Journal of Science and Technology Research 4(4) 2022 pp. 186-197 ISSN-2682-5821

NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

# Investigating the Effect of Flexural Strength of I and Box African Birch Built-up Beam on Nail Spacing

***U.N. Wilson[a], J.E. Sani[a], J.A. Sadiq[a], M.T. Abdulwahab[b*], P. Abubakar[c], R.O. Rahmon[c]***

[a]Department of Civil Engineering, Nigerian Defence Academy Kaduna, Nigeria
[b]Department of Civil Engineering, Bayero University Kano, Nigeria.
[c]Department of Civil Engineering, University of Ilorin, Nigeria.

## Article Info

***Keywords*:**
*African birch, Box section, Built-up beam, Flexural strength, I-section, Nail spacing*

*Received 23 November 2022*
*Revised 06 December 2022*
*Accepted 07 December 2022*
*Available online 27 December 2022*

**https://doi.org/*10.5281/zenodo.7486333***

## Abstract

*Structural timber is gaining popularity in the construction industry; however, there is an urgent need to examine its safety in terms of strength and sectional properties. This paper seeks to examine the effect of flexural/bending strength of I and box African birch built-up beam sections on nail spacing. The air-dried African birch (Anogeissus leiocarpus) timber was obtained from a local timber market in Kaduna, Nigeria, the Pantaka market. The timber was sawed into sizes before being assembled into I and box built-up sections. Using a 2 mm diameter, 2-inch steel nail, forty (40) built-up beams were created. The dimensions of the I and box built-up beams were 500 x 75 x 20 mm and 500 x 40 x 20 mm, respectively. The samples were then subjected to five-point flexural loading at 6.6 mm/min using the Digital Board Universal Testing Machines (UTM). The nail sizes and spacing were chosen in accordance with BS 5268 Table 60. (2002). The flexural strength properties were determined at a moisture content of 18%, in accordance with the British Standard BS 373 (1957). Under the ultimate limit state of loading, statistical analysis, structural safety analysis, and probability of failure were established for the African birch timber as structural members in bridge beams and general construction works in accordance with BS 5268 (2002). A reliability and sensitivity analysis were also performed. Conclusively, the box section has a higher safety index than the I section, while the I section has a higher safety index than the solid section. The obtained results will serve as a guide for structural timber designers as well as other timber users. As a result, additional research can be conducted on other mechanical properties of African birch timber, such as compressive, tensile, and shear strength to determine structural safety.*

## 1. Introduction

As part of the mechanical properties to be considered for the classification of any timber specie, the flexural or bending strength is an important one that cannot be discountenanced. Among the 200,000 hardwood species, 1000 softwood species, and 2,300 tree species identified as commercially important in Nigeria, according to [1], only a few have been reported to have been characterized. Table 1 contains a list of timber species whose bending stresses have been determined for the various grade stresses as defined by the Nigerian Code of Practice NCP 2 [2] for categorizing timber based on the level of strength-reducing property present.

Table 1: Bending Stresses Parallel to Grain for Some Nigerian Timber Species at a Moisture Content of 18% (Adapted from Aguwa [3]).

| **S/N** | **Specie** | **Mean Failure Stress (N/mm$^2$)** | **Standard Deviation (N/mm$^2$)** | **Basic Stress (N/mm$^2$)** | **Grade 80 Stress (N/mm$^2$)** | **Grade 63 Stress (N/mm$^2$)** | **Grade 50 Stress (N/mm$^2$)** | **Grade 40 Stress (N/mm$^2$)** |
|---|---|---|---|---|---|---|---|---|
| 1 | Abura | 74.06 | 7.10 | 20.62 | 16.50 | 12.99 | 10.31 | 8.25 |
| 2 | Afara | 75.02 | 11.96 | 16.90 | 13.52 | 10.65 | 8.45 | 6.76 |
| 3 | Apa | 121.44 | 16.30 | 29.92 | 23.94 | 18.85 | 14.96 | 11.97 |
| 4 | Ara | 48.84 | 9.01 | 9.98 | 7.98 | 6.29 | 4.99 | 3.99 |
| 5 | Araba | 31.85 | 3.42 | 8.56 | 6.85 | 5.39 | 4.28 | 3.42 |
| 6 | Ayo | 87.67 | 11.11 | 22.15 | 17.72 | 13.95 | 11.08 | 8.86 |
| 7 | Danta | 119.27 | 11.45 | 33.19 | 26.55 | 20.91 | 16.60 | 13.28 |
| 8 | Ebony | 129.28 | 16.10 | 32.90 | 26.32 | 20.73 | 16.45 | 13.16 |
| 9 | Ekki | 138.32 | 14.52 | 37.45 | 29.96 | 23.59 | 18.73 | 14.98 |
| 10 | Gmelina | 67.07 | 12.14 | 13.90 | 11.12 | 8.76 | 6.95 | 5.56 |
| 11 | Iroko | 93.81 | 11.98 | 23.61 | 18.89 | 14.87 | 11.81 | 9.44 |
| 12 | Lagos Mahogany | 74.80 | 14.14 | 15.00 | 12.00 | 9.45 | 7.50 | 6.00 |
| 13 | Mansonia | 105.37 | 17.35 | 23.27 | 18.62 | 14.66 | 11.64 | 9.31 |
| 14 | Obeche | 76.58 | 14.44 | 15.39 | 12.31 | 9.70 | 7.70 | 6.16 |
| 15 | Okan | 127.53 | 11.51 | 36.10 | 28.88 | 22.74 | 18.05 | 14.44 |
| 16 | Okwen | 89.60 | 12.23 | 21.90 | 17.52 | 13.80 | 10.95 | 8.76 |
| 17 | Omu | 94.49 | 13.21 | 22.84 | 18.27 | 14.39 | 11.42 | 9.14 |
| 18 | Opepe | 131.54 | 12.25 | 36.91 | 29.53 | 23.25 | 18.46 | 14.76 |
| 19 | Sapele Mahogany | 84.63 | 9.60 | 22.31 | 17.85 | 14.06 | 11.16 | 8.92 |
| 20 | Walnut | 61.97 | 9.02 | 14.68 | 11.74 | 9.25 | 7.34 | 5.87 |

