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Evaluation of Physical and Mechanical Properties of Selected Wood Species obtained from Saw Mills in Akure, Nigeria

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ABSTRACT: The strength and sorption properties of selected wood species obtained from saw mills in Akure Nigeria were investigated based on key index properties such as density, bending strength and dimensional stability using appropriate standard experimental techniques. Data obtained from the experimental investigation revealed that the wood species ranged from low density 442.8 kg/m^3 for *Terminalia superba* (Afara), through medium density 464 kg/m^3 and 552.8 kg/m^3 for *Pycnanthus angolensis* (Akomu) and *Gmelina arborea* (Gmelina) respectively, to high density 635.7kg/m^3 and 678.2 kg/m^3 for *Milicia excelsa* (Iroko) and *Stereospermum acuminatissimum* (Omo cedar) respectively. The bending strength values obtained qualified the wood species classification into low bending strength (25 N/mm^2 – 75 N/mm^2) for Afara, Akomu and Gmelina and the medium static bending strength in the range (75 N/mm^2 – 125 N/mm^2) for Iroko and Omo cedar. Furthermore, results of volumetric shrinkage and swelling are 7.21%: 5.04%, 7.75%: 5.26% and 7.84%: 6.69% for Afara, Akomu and Gmelina respectively while Iroko and Omo cedar recorded 10.95%: 7.84% and 11.08%: 11.08%. These updated results could be useful for wood selection for building construction application; for structural members in roofing, posts and beams.

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Evaluation of the physical and mechanical properties of wood species has become necessary due to the constantly changing supply chain of wood due to the combined effect of high demand for wood for a wide array of applications especially building construction and the progressive decline in the forest resource of the country as an effect of deforestation (ASTM-D143, 2009). There has been noticeable decline in the quality of wood (Falemara, *et. al.,* 2012) the effect of which has implications in engineering design for wood application. Consequently, there is the need to continuously evaluate the existing supply as a way to inform reasonable review of performance standards including consideration of lean designs or the pursuit of other value addition procedures such as glue lamination to enhance mechanical properties to cope with the available supplies. Furthermore, there is the need to profile lesser-known species as a way to correct the imbalance in wood demand between economic species and non-economic species. In view of the fact that wood is an eco- friendly material, it is important to ensure its competitiveness by obtaining up – to - date reliable data on key mechanical and physical properties so as to ensure that such properties are matched with appropriate application. This guarantees that some level of quality control is upheld in the consumption of wood across various areas of application. This study focuses on density a key physical property of wood for evaluation of wood quality. Density is an indication of the quantity of woody material in any wood species at a certain moisture content usually from 12 % to 18% (Zobel and Jett, 1995). Furthermore, density correlates positively with another index property, bending strength.

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Bending strength is an index strength property for determining the engineering suitability of wood. Bending strength test is a measure of resistance to deformation due to a combination of tension, compression and torsion. Furthermore, because wood is a hygroscopic material, evaluating sorption properties that affect dimensional stability is important for managing serviceability issues related to moisture variation once wood is in use. This study therefore aims to assess the strength and sorption properties of selected wood species obtained from saw mills in Akure Nigeria.

MATERIALS AND METHOD

Collection of Material and Description of Equipment Used: The materials used in this research were five freshly cut wood samples from *Terminalia superba* (Afara), *Pycnanthus angolensis* (Akomu), *Gmelina arborea* (Gmelina), *Milicia excelsa* (Iroko) and *Stereospermum acuminatissimum* (Omo cedar) with average age of 10 – 15 years obtained from one of the saw mills in Akure. Two sets of samples 20 mm x 20 mm x 60 mm and 20 mm x 20 mm x 300 mm were prepared for determination of physical and mechanical properties respectively as shown in plate 1. The moisture content of the wood samples was controlled in an electric oven regulated within a temperature range of 103 ± 3^0 C. The density was determined using an electronic weighing balance with precision to 0.1 decimal place. Bending strength test was conducted for determination of modulus of rupture (MOR) on a 20 kN universal testing machine equipped with a computerized data acquisition system at the Department of Forestry and Wood Technology, Federal University of Technology Akure.

Plate 1: Samples for determination of basic physical and mechanical properties

Basic Properties Determination

(a) Moisture content determination: Moisture content was determined by oven drying at a temperature of 105 ^{o} C for 24 hours. The moisture content (MC) in percentage was then determined according to equation (1):

$$MC = \frac{W_g - W_d}{W_d} \times 100 \qquad (1)$$

Where W_g is the green weight and W_d is the dry weight of the wood specimens.

