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Wood Species**

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## DIMENSIONAL STABILITY OF CHEMICALLY MODIFIED *NAUCLEA DIDERICHII* (DE WILD & TH. DUR) WOOD SPECIES

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**ABSTRACT:** Effect of chemical modification was investigated on dimensional properties of *Nauclea diderichii* using acetylation method; this was done to examine the durability of the wood when exposed to moist environment. Experimental samples of dimensional size 6 cm x 0.8 cm x 0.8 cm were treated with acetic anhydride at 105 °C and tested for dimensional stability. Dimensional properties such as density, weight, anti-shrink efficiency, volumetric swelling coefficient, water absorption and thickness swelling are determined. The untreated and treated samples were submerged in water soak test for the periods of 24 hours. The results show that density of untreated and treated *Nauclea diderichii* wood falls within the range of 0.53 to 0.56 g/cm<sup>3</sup> and 0.58 to 0.59 g/cm<sup>3</sup>. The weight of the wood was found to decrease by 24.2 to 15.2 % and 24.8 to 16.2 % for untreated and treated wood samples. The values obtained for anti-shrink efficiency and volumetric swelling coefficient ranged from 2.17 % to 2.48 % and 2.70 % to 3.13 % across the Tree stem portion of the wood. The decrease and increase in activities of water absorption and desorption for *Nauclea diderichii* wood samples acetylated both across and along the Tree stem portion was encouraging. Acetylation of *Nauclea diderichii* shows significant influence on thickness swelling and water absorption at 1 hr, anti-shrink efficiency, volumetric swelling coefficient and weight across the tree stem portion. This study revealed that treatment of *Nauclea diderichii* with acetic anhydride for dimensional stability formed polymeric reaction in the wood that displaced bound water found in cell lumen and rendered it well suited for application in moist environment.

**Keywords:** Acetic, Anti-shrink, Hygroscopicity, Volumetric, Shrinkage.

### 1. INTRODUCTION

Wood as raw material contributes significantly in improving a nation's economic base, industrialization and comfort of its teeming population. Sawn wood is the most diversified and it serves as raw material for the production of furniture and furniture components, floor parquets and other secondary wood products (Larinde *et al.*, 2010). The integration of wood products into the market has moved the modern

innovative technology forward; high demand is daily witnessed in wood-based products comprising sawn wood, veneer and plywood, particleboard, match splint, pulp and paper, transmission poles (Halligan 2002, Panshin and Dezieuw 2003, Stamm and Bechler 2006).

Wood is available in wide varieties as a result of grain pattern, color and density. It displayed resistance to mild chemicals and also insulates against electricity

and heat (Rowell 1983, Rugevitsa and Svelte 2006). Wood can be attacked by deteriorating agents and marine borers due to the presence of succulent holocellulose in wood. It has the ability to shrink and swell with changes in humidity. It also varies in strength along different directions (Popper and Bariska 2005). Due to these variations, wood is known to be isotropic in nature. However, wood properties can be altered through modification process. Wood modification is the bulking of wood with chemicals to improve its resistance to bio deteriorating agents and dimensional instability. This is the process where chemicals are directly applied to wood to modify or reduce its shrinkage and swelling ability through acetylation method (Fuwape and Aina 2010, Popper and Bariska 2000, Popper and Bariska 2005).

Wood is a biodegradable material for organisms that recognize component such as polymers (polysaccharides) for survival. These polymers are found in wood cell wall and the presence of enzymes systems in wood has capability of hydrolyzing the polymers into digestible units for the organisms (Minato and Mizukami 2009). Hemicelluloses are the first to be attacked in wood component because they are accessible and this is attributed to wood strength. Wood strength depends on the presence of high molecular weight of cellulose found in it. The biological degradation of wood through oxidation, hydrolysis and dehydration reaction leads to loss of strength in wood (Fiest *et al.*, 1991).

Chemical modification of wood through acetylation with acetic anhydride gives an approximate 20 % weight gained (based on original oven dry weight of wood), results shows that modified wood greatly reduced hygroscopically by 70% dimensional stability based on a water soaking test (Rowell and Ellis 1999, Rowell 2006). Chemical modifications of wood also improve impacts resistance to bio-deteriorating agents such as termites and marine organisms. It also helps to change the hydrophilic nature of wood. It has been noted that an increase in dimensional stability of woods depends on adequate distribution of reacted chemical in water accessible region of the cell wall (Risi 2008).

It is essential that the chemical use for wood modification should have the capability to swell the wood, facilitate penetration and retention. This reacts directly with the cell wall polymer. Bulking of wood cell wall with bonding chemicals has tendency to reduce the swelling or shrinkage nature of wood to moisture exposure. Chemical modification of wood cell wall polymer products of great enhanced wood properties with better resistance to any biological deteriorating agents. This reaction is based on the theory that the enzymes found in wood must not have direct contact with the substrate which is being

protected by water resistance chemicals (Rowell and Ellis 1999, Stamm and Bechler 2006).

