Available online at www.equijost.com

Equity Journal of Science and Technology, 2022 9(2): 12 - 17

ISSN 2354-1814; E-ISSN 2683-5961

EQUIJOST *An Official Publication of Kebbi State University of Science and Technology, Aliero, Nigeria*

Hygroscopicity, anti-swell efficiency and dimensional stability of castor oil – treated Caribbean pine (*pinus caribaea* morelet) wood

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Abstract

Wood is hygroscopic, rendering it to become dimensionally unstable when exposed to moisture fluctuations during service, none more so in *Pinus caribaea* wood. Preventing such occurrences in the wood is therefore crucial to its sustainable utilization. This can be achieved by treating the wood with hydrophobic substances such as castor seed oil (CSO). Five (5) trees of 31-year-old *P. caribaea* wood were harvested at Shasha Forest Reserve, Southwest Nigeria. Bolts of 50 cm long were obtained from each felled tree at the top (90%), middle (50%) and base (10%) of their merchantable lengths. The samples were oven-dried and treated with four formulated oil concentrations prepared from mechanically extracted CSO - 0%, 10%, 20% and 30% using the soaking method. The treated and control samples were evaluated for their water absorption, dimensional swelling (WA) and anti-swell efficiency (ASE). Data analysis was performed using ANOVA. The result show that sampling height had no significant influence (P>0.05) on the evaluated parameters while CSO concentration significantly influenced both the water absorption and tangential swelling (P<0.05) of the wood samples. All the oil treatments significantly reduced the water absorption in the wood (P<0.05). ASE value was highest for the wood treated with the 30% CSO. Overall, the 30% CSO concentration performed best for most of the properties evaluated. However, the little effectiveness of the CSO in improving the wood dimensional stability may be associated with its method of application. Further study on the thermal treatment of the wood with CSO is therefore suggested.

Keywords: Castor seed oil, Carribean Pine, Hygroscopicity, Dimensional swelling, Soaking, Anti-swell efficiency

1. Introduction

Wood is an organic material made up of three major polymeric units, namely: cellulose, hemicellulose and lignin [1]. The cellulose is a structural compound which gives the wood its structural support while the lignin acts as a binding material of the wood cells [2, 3]. However, the cellulose and the hemicellulose component of the wood are hygroscopic, making wood readily receptive to moisture [4]. This presents some major problems in wood utilization, causing wood to become dimensionally unstable as a result of moisture fluctuations in the wood cell wall. It is more worrisome due to the fact that it may constitute hazard in case of sudden failure during service in some particular structural applications [5]. In addition, allowing wood to shrink or swell may result into some wood defects such as checks or splits which reduces its life span for the intended purpose [6-8]. Thus, procedures to eliminate or reduce these occurrences in wood should be of prime importance.

Pinus caribaea, also known as Carribean pine, is gaining more attention for use in the Nigerian wood industry for structural applications. Its figure and grain pattern, coupled with its relatively moderate density makes it suitable for a considerable number of structural uses. However, inefficient utilization of timbers in the face of the teeming population, coupled with the attendant increase in wood demand for structural use makes it imperative to design a sustainable utilization regime for the available timber species in the country. As reported by Adenaiya and Ogunsanwo [9], *P. caribaea* is a highly porous wood, hence, the necessity for its treatment to reduce its dimensional instability during service. Treatment of wood with oils may be an effective way in controlling dimensional instability in wood when in contact with moisture as the hydrophobic nature of oils can prevent penetration of water into wood [5, 10-12]. Encouraging results in the use of some vegetable oils in reducing moisture absorption and dimensional instability have been documented by several studies [5, 11-13]. However, the suitability of castor seed oil in controlling this unwanted phenomenon in *P. caribaea* and other wood species is yet to be explored. The potentials of the castor plant remain grossly untapped in Nigeria, therefore, making this research important as a means of discovering a possible area in the wood industry where the plant may be explored for commercial purposes.

2. Materials and Methods

2.1 Sample procurement

Five defect-free 31-year-old *Pinus caribaea* trees were harvested from pine plantation within Shasha Forest Reserve, Osun State, Nigeria, located between Lats. 7^0

and 7^0 30' N and Longs. 4^0 and 5^0 E. Bolts of 50cm in length were obtained from the top (90%), middle (50%) and base (10%) of the merchantable lengths of the trees. The bolts were coated with pentachlorophenol to prevent attack by blue-stain fungi before transporting them to the Department of Forest Resources Management wood workshop for further processing.