(b). Density determination: Density was determined according to ASTM D143 - 09 after oven-drying for 24 hours using equation (2):

$$\rho = \frac{M}{V} \qquad (2)$$

Where M is oven dry mass of specimen and V is the dry volume of the specimens.

(c). Volumetric shrinkage: Green wood samples were loaded into the oven and dried to a constant weight after which dimensional changes due to moisture loss were determined according to equation (3):

$$V_s(\%) = \left[\frac{V_g - V_{od}}{V_{od}}\right] 100 \qquad (3)$$

Where V_s is the volumetric shrinkage of wood sample, V_{od} is the oven dried volume and V_g is the green volume.

(d) Volumetric swelling: Similarly, change in dimension after 72 hours immersion in water was measured and the volumetric swelling computed using equation (4)

$$V_{sw}(\%) = \left[\frac{V_{ws} - V_d}{V_d}\right] 100 \qquad (4)$$

Where V_{sw} is volumetric swelling of wood sample, V_{ws} is water swollen volume after soaking and V_d is dry volume before soaking.

(e) Static bending test: Bending strength (σ) also known as Modulus of Rupture (MOR) was determined using center point loading applied at a distance of 130 mm away from each support as shown in figure 1. The modulus of rupture was then calculated using equation (5):

$$\sigma = \frac{3 \times P_{max} \times L}{2 \times b \times h^2} \qquad (5)$$

where, P_{max} is maximum load applied to point of failure (N), L is span of specimen (mm), b is breadth of specimen (mm) and h is depth of specimen (mm).

Similarly, modulus of elasticity (MOE) was determined using:

$$MOE = \frac{PL^3}{4 \times \Delta \times b \times h^3} \quad (6)$$

where *P* is load at the limit of proportionality (N), L is the loading span of the test specimen (260 mm), b and h are breadth and depth respectively of the test specimen (mm) and Δ is deflection at the limit of proportionality (mm).

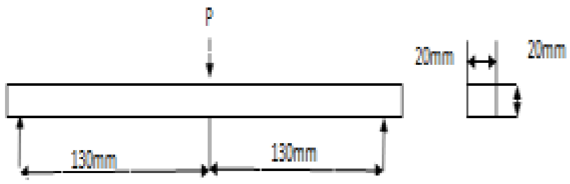

Fig 1: Static bending test setup

(f). *Tensile strength parallel to grain:* Tensile strength parallel to grain was conducted on waisted specimens according to ASTM D 143 as shown in figure 2

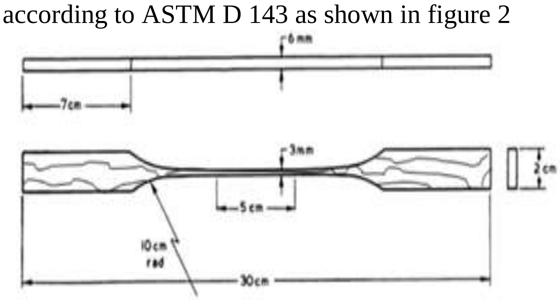

Fig 2: specimen for tensile strength test

The tensile strength of the wood samples was computed using equation (7):

$$f_y = \frac{F_l}{A_m} \quad (7)$$

where f_y is the ultimate tensile strength (N/mm^2), F_l is the maximum load before failure (N) and A_m is minimum original cross-sectional area (mm^2).

(g). *Compressive stress parallel to the grain:* Compressive strength parallel to grain was carried out on compressive testing machine using the specimen dimension shown in figure 3.

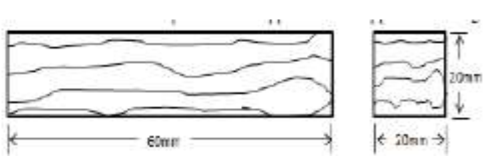

Fig 3: Specimen dimension for compression parallel to grain

The compressive strength was then determined using equation (8):

$$F_c = \frac{P_l}{A_m} \quad (8)$$

Where F_c is the compressive strength (N/mm^2), P_l is the axial compressive force applied to the specimen (N) and A_m is the cross-sectional area of the specimen (mm^2).

