental conditions. This accounts for the rough distinction between juvenile and mature wood within the stem (Smith et al, 2003). As a main consequence of this inherent anatomical variability, the physical and mechanical properties of wood vary spatially within the stem, both radially (horizontal variation) and longitudinally (vertical variability). Most of the studies about this topic are concerned with the anatomical and physical properties of wood (Zobel, 1999).

Methodology:

The mathematical tool known as volume integral expresses the morphological behavior of timber beam in its three different directions and it is of the form:

$$\int_V Fdv$$

Where, F is the vector field at each point of V and on its boundary surface, S

dV is the infinitesimal volume element.

But Stroud K. A. & Booth D. H. (2011) stated that for a rectangular section, the vector field, $F = xyi + zj - x^2k$3.1

In Cartesian coordinate, $dV = dxdydz$ 3.2

$$\Rightarrow \int_V Fdv = \int_{z_1}^{z_2} \int_{y_1}^{y_2} \int_{x_1}^{x_2} Fdxdydz$$
..... 3.3

Substituting the value of the vector field F, we have:

$$= \int_{z_1}^{z_2} \int_{y_1}^{y_2} \int_{x_1}^{x_2} (xyi + zj - x^2k) dxdydz$$
..... 3.4

Integrating with respect to *x*-direction, we have:

$$= \int_{z_1}^{z_2} \int_{y_1}^{y_2} \left\{ \frac{x^2}{2} yi + xyz - \frac{x^3}{3} k \right\}_{x_1}^{x_2} dydz$$
..... 3.5

Integrating with respect to *y*-direction yields:

$$= \int_{z_1}^{z_2} \left\{ \frac{x^2 y^2}{4} i + xyzj - \frac{x^3}{3} yk \right\}_{y_1}^{y_2} dz$$
.....3.6

Integrating with respect to *z*-direction also yields:

$$= \left\{ \frac{x^2 y^2}{4} zi + \frac{xyz^2}{2} j - \frac{x^3}{3} yzk \right\}_{z_1}^{z_2} \dots\dots\dots 3.7$$

⇒

$$\int_V Fdv = \int_{z_1}^{z_2} \int_{y_1}^{y_2} \int_{x_1}^{x_2} (xyi + zj - x^2k) dx dy dz$$

$$= \left\{ \frac{x^2 y^2}{4} zi + \frac{xyz^2}{2} j - \frac{x^3}{3} yzk \right\}_{z_1}^{z_2} \dots\dots\dots 3.8$$

Equation 3.8 is the volume integral strength at the respective directions.

After the analysis a mathematical graphical method was used for the interpretation of the volumetric strength results.

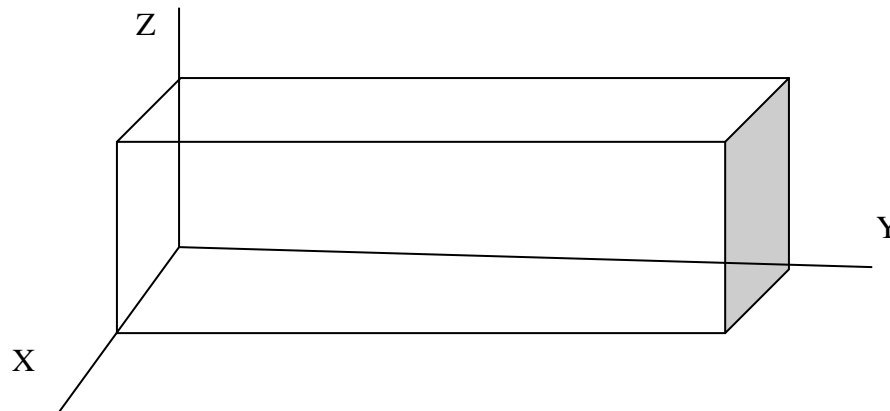


Figure 1.0: showing the 3-dimansional domain of the solid timber beam

- Where X = Tangential direction of the timber grain (*i*-direction)
- Y = Longitudinal direction of the timber grain (*j*-direction)
- Z = Radial direction of the timber grain (*k*-direction)

After the analysis the morphological values generated was used in determination of the ultimate bending strength of the solid timber beam assuming Timber samples to be Ekki *lophira alata*, dry grade 80%, Density 1,136Kg/m³, strength group N₁, Elasticity 15,000 N/mm²

