

Preliminary evaluation of loss in physico-mechanical properties of woods recovered from construction site

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ABSTRACT

A construction site within the University of Ibadan campus was randomly selected to compile relevant information on generated lignocellulosic wastes, the wastes were characterised and samples were collected. Collected samples were pre-processed before the strength loss was investigated. Three predominant wood species were selected from the recovered wood samples for evaluation of changes in some physical and mechanical properties using ASTM D143 (2000), BS 373 (1957), and NPC2 (2005) standards. The physico-mechanical properties evaluated include percentage Moisture Content (MC), Density (ρ), Bending Strength (Fb), Compression Parallel to Grain (C//) Compression Perpendicular to Grain (C $\perp$), and Shear Strength (τ) using Instron Universal Testing Machine. The predominant three species investigated are *Funtumia africana*, *Khaya grandifoliola*, and *Ficus mucoso*. From the site record, the average MC was 20% while the average MC had reduced to 16.65%, 17.43%, and 16.95%, respectively for *Funtumia africana*, *Khaya grandifoliola*, and *Ficus mucoso*. The ρ values were 570.54Kg/m³, 515.9Kg/m³ and 550.24Kg/m³, respectively. The Fb (48.88N/mm², 62.82N/mm² and 37.69N/mm²); C// (26.38N/mm², 8.22N/mm² and 37.69N/mm²); C $\perp$ (20.04N/mm², 16.60N/mm², 23.34N/mm²); τ (1.80N/mm², 2.24N/mm² and 2.36N/mm²); MOE (3882.61N/mm², 2759.91N/mm² and 6323.60 N/mm²) and MOR (8618.74N/mm², 7736.95N/mm² and 8675.01N/mm²), respectively. Though there was evidence of a black stain on a handful of the samples after 3 months on site, the values obtained for both physical and mechanical properties indicated an insignificant loss in these properties when compared with the standard values. Thus, the wood waste if retrieved on time, will be adequate for the manufacturing of semi-structural and non-structural items.

Keywords: Construction site, lignocellulosic waste, characterisation, strength loss, re-use

INTRODUCTION

Construction Waste is defined as "Building and site improvement materials and other solid waste resulting from construction, remodeling, renovation, or repair operations" (EPA, 2007). These materials include wood, bamboo, concrete, bricks, iron, and glass amongst others, and the term "construction and demolition" (C&D) waste is frequently used interchangeably (USEPA, 2016). Most of these

site materials especially those of lignocellulosic origins as expensive as they are, are allowed to waste due to poor management and left to constitute nuisances such as fire hazards, closets for dangerous animals, micro-organisms, and so on (Shen and Tam, 2002; Adewole, 2009; Egun, 2012). Leaving lignocellulosic waste to decay is because of the burden of disposal on the country's budget resulting not only in the deterioration of the

environment but also the loss of potentially valuable materials that can be developed for producing several innovative items (Aderibigbe *et al*, 2017; Wahab and Lawal, 2011). However, in urban cities across the country, C&D activities are estimated to be one of the highest producers of reusable lignocellulosic waste and serve among low-income earners as the cheapest source of cooking energy (Popoola *et al*, 2013). In most places where lignocellulosic wastes are not frequently put to use as fuel, they can suffer bio-deterioration ranging from decolouration, insect attack and also deterioration due to cracks and splits (Eze *et al*, 2017). Deterioration may spread to parts of the building and can invade valuable materials. They pose a fire risk and occupy valuable space (Eze *et al*, 2017). Hence the need to recover, recycle, and reused lignocellulosic waste from construction sites (Adewale *et al*, 2018).

Wood has been identified as the chief waste amongst lignocellulosic waste in construction sites serving as materials for roofing, formwork, props, and support materials and contributing a significant percentage during the process, (Eze *et al*, 2017, Obia *et al*, 2017) after which they become waste generated onsite or at most become a source of biofuel. It has been reported that wood waste is a major source of energy and accounts for about 80% of total primary energy consumed in Nigeria (Juliet *et al*, 2016; Popoola *et al*, 2013; Edirin and Nosa 2012) and one of the largest polluters of the construction site (Eze *et al*, 2017). For the proper reuse of wood waste, it is important to evaluate the level of its physical and mechanical properties in order to find suitable means of application (Aderibigbe *et al*, 2017; Adewole *et al*, 2018).