Other Nigerian-grown timber with identified bending/flexural strength are Shea butter (*Vitellaria paradoxa)* with a basic bending strength of 36.13 N/mm$^2$ at 18% moisture content by [4]; *Vitex doniana, Ceiba pentandra and Pseudocedrela kotschyi* with bending strength of 30.10 N/mm$^2$, 21.99 N/mm$^2$ and 39.42 N/mm$^2$ respectively at 12% moisture content [5]. Neem tree (*Azadirachta indica)* and Negro pepper (*Xylopia aethiopica)* graded into D40 and D70 according to BS 5268 [7] with basic bending stress of 8.89 N/mm$^2$ and 37.49 N/mm$^2$ at 18% moisture content respectively [6]. *Irvingia gabonensis* at 12% moisture content has a bending stress of 36.60 N/mm$^2$ and was categorised as a D70 timber under the BS 5268 [7, 8]. The results of Bending Stresses parallel to grain at 18% moisture content of other known Nigerian Timber Species are presented in Table 2.

Table 2: Bending Stresses Parallel to grain at a moisture content for other Nigerian Timber Species by different authors

| S/N | Species | **Basic stress** | Grade 80 Stress (N/mm$^2$) | Grade 63 Stress (N/mm$^2$) | Grade 50 Stress (N/mm$^2$) | Grade 40 Stress (N/mm$^2$) | Author |
|---|---|---|---|---|---|---|---|
| 1. | Shea butter | 36.13 | 28.90 | 22.76 | 18.07 | 14.45 | Jimoh and Aina (2017a) |
| 2. | *Vitex doniana* | 30.10 | 24.08 | 18.96 | 15.05 | 12.04 | (Jimoh and Ibitolu 2018 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3. | *Ceiba pentandra* | 21.99 | 17.59 | 13.85 | 11.00 | 8.80 | (Jimoh and Ibitolu 2018 |
| 4. | *Pseudocedrela kotschyi* | 39.42 | 31.54 | 24.83 | 19.71 | 15.77 | (Jimoh and Ibitolu 2018 |
| 5. | Neem tree | 8.89 | 7.11 | 5.60 | 4.44 | 3.56 | Jimoh and Aina (2017b) |
| 6. | Negro pepper | 37.49 | 29.99 | 23.62 | 18.75 | 15.00 | Jimoh and Aina (2017b) |
| 7. | *Irvingia gabonensis* | 36.60 | 29.28 | 23.06 | 18.3 | 14.64 | Osuji and Inerhunwa (2017) |
| 8. | *Mitragyna spp.* | 17.90 | 14.32 | 11.27 | 8.95 | 7.16 | Osuji and Inerhunwa (2017) |
| 9. | *Uapaca guineesis* | 34.88 | 27.90 | 21.97 | 17.44 | 13.95 | Osuji and Inerhunwa (2017) |
| 10. | *Xylopia spp.* | 14.24 | 11.39 | 8.97 | 7.12 | 5.70 | Osuji and Inerhunwa (2017) |
| 11. | *Xanthoxylon senegalensis* | 24.15 | 19.32 | 12.08 | 12.08 | 9.66 | Osuji and Inerhunwa (2017) |
| 12. | *Stauditia stipitata* | 45.80 | 36.64 | 22.9 | 22.90 | 18.32 | Osuji and Inerhunwa (2017) |
| 13. | African birch | 19.78 | 15.82 | 9.89 | 9.89 | 7.91 | Bello and Jimoh (2018) |

Apart from considering the flexural strength of certain timber sections for the purpose of classification and gradation, it is also important to investigate the flexural strength of built-up sections with which the (classified) timbers have been used to fabricate. Wilson et al. [11] asserts that, similarly to built-up sections in structural steel, built-up sections for timbers can be achieved by joining different timbers in any desired geometry with the intent of primarily increasing the sections of the timber beyond the naturally existing ones and thus improving their capacities. Screws, nails or glues could be used as the medium of joining the individual members that make up the built-up section. Studies by [12], [13], [14] and [15] have revealed that the diameters of connectors show a linear relationship with withdrawal resistance and that the screw-withdrawal resistance is usually higher than the nail-withdrawal resistance. Chien et al. [16] investigated the flexural performance of a glue-jointed and screw-jointed built-up beam of Japanese cedar (*Cryptomeria japonica*). The study found that using glue increases flexural rigidity in the beam, whereas using self-tapping screws resulted in built-up beams with high ductility but low flexural bearing capacity when compared to its glue-jointed counterpart. The work also demonstrated that while a smaller spacing between the screws can improve flexural load-bearing performance, it can also cause excessive split cracks in the wooden components.