The degree of dimensional stability for wood through different treatment is described by variety of terms such as anti-shrink efficiency (ASE), Swelling percent (SP) and dimensional stabilization efficiency (DSE). Many researchers have studied swelling capacity of various wood species using various organic liquids as treatment (Ashton 2000, Kumar *et al.*, 2003, Rugevitsa and Svelte 2006). The wood products users are currently interested in durable and highly dimensionally stable wood-based products. Due to this reason, many indigenous grown wood species in Nigeria need to be investigated for durability. Therefore, this study aims to investigate the effect of chemical modification treatments on physical properties of *Nauclea diderichii* wood.

## 2. MATERIALS AND METHODS

### 2.1 Materials

*Nauclea diderichii* employed for the research investigation was identified by specialists in Herbarium section of the Department of Forest Ecology and Biosphere at Forestry Research Institute of Nigeria (FRIN), Ibadan. Three trees were felled from FRIN Research plot at Onigambari town, Ibadan which is located at coordinates of Longitude 3°49'59.99" and Latitude 7°7'59.99". The age of trees felled ranged between 30 to 34 years old. After felling, the logs were conveyed to the Sawmill section of the Department of Forest Products Development and Utilization at FRIN for conversion into planks of dimensional size of 2.5 cm x 30 cm x 360 cm using CD – 6 bandsaw in through and through method. The planks were further cut into dimensional size of 6 cm x 0.8 cm x 0.8 cm in accordance with (Chow 1998) of (FPL 1999). Total numbers of 72 samples were derived altogether at various levels. 24 samples were derived from 3 trees, sectioned into three portions (Top, Middle and Base) and three positions (Longitudinal, Radial and Tangential). Total number of 36 wood samples were untreated that serves as control while another 36 wood samples were also treated to serves as treatments.

### 2.2 Treatment Procedures

Wood samples of 6 cm x 0.8 cm x 0.8 cm dimension were oven-dried to attain 12 % moisture content at a constant temperature of 105 °C for 24 hours. The oven-dried wood specimens were soaked in solution of Benzene and Ethanol at a ratio of 3:1 for 1 hour and later soaked in acetic anhydride for 24 hours. Then, the acetylated wood samples were oven dried at 105 °C for 24 hours. The acetylated and non acetylated wood samples were submerged in water soak test for the period of 24 hours to determine the volumetric swelling

coefficient, anti-shrink efficiency, weight gain and wood density. In order to ascertain the movement of moisture in relation to absorption and desorption in wood, properties such as thickness swelling and water absorption were carried out at 1 hour and 24 hours for acetylated and non acetylated wood samples. These physical properties were calculated in accordance with the equations developed by (Chow 1998) and the formulae are presented below;

Wood density is determined through the basic density method which is the oven-dry-volumetric method i.e.

$$\text{Density} = \frac{\text{Mass}}{\text{volume}} \text{ (g/cm}^3\text{)}. \text{ (Equation 1)}$$

$$\text{Anti-shrink efficiency (ASE)} = \frac{S_2 - S_1}{S_1} \times 100 \text{ (Equation 2)}$$

Where ASE= Reduction in swelling or anti-shrink efficiency;  $S_1$ = Untreated volumetric swelling coefficient and  $S_2$ = Treated volumetric swelling coefficient.

$$\text{Volumetric swelling coefficient (S)} = \frac{V_2 - V_1}{V_1} \times 100 \text{ (Equation 3)}$$

Where  $V_1$ = Volume of the over-dried wood sample before treatment,  $V_2$ = Volume of the wood sample after treatment.

$$\% \text{ T.S (Thickness swelling)} = \frac{\text{Increase in thickness dimension}}{\text{Original thickness before exposure}} \times 100 \text{ (Equation 4)}$$

The data collected for density, weight gain, anti-shrink efficiency and volumetric swelling coefficient were analyzed using 2 x 3 factorial experiments in completely randomized design (CRD) at 5 % level of probability while data collected for thickness swelling was also analysed using 2 x 3 x 3 factorial experiment in CRD at 5 % level of probability. Descriptive statistic was used to determine the average values while bar chart and line graph were used to explain the extent of variation between the main factor A (samples for untreated and treated) and B (stem portion at Top, Middle and Base) and C (Tree stem position at Longitudinal, Radial and Tangential).

