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An Investigation into the Strength Properties of Three Reclaimed Structural Timber Joist Within the University of Ibadan Community

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Abstract: Background and Objective: The investigation presents the results of selected test assessment on physico-mechanical properties of three selected wood residues within the University of Ibadan Campus, Oyo State, Nigeria. Often, reclaimed planks were considered as useful material for heating and energy production, hence, potential re-usability of these residues for plate rack production were determined. Materials and Methods: Four planks of the selected three wood samples each were collected from the University of Ibadan community. The 12 pieces wood samples were cleaned, plained, and converted into required dimension; samples were dried to about 12%moisture content before tests. Selected physico-mechanical properties test (moisture content, volumetric shrinkage, modulus of elasticity, and modulus of rupture were carried out according to ASTM standards. The data obtained were subjected to analysis of variance (ANOVA). Results: The results of mean density show that *Gliricidia sepium, Milicia excelsa* and *Funtumia elastica* had 1032±0.97kg/m^3, 548±0.57kg/m^3 and 613±0.33kg/m^3, respectively. The mean value for moisture content of *G. sepium, M. excelsa and F. elastica* ranges from 12.47±1.21, 20.84±1.21 and 18.13±1.21, respectively. While, volumetric shrinkage of *G. sepium, M. excelsa and F. elastica* ranged from 20.55±2.79, 7.48±2.79 and 11.43±2.79. The *G. sepium, M. excelsa and F. elastica* had MOE values of 8793.13±643.43 N/mm^2, 8083.64±643.43 N/mm^2 and 4299.54±643.43N/mm^2. The mean values for MOR of *G. sepium, M. excelsa and F. elastica* ranges 404.69±12.362 N/mm^2, 434.27±12.36N/mm^2 and 388.34±12.36N/mm^2. Conclusion: *Gliricidia sepium* wood had the highest mean density, low shrinkage value and modulus of elasticity. Therefore, it was found most suitable wood slab for plate rack production from reclaimed wood joist.

Keywords: *Gliricidia sepium*, *Milicia excelsa*, *Funtumia elastica*, Density, Moisture Content, Shrinkage, Modulus of Elasticity, Modulus of Rupture

1. Introduction

Wood is a hardened, fibrous structural tissue found in the stems and roots of trees and other woody plants. It has been used for hundreds of thousands of years for both fuel and as a construction material [1]. Wood has been found to be an important raw material that contributes exceptionally in improving the country's economic base, industrialization and comfort of the cooperate population. It is considered indispensable and highly demanded in spite of many substitute materials-like iron, plastic, concrete and steel [1]. These substitutes have not always being successful because of their difficulties in matching the versatility and intrinsic properties of wood as a natural engineering material [2, 3]. The inherent properties of wood such as easy workability, gluability and high strength have led to the perpetual interest and demand of wood and its products [4]. It is an anisotropic material which presents differential properties in different structural directions. The use of wood is usually restricted due to its swelling and shrinkage at different relative humidity and temperature. The change in wood dimensions owing to variability in the moisture content of wood is of great concern in wood utilization. The anisotropic nature of wood is very important to studies of their characteristics and is related with their moisture content. The dimensions of wood undergo variations according to the increase or decrease in moisture content [5]. Density is the major factor used to determine most properties of wood [6]. It affects wood shrinkage and swelling, machinability, surface texture and micro smoothness, gluability, penetrability of fluids and gases, among others. Wood tends to experience the greater part of its expansion and contraction in one particular direction. Wood movement parallel to the grain is negligible whereas expansion and contraction across the grain is significant [7].