The effect of varying nailing density on the flexural properties of vertically laminated steel-timber flitch beams was investigated by [17]. According to the findings of the study, an increase in nail density results in a slight improvement in flexural stiffness but an abrupt decrease in flexural strength.

This work attempts to investigate the effect of flexural strength of I and box nail-jointed built-up beam on the nail spacing. The Nigerian-grown African birch also known as the ‘chewing stick tree’ was used for this study. The approach employed is the shear flow concept. In this work, the failure bending strength was used to obtain the maximum shear force with which the shear flow and the minimum nail spacing were ultimately determined. This was then used to formulate a model with which nail spacing for identified built-up sections can be predicted having known the flexural strength.

## 2. Methodology

Air-dried African birch (*Anogeissus leiocarpus*) timber species used for this research work were purchased from a local timber market, the Pantaka market in Kaduna metropolis, Nigeria. The timber from the sawmill market were sourced from Ado in Ekiti State of Nigeria. The timber was sawn into sizes and assembled into I and box built-up sections. Twenty (20) I and box built-up beam sections making a total of forty built-up beams altogether were fabricated using a 2 mm diameter, 2 inches steel nail. The I and box built-up beams had dimensions of 500 mm x 75 mm x 20mm and 500 mm x 40 mm x 20 mm respectively as these were selected to fit the testing machine which was used for the flexural test. The samples were then subjected to five-point flexural loading test using the Digital Board Universal Testing Machines (UTM) at a constant speed of 6.6 mm/min and the failure loads recorded. The sizes and spacing are of the nail were selected in accordance with Table 60 of BS 5268 [7] part two. This stipulates that for end distance parallel to grain of 20d, an inter-nail spacing (nail-to-nail distance parallel to grain) of 20d is required without pre-drilled hole for nail in timber-to-timber joints.

A sketch which illustrates the loading pattern of the flexural test is shown in Figure 1 while the experimental set up which shows the Digital Board Universal testing machine is presented in Figure 2.

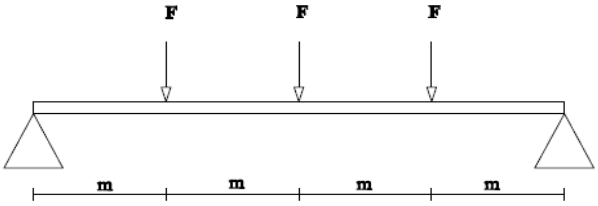

Figure 1: Sketch of loading pattern for the flexural test

Figure 2: Box Specimen loaded on the Digital Board Universal testing machine

## 2.1 Shear flow and nail spacing in the built-up members

In estimating the nail spacing for the built-up beams, the shear flow must be evaluated as it relates to the nail spacing by Equation 1.

$$S = \frac{C_f n}{q} \qquad (1)$$

Where S = longitudinal fastener spacing (in direction of the beam longitudinal axis)

$C_f$ = shear capacity of a single fastener (kN)

$n$ = number of fasteners crossing $A'$

$$q = \frac{VQ}{I} \qquad (2)$$

Where q = shear flow (force per unit distance)

$V$= internal resultant shear force (from shear diagram)

$I$= moment of inertia of the built-up section

$$Q = \overline{y}' A' \qquad (3)$$

where $A'$= the area of the section for which shear flow is to be calculated

$\overline{y}'$= distance between neutral axis and midpoint of $A'$

Combining Equations (1) and (2) ultimately results in

$$S = \frac{C_f n\, I}{VQ} \qquad (4)$$

## 2.2 Reliability Analysis

The findings of the reliability analysis conducted on built-up sections of Nigerian-grown African birch timber subjected to bending forces in order to determine its structural performance as a timber bridge beam. The flexural strength properties were determined at an 18% moisture content using the British Standard BS 373 [18] methods for testing small clear specimens of timber. The determined flexural strength properties were used in a statistical analysis. Structural safety analysis for the ultimate limit state of loading of African birch timber used for structural members in bridge beams and general construction works in accordance with BS 5268 [7]. The African birch timber bridge beam's reliability was assessed using the first-order reliability method (FORM). Sensitivity analysis was performed by varying the depth of the beam, imposed live load, beam breadth, unit weight of the timber, beam span, and end bearing length. The failure probability of a Nigerian grown African birch timber built-up beam structure in flexure was determined under various design conditions.