### 3. RESULTS AND DISCUSSION

#### 3.1 Effect of acetylation treatment on weight of *Nauclea diderichii*

Table 1 presented the average percentage weight values obtained for acetylated *Nauclea diderichii* samples along the wood stem portions. There was an

increase in weight of *Nauclea diderichii* from the base portion to the top portion of the wood (Fig. 2). The weight values obtained from the different stem portions of treated and untreated *Nauclea diderichii* were 4.83 g, 3.87 g, 3.33 g and 4.72 g, 3.80 g, 3.30 g for Top, Middle and Base portions (Table 1). The weight values obtained for untreated *Nauclea diderichii* decreased accordingly by 24.2 % to 15.2 % from the Top portion of the wood to the Base portion of the wood but after treated the weight values of the wood still decreases from 24.8 % and 16.2%. This study shows that percentage of acetic anhydride absorbed by the treated *Nauclea diderichii* varied across the stem portions from 2.12 %, 1.84 % and 0.91 % for the Top, Middle and Base portion of the wood; this also confirmed that Top portion of the wood absorbed more acetic anhydride than the Middle and Base portion of the wood. These variations in weight gain of treated *Nauclea diderichii* wood along the stem portion can be attributed to the vessels found along the stem portion of the wood. Probably the vessels might be filled with tyloses at the base more than at the top portion of the wood. This makes the Top portion of the wood to accommodate more chemical into its vessels that gives higher weight gain values than the Middle and Base portion of the treated wood. This reaction thus makes the wood to be dense. Table 2 revealed that acetylation of *Nauclea diderichii* wood samples across tree portion has significant effect on its weight. Similar results were discussed in chemical modification of wood using acetylated wood, chlorine in epichlorohydrin-reacted wood (Rowell, 1983)

#### 3.2 Effect of acetylation treatment on wood density

Table 1 revealed the average density of untreated and treated *Nauclea diderichii* wood samples. As illustrated in Fig 1, the average density for the treated and untreated *Nauclea diderichii* wood samples were found to ranged from 0.53 g/cm<sup>3</sup> and 0.59 g/cm<sup>3</sup> across the Tree portion. The density obtained for untreated and treated *Nauclea diderichii* at the Top portion had 0.53 g/cm<sup>3</sup> and 0.58 g/cm<sup>3</sup> while at the Middle portion, the wood had 0.54 g/cm<sup>3</sup> and 0.59 g/cm<sup>3</sup> for untreated to treat *Nauclea diderichii* wood samples and at the Base portion, the wood had 0.56 g/cm<sup>3</sup> and 0.59 g/cm<sup>3</sup>. As illustrated in Fig. 1, the density values observed shows that untreated *Nauclea diderichii* wood samples increased from Top portion to Base portion of the wood but after acetylated, the density follows the same trend pattern but has the same values at the Middle and Base portion of the wood. It was shown and revealed in Fig 1 that treated *Nauclea diderichii* wood samples are denser than untreated *Nauclea diderichii* wood samples due to the bulk density of acetic anhydride at 1.08 g/ml which is greater than density of water at 1.00 g/ml. This observation agrees with (Dreher *et al.*, 2001) that explained that acetylated wood was dense than

untreated wood due to fewer fibers of lignocelluloses per unit volume found across the internal structure of the wood. In addition, the cell reactive component presents in the wood cell wall with moisture play a significant role. The amount of moisture in acetylation process causes a permanent loss of cellulose crystallinity (Arni and Gray 2007); the loss of crystallinity yields a uniform distribution of acetyl groups in cellulose. It has been noted that percentage of moisture between 2 to 5 % will give best reaction but above this level, the water hydrolyzes the acetic

anhydride to produce acetic acid (Rowell 1983). This loss by hydrolysis accounts for a 5.7% loss of anhydride with each 1% of water found in the wood (Arni and Gray 2007, Koppers 2005). The rate of acetylation decreases as the moisture content increases (Rowell 2006). Increase in adequate distribution of chemical in water accessible region of cell wall of the wood tends to increase the density of the acetylated wood. As presented in Table 2, the effect of chemical modification of *Nauclea diderichii* wood samples has significant effect on density of wood.