2.2 Bolt conversion and sample preparation

The bolts were quarter-sawn into dimensions 6cm x 2cm x 2cm such that the tangential and radial faces were exposed and the wood grains aligned with the longitudinal axis [14]. The samples were dried in the oven to a constant weight at 103^0C for 18 hours, then subsequently stored in air-tight bags.

2.3 Castor seed collection and oil extraction

Ripe castor seeds (*Ricinus communis var Gibsonii*) growing in the wild were sourced in large quantities within Ibadan, Oyo State. The seeds were dehauled, air-dried and grounded into paste. Oil was mechanically extracted from the grounded seeds using a cold press until the oil stopped dripping out from the seeds.

2.4 Treatment of wood samples

The extracted castor oil was diluted with kerosene into four different concentrations using the volume-to-volume method as adopted by Olajuyigbe et al. [15] and Adenaiya et al. [16]. These are represented as follows: 0% (Kerosene alone), 10%, 20% and 30% concentrations. The previously conditioned wood samples obtained from different heights (top, middle and butt) of the trees were completely submerged in a cold bath of the four castor-oil formulations for 24 hours. After the treatment, each test block was allowed to drain and reweighed to determine the preservative absorption. The preservative absorption by the wood samples was estimated using the method employed by Olajuyigbe et al. [15] and Adenaiya et al. [16] as given below:

$$Absorption\ (Kg/m^3) = \frac{10^6 \times WPA}{10^3 \times V} \qquad (1)$$

Where, WPA = Weight of preservative absorbed, V = Volume of wood sample

2.5 Water absorption test

The treated and untreated (control) wood samples were soaked in distilled water in a container for 14 days. The water was changed daily and after 14 days, the weights of the wood samples were measured. The water absorption was estimated using the procedure adopted by Erakhrumen and Ogunsanwo [5] as described below:

$$Water\ Absorption\ (\%) = \frac{(W_1 - W_o)}{W_o} \times 100 \qquad (2)$$

Where, W_0 = Initial weight of treated wood before soaking in water, W_1 = Final weight of treated wood after soaking in water

2.6 Percentage swelling and Anti-swelling tests

The treated and untreated wood samples were coded as 'R', 'T' and 'L', depicting radial, tangential, and longitudinal planes respectively. Dimensions below FSP along these three planes were taken with the aid of a digital vernier calliper and recorded. Saturated dimensions of the wood samples along these planes were also measured and the percentage swelling along these planes was estimated using the method employed by Islam et al. [17] which is given as:

$$S_w\ (\%) = \frac{D_s - D_o}{D_o} \times 100 \qquad (3)$$

Where: S_w (%) = Swelling (Either S_wR or S_wT or S_wL); D_s = Dimension at saturated condition; D_0 = Dimension before soaking; S_wR = Radial swelling; S_wT = Tangential swelling; and S_wL = Longitudinal swelling. Volumetric swelling (V_{sw}) was estimated following the procedure adopted by Kord *et al.* [18] and Modes *et al.* [19] which is given by the relation:

$$Vsw = SwR + SwT + SwL \qquad (4)$$

ASE was estimated based on the relationship described below as adopted by Modes *et al.* [17]:

$$ASE(\%) = \frac{V_2 - V_1}{V_2} \times 100 \qquad (5)$$

Where: ASE (%) = Anti-Swelling Efficiency, V_2 (%) = Volumetric Swelling Coefficient of untreated wood sample**,** V_1 (%) = Volumetric Swelling Coefficient of treated wood sample

2.7 Experimental Design and Statistical Analysis

The experimental design adopted was a Factorial experiment in Completely Randomized Design, involving 3 sampling heights (Top, middle and base) and 5 concentration levels (Control, 0%, 10%, 20% and 30%). The experiment was replicated 5 times. Analysis of Variance (ANOVA) was used to analyse the data generated while Duncan Multiple Range Test (DMRT) was used to separate means where significant differences were observed.

3. Results and Discussion

3.1 Water Absorption

The water absorption of the wood samples is depicted in Table 3.1. Based on sampling height, water absorption of the wood samples ranged between 43.93% to 49.21%. A consistent increase in water absorption was noted from the base to the top of the tree. This observation may be associated with the increasing level of preservative saturation in the wood from the top to the base [16], with the wood samples that are highly saturated with preservative having less space to hold water in.

For preservative concentration on the hand, water absorption of the wood samples ranged from 39.02% to 72.25%. The control wood samples absorbed water the most while the least was observed for wood samples treated with kerosene alone. Water absorption in the wood samples tended to increase with increasing preservative concentration from 0% to 20%, followed by a sharp reduction in the wood samples treated with the 30% preservative concentration. This suggests that the introduction of more oil into the wood at the 30% concentration as reported in a similar study by Adenaiya et al. [16] was able to improve the hydrophobicity of the wood, as the wood samples treated with the 30% preservative reduced water absorption by 50% relative to the control wood samples. Preservative concentration was observed to significantly influence water absorption ($p<0.05$), while sampling height and the interaction effect had no marked influence ($p>0.05$) on water absorption (Table 3.4). The LSD shows that water absorption for all the treated wood samples significantly differed from that of the control samples (Table 3.1).