RESULTS AND DISCUSSION

Density: The mean density value for each of the species in figure 4 shows recorded values as follows *Afara*, 442.8 ± 6.22 kg/m^3 and *Akomu*, 464 ± 13.27 kg/m^3. *Gmelina* recorded a mean density of 552.8 ± 15.01 kg/m^3 while *Iroko* recorded a mean density of 635.9 ± 9.3 kg/m^3. Similarly, *Omo cedar* recorded a mean value of 678.2± 16.9 kg/m^3. The result of analysis of variance (α = 0.05) for the density of the species showed that there is significant difference ($p < 0.05$) in the mean density among the wood species ($p = 0.000$).

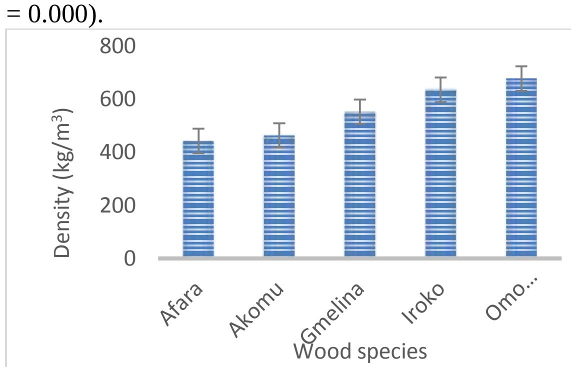

Fig 4: mean density of the selected wood species

Volumetric Shrinkage and Swelling: The result of volumetric shrinkage in figure 5 shows that *Afara* has a mean value of 7.21%, *Akomu* 7.75%, and 7.84% for *Gmelina*. *Iroko* has a mean value of 10.95% while *Omo cedar* has a mean shrinkage value of 11.08%. Analysis of variance was conducted to test the variance of mean shrinkage values among species. The result showed that the mean volumetric shrinkage among the species was significantly different ($p < 0.05$). Similarly, the mean volumetric swelling values among the species is presented in figure 6 where it is shown that *Omo cedar* has the highest mean value of volumetric swelling of 7.91± 3.11%. This is followed by *Iroko* with a mean value of 7.84 ± 3.06%. *Afara* has the lowest mean volumetric swelling value of 5.04 ±1.46% lower than *Akomu* and *Gmelina* with swelling values of 5.26 ± 1.79% and 6.69 ± 3.17% respectively. The mean values of volumetric swelling were analyzed for variance among the species using ANOVA and the result showed that the mean values were generally significantly different ($P < 0.05$) among the wood species ($p = 0.000$).

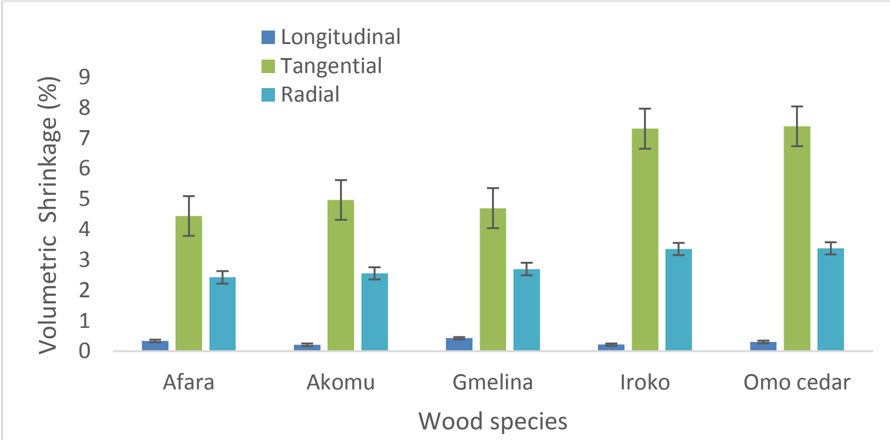

Fig 5: Volumetric shrinkage values along the longitudinal, tangential and radial planes