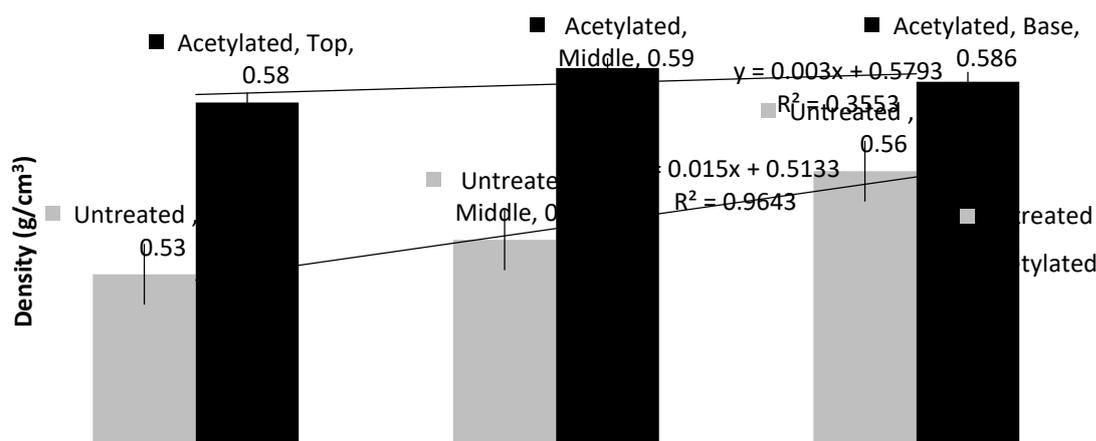


Fig. 1: Density of untreated and treated *Nauclea diderichii* wood

### 3.3 Anti-shrink efficiency and volumetric swelling coefficient of acetylated wood

Table 1 presented the average percentage anti-shrink efficiency and volumetric swelling efficiency values obtained for untreated and treated *Nauclea diderichii* wood samples. As presented in Table 1, the result obtained shows that there are variations in anti-shrink efficiency of the wood samples which varies from 2.61 %, to 2.48 % and 2.17 % for Top, Middle and Base portion of the Tree stem portion respectively. Also, it revealed that values obtained for volumetric swelling coefficient of the wood samples varies from Top, Base and Middle for 3.13 %, 3.00 % and 2.70 % respectively. The values obtained for volumetric swelling coefficients are rarely the same and this observation can be due to the potential reactants which contains same functional and hydroxyl group in wood component. As presented in Table 1, the result obtained shows that there are variations in anti-shrink efficiency and volumetric swelling coefficient within the Tree stem portion of the wood both before and after treatment. The result obtained indicated that at 120 °C,

the reaction of the chemical within the wood structure is rarely the same that the extent in the changes in volume of the wood can be attributed to the chemical found within the Tree stem portion of the wood, these chemical components has helped to increase the volume due to chemical bulky of the cell wall. This observation is in line with findings of (Popper and Bariska 2005, Pratt 2004) that wood swells when wet and shrinks when dry due to its hygroscopic nature. These findings show that chemical modification has helped the wood to reduce amount of water present in the cell wall, which conversely inhibits the lignin component of the wood, which concurred with previous findings of (Risi 2008, Rowell 2006), that cellulose, hemicellulose and lignin are polymers composite of wood, these polymers make up the walls that are responsible for most of the exhibited physical and chemical properties in wood. The outcome of result obtained from the statistical analysis test confirmed that there were significant differences within the untreated and acetylated (modified) wood for anti-shrink efficiency and volumetric swelling coefficient.

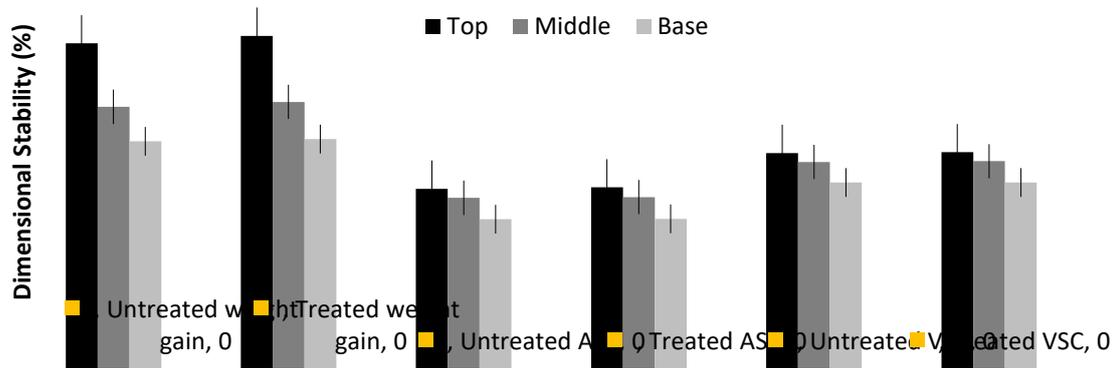


Fig. 2: Dimensional properties for untreated and treated *Nauclea diderichii* wood