Wood characterization is the process of identifying the physical and mechanical properties of wood species for structural purposes (Jimoh *et al*, 2017, Jimoh and Rahmon, 2018). The major reason for engineered construction is to develop structures that adequately fuse together safety, economy, function, and aesthetics (Aguwa, 2012). Mechanical properties such as the strength and stiffness of materials are vital for the design of load-carrying structures. Physical properties in line with density, moisture content, form, and appearance are also essential feature

requirements when thinking of suitable ways of application (Moody and Hernandez 1997; Sylvester and Iziengbe, 2017). This study evaluated selected physical and mechanical properties of three predominant wood species that were recoverable from the site where the study was carried out with a view to ascertaining their suitability for the production of semi-structural items like furniture.

MATERIALS AND METHODS

The wood wastes used for this study were retrieved from a 6' flat multi-storey building at Elliot Close, University of Ibadan (UI), and Nigeria. Samples were prepared at the Technical Support Wood Workshop of the Faculty of Technology, UI, Nigeria. This study considered two physical properties: Moisture Content (MC) and Density (ρ) and four mechanical properties: Bending Strength (Fb), Compression Parallel to Grain (C//), Compression Perpendicular to Grain (C $\perp$), and Shear Strength (τ) as well glue-line strength adequacy test. In accordance with BS 373 (1957) and ASTM D143 (2000), the tests were conducted using Universal Testing Machine jointly owned laboratory of the Departments of Agricultural and Environmental Engineering and Wood Products Engineering, UI. The MC of 5 samples of each of the three selected wood species was determined in accordance with BS 373 (1957). Five samples each of sizes (20x20x40) mm were prepared from the recovered wood wastes. The initial weight for each sample was ascertained with a weighing balance before oven drying at a constant rate of $103 \pm 2^\circ \text{C}$ re-weigh and continuing drying until a constant mass was obtained. The initial and oven-dry mass of each sample was recorded and the MC was obtained using equation (1).

$$MC = \left(\frac{m_1 - m_2}{m_2} \right) 100\% \quad \dots\dots\dots (1)$$

Where; MC = moisture content, M_1 = Initial mass of timber before oven drying, m_2 = final mass of timber after oven dried.

The density of five samples from each species of recovered wood waste with sizes (20x20x40) mm were used for the determination of the density in accordance with BS (1957) using Equation (2)

$$\rho = \frac{m}{v} \quad \dots\dots\dots (2)$$

Where; ρ = density, m = the mass of the timber specimen, v = volume of the timber specimen.

Basic stresses for bending, tensile, compressive, shear parallel to the grain, and compressive stress perpendicular to the grain, were calculated from failure stresses using equation (3) while equation (4) was used for determining the MOE

$$f_b = \frac{f_b - k_p \sigma}{k_r} \dots\dots\dots (3)$$

Where; f_b = basic stress, mean failure stress at 18% moisture content, σ = standard deviation of failure stress, k_r = reduction factor given in table 3.1, k_p = modification factor = 2.33, 1.96 for compression perpendicular to grain stress

Table 1: Reduction factor (k_r) for wood species

State of Stress	k_r
Bending, tension and shear parallel to the grain	2.25
Compression parallel to the grain	1.4
Compression perpendicular to the grain	1.2

Source: Aguwa et al., 2015; Ozelton and Baird, 1981

$$E_N = E_{\text{mean}} - \frac{2.33\sigma}{\sqrt{N}} \dots\dots\dots (4)$$

Where; E_N = statistical minimum value of E appropriate to the number of pieces N acting together (where $N=1$, E_N becomes the value for E_{min}), σ = standard deviation.

For the basic stress adjustment factor, the 18% MC adjustment for characteristic density of timber species as required by NCP2 (2005) was computed using equation (5) given in NCP2 (2005)

RESULTS AND DISCUSSION

Table 2 presents the values of the air-dry moisture content results for the samples of *Khaya grandifoliola*, *Ficus mucoso*, and *Funtumia africana*. The mean values of moisture content were 16.67%, 18.25%, and 16.92% respectively which indicated a reduction in MC when compared with the MC when the wood was brought into the site for use. That is, the species self-air dried to the new moisture content within the 3 months they have remained on site. It implies that before the samples can be re-used for manufacturing items to be utilised indoors, they may require to be dried further to MC of about 10% for more stability in service.

