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Water Imbibition Capacity of Some Nigerian Timbers: A Function of Wood Density and Structure

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Abstract: *Wood is a heterogeneous, hygroscopic, cellular and anisotropic material of biological origin. The properties of wood that make it an ideal raw material for several purposes are mainly determined by the specific architecture of the cell walls. Moisture content, porosity and water imbitition capacity contribute to the quality of timber. The examination of the internal microscopic structure of the timber samples will be done by Scanning Electron Microscopy (SEM). Of the fifty-three timbers studied, thirty-two were of medium density (0.403 ± 0.020 to 0.715 ± 0.011 g/cm^3) , ten were of low density (0.256 ± 0.008 to 0.380 ± 0.012 g/cm^3) and eleven were quite dense (0.784 ± 0.020 to 1.111 ± 0.039 g/cm^3), with Ricinodendrom heudelotti having the least value and Irvinga smithii, the highest. Water imbibitions capacity after 24 hours was quite high for Ricinodendrom heudelotti and Ceiba pentandra while that for Irvinga smithii, Lophira lanceolate, Khaya senegalensis and Erythrophleum suaveolens were low. There was an inverse relationship between the maximum moisture content of these wood samples and their density. The scanning electron micrographs of selected timbers present ring- porous hardwoods as well as diffuse- poruos hardwoods.Fibrous nature of Entradrophragma utile and Hollarhena floribunda may account for their high moisture content (MC) values while the spherical granules in Tetrapluera tetraptera are suspected to be hydrophobic since the water imbibition capacity observed after 24h was lower than those of similar density.*
Keywords: *Wood density, water imbibition capacity, porosity index, moisture content, Scanning Electron Microscopy.*

I. Introduction

Wood is a very important raw material; not only is it used for literally hundreds of products but also it is a renewable natural resource. It is a hard fibrous tissue found in many plants. Wood is a heterogeneous, hygroscopic, cellular and anisotropic material of biological origin. Wood (or xylem in a more strict sense) conducts water and mineral salts from root to the leaf and gives mechanical strength to the plant body. It is composed of cells and the cell walls are made up of microfibrils of cellulose (40-50%) and hemicelluloses (15-35%) impregnated with lignin (15-25%) and extractives [Rowell et al, 2005]. The properties of wood that make it an ideal raw material for several purposes are mainly determined by the specific architecture of the cell walls. These properties include moisture content, density, mechanical, thermal, electrical, decay and chemical resistance properties. Moisture content, susceptibility to insect attacks, workability, grains, colour, porosity and capacity to take polish and varnish contribute to the quality of timber [Dutta, 1995]. The examination of the internal microscopic structure of the timber samples was done by Scanning Electron Microscopy(SEM). These timbers were classified with respect to their density and porosity indices which give a guide to their permeability and strength properties.

Moisture Content

Due to the need for water as part of the photosynthesis and growth process, wood in growing trees contains a considerable amount of water, commonly called sap. The water in wood is either held within cell walls by bonding forces (hydrogen bonding) between water and cellulose molecules or contained in the cell cavities and not held by these forces. In the first case, it is referred to as bound water and in the latter case, as free water. The amount of water in wood, called the moisture content, is expressed as a percentage of the dry weight and is dependent on the relative humidity and temperature of the surrounding air. The ability of wood to lose or gain water content affects its structural properties such as weight, dimensions and strength characteristics [http://www.cof.orst.ed/cof/teach/for111/Brownlectures/Basic wood properties.pdf].