Table 5: Probability distribution and statistical parameters for variables

| Basic variables | *Probability distribution* | *Mean ($\bar{x}$)* | *COV (%)* |
|---|---|---|---|
| UDL ($w$= kN/m) | *Lognormal* | *17.02* | *0.06* |
| Live Load (N/m$^2$) | *Lognormal* | $9.5\times 10^3$ | *0.2* |
| Span (L =m) | *Normal* | *5000* | *0.03* |
| Breadth (b=mm) | *Normal* | *1500* | *0.06* |
| Depth (H=mm) | *Normal* | *400* | *0.06* |

The limit state or performance function in bending as given by (Nowak and Collins, [19]) is

$$g_x = f_p - f_a$$

Where, $f_p$ = permissible (basic) stress

$f_a$ = actual stress

Using the permissible stress as the basic stress, the limit state of the I- section can be written as

$$g_x = 88.077 - \frac{3wl^2}{4bh^2}$$

the limit state of the solid section can be written as

$$g_x = 28.517 - \frac{3wl^2}{4bh^2}$$

the limit state of the I- section can be written as

$$g_x = 206.948 - \frac{3wl^2}{4bh^2}$$

Where $w$= is the unit weight of the timber

$l$= is the span of the timber

$b$= is the breadth of the timber section

$h$ = is the height of the timber

## 3. Results and Discussion

### 3.1 Flexural Test Results

The flexural test results for the I and box built-up beams are shown in Tables 3 and 4, respectively. The I beams are labeled LL, while the box beams are labeled BL. The observed failure loads and reactions (which are the maximum shear forces) were recorded. These maximum shear force values were used in Equation (4) to calculate the corresponding minimum nail spacing for the various sections. The values of the parameters for which the minimum spacing were evaluated are thus:

| For I section | For box section |
|---|---|
| $I = 2.11 \times 10^6$ mm$^4$ | $I = 3.2 \times 10^6$ mm$^4$ |
| $A = 45 \times 20 = 900$ mm$^2$ | $A = 80 \times 20 = 900$ mm$^2$ |
| $Q = 900 \times 32.5 = 29\ 250$ mm$^3$ | $Q = 1600 \times 30 = 48\ 000$ mm$^3$ |
| $C_f = 460.05$ N/mm$^2$ | $C_f = 460.05$ N/mm$^2$ |
| n= 1 | n= 2 |

Table 3: Flexural test result for I- built-up beam section

| Specimen Mark | Failure load (kN) | Reaction (kN) |
|---|---|---|
| LL1 | 32.20 | 16.1 |
| LL2 | 24.50 | 12.25 |
| LL3 | 40.10 | 20.05 |
| LL4 | 45.40 | 22.7 |
| LL5 | 44.80 | 22.4 |
| LL6 | 38.90 | 19.45 |
| LL7 | 36.30 | 18.15 |
| LL8 | 34.70 | 17.35 |
| LL9 | 42.00 | 21 |
| LL10 | 28.00 | 14 |
| LL11 | 34.50 | 17.25 |
| LL12 | 37.40 | 18.7 |
| LL13 | 30.30 | 15.15 |
| LL14 | 38.20 | 19.1 |
| LL15 | 45.20 | 22.6 |
| LL16 | 41.70 | 20.85 |
| LL17 | 42.40 | 21.2 |
| LL18 | 43.60 | 21.8 |
| LL19 | 45.70 | 22.85 |
| LL20 | 40.20 | 20.1 |

Table 4: Flexural test result for Box- built-up beam section

| Specimen Mark | Failure load (kN) | Reactions (kN) |
|---|---|---|
| BL1 | 44.20 | 22.1 |
| BL2 | 42.80 | 21.4 |
| BL3 | 43.50 | 21.75 |
| BL4 | 31.20 | 15.6 |
| BL5 | 44.50 | 22.25 |
| BL6 | 42.20 | 21.1 |
| BL7 | 44.50 | 22.25 |
| BL8 | 43.00 | 21.5 |
| BL9 | 43.50 | 21.75 |
| BL10 | 39.00 | 19.5 |
| BL11 | 42.40 | 21.2 |
| BL12 | 38.60 | 19.3 |
| BL13 | 45.80 | 22.9 |
| BL14 | 40.40 | 20.2 |
| BL15 | 43.20 | 21.6 |
| BL16 | 37.00 | 18.5 |

| | | |
|---|---|---|
| BL17 | 39.80 | 19.9 |
| BL18 | 40.60 | 20.3 |
| BL19 | 42.80 | 21.4 |
| BL20 | 40.60 | 20.3 |

Graphs of minimum spacing against maximum shear force were plotted for both the I and box section and are shown in Figures 3 and 4. It can be observed that there is a negative linear relationship between the nail spacing and the shear force gotten from the failure strength of the flexural test.