Also, the values obtained for *Khaya grandifoliola*, *Ficus mucoso*, and *Funtumia africana* densities respectively were presented

$$\rho_{k,18\%} = \rho_w \left[1 - \frac{(1-0.5)(u-18)}{100} \right] \dots\dots\dots (5)$$

Where; $\rho_{k,18\%}$ = characteristic density at 18% MC, ρ_w = characteristic density at the MC during the bending test, (kg/m³), u = measured MC, (%).

The Adjustment of characteristic values of bending, compressive, shear parallel to the grain, compressive stress perpendicular to the grain, from the measured MC to 18% MC (NCP2, 2005) was computed from equation (6)

$$F_{m,18\%} = \frac{f_{\text{measured}}}{1+0.0295(18-u)} \dots\dots\dots (6)$$

Where; $F_{m,18\%}$ = characteristic bending strength at 18% MC, u = measured MC (%), f_{measured} = characteristic bending strength at the measured MC (N/mm²).

The adjustment for MOE from the measured MC to 18% MC in line with NCP2 (2005) requirements was also made based on the characteristic values of samples computed using equation (7)

$$E_{m,18\%} = \frac{E_{\text{measured}}}{1+0.0143(18-u)} \dots\dots\dots (7)$$

Where; $E_{m,18\%}$ = characteristic bending MOE at 18% MC, E_{measured} = characteristic MOE at the measured MC (N/mm²) and u = measured MC (%).

in Table 3. The minimum, maximum, average, standard deviation and coefficient of variance are equally shown in the Table 3. The mean value of density at the air-dry condition for *Khaya grandifoliola*, was 570.54 with a standard deviation and coefficient of variance of 86.70kg/m³ and 15.19% respectively. *Ficus mucoso* was 515.9 with a standard deviation and coefficient of variance of 90.32kg/m³ and 17.19% respectively. *Funtumia africana* was 550.24 with a standard deviation and coefficient of variance of 31.21kg/m³ and 5.67% respectively. The density values obtained were within the range of 350 to 600kg/m³. The density of each species at 18% moisture content is also shown in the table. The 18% density values were observed to be higher when compared with the air-dry density for *Khaya grandifoliola*, and *Ficus mucoso*, and lower for *Funtumia africana*, at 572.81,

516.26, and 546.06kg/m³ respectively. The values compared well with the values recorded for each of the species in works of literature (NCP 2, 2005; FAO, 2021).

Table 2: Moisture Content Profile of Test Samples

Specie Name	Measured Moisture Content (%)		Coef. of Var.		
	Min.	Max.	Mean	Std. Dev.	
<i>Khaya grandifoliola</i>	16	17.4	16.48	0.563028	3.416
	12.6	18.4	16.5	2.246108	13.61
	16.8	17.6	17.2	0.282843	1.644
	12.9	17.9	16.51	1.469278	8.899
			16.6725		
<i>Ficus mucuso</i>	16.5	19.3	18.06	1.050238	5.815
	16.6	20.5	18.78	1.878031	10
	16.1	19.9	17.86	1.44672	8.1
	15.8	20.1	18.29	1.890003	10.33
			18.2475		
<i>Funtumia africana</i>	15.3	16.6	16.04	0.598331	3.73
	15.3	17.1	16.2	0.640312	3.953
	17.9	23.2	19.52	2.125324	10.89
	14.5	17.5	15.92	1.135097	7.13
			16.92		

Table 3: Summary of Density

Wood Species	Density (kg/m ³) at Air-Dry Condition					
	Min.	Max.	Mean	Std. Dev.	Coef. of Var.	Density at 18%
<i>Khaya grandifoliola</i>	425.37	647.8	570.54	86.7097	15.1979	572.819
<i>Ficus mucuso</i>	359.02	573.66	515.9	90.32271	17.5077	516.264
<i>Funtumia africana</i>	522.93	600.98	550.24	31.21951	5.67376	546.062

The basic stresses for the three selected species at the air-dry condition of 18% moisture content are presented in Tables 4 and 5. The adjustment of basic stress values to an equivalent 18% MC was in line with environmental conditions in Nigeria as stipulated in NCP2 (2005). The basic stresses calculated were basic bending stress parallel to the grain, basic compressive stress parallel to the grain, basic shear stress, and basic compressive stress perpendicular to the grain. The Modulus of Elasticity in bending and the Modulus of Rigidity in Bending are also shown in the tables 4 and 5.