### 3.4 Effect of wood Acetylation on water absorption

Table 1 shows the average percentage water absorption values obtained for acetylated and untreated *Nauclea diderichii* wood samples. Water absorption values obtained for untreated and treated *Nauclea diderichii* samples at 1 hour and 24 hours ranged from 9.63 % to 15.64 % and 36.08 % to 42.29 %. The water absorption values obtained within the Tree stem portion for untreated and treated samples were 15.35 %, 14.57 %, 15.64 % and 10.35 %, 9.63 %, 10.64 % for Top, Middle and Base respectively. The same trend was observed for both untreated and treated samples for 1 hour (Fig. 3). Water absorption values for untreated and treated samples decreased by 32.6 %, 33.9 % and 32.0 % for the Top, Middle and Base portion of the wood respectively. As the period of samples increases in water soak test to 24 hours, the trend pattern was similar to the previous exposure (Fig. 3). At 24 hours, the water absorption values for untreated and treated

*Nauclea diderichii* were 41.56 %, 41.08 %, 42.29 % and 36.64 %, 36.08 %, 37.30 % respectively for the Top, Middle, Base portion of the wood (Table 2). The percentage water absorption decreased by 11.8 %, 12.2 % and 11.8% from untreated to treated samples at Top, Middle and Base portion of the wood. As illustrated in Fig. 3, water absorption obtained greatly reduces when compared with that of untreated samples. This could be due to the restriction in pores and spaces found in the cell wall of the wood which also varies along the stem and by bulking chemical into the cell cavity in the pores space found in the internal structure of the wood.; it reduces permeability of the wood to gases diffusion than when compare with the acetylated wood. As presented in Table 2, water absorption was seen to be significant for samples (both treated and untreated) and Tree stem portion at 1 hour while only between the samples that was significant in water absorption at 24 hours. This is in agreement with findings in (Tarkwo and Stamm, 2006).

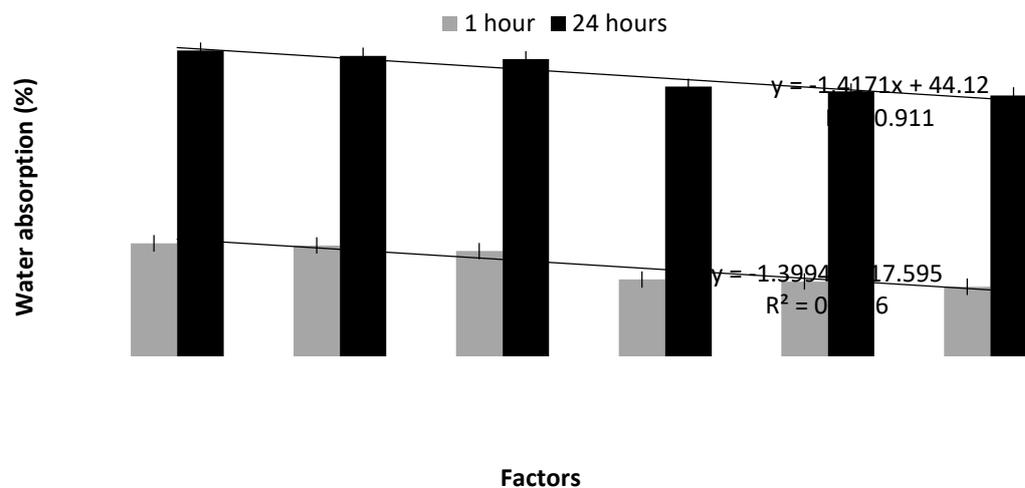


Fig. 3: Water absorption for untreated and treated *Nauclea diderichii*

Table 1: Mean values for density and physical properties of untreated and acetylated *Nauclea diderichii*

Untreated			Acetylated			Physical properties
Top	Middle	Base	Top	Middle	Base	
0.56 <sup>b</sup>	0.53 <sup>b</sup>	0.54 <sup>b</sup>	0.575 <sup>a</sup>	0.59 <sup>a</sup>	0.59 <sup>a</sup>	Density (g/cm <sup>3</sup> )
4.72 <sup>a</sup>	3.80 <sup>b</sup>	3.30 <sup>c</sup>	4.83 <sup>a</sup>	3.87 <sup>b</sup>	3.33 <sup>c</sup>	Weight (%)
15.64 <sup>a</sup>	15.35 <sup>a</sup>	14.57 <sup>b</sup>	10.64 <sup>a</sup>	10.35 <sup>a</sup>	9.63 <sup>b</sup>	Water absorption (%) after 1 hr
42.29 <sup>b</sup>	41.56 <sup>b</sup>	41.08 <sup>b</sup>	37.30 <sup>a</sup>	36.64 <sup>a</sup>	36.08 <sup>a</sup>	Water absorption (%) after 24 hrs
2.61 <sup>a</sup>	2.48 <sup>b</sup>	2.17 <sup>c</sup>	2.63 <sup>a</sup>	2.49 <sup>b</sup>	2.18 <sup>c</sup>	Anti shrink efficiency (%)
3.13 <sup>a</sup>	3.00 <sup>b</sup>	2.70 <sup>c</sup>	3.14 <sup>a</sup>	3.01 <sup>b</sup>	2.70 <sup>c</sup>	Volumetric swelling coefficient (%)