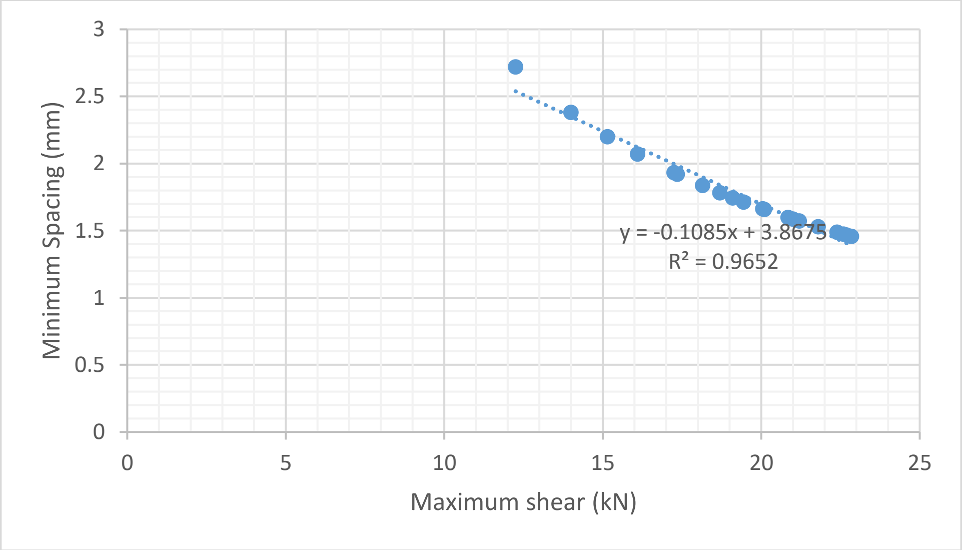

Figure 3: Spacing-Shear relationship for I- built-up section

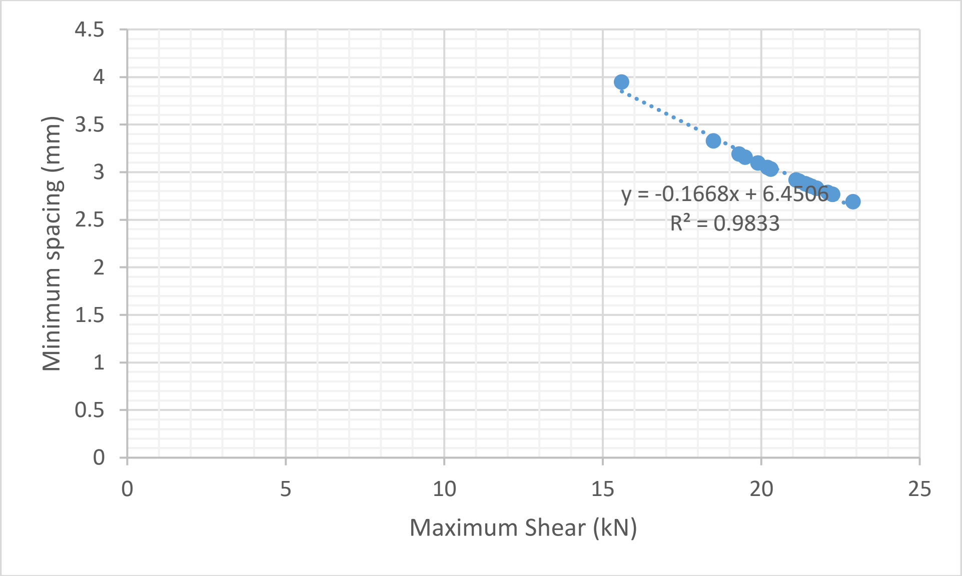

Figure 4: Spacing-Shear relationship for box- built-up beam

### 3.2 Reliability Assessment Results

Figure 5 depicts the relationship between the safety index and the uniformly distributed load (UDL) of African birch solid, I, and box built-up sections. The figure shows that the Box section had the highest safety index, followed by the I section and then the solid section. The safety index is arranged in descending order, as follows: Box section > I section > Solid section. As the uniformly distributed load (UDL) increases, so does the safety index.

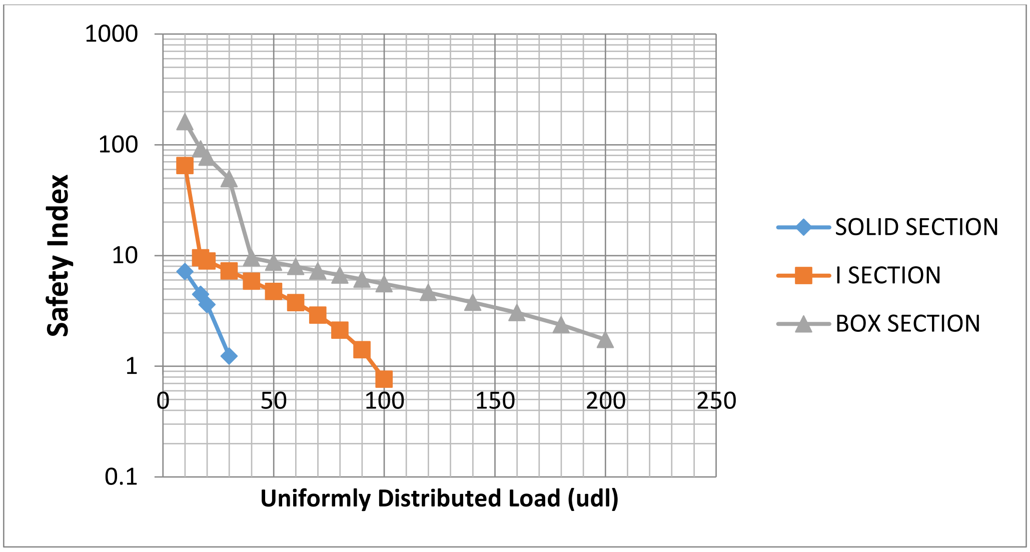

Figure 5: Safety index-uniformly distributed load relationship of solid and built-up sections