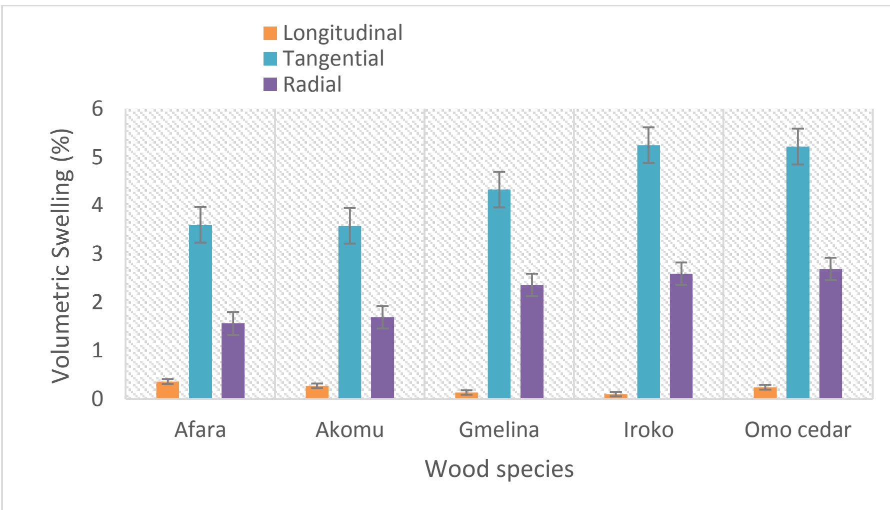

Fig 6: Average volumetric swelling values in perpendicular planes among species

Modulus of elasticity: The mean values of MOE for *Afara*, *Akomu*, *Milicia*, *Gmelina* and *Omo cedar* presented in figure 7 shows that the mean value of MOE of *Afara* is 4500 ± 446.1 N/mm^2 which is the lowest among the selected species followed by *Akomu* with a mean MOE of 5450 ± 915 N/mm^2, and *Gmelina* with mean MOE of 5900 ± 1624.3N/mm^2. Furthermore, *Iroko* had a mean MOE of 7600 ± 1259.6N/mm^2 and *Omo cedar* had the highest MOE of 8150 ± 1635.2 N/mm^2. The ANOVA result for the modulus of elasticity (MOE) of the species showed that the effect of species on the modulus of elasticity (MOE) is significant ($p < 0.05$). Furthermore, HSD post hoc analysis was conducted to identify the specific area of differences among the species. Sequel to the HSD analysis the species are grouped into homogenous groups of means of modulus of elasticity. The results show that *Afara*, *Akomu* and *Gmelina* are grouped into a homogenous subset A ($p = 0.399$) where the mean MOE of the group is 5283 N/mm^2 while *Akomu*, *Gmelina* and *Iroko* are grouped into another subset B ($p = 0.065$) with mean MOE of 6317 N/mm^2. Similarly, *Iroko* and *Omo cedar* are grouped in Subset C ($p = .956$) with mean MOE of 7875 N/mm^2.

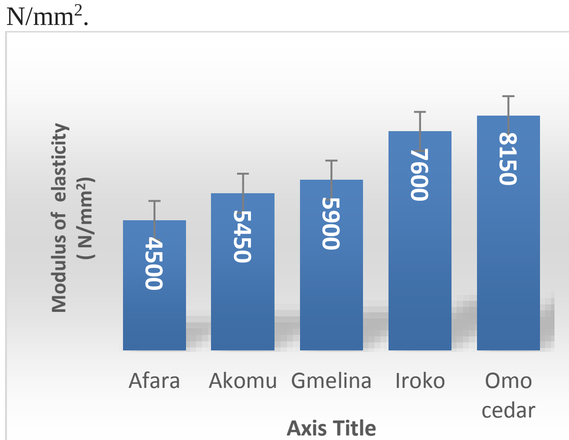

Fig 7: MOE in bending among the selected species

Static bending strength: The bending strength result showed that *Afara* recorded a mean bending strength of 37.3 ± 3.65 N/mm^2 while *Akomu* had a mean value of 47.8 ± 9.27 N/mm^2. *Gmelina* recorded a mean value of 48.2 ± 11.51 N/mm^2, *Iroko* recorded mean bending strength of 76.1 ± 7.44 N/mm^2 while *Omo cdedar* had 77.1 ± 8.49 N/mm^2. The bending strength values obtained in this study for the species as shown in figure 8 are similar to the findings from other studies such that *Afara*, *Akomu* and *Gmelina* belong to bending strength class categorized as low static bending strength ranging from 25 N/mm^2 – 75 N/mm^2 while *Iroko* and *Omo cedar* belong to the medium static bending strength class ranging from 75 N/mm^2 – 125 N/mm^2, (Kimpouni, 2009; Frake, 2021). The bending strength values are also consistent with the density class of the species. However, the bending strength for *Afara* in this study differed greatly from that reported in Frake datasheet (Frake, 2011) but is in the same strength range reported by Kimpouni (2018). Similarly, *Akomu* differed from the 60 N/mm^2 reported from previous studies Kimpouni, (2009). For *Gmelina*, the 48.2 N/mm^2 bending strength was similar to that obtained by Ogunsanwo and Akinlabi (2011). The bending strength of 76.1 N/mm^2 obtained for *Iroko* is similar to that obtained by Amoah *et.al*, (2012) and aligns with findings of Kimpouni (2009). For *Omo cedar,* no mechanical property data was found in the literature for the wood species to corroborate the findings from these study as it is a lesser known species. Furthermore, a one-way ANOVA between subjects was conducted to compare the effect of wood species on bending strength capacity of *Afara*, *Akomu*, *Gmelina*, *Iroko* and *Omo cedar*. There was significant effect of the wood species on the bending strength capacity at $p < 0.05$ for the various species ($p = 0.000$).