Density and Specific Gravity

Density is a substance's mass per unit volume. Wood density varies with moisture content which affects both mass and volume. The density of the substance that makes up a wood cell wall has been found to

be about 1.5 g/cm^3, but that of an actual wood sample is usually less than 0.9 g/cm^3 since it contains air in the cell lumens [NAFI, 2004]. Wood density is classified by the International Association of Wood Anatomists (IAWA) in the following manner: low, ≤ 0. 400 g/cm^3, medium, 0. 400 – 0.750 g/cm^3 and high, ≥ 0.750 g/cm^3 [Reyes, 1992]. Specific gravity (SG) is the density of a substance relative to the density of water and is sometimes known as 'relative density or basic density'. The specific gravity of wood is influenced by moisture content, proportion of wood volume made of various kinds of cell types and cell wall thickness and size of cells and cell lumens[Wiedenhoeft, 2010]. Maximum moisture content, M_{max}, for any specific gravity can be calculated from: $M_{max} = 100\ (1.54 – G_b)/1.54G_b$
where G_b is basic specific gravity (based on oven dry weight and green volume) and 1.54 is specific gravity of wood cell walls [Winnandy, 1994; Encyclopedia of Wood by USDA].

Scanning Electron Microscopy (SEM)

Scanning electron microscopy is a type of microscopy that images a sample by scanning it with a high-energy beam of electrons in a rather faster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample surface topography, composition and other properties. This technology has changed the ways of investigating materials by allowing researchers to image and obtain non-destructive analyses of micron-sized samples. The SEM is a microscope that uses electrons rather than light to form an image [http://www.mos.org/s/n/SEM]. This technique has many advantages which include, having a large depth of field , producing images of high resolution and easy preparation of samples. This condition is achieved for wood by coating the samples with carbon followed by gold-palladium. [McMillin, 1977].

II. Experimentals

Samples collection

Tropical timbers were sourced from the Rain Forest and Guinea Savanna regions of Nigeria, particularly from Enugu, Kogi, Anambra and Edo States.

Density Measurements.

Each of the timber species was cut into cubes of sides 25cm. Five cubes were randomly selected from each of the timber species. The weights (W_1) of the freshly cut cubes were taken and the volume (V_1) calculated by measuring the length, breadth and height of the cubes. The wet density D_w was then calculated using the formula:

$$D_w = \frac{W_1}{V_1} \ (g/cm^3)$$

For oven-dry density (ODD) measurement, these cubes were dried in an oven at 105^{0}C for 48 hours and the weight (W_2) and volume (V_2) of the oven-dried cubes was used for the calculation. Each experiment was repeated five times and the results averaged.

Measurement of Water Imbibitition Capacity

This was determined using the modified ASTM D-1037 method by immersing five cubes of each of the timber species in water for 1h and 24 h and weighing the wet cubes (W_3), one at a time, after the respective stipulated times. Water imbitition capacity =

$$\frac{W_3 - W_2}{W_2} \times 100\ (\%)$$

Five readings were made for each timber species and the average taken.

Scanning Electron Microscopy (SEM)

Using the and Scanning Electron microscope (SEM) Model EVO MA 10 at SHESTCO, Abuja, the cellular structure/ morphology of the wood samples was obtained.

III. Results And Discussions

The results of the ovendry density measurements of the timbers (Table 1) indicate that the density values of the timbers were in the range of 0.256 ± 0.008 g/cm^3 to 1.111 ± 0.039 g/cm^3, with *Ricinodendrom heudelotti* having the least value and *Irvinga smithii*, the highest. Of the fifty-three timbers,arranged in increasing order of denisty, thirty-two were of medium density (0.403 ± 0.020 to 0.715 ± 0.011 g/cm^3) , ten were of low density (0.256 ± 0.008 to 0.380 ± 0.012 g/cm^3) and eleven were quite dense (0.784 ± 0.020 to 1.111 ± 0.039 g/cm^3). This concurs with the observation made by Reyes et al [1992] that the most frequent wood densities in tropical American, Asian and Africa timber species compiled were 0.5 to 0.8 g/cm^3. The values for the corresponding wet densities followed nearly the same trend but were noticably different for *Buchozia curiacea* and *Cassia nodosa* which have very high and low wet densities, respectively, when compared to their ODDs.