From table 10 NCP 2: 1973 the unit flexural stress at the respective directions are as follows:

At the Tangential direction 28N/mm²

At the Radial direction $22.4N/mm^2$

At the Longitudinal direction $5.6N/mm^2$

According to Timber Design and Construction Handbook (1956), the ultimate bending strength, M of a rectangular timber beam is :

$$M = \frac{Ffb d^2}{6} \dots\dots\dots 4.16$$

In which,

F is the form or depth factor, *f* is the unit flexural stress in the extreme fiber, b is the width of the beam and d is the depth of the beam.

But the generated morphological values at the respective directions (Tangential, Radial and Longitudinal) is equal to

$$= \frac{Fbd^2}{6} \dots\dots\dots 4.17$$

Also the unit flexural stress in the extreme fiber is obtained from Table 10 NCP 2: 1973

Therefore the ultimate bending strength,

M = generated morphological mode × *f*, the unit flexural stress in the extreme fiber.

Results:

Table 4.4: Showing the summary of initial volumetric strength mode of timber samples in Batch A

S/N	Timber Sample (mm)	Tangential Direction (mm^3)	Longitudinal Direction (mm^3)	Radial Direction (mm^3)
1.	25 × 25 × 100	39,062,500	781,250	13,020,832.5
2.	30 × 30 × 100	67,500,000	1,350,000	27,000,000
3.	35 × 35 × 100	107,187,500	2,143,750	50,020,950
4.	40 × 40 × 100	120,000,000	3,200,000	85,333,200
5.	45 × 45 × 100	227,812,500	4,556,250	136,687,500