Tensile Strength Parallel to Grain: The mean tensile strength values of wood species displayed in figure 8 show that *Afara* has a mean tensile strength of 42 ± 7.2 N/mm^2, *Akomu* has the lowest mean tensile strength value of 38 ± 10.4 N/mm^2 while *Gmelina* has a mean tensile strength of 45 ± 3.4 N/mm^2. Furthermore, *Iroko* has mean tensile strength of 54 ± 5.9 N/mm^2 while *Omo cedar* has a mean tensile strength of 76 ± 11.82 N/mm^2. The mean tensile strength values were compared among species where the analysis of variance result showed that the difference in tensile strength among species was significant at p = 0.000. Generally, the tensile strength values agreed with the influence of density on mechanical strength.

Compression Parallel to Grain: The mean compressive strength test result displayed in figure 8 revealed that *Afara* had the lowest mean compressive strength parallel to grain of 26 N/mm^2. This is followed by Gmelina with 33 N/mm^2. *Akomu* has a mean compressive strength of 34 N/mm^2 and *Iroko* has a mean compressive strength of 50.7N/mm^2 while Omo *cedar* recorded the highest mean compressive strength of 60.5 These values are consistent with the strength range of 26 N/mm^2 – 67 N/mm^2, 38 N/mm^2 – 39.5 N/mm^2, 20 N/mm^2 -39 N/mm^2 and 42 N/mm^2 -65 N/mm^2 for *Afara*, *Akomu*, *Gmelina and Iroko* reported in literature (Kimpouni, 2018). Furthermore, the value obtained for *Iroko* aligns with that reported by (IITO, 2021) and is higher than that obtained by Aguwa and Sadiku (2012). However, *Omo cedar* is a lesser-known wood species with no mechanical strength reported in literature. Nevertheless, its compressive strength value viz -a – vis its density showed consistency. The effect of species was tested on the mean compressive strength results using analysis of variance which showed that the effect of species on the mean values of compression parallel to grain was statistically significant ($p = 0.000$). This aligns with the general understanding that compressive strength parallel to grain like other wood properties varies within and between species (Winandy, 1994).

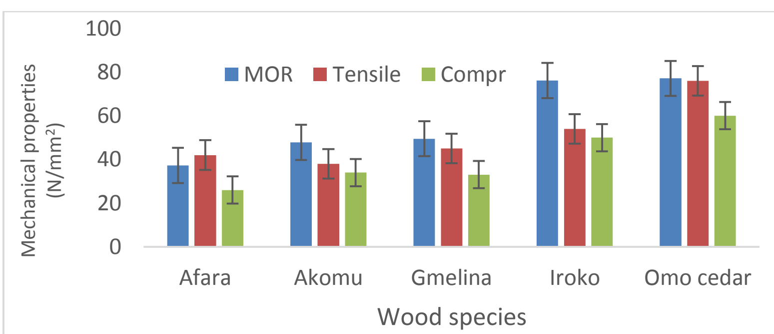

Fig 8: Basic mechanical properties of selected wood species

Density: Density varied significantly between the wood species. The density range according to Owoyemi *et al.*, (2014) is from low density (442.8 kg/m^3 and 464 kg/m^3) for *Afara* and *Akomu* to medium density (552.8 kg/m^3) for *Gmelina* and to high density (635.7 Kg/m^3 and 678 kg/m^3) for Iroko and Omo cedar. The variation in wood density according to Dinwoodie and Desch (1991) is adduced to effect of growth rate, genetic make up and conditions in the growth location. Density is an important indicator of wood quality. Delicne in wood quality can be determined from inspecting density values. As an evidence of decline in wood quality Afara which recorded a value of 442.8 kg/m^3 in the low density class was previously reported to be within the medium density class according to Falemara *et al.*, (2012). Furthermore there are more wood species in use with no technical data to inform there utilization. One of such species is S*tereospermum accuminatissimum* which is locally known as Omo cedar. Data on index property of this wood species was not found in literature. From this study, Omo cedar fell into the medium density with a density of 678 kg/m^3 which makes it within the same class with Iroko which is a widely explored species.