Moisture Content

It is observed that the moisture content of the timbers were relatively the same, with an average value of 14.819 ± 3.710% (Table 1). Timbers such as *Cassia nodosa* (6.019%), *Anacardium* occidentalis (7.848%), and Erythrophilum *suaveolens* (8.230%) had MC values much lower than air dry wood while those for *Entandrophragma utile* (22.83%), *Hollarrhena floribunda* (24.25%) and *Buchozia curiacea* (31.95%) were much higher. This condition may be attributed to the chemical composition of the individual wood and the void volume in the wood [Siau, 1971].

Table 1: Results of water imbibition capacity of the various timbers after 1h and 24 h.

Botanic name	Oven dry Density(g/cm3)	Class of density	Specific Gravity, Gb*	Actual MC (%)	Moisture after 1h, %	Moisture after 24h,%	Maximum MC, % (Calculated)
Ricinodendrom heudelotti	0.256 ± 0.008	Low	0.226	13.292	89.4	226.3	378.4
Ceiba petandra	0.281 ± 0.019	Low	0.241	16.881	62.7	182.2	350.8
Xylopia aethiopica	0.283 0.032	Low	0.251	13.009	65.8	109.4	334.1
Hollarrhena floribunda	0.308 ± 0.020	Low	0.248	24.251	44.6	117.5	337.9
Cassia nodosa	0.311 ± 0.021	Low	0.294	6.019	39.4	109.1	275.7
Daniella ogea	0.344 ± 0.048	Low	0.298	15.354	32.3	91.5	270.3
Spondias mombium	0.350 ± 0.025	Low	0.307	13.901	45.1	101.7	260.5
Triplochyton scleroxylon	0.380 ± 0.007	Low	0.329	15.528	33.2	87.6	239.1
Distemonthus benthamiamus	0.380 ± 0.012	Low	0.330	15.188	38.3	107.1	237.8
Hannoa klaineana	0.403 ± 0.020	Low	0.355	13.628	36.4	93.8	216.7
Anacardium occidentalis	0.443 ± 0.043	Medium	0.411	7.848	65.1	104.3	178.3
Tetrapleura tetraptera	0.467 ± 0.018	Medium	0.406	15.086	20.9	58.8	181.3
Pterocarpus soyauxi	0.470 ± 0.014	Medium	0.412	13.982	27.5	80.1	177.8
Anthocleista djalonensis	0.470 ± 0.073	Medium	0.407	15.705	20.8	69.4	181.0
Terminalia superb	0.478 ± 0.024	Medium	0.421	13.506	20.0	73.3	172.6
Buchozia curiacea	0.503 ± 0.021	Medium	0.381	31.954	20.5	71.7	197.3
Diospros dendo	0.504 ± 0.027	Medium	0.429	17.578	23.2	57.6	168.1
Crescentia cujete	0.520 ± 0.019	Medium	0.451	15.425	18.0	64.5	156.9