Figure 6 shows the relationship between safety index and uniformly distributed load (UDL) of solid, I and box built-up sections for African birch. Box section of African birch had the highest safety index in relation to the span of the timber, followed by I section and then the solid section. The safety index of the African birch decreases with an increase in the span of the timber sections. The order of decreasing is as follows: Box section > I section > Solid section. The safety index reduces as the span of the timber section increases.

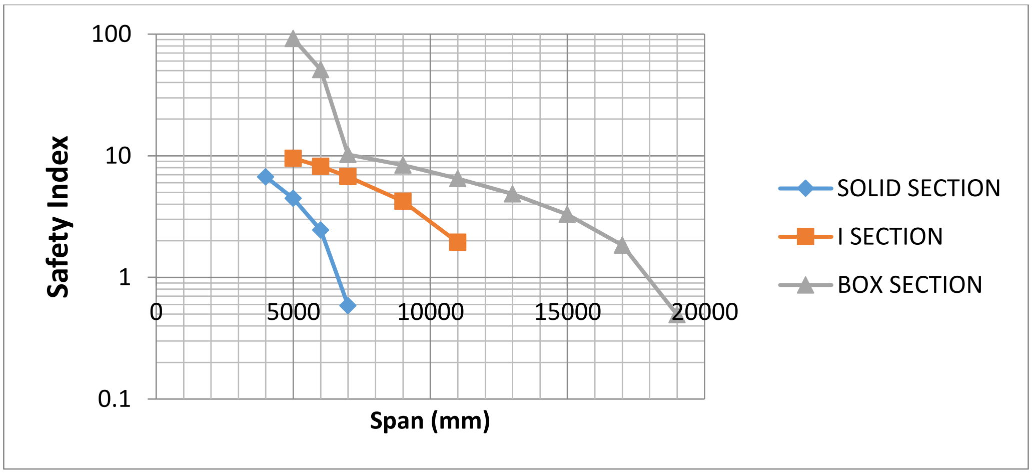

Figure 6: Safety index-span relationship of solid and built-up sections

The results of the relationship between safety index and the breadth of solid, I and box built-up sections for African birch timber sections are presented in Figure 7. Box section of African birch had the highest safety index in relation to the breadth of the timber section, followed by I section and finally the solid section. The safety index of the African birch increases as the breadth of the timber beam section increases. The order of increasing is as follows: Solid section < I section < Box section. The safety index increases as the width of the timber section increases.

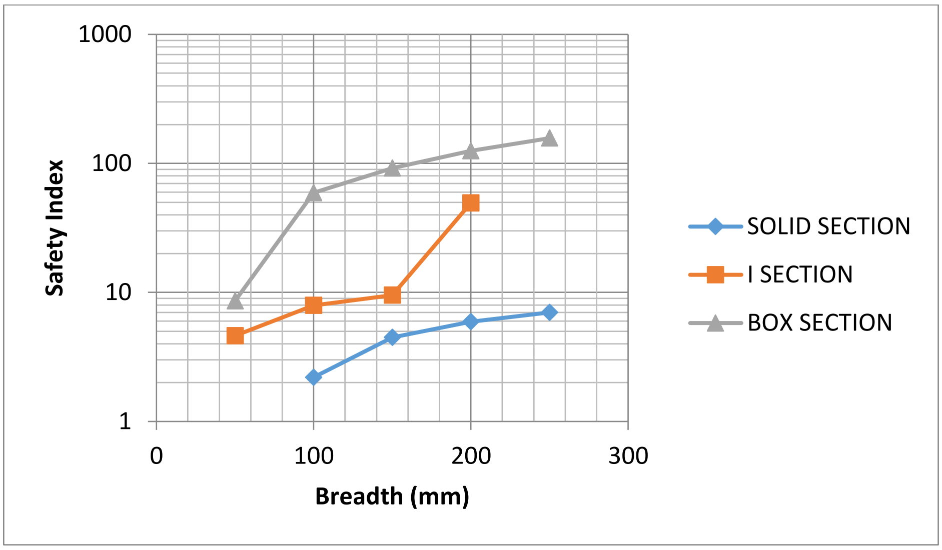

Figure 7: Safety index-breadth relationship of solid and built-up sections

Figure 8 shows the relationship between the safety index and the depth of solid, I, and box built-up sections made of African birch timber. The African birch solid section had the lowest safety index in relation to timber depth, followed by the I section and finally the box section. As the depth of the timber beam section increases, so does the African birch's safety index. The following is in ascending order: Section I Sections that are solid Section of the box The safety index rises as the depth of the timber beam section increases.