Means followed by the same alphabet in the column under each factor are not significant at  $P > 0.05$

Table 2: Results of analysis of variance for density and physical properties

Source of variance	df	Weight		density		WA after 1hr		WA after 24 hrs		ASE		VSC	
		F-Cal	Sig	F-Cal	Sig	F-Cal	Sig	F-Cal	Sig	F-Cal	Sig	F-Cal	Sig
Samples	1	65.437	0.00*	9.493	0.00*	317.303	0.00*	71.808	0.00*	63.237	0.00*	64.124	0.00*
Tree portion	2	4.397	0.01*	0.194	0.824 <sup>n</sup>	4.963	0.01*	1.446	0.25 <sup>ns</sup>	2.145	0.02*	4.387	0.01*
Sample * Tree portion	2	0.063	0.94 <sup>ns</sup>	1.177	0.315 <sup>n</sup>	0.06	0.996 <sup>n</sup>	0.002	0.99 <sup>ns</sup>	0.064	0.95 <sup>n</sup>	0.062	0.94 <sup>ns</sup>

\*represents significant while ns represents not significant at  $P > 0.05$

### 3.3.

#### Effect of wood acetylation on Thickness swelling

As presented in Table 3, the average percentage thickness swelling values obtained for untreated and acetylated *Nauclea diderichii* wood samples ranged from 0.37 % to 1.56 % and 0.34 % to 3.10 % for 1 hour while 1.05 to 2.86 % and 0.29 % to 6.60 % for 24 hours. The thickness swelling values obtained for untreated and acetylated *Nauclea diderichii* for 1 hour had 0.85% and 1.85 % but at Tree stem portions, the thickness swelling values were 1.18 %, 1.27% and 1.61 % at Base, Middle and Top portion respectively. Similarly, the thickness swelling values obtained across the Tree stem positions were 0.51 %, 1.75 % and 1.79 % at longitudinal, radial and tangential position of the wood.

The thickness swelling values for untreated and treated wood varies considerably, which was found to be always higher at the Top, Middle, and Base; and lowest in longitudinal position and highest in tangential position follows by in radial position (Fig. 4 and 5). It was revealed that *Nauclea diderichii* wood increased in swelling percentage by 147.1 %, 141.9 % and 85.0 % for Base, Middle and Top portion from untreated to treated wood after submerged in water soak test for 1 hour. Similarly, it also increased in swelling capacities across the Tree stem positions by 37.2 %, 210.9 % and 132.5 % for longitudinal, radial and tangential position after 1 hour. But at 24 hours of water exposure, untreated and acetylated *Nauclea diderichii* wood had swelling capacities of 1.80 % and 3.80 %, while at Tree stem portions by 2.70 %, 2.80 % and 2.91 % for Base,

Middle and Top portion of the wood. Similarly at Tree stem position, the swelling capacities were 0.76 %, 3.55 % and 4.09 % for longitudinal, radial and tangential position of the wood. It has been revealed that after modification of *Nauclea diderichii* with acetic anhydride, the swelling capacity of the wood after immersion for 24 hours had highest swelling percentage at the Base portion by 132.9 %, followed by Top portion with 106.1 % and least at the middle by 100.0 %.

Similarly, across the Tree stem position, swelling capacity of *Nauclea diderichii* wood was highest at tangential position by 94.2 % followed by at Radial position with 86.3 % and least percentage at longitudinal position by 20.0 %. This could be as a result of exist chemical reaction between the wood and acetic anhydride, thus gives acetylation of the wood by substituting the hydroxyl groups found in the cell wall of the wood. It has been stated that acetylated wood has the potential of imparting high dimensional stability and changing the hydrophilic nature of wood completely (Rowell 2006, Ashton 2000). Acetylated wood appears to offer the wood with the least changes in the desirable properties of the wood. More so, acetylated wood has reduced permeability to gases compared with treated wood (Kumar *et al.*, 2003). This might be due to the bulking chemical restricting pore space in the wood. This finding agrees with previous studies carried out by (Popper and Bariska 2005, Rowell and Ellis 1999, Stamm and Bechler 2006).