The results of basic stresses presented in Tables 4 and 5 showed that basic stresses decreased as moisture content were adjusted to 18% for *Khaya grandifoliola*, and *Funtumia africana* and increased for *Ficus mucuso* as moisture content were adjusted to 18%. This can be attributed to the movement of the average moisture content of the three species when modified to from the 18% moisture content. The bending strength for *Khaya grandifoliola*, *Ficus mucuso*, and *Funtumia africana* at the measured MC corresponding to the bending

test were 48.88, 62.82, and 37.69N/mm² respectively. The adjusted values of bending strength to 18% MC decrease to 35.07 and 34.39N/mm² for *Khaya grandifoliola*, and *Funtumia africana* respectively, and increased to 107.81N/mm² for *Ficus mucuso*. Bending strength increases for any value of MC above 18%. This is because the denominators of equations are less than unity when MC is greater than 18% (Abubakar and Nabade, 2013). For *Ficus mucuso* MCs were greater than 18%. A comparison using *Khaya grandifoliola* in Table 6 presented tabulated data from NPC2 (2005) and basic stress and density values of *Khaya grandifoliola* at 18% Moisture content. Experimental values were lower in density, shear, and Modulus of Elasticity with 574kg/m³, 1.29N/mm², and 2827N/mm² respectively compared to the tabulated data of 672kg/m³, 1.80 N/mm² and 10600 N/mm² but higher in bending, compression parallel to grain and compression perpendicular to grain test by 35.07 N/mm², 18.92 N/mm² and 14.37 N/mm² compared to the tabulated data of 22.40N/mm³, 18.00 N/mm², and 4.00 N/mm² (Ozelton and Baird, 1981). The importance of this is that recovered

wood wastes of these predominant species considered by this study if retrieved from the site within 3 months will still pose adequate

strength that will make them useful for manufacturing of semi-structural and non-structural items like furniture and novel items.

Table 4: Basic Stresses at Air-Dried Moisture Content

Wood species	Bending (N/mm ²)	Comp. parallel (N/mm ²)	Comp. perp. (N/mm ²)	Shear parallel (N/mm ²)	MOE (N/mm ²)	MOR (N/mm ²)	Bondline Shear (N/mm ²)
<i>Khaya grandifoliola</i>	48.88789	26.3809	20.0447	1.80218	3882.607	8618.743	
<i>Ficus mucoso</i>	62.82439	8.2279	16.6065	2.24983	2759.91	7736.955	2.330732
<i>Funtumia africana</i>	37.69003	23.1012	23.3492	2.36618	6323.603	8675.008	

Table 5: Basic Stresses at 18% Moisture Content

Wood species	Bending (N/mm ²)	Comp. parallel (N/mm ²)	Comp. perp. (N/mm ²)	Shear parallel (N/mm ²)	MOE (N/mm ²)	MOR (N/mm ²)
<i>Khaya grandifoliola</i>	35.07166	18.9254	14.3798	1.29287	2827.081	6275.652
<i>Ficus mucoso</i>	107.8166	14.1204	28.4994	3.86107	4807.42	13476.81
<i>Funtumia africana</i>	34.93324	21.4115	21.6413	2.19311	5948.903	8160.978

Table 6: Comparison of Basic Properties of *Khaya grandifoliola* with NCP2 (2005) Data at 18% MC

<i>Khaya grandifoliola</i>	Density (kg/m ³)	Bending (N/mm ²)	Comp. parallel (N/mm ²)	Comp. perp. (N/mm ²)	Shear parallel (N/mm ²)	MOE (N/mm ²)
NPC2 (2005)	672	22.40	18.00	4.00	1.80	10,600
Results from Test	574	35.07	18.92	14.37	1.29	2,827

CONCLUSIONS

This study has been able to evaluate some selected physical and mechanical properties of *Funtumia africana*, *Khaya grandifoliola*, and *Ficus mucoso* wood waste retrieved from the construction site after 3 months of staying on site. Though there was evidence of a black stain on a handful of the samples after 3 months on site, the values obtained for both physical and mechanical properties indicated an insignificant loss in these properties when compared with the standard values. Therefore, if wood wastes are retrieved on time from the construction site, their strength will still be adequate to re-use them for the manufacturing of a wide range of semi-structural and non-

structural items both for indoor and outdoor uses. This paper, however, recommends further study in the area of wholesome characterisation of different lignocellulosic wastes retrievable from the construction sites in line with usability for making re-constituted wood products to maximise their re-use.

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