According to [8], degree of swelling and shrinkage of wood differs from species to species as well as from piece to piece. It was further noted by [9] reported that density, direction of measurement and relative humidity are some of the factors responsible for dimensional instability of wood in service. Wood in service are generally subjected to fluctuating atmospheric humidity due to their hygroscopic nature. They swells and also shrinks continually which might cause a piece of wood not worked as designed causing millions of pounds to be spent on varnishes and paints each year to try to stop water getting into wood [10]. There has been a lot research carried out on the physical and mechanical properties of different timber species. However, in this study, selected physical and mechanical properties of the residue of three different tree species within the University of Ibadan campus was carried out with a view of making use of this reclaimed timber residues in the production of kitchen utensils.

2. Materials and Methods

2.1 Study Area

The materials for this study was obtained within the campus of the University of Ibadan, further planks processing and investigation was conducted in the Department of Forest Production and Products, Faculty of Renewable Natural Resources, University of Ibadan campus, Ibadan, Oyo state, Nigeria. The University is situated at about 5km North of Ibadan city on Latitude 7°27'N and Longitude 3°54'E at an altitude of 200m. The mean annual rainfall is 200mm with distinct wet (April-October) and dry (November-March) season. Mean monthly temperature is between 26-28°C with February being the hottest month [11].