Harungana madagasceriensis	0.532 ± 0.066	Medium	0.471	12.949	19.3	49.5	147.5
Morinda lucida	0.535 ± 0.005	Medium	0.458	16.895	21.1	64.5	153.6
Prosopis Africana	0.547 ± 0.027	Medium	0.483	13.422	26.3	74.9	142.3
Vitex doniana	0.554 ± 0.031	Medium	0.489	13.235	24.3	88.1	139.6
Alchornea cordifolia	0.564 ± 0.048	Medium	0.508	11.092	41.8	90.0	132.1
Terminalia ivorensis	0.571 ± 0.036	Medium	0.507	12.657	10.9	44.4	132.2
Celtic zenkeri	0.592 ± 0.024	Medium	0.508	16.464	42.3	100.0	131.8
Daniella oliveri	0.598 ± 0.014	Medium	0.530	12.957	26.7	71.7	123.8
Cola hipsida	0.611 ± 0.098	Medium	0.541	12.952	16.1	58.0	120.0
Manilkara obovata	0.623 ± 0.031	Medium	0.531	17.333	16.9	54.3	123.3
Cassia sieberiana	0.625 ± 0.017	Medium	0.531	17.743	17.2	60.5	123.4
Entandrophragma utile	0.625 ± 0.110	Medium	0.509	22.830	42.9	84.7	131.5
Nauclea latifolia	0.627 ± 0.028	Medium	0.543	15.525	23.6	56.3	119.3
Parkia biglobosa	0.629 ± 0.013	Medium	0.543	15.795	20.8	64.8	119.1
Detarium microcarpum	0.629 ± 0.037	Medium	0.543	15.919	17.0	60.1	119.3
Tecoma stans	0.641 ± 0.146	Medium	0.549	16.702	34.9	90.9	117.1
Pentadesma butyracea	0.642 ± 0.032	Medium	0.563	14.089	20.2	58.1	112.6
Albizie adianthifolia	0.649 ± 0.040	Medium	0.568	14.271	20.6	66.8	111.0
Ficus platyphylla	0.664 ± 0.015	Medium	0.579	14.824	16.5	56.3	107.9
Topinanthus globiferus	0.668 ± 0.064	Medium	0.579	15.498	13.7	43.8	107.9
Parkia bicolor	0.670 ± 0.024	Medium	0.590	13.634	26.5	63.6	104.6
Albizie ferruginea	0.687 ± 0.026	Medium	0.598	14.817	8.7	30.5	102.3
Myrianthus aboreus	0.706 ± 0.076	Medium	0.619	13.953	21.9	58.3	96.5
Afzelia Africana	0.715 ± 0.011	Medium	0.637	12.159	8.5	29.0	92.0
Penthacletha macrophylla	0.784 ± 0.020	High	0.683	14.784	11.8	46.9	81.6
Eucalyptus globules	0.786 ± 0.021	High	0.682	15.336	22.8	60.6	81.7
Spathodea campanulata	0.786 ± 0.101	High	0.669	17.611	14.1	48.7	84.6
Brastegia eurycoma	0.794 ± 0.051	High	0.698	13.791	7.2	31.8	78.4
Pycnanthus angolensis	0.864 ± 0.038	High	0.777	11.263	9.9	33.5	63.8
Nauclea diderichii	0.896 ± 0.074	High	0.785	14.208	9.7	36.2	62.5
Lophira lanceolate	0.897 ± 0.018	High	0.778	15.260	4.7	18.9	63.5