Table 3.1: Water absorption of the wood samples

Concentration	Sampling Height			Mean
	Top (Kg/m^3)	Middle (Kg/m^3)	Base (Kg/m^3)	
Control	74.63 ± 1.27^{aA}	75.33 ± 2.67^{aA}	66.79 ± 5.66^{aA}	**72.25 ± 2.22^{A}**
0% (Kerosene)	41.13 ± 5.41^{aB}	40.24 ± 5.60^{aB}	35.69 ± 3.95^{aB}	**39.02 ± 2.77^{B}**
10%	42.32 ± 4.66^{aB}	39.76 ± 3.38^{aB}	37.59 ± 1.37^{aB}	**39.89 ± 1.90^{B}**
20%	42.89 ± 6.02^{aB}	41.80 ± 2.55^{aB}	42.66 ± 1.85^{aB}	**42.45 ± 2.10^{B}**
30%	45.06 ± 5.21^{aB}	37.31 ± 2.46^{aB}	36.93 ± 4.30^{aB}	**39.77 ± 2.43^{B}**
Mean	**49.21 ± 3.27^{a}**	**46.89 ± 3.25^{a}**	**43.93 ± 2.84^{a}**	

*Means with the same uppercase superscript within the same column are not significantly different ($p<0.05$)
* Means with the same lowercase superscript along the same row are not significantly different ($p<0.05$)

3.2 Longitudinal Swelling

Based on sampling height, longitudinal swelling values recorded ranged from 0.26% - 0.29% (Table 3.2). The wood samples at the base had the least longitudinal swelling while those at the middle swelled most in the axial plane. The range of longitudinal swelling observed in this study falls within the limits of longitudinal swelling reported for normal wood which ranges between 0.1 - 0.4% [10]. The higher longitudinal swelling observed in the top and middle wood suggests the presence of higher microfibrillar angles in both wood, typical of juvenile wood [20].

On the other hand, a similar range of longitudinal swelling values between 0.26% - 0.29% was observed for the preservative concentrations (Table 3.3). The control samples swelled most longitudinally while the least swelling was observed in wood samples treated with the 30% preservative. This indicates that treatment of the wood with the 30% preservative had some form of influence on reducing longitudinal swelling in the wood. Sampling height, preservative concentration nor the interaction of both had no significant effect ($p>0.05$) on the longitudinal swelling of the wood samples (Table 3.4).

3.3 Tangential Swelling

Based on sampling height, tangential swelling values recorded ranged from 7.28% - 7.98% (Table 3.2). The wood samples at the middle had the least tangential swelling while those at the base swelled most tangentially.

For the oil concentration, tangential swelling ranged between 7.09% -8.82% (Table 3.3). The highest tangential swelling was observed in the control wood samples while it was least in wood samples treated with the 30% preservative. There was a slight increase in the tangential swelling of wood samples treated with the 20% oil concentration which may be related to anatomical variations in the wood samples treated with the 20% oil concentration. It was observed that the preservative treatments in general reduced tangential swelling by 12% - 20% when compared to the control samples. Preservative concentration had a profound effect ($p<0.05$) on tangential swelling of the wood samples. However, sampling height nor the interaction effect of both did not significantly influence ($p>0.05$) the tangential swelling of the wood samples (Table 3.4). Means separation using the LSD indicates that tangential swelling in wood samples treated with 0%, 10% and 30% were significantly reduced compared to both the control wood samples and those treated with 20% preservative concentration (Table 3.3).

3.4 Radial Swelling

Based on sampling height, radial swelling values recorded ranged from 4.17% - 4.39% (Table 3.2). The wood samples at the middle had the least radial swelling while those at the base had the highest radial swelling. This pattern of swelling along the bole is similar to the observed pattern of tangential swelling along the bole.

On the other hand, radial swelling based on preservative concentration ranged between 3.97% - 4.69% (Table 3.3). The least radial swelling occurred in wood samples treated with kerosene alone while radial swelling was highest in the control samples. Preservative treatments resulted in a reduction of radial swelling by 0.07% - 15% in comparison with the control samples. According to Usta and Guray [21], the anisotropic property of wood causes it to exhibit differential dimensional changes along the three different structural planes. Generally, it is believed that tangential swelling is approximately twice that of radial swelling [10]; the observation in this study which also conforms with this general view. The reduction in radial swelling in comparison with tangential swelling is believed to be as a result of the restraining factor of the rays [6, 23]. Radial swelling was insignificantly influenced ($p>0.05$) based on sampling height, preservative concentration and the interaction effect of both (Table 3.4).