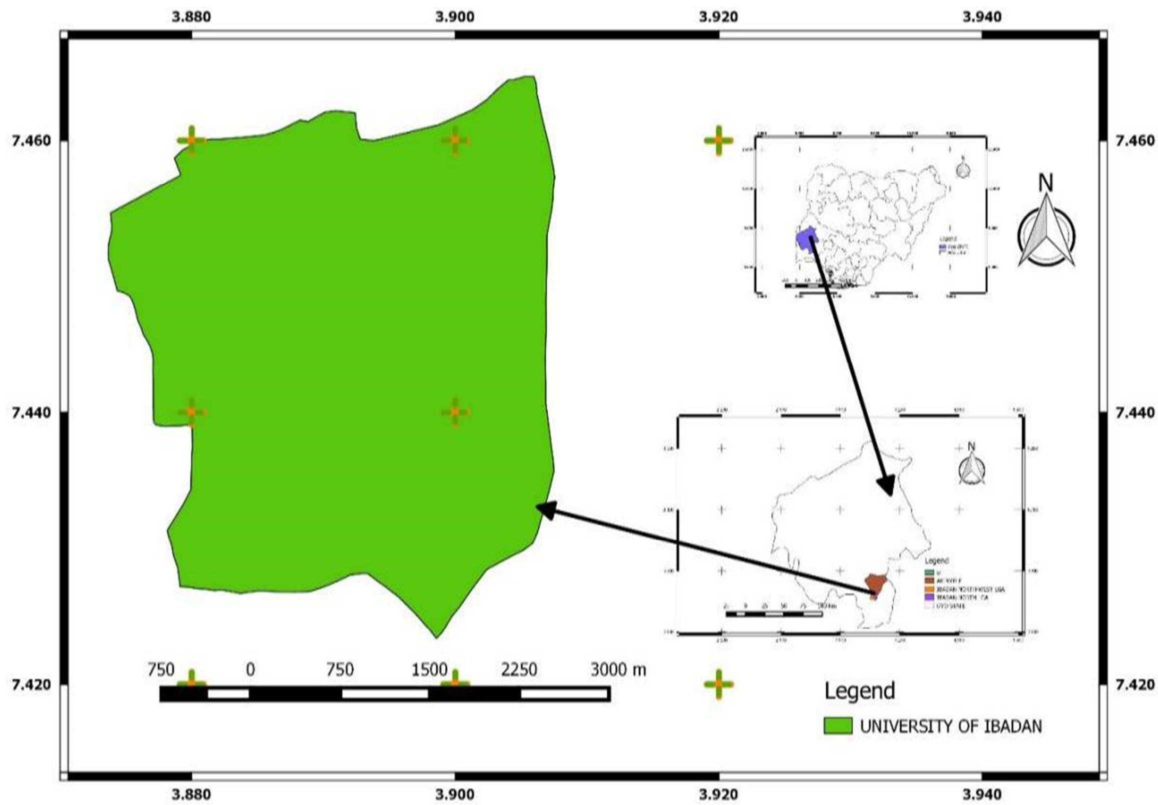

Figure 1. *Map showing study area within the University of Ibadan.*

Sample collection and preparation: The wood slabs were collected at different places, within the campus community. Four *Gliricidia sepium* slabs were collected along Amina road, besides Industrial Training Coordinating Center building, University of Ibadan. Four *Funtumia elastica s*labs were collected inside the Vice Chancellor lodge along Sankore road. While, four *Milicia excelsa* slabs were also collected at department of Forests Production and Products workshop. The slabs of each wood species were cleaned, plained and trimmed to standard size of 20mm x 20mm x 60mm for physical properties determination as well as 10mm x 10mm x 300mm for determination of mechanical properties following [12] standards.

2.2. Physical Properties Determination

2.2.1. Determination of Density

60 test samples of dimension (20×20×60) mm^3 were collected from the reclaimed planks obtained from each of the four planks. Five (5) samples were taken from each and replicated totalling 20 samples for *G. sepium*, *M. excelsa* and *F. elastica,* respectively given a total of 60 test sample. The test samples for density determination were submerged in distilled water for 72 hours [13]. According to [14], samples were taken out to drain properly and then oven-dried at 103±2°C. Following this, the samples were weighed using a sensitive measuring scale at the interval until a steady weight was attained. The samples were then weighed after being cooled in a dry gel desiccators. Density gradients were determined following the procedure by [15].

$$D = \frac{M}{V}\left(\frac{kg}{m^3}\right) \quad (1)$$

Where: D=Density, M = weight of the wood, V = volume of the wood.

2.2.2. Determination of Moisture Content

From each of the three reclaimed wood species, test samples for moisture content determination were chosen. By weighing the samples and then oven-drying them, the moisture content was calculated. Before drying began, the samples' initial weight was noted. According to [14], the samples were put into a Gallemp oven at 103±2°C and left there until their weight remained constant. After the samples had time to cool, the final weight was noted. The formula below was used for the moisture content determination.

$$M.C = \frac{w1-w2}{w2} \times 100 \quad (2)$$

Where: w_1= weight of the sample before drying, w_2= weight of the sample after drying.

2.2.3. Determination of Percentage Shrinkage

For this test, 60 pieces of (20×20×60) mm test specimens were obtained, the test samples were appropriately labelled with the letters "T" and "R" for Tangential and Radial directions, respectively. To condition them to moisture above Fibre Saturation Point, they were soaked in distilled water for 72 hours (FSP). The test samples were then taken out one by one and allowed to drain off excess water before having their wet dimensions measured to the nearest millimeter using veneer calipers. After specimens had been oven-dried at 103±2°C to 12 percent moisture as described by [14].

$$S = \frac{D_s - Do}{D_s} \times 100 \quad (3)$$

Where: S = shrinkage%, D_0 = dimension of oven dry condition, D_S = dimension at saturated condition.

$$V_S = S_R + S_T$$

Where; Vs=Volumetric shrinkage, S_R= Radial shrinkage, S_T= tangential shrinkage.

This procedure is according to the approximation done by [16].

2.3. Mechanical Properties

2.3.1. Modulus of Rupture (MOR) Determination

Modulus of rupture was explained as the amount of force needed to cause the collapse of structural crush of a load [1]. The test sample dimensions required for modulus of rupture test are clear, non- defective and free of knots samples of (20mm×20mm×300) mm dimensions as described by the [17].

$$MOR = \frac{3PL}{2bd^2} \quad (4)$$

Where:

P = load at some point below the proportional limit (N), L =distance between supports for the beam (mm), b= beam width (mm), d = thickness (depth) (mm).