Piptadeniastrum africanum	0.963 ± 0.069	High	0.856	12.575	7.0	25.1	51.9
Erythrophleum suaveolens	1.069 ± 0.041	High	0.988	8.230	-0.2	11.2	36.3
Khaya senegalensis	1.106 ± 0.036	High	0.971	13.874	3.2	16.5	38.0
Irvingia smithi	1.111 ± 0.039	High	0.975	13.964	13.2	30.6	37.7

Water imbibition capacity

Fig.1 shows that after 24 hours of immersion in water the timber samples had not imbibed their maximum capacity and that the % difference reduced as the density of the timbers increased (59.9 to 30.7%). The maximum moisture content of wood is reached when the cell walls and cell lumens are completely filled with water. When specific gravity is high, lumen volume is low and maximum MC is therefore restricted [Simpson, 1993]. Water imbibitions capacity after 24 hours was quite high for *Ricinodendrom heudelotti* and *Ceiba pentandra* when compared to their corresponding values after 1 hour immersion; while that for *Irvinga smithii, Lophira lanceolate, Khaya senegalensis and Erythrophleum suaveolens* were low..

Fig. 1: Plot of moisture absorbed vs. oven-dry density of timber species.

Scanning Electron Microscopy

The scanning electron micrographs of selected timbers, in ascending order of density, are presented in Figs. 2-9; present ring- porous hardwoods as well as diffuse- porous hardwoods. The moisture content of these wood whose micrographs are shown in these figures have been shown to fall within the range 7.848 to 24.25% with the least being *Anacardium occidentalis* (Fig. 5), and the highest Hollarhena *floribunda* (Fig.3). However, most of the values were within the mean value of 15 2%. A closer look at the micrographs of *Entradrophragma utile* (Fig.9) and *Hollarhena floribunda* shows some similarities in the fibrous nature which may account for their high moisture content (MC) values of 22.83% and 24.25%, respectively. Fibrous tissues may retain more water in the cell walls. The rather low MC value for *Anacardium occidentalis* cannot be readily explained, except that the non-porous or compact nature of the sample was evident despite its medium density. The spherical granules observed in *Tetrapluera tetraptera* (Figs. 6), having a density of 0.467g/cm^3 are suspected to be hydrophobic since the water imbibition capacity observed after 24h was lower than those of similar density.

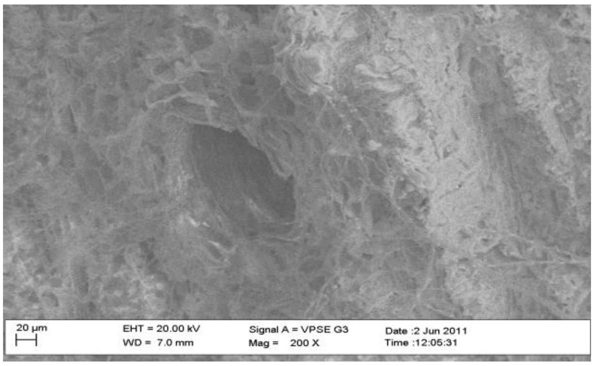

Fig.2: Scanning Electron micrograph of *Ricinodendrom heudelotti*

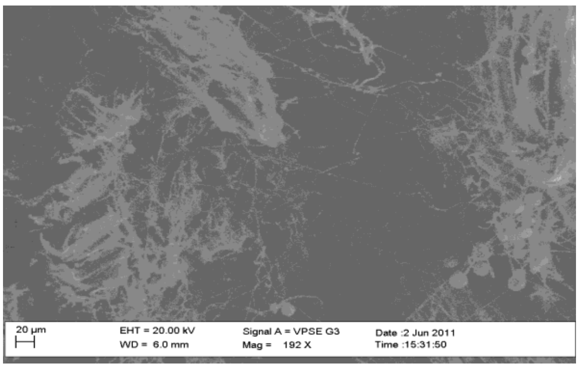

Fig.3: Scanning Electron micrograph of *Hollarrhena floribunda*

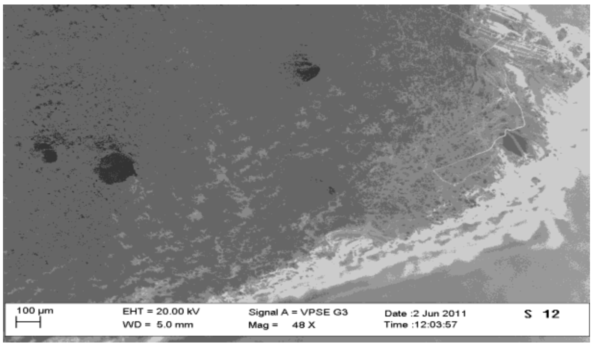

Fig.4: Scanning Electron micrograph of *Triplochyton scleroxylon*, (Mag= 48X)