Volumetric shinkage and swelling: The result of volumetric shrinkage is consistent with findings documented in literature that higher shrinkage is connected with higher density (Glass and Zelinka, 2021) because of the microstructure of the cell wall of high-density wood (Schulgasser and Witztum, 2011). This implies that where large moisture variation in service is anticipated, that is, extensive moisture loss under external conditions or at periods of low relative humidity, provisions must be made to mitigate the effect of dimensional and mechanical disruption associated with wood shrinkage including warping, checking and splitting of wood. One of such provisions would be to dry wood to equilibrium moisture content to minimise moisture movement during service life. Similarly the values obtained for volumetric swelling across different planes and different species is an indication of anisotropy in wood dimensional stability. The longitudinal plane recorded the least volumetric swelling value. Similarly, the result of volumetric swelling for the selected species obtained from laboratory investigation are within the range for most wood species and were found to vary with wood species and wood density. With increasing dry wood density, the value of swelling was found to increase (Rowell, 2005). Also, that volumetric swelling in wood is density dependent is consistent with the body of knowledge on wood dimensional stability (Schulgasser and Witztum, 2011).

Bending strength: The variation in the bending strength values obtained in this study and previous studies is typical of wood as a construction material due to growth conditions of the tree, portions of the tree where the specimens are obtained e.g., matured heart wood or sapwood (Frake, 2021) and the felling age due to over logging (Ogunsanwo and Akinlabi, 2011). Furthermore, in recognition of the possibility of vast strength variations within species and changing supply conditions, the need for continuous evaluation of strength properties of wood remains relevant in advancing wood utilization (ASTM-D143, 2009). Moreover, the reality of variation in wood properties within and between species is a relevant argument for adopting engineering interventions such as glue lamination to make for superior and more stable properties in wood mechanical property suitable for structural application. From this study, it is seen that wood bending strength as with other wood properties is affected by density and species as shown by a representative Bending strength – Density plots in figure 9. This finding aligns with evidences in literature (Winnady, 1994; Rajamanickam *et al.*, 2021).

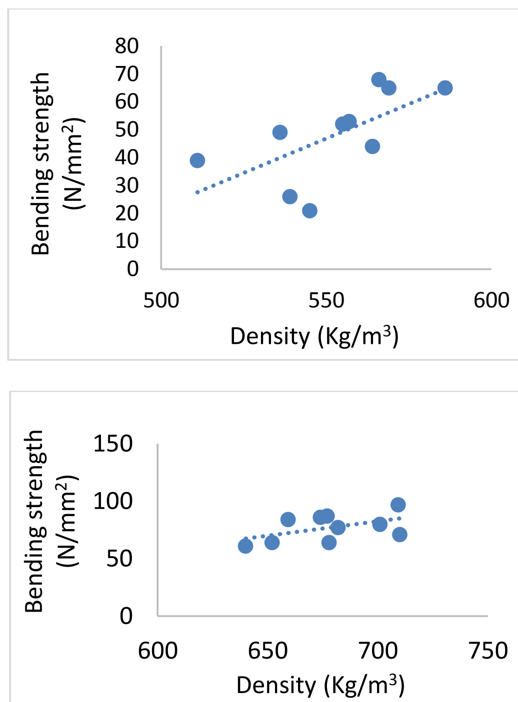

Fig 9 : Representative Bending strength – density plot for *T. Superba and S. Accuminatissimum* showing density and species effect on Bending strength

Tensile and compressive strength parallel to grain: The results from density and mechanical properties in figure 4 and figure 8 shows a positive relationship between density and tensile and compressive strength parallel to grain. It is clear that the amount of woody materials which density indicates governs the quality of wood and the values of the mechanical strength that can inform wood utilization (Miyoshi *et al.*, 2018).

Conclusion: The outcome of the study shows that the effect of species and density was significant on bending strength. Wood quality re-evaluation is importnat because of changes in wood quality supply. Omo cedar a lesser known wood species showed physical and mechancal properties similar to Iroko indicating that technical data is needed for alternative wood species. Based on the result Omo cedar is recommended as an alternative to Iroko. The study besides affirms that wood properties can be evaluated with lesser destructive assesssment using density as an indicies of quality as other properties assesed align positively with it.

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