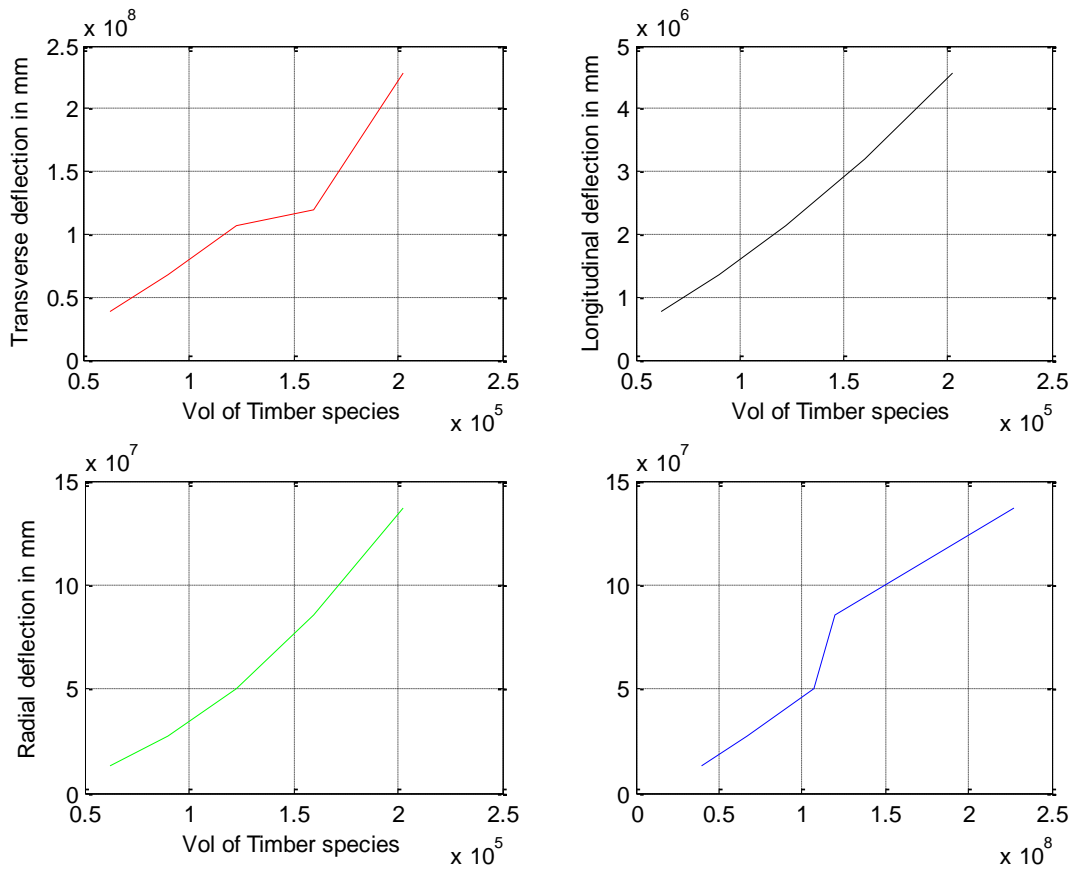
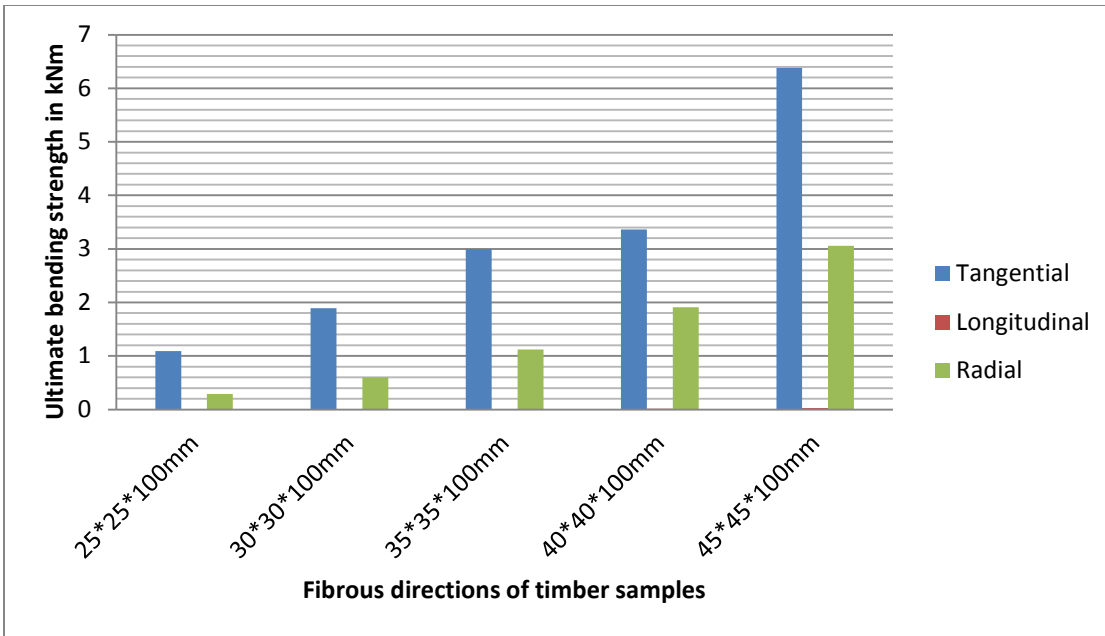


Table 4.5: Showing the ultimate bending strength in kNm of timber samples in Batch A

S/N	Timber Sample (mm)	ULTIMATE BENDING STRENGTH (kNm)		
		Tangential Direction	Longitudinal Direction	Radial Direction
1.	25 × 25 × 100	1.09	4.38×10^{-3}	0.29
2.	30 × 30 × 100	1.89	7.56×10^{-3}	0.60
3.	35 × 35 × 100	3.00	12.01×10^{-2}	1.12
4.	40 × 40 × 100	3.36	17.92×10^{-2}	1.91
5.	45 × 45 × 100	6.38	25.52×10^{-2}	3.06