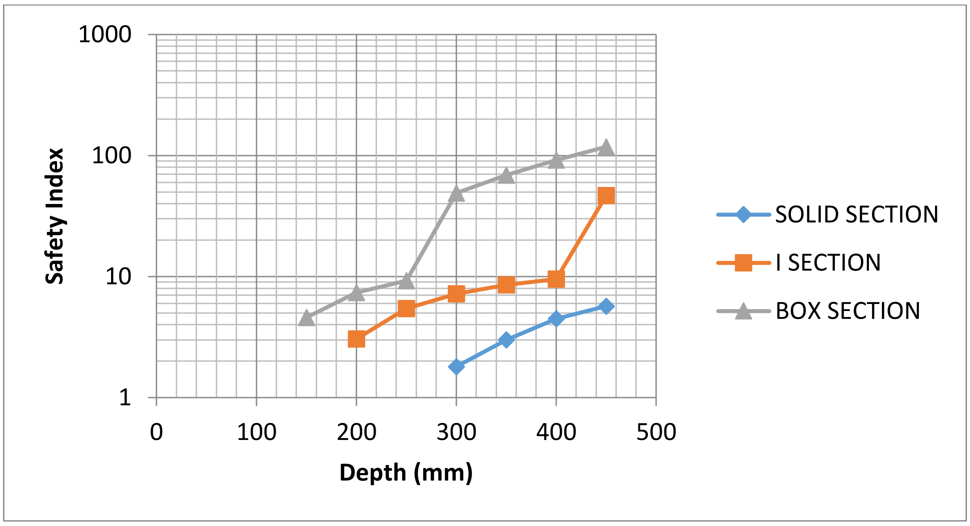

Figure 8: Safety index-depth relationship of solid and built-up sections

Figure 9 shows the results of the relationship between the maximum safe uniformly distributed load (UDL) capacity and the grades and sections of the solid, I and box built-up sections of African birch. It was observed that solid section has the highest strength values for the basic stress as well as all other grades of timber sections such as 80, 63, 50 and 40 grade stresses for the considered African birch.

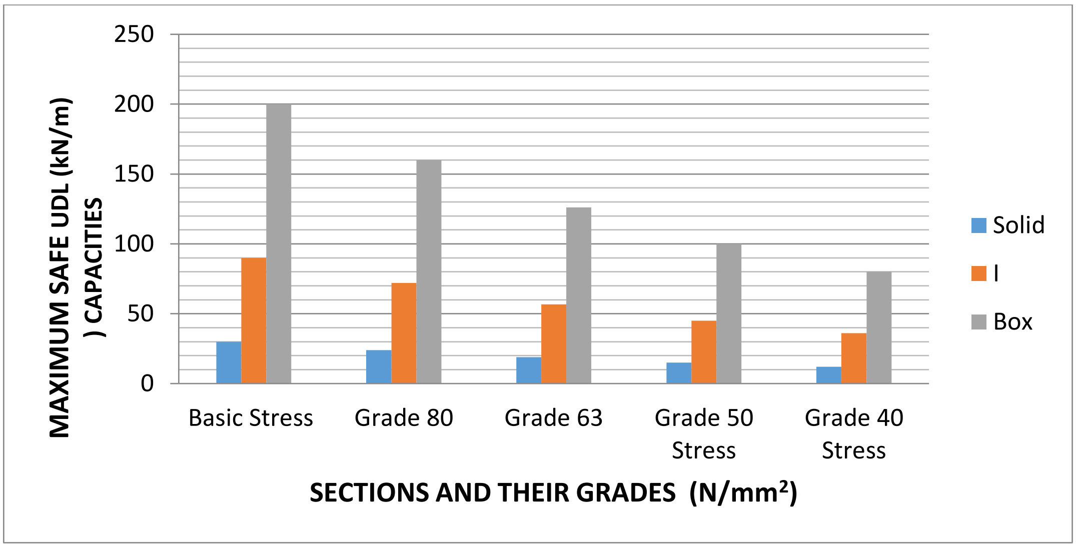

Figure 9: Maximum safe UDL-Section relationship of solid and built-up sections

## 4. Conclusion

The overall findings of this study show that the safety index of the box section is greater than that of the I section, and the I section is greater than the solid section. The results obtained can be used as a guide for structural timber designers and other timber users. Other mechanical properties, such as compressive, tensile, and shear strength, can be studied further to determine structural safety.

## Nomenclature

| | |
|---|---|
| A,B | Regression coefficients |
| $a_s$ | Reaction surface area |
| $D^{eff}$ | Effective diffusion coefficient ($Sm^{-1}$) |
| $D_i$ | Diffusivity ($Sm^{-1}$) |
| DOE | Design of Experiment |
| E | Energy density(Wh/kg) |
| $E_{cell}$ | Specific Energy(Wh/kg) |
| F | Faradays constant |
| I | Load current density ($Am^{-2}$) |
| J | Reaction current density($Am^{-2}$) |
| $K^{eff}$ | Effective conductivity($Sm^{-1}$) |
| L | Length |
| $m_{cell}$ | Total weight of cell (kg) |
| R | Radial coordinate in spherical particle ($\mu$m) |
| $R^2$ | Correlation factor |
| $r_p$ | Particle radius ($\mu$m) |
| T | Time |
| $t_{dis}$ | Discharge time(s) |
| $T_e$ | Temperature($^0$C) |
| $T_i$ | Electrode thickness |
| $t_+^0$ | Transference number |
| $U_{ocp}$ | Open circuit potential (V) |