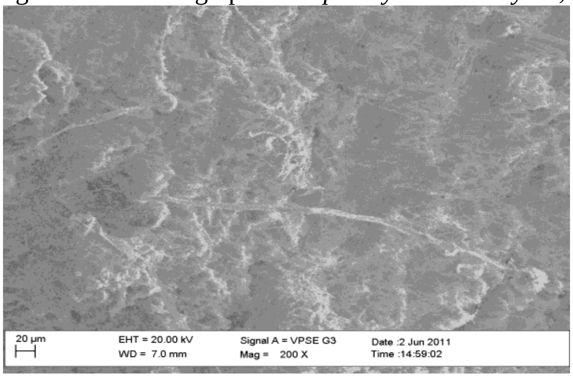

Fig.5: Scanning Electron micrograph of *Anacardium occidentalis*

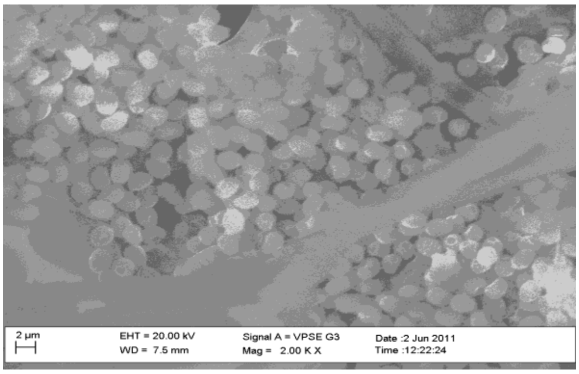

Fig.6: Scanning Electron micrograph of *Tetrapleura tetraptera* (2000X)

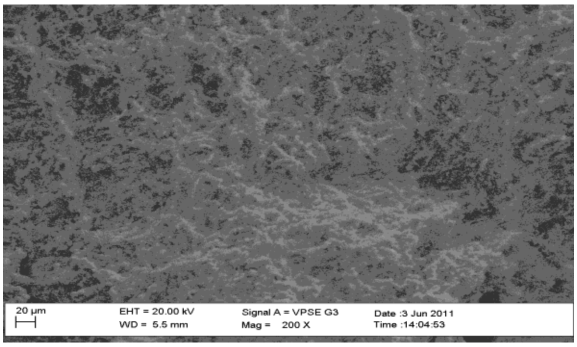

Fig.7: Scanning Electron micrograph of *Terminalia superba*

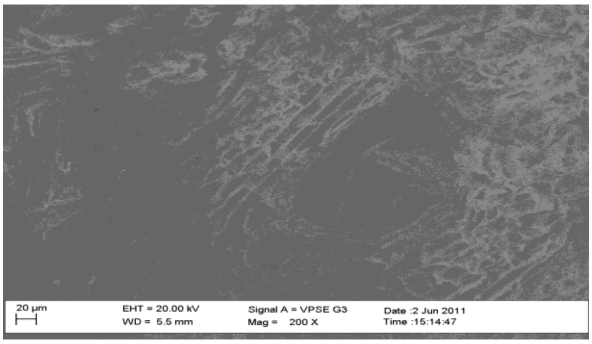

Fig.8: Scanning Electron micrograph of *Diospros dendo*

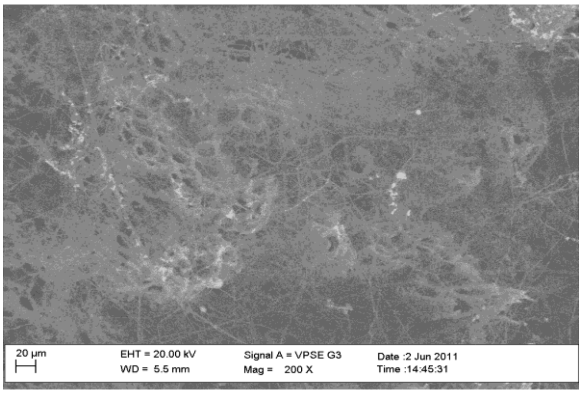

Fig.9: Scanning Electron micrograph of *Entandrophragma utile*

IV. Conclusions

This study investigated the density and water imbitition capacity of fifty-three Nigerian timbers and the scanning electron microscopy of selected timber species. The following conclusions could be drawn:
Most of the timbers are of medium density; *Ricinodendrom huedelotti* is the least dense (0.256 ± 0.008 g/cm^3) while *Irvinga smithii* is the most dense (1.111 ± 0.039 g/cm^3*)*.

- There was an inverse relationship between the maximum moisture content of these samples and their density.
- The scanning electron micrographs of selected timbers present ring- porous hardwoods as well as diffuse- poruos hardwoods.

The recommended practice is that the quality needed for a particular function can be specified and timbers can then be selected from the orderly graded system developed to serve the interests of the users and the producers to avoid more cost and waste.

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