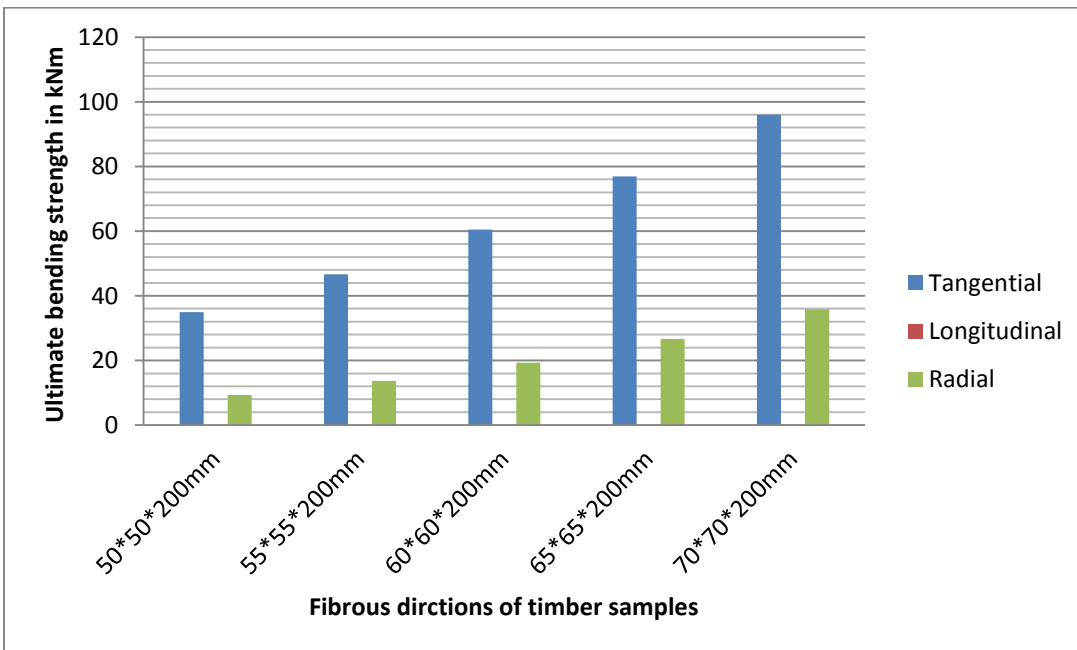
Graph 4.16: Graph showing the ultimate bending strength of timber samples in Batch A.

Table 4.6: Showing the summary of initial volumetric strength mode of timber samples in Batch B

S/N	Timber Sample (mm)	Tangential Direction (mm^3)	Longitudinal Direction (mm^3)	Radial Direction (mm^3)
1.	50 × 50 × 200	1,250,000,000	12,500,000	416,666,700
2.	55 × 55 × 200	1,663,750,000	16,637,500	610,041,630
3.	60 × 60 × 200	2,160,000,000	21,600,000	864,000,000
4.	65 × 65 × 200	2,746,250,000	27,462,500	1,190,041,710
5.	70 × 70 × 200	3,430,000,000	34,300,000	1,600,666,200

Table 4.7: Showing the ultimate bending strength in kNm of timber samples in Batch B

S/N	Timber Sample (mm)	ULTIMATE BENDING STRENGTH (kNm)		
		Tangential Direction	Longitudinal Direction	Radial Direction
1.	50 × 50 × 200	35.00	0.07	9.33
2.	55 × 55 × 200	46.59	0.09	13.66
3.	60 × 60 × 200	60.48	0.12	19.35
4.	65 × 65 × 200	76.90	0.15	26.66
5.	70 × 70 × 200	96.04	0.19	35.85