| | |
|---|---|
| V | Terminal voltage |
| Y | Dependent variable(Regression) |

Greek letters

| | |
|---|---|
| $\sigma^{eff}$ | Effective conductivity ($Sm^{-1}$) |
| Z | Dimensionless energy |
| Λ | Dimensionless diffusivity |
| Φ | Specific modulus($m^2/s^2$) |
| Ψ | Experimental correlation coefficient function |
| $\delta$ | Dimensionless electrode thickness |
| $\varepsilon$ | Volume fraction |
| $\theta$ | Correlation coefficient |
| $\varphi_1$ | Electronic Potential (V) |

## References

[1] Oluyege, A.O (2007). Wood: A Versatile Material for Natural Development. Inaugural Lecture Series 45, delivered at the Federal University of Technology Akure.

[2] Nigerian Standard Code of Practice, NCP 2 (1973): The use of Timber for Construction. Nigerian Standards Organisation, federal Ministries of Industries, Lagos, Nigeria, pp. 71.

[3] Aguwa, J. I. (2016). The Nigerian Structural Timber. Published and Printed by Ahmadu Bello University Press Ltd., Samaru, Zaria. Nigeria. ISBN: 978-978-54683-2-5, 5 and 6.

[4] Jimoh A.A. and Aina S.T. (2017a). Charaterisation and grading of two selected timber species grown in Kwara state Nigeria. Nigerian Journal of Technology (NIJOTECH), 36 (4), 1002-1009.

[5] Jimoh A.A. and Ibitolu B.J. (2018). Charaterisation and grading of three selected timber species grown in Kwara state Nigeria according to EN 338 (2009) for Structural Use. Nigerian Journal of Technology (NIJOTECH), 37 (2), 322-329.

[6] Jimoh, A.A. and Aina, S. (2017b). Statistical Analysis of Properties of Timber Species for Structural Use. Journal of EEA, Vol. 35, PP. 8 – 16.

[7] BS 5268 (2002). The structural use of timber part 2; for permissible stresses, materials and workmanship. 5th ed. London: British Standards Institution, 176p.

[8] Aguwa J.I. Chukwu P.C. and Auta S.M. (2015). Characterisation and Grading of South Eastern Nigerian-grown *Irvingia gabonensis* Timber in Accordance with BS 5268. USEP Journal of Research of Information in Civil Engineering, Vol. 12, No. 2, PP. 720 – 731.

[9] Osuji, S. and Inerhunwa, I. (2017). Characterisation and Strength Classification of Timber Species in Akwa Ibom State, Nigeria for Structural Engineering Applications. International Journal of Engineering Research and Application, Vol. 7, Iss. 10, PP. 01 – 09.

[10] Bello A. A. and Jimoh A. A. (2018). Some Physical and Mechanical Properties of African Birch (Anogeissus leiocarpus) Timber. Journal of Applied Science and Environmental Management, Vol. 22, No. 1, PP. 79 – 84.

[11] Wilson U.N., Adedeji A.A., Oriola F.O.P., Sani J.E., Alomaja J.A. (2019). Comparative Reliability Assessment of a Solid and Nail-jointed ISection of Nigerian-Grown African Birch (Anogeissus leiocarpus) Timber Column. International Journal of Scientific and Engineering Research. Vol., 10, Issue 4.

[12] Broker, F.W. and Krause, H.A. (1991). Preliminary investigations on the holding power of dynamically loaded wood-screws. Holz Roh Werkst., 49, 381–384.

[13] Meghlat, E.M.; Oudjene, M.; Ait-Aider, H.; Batoz, J.L. (2013). A new approach to model nailed and screwed timber joints using the finite element method. Constr. Build. Mater. 41, 263–269.

[14] Yeh, M.C., Hsieh, C.H. (1995). An evaluation on withdrawal resistance of nail joints for domestic Cryptomeria japonica sawn lumber. For. Prod. Ind. 14, 551–564. (In Chinese).

[15] Bues, C.T., Schulz, H.; Eichenseer, F. (1987). Investigation of the pull-out resistance of nails and screws in pine wood. Holz Roh Werkst. 45, 514.

[16] Chien, T.P., Yang, T.H. and Chang, F.C. (2019). Flexural Performance of Built-Up Beams Made with Plantation Wood. Forests, Vol. 10, No. 647, PP. 1 – 11.

[17] Alam, P. and Ansell, M. (2012). The Effects of Varying Nailing Density Upon the Flexural Properties of Flitch Beams. Journal of Civil Engineering Research, Vol. 2, No. 1, PP. 7 – 13.

[18] BS 373 1957, Methods of testing small clear specimens of timber, British Standards Institution, 2 Park Street, London WIA 2BS,1957.

[19] Nowak AS, Collins KR (2000). Reliability of Structures, McGraw-Hill Companies, USA. pp. 337.