The percentage water absorption of acetylated wood increased with percentage thickness swelling due to increase in wood volume upon treatment with increasing chemical proportion to 25 % weight. As presented in Fig. 4 and 5, the thickness swelling of untreated samples was higher than those of acetylated

wood samples, apparently the thickness swelling values recorded for acetylated wood samples were lower. This might be due to the bulking of the wood fiber through reaction with acetic anhydride. The study shows that acetylated wood samples found to be denser and more dimensionally stable with fewer fibers of lignocelluloses per unit volume than untreated wood samples, and this agrees with (Dreher *et al.*, 2001). The physical properties of acetylated samples were better in terms of dimensional properties than those of untreated samples. It was generally observed in Fig. 2 that upon chemical addition to about 25 %, the weight gain of the wood can be derived at the point which the treated volume is approximately equal to the green volume of the wood. This shows that moisture content has an influence on chemical treatment of wood and composites as well. This is in line with (Desch and Dinwoodie 1999) that when wood dries from above the fiber saturation point (F.S.P) to the over-dried state, the change in the longitudinal dimension is small compared with the radial which is moderately lower and the tangential which is often high; thus, it tends to shrink; but when the bulked wood comes in contact with water, very little additional swellings can take place.

The results obtained for statistical analysis is presented in Table 4, showed that all factors (sample, Tree portion and Tree stem position) were significant for thickness swelling at 1 hour, while all the factors except Tree portion were significant at 5 % level of probability for thickness swelling at 24 hours. This implies that after 1-hour immersion test, acetylation treatment at Tree portion and position has significant influence on dimensional properties of the wood. At 24 hours, it is the same for samples treated with or without acetylation at Tree position (Longitudinal, Radial and Tangential) but not at Tree portion.

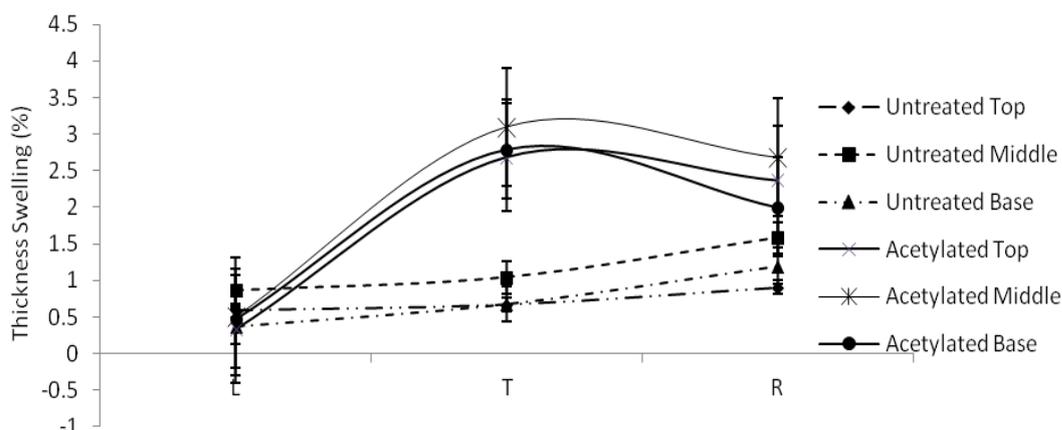


Fig. 4: Thickness swelling of untreated and treated *Nauclea diderichii* after 1 hr of water immersion test

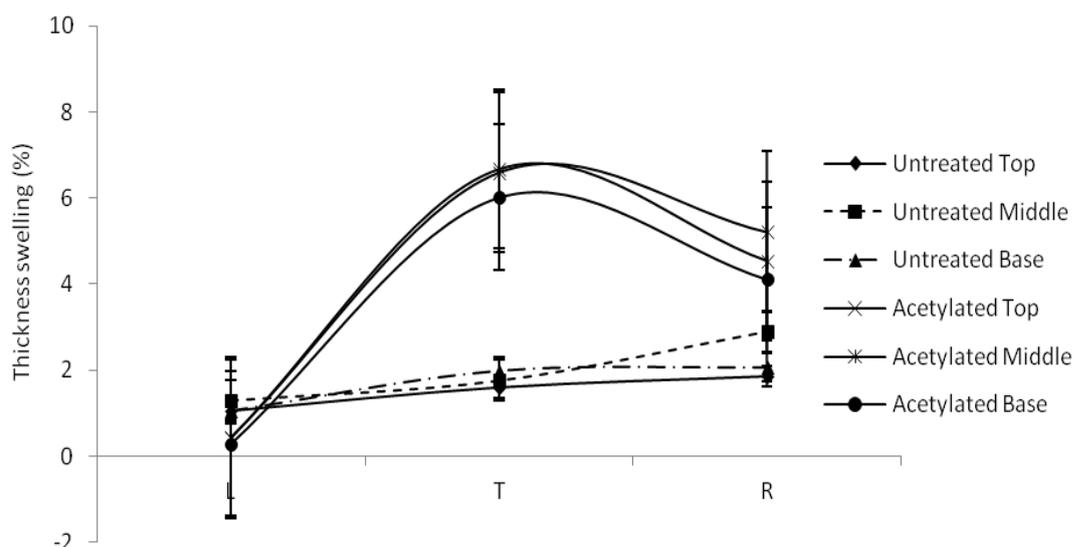


Fig. 5: Thickness swelling of untreated and treated *Nauclea diderichii* wood after 24 hours of water immersion test