2.3.2. Modulus of Elasticity (MOE)

Determination: Modulus of elasticity may be defined as the measurement undertaken for the resistance to bending, or stiffness of a beam or other wood member. This is the material's capacity to retrieve its initial size or shape when it is under strain [1]. Meanwhile, [14] claimed that a wood member's potential to tilt easily and recover normal shape is considered versatility, and toughness has termed the capacity to withstand tilting. This is calculated using the equation according to [17].

$$MOE = \frac{PL^3}{4bd^3\,\Delta} \quad (5)$$

Where:

P = load at some point below the proportional limit (N).

L = distance between supports for the beam (mm).

b = beam width (mm), d = thickness (depth) of the beam (mm), D = deflection.

Delta (D) which is the deflection of beam center at the proportional limit was taken directly from the calculation on the Universal Testing machine during the MOE test.

Data Analysis: Data was analyzed using Analysis of variance (ANOVA) in a completely randomized design (CBD) with five replicates each. Duncan Multiple Range Test (DMRT) was used to determine the treatment of separations to know the differences between the means and to choose the best treatment combination from the considered parameters.

3. Results and Discussion

3.1. Physical Properties

3.1.1. Wood Density

The results of some physical properties (density, moisture content and shrinkage) of 3 three wood species are presented in the Table 1. Significant differences were observed among species. The mean values for the density (kg/m^3) of the species under investigation are 1032.97±54.34, 613.32±20.51 and 548.57±42.09 for *Gliricidia sepium, Milicia excelsa* and *Funtumia elastica,* respectively. There were statistical differences between the densities of the species. *Gliricidia sepium* is a wood of high density.

The result of this study was in accordance with [18, 19, 20] where the species of *G. sepium* was compared with other hardwood species such as *Dalbergia melanoxylon, Diospyrus spp. and Lophira alata.* Also, [13] got a value of 650.41±1.29 for density of *Milicia excelsa* this is very close to the one gotten in this study. Results of this study are in line with the reports given by [21, 22]. Wood with high density are not usually degraded easily which could be attributed to relatively low levels of air or moisture in the wood cells coupled with a very thick cell wall. This can constitute a natural barrier to bio deteriorating agents. Therefore, it was reported that the higher the density of a wood, the greater its resistance. Also worthy of note is the age of wood. The age could also be responsible for high resistivity of wood to deterioration.

3.1.2. Moisture Content

The average values for moisture content (%) of the species under investigation are *Gliricidia sepium* has mean value of 12.47±1.2 which was higher compare to what was observed by [20] on their preliminary report on utilization potential of *Gliricidia sepium*. *Milicia excelsa* has mean value of 20.84±1.20. *Funtumia elastica* has mean value of 18.13 ±1.20.

However, Duncan Multiple Range Test result showed that the moisture content of *Milicia excelsa and Funtumia elastica* were statistically similar while that of *Gliricidia sepium* was different (p≤0.05).

3.1.3. Percentage Shrinkage

The mean values for radial shrinkage of the species under investigation are as observed as *Gliricidia sepium* has mean value of 9.94±1.58. *Milicia excelsa*, has mean value of 3.54±1.21. *Funtumia elastica* has mean value of 4.7±1.21. The mean values for Tangential shrinkage of the species under investigation are *Gliricidia sepium* which has mean value of 10.61±1.66. *Melicia excelsa* has mean value of 3.942±1.66. *Funtumia elastica* has mean value of 6.68±1.66. The values for volumetric shrinkage of the species under investigation are given as. *Gliricidia sepium* has mean value of 20.551±2.786. *Milicia excelsa*, has mean value of 7.476±2.786 and *funtumia elastica* has mean value of 11.428 ±2.786.

As presented in the Table 1, shrinkage along the tangential dimension is more than that along the radial dimension. This observation is similar to that reported by [23, 24]. From their research, they observed that shrinkage is highest in the tangential direction. Similarly, [25] reported that tangential shrinkage is about half as much in radial and much less along the longitudinal direction. From this study, it is also clear that radial shrinkage is lower than tangential shrinkage.