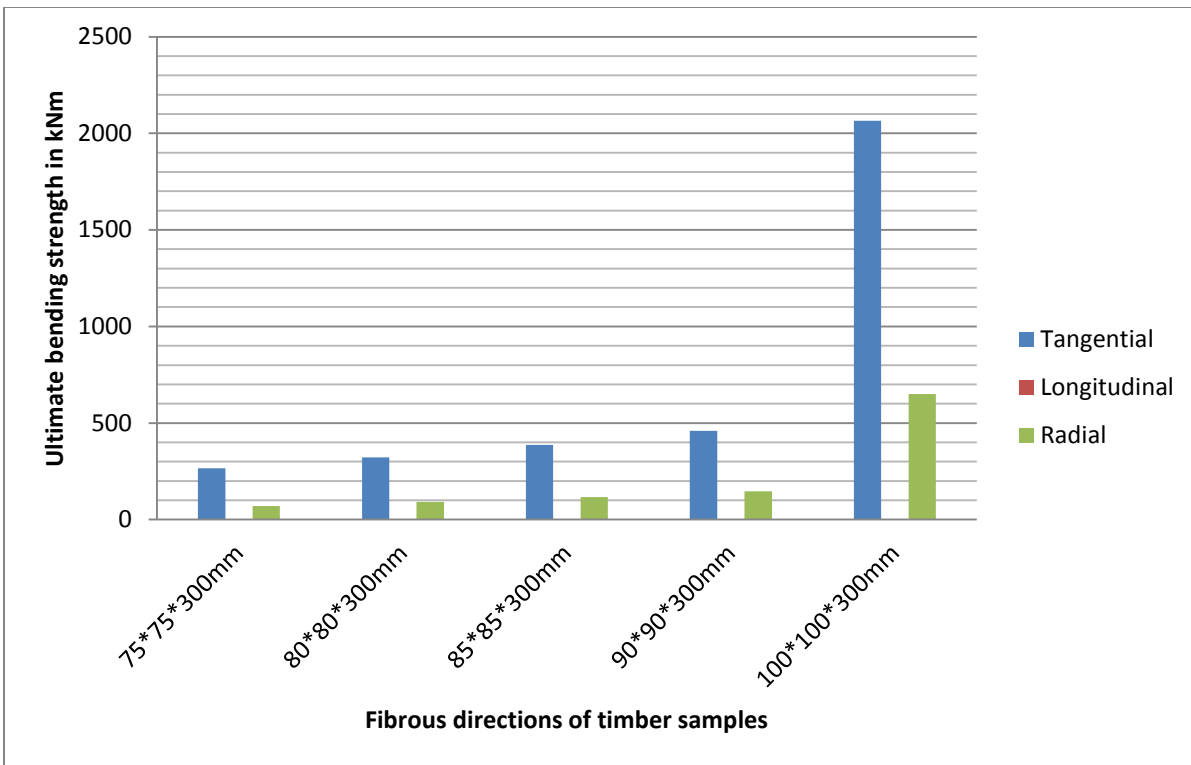
Graph 4.17: Graph showing the ultimate bending strength of timber samples in Batch B.

Table 4.8: Showing the summary of initial volumetric strength mode of timber samples in Batch C

S/N	Timber Sample (mm)	Tangential Direction (mm ³)	Longitudinal Direction (mm ³)	Radial Direction (mm ³)
1.	75 × 75 × 300	9,492,187,500	63,281,250	3,164,062,500
2.	80 × 80 × 300	11,520,000,000	76,800,000	4,096,000,080
3.	85 × 85 × 300	13,818,195,000	92,118,750	5,220,061,650
4.	90 × 90 × 300	16,402,500,000	109,350,000	6,561,000,000
5.	100 × 100 × 300	22,500,000,000	150,000,000	9,999,999,000

Table 4.9: Showing the ultimate bending strength in kNm of timber samples in Batch C

		ULTIMATE BENDING STRENGTH (kNm)		
S/N	Timber Sample (mm)	Tangential Direction	Longitudinal Direction	Radial Direction
1.	75 × 75 × 300	265.78	0.35	70.88
2.	80 × 80 × 300	322.56	0.43	91.75
3.	85 × 85 × 300	386.91	0.52	116.93
4.	90 × 90 × 300	459.27	0.61	146.97
5.	100 × 100 × 300	2,064.52	2.75	650.52



Graph 4.18: Graph showing the ultimate bending strength of timber samples in Batch C.

Conclusions: The following conclusions were made:

- I. That the maximum volumetric strength for all the sizes of the solid timber beam analyzed in the three (3) Batches (A, B and C) occurred at the tangential axis which is perpendicular to the grain direction and tangent to the growth ring (x-direction) followed by the volumetric strength of the radial axis which is also perpendicular to the grain direction and normal to the growth ring (z-direction). While the least volumetric strength occurred at the longitudinal axis which is parallel to the grain direction (y-direction).
- II. Furthermore, the result of the analysis also showed that increase in timber morphology increases the volumetric strength at the respective three (3) perpendicular directions.
- III. It has been evidently been noticed that a solid timber beam has its highest and weakest volumetric strength zone at the tangential and longitudinal directions respectively.
- IV. Volume Integral ($\int_V Fdv = \int_{x_1}^{x_2} \int_{y_1}^{y_2} \int_{z_1}^{z_2} Fdzdydx$) is a good mathematical tool to analyze the morphological variation of volumetric strength mode in structural timber beam

because it shows the respective volumetric strength behavior at the respective principle axes (tangential, longitudinal and radial directions respectively) of the timber member.

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