Table 3: Mean values of thickness swelling for untreated and treated *Nauclea diderichii*

Factors	Untreated <sup>(b)</sup>			Acetylated <sup>(a)</sup>			Physical properties (%)
	Top	Middle	Base	Top	Middle	Base	
Longitudinal <sup>(a)</sup>	0.786 <sup>b</sup>	0.629 <sup>a</sup>	0.373 <sup>a</sup>	0.338 <sup>a</sup>	0.474 <sup>b</sup>	0.481 <sup>a</sup>	Thickness swelling after 1 hr
Radial <sup>(b)</sup>	1.563 <sup>b</sup>	1.203 <sup>a</sup>	0.914 <sup>a</sup>	2.368 <sup>a</sup>	2.680 <sup>b</sup>	1.767 <sup>a</sup>	
Tangential <sup>(b)</sup>	1.041 <sup>b</sup>	0.667 <sup>a</sup>	0.468 <sup>a</sup>	2.690 <sup>a</sup>	3.100 <sup>b</sup>	2.789 <sup>a</sup>	
Longitudinal <sup>(a)</sup>	1.312 <sup>a</sup>	1.052 <sup>a</sup>	1.070 <sup>a</sup>	0.433 <sup>a</sup>	0.415 <sup>a</sup>	0.287 <sup>a</sup>	Thickness swelling after 24 hrs
Radial <sup>(b)</sup>	2.863 <sup>a</sup>	1.859 <sup>a</sup>	2.703 <sup>a</sup>	5.209 <sup>a</sup>	4.532 <sup>a</sup>	4.108 <sup>a</sup>	
Tangential <sup>(c)</sup>	1.990 <sup>a</sup>	1.771 <sup>a</sup>	1.565 <sup>a</sup>	6.600 <sup>a</sup>	6.583 <sup>a</sup>	6.018 <sup>a</sup>	

Means followed by the same alphabet in the column under each factor are not significant at  $P > 0.05$

Table 4: Results of analysis of variance conducted of thickness swelling for untreated and treated *Nauclea diderichii*

Source of variance	df	Thickness swelling after 1 hr		Thickness swelling after 24 hrs	
		F -Cal	Sig	F -Cal	Sig
Samples	1	65.437	0.00*	143.442	0.00*
Tree portion	2	4.397	0.01*	0.566	0.57 <sup>ns</sup>
Stem position	2	45.558	0.00*	152.273	0.00*
Sample * Tree portion	2	0.063	0.94 <sup>ns</sup>	3.395	0.04*
Sample * Stem position	2	28.566	0.00*	87.043	0.00*
Tree portion * Stem position	4	0.386	0.82 <sup>ns</sup>	0.018	0.99 <sup>ns</sup>
Sample * Tree portion * Stem position	4	0.989	0.41 <sup>ns</sup>	1.116	0.35 <sup>ns</sup>

\*represents significant while ns represents not significant at  $P \leq 0.05$

#### 4. CONCLUSIONS AND RECOMMENDATIONS

Based on the findings, it can be concluded that;

- Acetylation had significant effect on density, anti-shrink efficient, volumetric swelling coefficient and thickness swelling of *Nauclea diderichii* wood. Thus, the weight of acetylated wood samples increases from 2.82 to 5.06% while the anti-shrink efficiency of the acetylated samples also ranges from 1.86 to 3.15%.
- The acetylated wood samples were generally denser than untreated samples. Acetylation method of modified wood improved

dimensional stability of *Nauclea diderichii* wood. The thickness swelling of the treated wood samples is considerably lower than that of untreated samples.

- The future of chemical modification of wood lies in end-product property enhancement. If the level of chemical addition were high enough, the dimensional stability and some degree of resistance to biological attack would also be achieved.
- Thus, there is need to chemical modification to provides better dimensional stability to wood which depends on adequate distribution of

- reacted chemical permanently bounded in water accessible regions of the cell wall.
- v. Based on the result of findings from this study, it is therefore recommended that chemical modification using acetylated method has potential of preventing wood against water, thus make the wood to be dimensionally stable and reduce its hygroscopicity.
  - vi. Further research work should be carried out to ascertain the best molar ratio to be used in acetylation of wood treatment against biodegrading agents

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