Table 1. *Mean values for the density, moisture content, radial, tangential and volumetric shrinkage of the reclaimed wood species.*

Species	Density (kg/m^3)	Moisture content (%)	Radial shrinkage (%)	Tangential shrinkage (%)	Volumetric shrinkage (%)
Gliricidia sepium	1032±0.97^a	12.47±1.21^a	9.94±1.58^a	10.61±1.66^a	20.55±2.79^a
Milicia excelsa	613±0.33^b	20.84±1.21^b	3.54±1.58^b	3.94±1.66^b	7.48±2.79^b
Funtumia elastica	548±0.57^c	18.13±1.21^b	4.75±1.58^b	6.68±166^b	11.43±2.79^b

Means with the same letter are not significantly different (Duncan's Multiple Test at *P*=.05)

3.2. Mechanical Properties

The results of some mechanical properties (modulus of elasticity and modulus of rupture) of the three wood species are as presented in the Tables 2 below.

Table 2. *Mean values of the modulus of rupture (MOR) and Modulus of Elasticity (MOE) of the reclaimed wood samples.*

Species	Modulus of Elasticity (N/mm^2)	Modulus of Rupture (N/mm^2)
Melicia excelsa	8793.13±643.43a	404.69±12.36a
Gliricidia sepium	8083.63±643.43a	434.27±12.36ab
Funtimia elastica	4299.54±643.43b	388.33±12.36b

Means with the same letter are not significantly different@ =0.05p

3.2.1. What Are MOR and MOE

Modulus of rupture reflects the maximum load carrying capacity of a member in bending and is proportional to maximum moment borne by the specimen. These values indicate that *Melicia excelsa* had the highest maximum load carrying capacity followed by *Gliricidia sepium. Funtumia elastica* had low load carrying capacity and elasticity. The modulus of rupture is an accepted criterion of wood strength [13]. Elasticity implies that deformations produced by low stress are completely recoverable after loads are removed. When loaded to higher stress levels, plastic deformation or failure occurs.

Significant differences were observed among the parameter measured. The mean values and standard deviation of modulus of elasticity (MOE) and modulus of rupture (MOR) of the species under investigation are also presented in the Table 2.

3.2.2. Modulus of Elasticity (MOE) and Modulus of Rupture Values

The result values for modulus of elasticity (MOE) of the species under investigation are as given below. *Melicia excelsa*, had mean modulus of elasticity of 879.13±64.43N/mm^2. *Gliricidia sepium*, had mean value of 8083.63±64.43N/mm^2. *Funtumia elastica* had mean value of 429.54±64.43N/mm^2. While, the values for modulus of rupture (MOR) of the species under investigation are as given below. *Melicia excelsa*, had mean modulus of rupture of 404.685 ±12.362 N/mm^2. *Gliricidia sepium* has mean value of 434.273±12.362N/mm^2. *Funtumia elastica* had mean value of 388.32±12.362N/mm^2.

4. Conclusion

The result finding from this study shows that the strength of selected wood species depends on its species. As such, different wood species have different mechanical and physical characteristics. Meanwhile, the results obtained in this study have provided quantitative information on the physical and mechanical properties of the residue of selected wood species. Re-usability of such wood plank will definitely reduce pressure on commercial timber which are fast disappearing from our forest due to several factors of deforestation. Reclaimed wood species can be used in determining the application of these woods such as in making of kitchen utensils like plate rack.

Significance Statement

This study discovers the reclaimed wood had flexural strength characteristic in terms of physical and mechanical properties that make it more valuable than heat and energy generation but re-utilisation potential to reduce pressure on known commercial timbers. This study will help the researcher to uncover the critical area of further area of utilisation that many researchers were able to explore. Thus, a new theory on reclaimed wood physico-mechanical properties parameters may be arrived at.

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