3.5 Volumetric swelling

Volumetric swelling was inconsistent along the tree bole, ranging between 11.73% - 12.63% (Table 3.2). It was observed that wood samples at the base had the highest volumetric swelling while the wood samples at the middle had the least. A similar observation was also reported for the wood of *Populus euramericana* by Kord *et al*. [18] who discovered that the basal wood (5% of total tree height) had the highest shrinkage. Reasons for this may be attributed to higher density of the wood at the base compared to other axial positions of the tree. As noted by Walker [24], woods with higher density have higher proportions of cell wall and lesser lumen volume and thus, tend to swell and shrink more.

Based on preservative concentration, volumetric swelling ranged between 11.49% - 13.81% (Table 3.3). The wood samples treated with the highest preservative concentration (30%) had the least volumetric swelling while the control samples swelled most volumetrically. Sampling height, preservative concentration nor their interaction were observed to insignificantly ($p>0.05$) influence volumetric swelling (Table 3.4). While there was no significant influence of preservative concentration on the volumetric swelling of the wood samples, it is worthy of note that the wood samples treated with the 30% preservative concentration reduced volumetric swelling when compared to the control samples by more than 16%. This reduction in hygroscopicity of the wood can be attributed to higher penetration of the oil into the cell wall matrix of the wood as reported in a similar study conducted by Adenaiya et al. [16].

Table 3.2: Mean Anisotropic Swelling of treated *P. caribaea* at varying sampling heights

Sampling Height	L.S (%)	T.S (%)	R.S (%)	V.S (%)
Top	0.28 ± 0.01^{a}	7.76 ± 0.32^{a}	4.31 ± 0.28^{a}	12.35 ± 0.53^{a}
Middle	0.29 ± 0.01^{a}	7.28 ± 0.37^{a}	4.17 ± 0.29^{a}	11.73 ± 0.56^{a}
Base	0.26 ± 0.01^{a}	7.98 ± 0.29^{a}	4.39 ± 0.28^{a}	12.63 ± 0.50^{a}

*Means with the same within the same column are not significantly different ($p<0.05$); L.S - Longitudinal swelling; T.S - Tangential swelling; R.S - Radial swelling; V.S - Volumetric swelling

Table 3.3: Mean Anisotropic Swelling of *P.caribaea* treated with varying concentrations of castor oil

Concentration	L.S (%)	T.S (%)	R.S (%)	V.S (%)
Control	0.29 ± 0.01^{a}	8.82 ± 0.42^{ac}	4.69 ± 0.36^{a}	13.81 ± 0.61^{a}
0% (Kerosene)	0.28 ± 0.02^{a}	7.60 ± 0.38^{b}	3.97 ± 0.42^{a}	11.85 ± 0.67^{a}
10%	0.27 ± 0.02^{a}	7.12 ± 0.33^{b}	4.29 ± 0.41^{a}	11.68 ± 0.72^{a}
20%	0.28 ± 0.01^{a}	7.72 ± 0.53^{bc}	4.37 ± 0.35^{a}	12.37 ± 0.77^{a}
30%	0.26 ± 0.02^{a}	7.09 ± 0.35^{b}	4.13 ± 0.29^{a}	11.49 ± 0.52^{a}

*Means with the same within the same column are not significantly different ($p<0.05$); L.S - Longitudinal swelling; T.S - Tangential swelling; R.S - Radial swelling; V.S - Volumetric swelling

Table 3.4: ANOVA for the treated *P. caribaea* wood properties

Wood properties	Df	Mean square	P- Value
Preservative Absorption			
Sampling Height	2	12053.542	0.14ns
Concentration	3	8657.854	0.235ns
Sampling Height x Concentration	6	9256.435	0.176ns
Residual	48	5893.904	
Total	59		
Water Absorption			
Sampling Height	2	174.82	0.131ns
Concentration	4	3091.034	0.000*
Sampling Height x Concentration	8	28.754	0.944ns
Residual	60	83.282	
Total	74		
Longitudinal Swelling			
Sampling Height	2	0.004	0.325ns
Concentration	4	0.002	0.702ns
Sampling Height x Concentration	8	0.002	0.761ns
Residual	60	0.004	
Total	74		

Table 3.4: *Cont….*

Wood properties	**Df**	**Mean square**	**P- Value**
Tangential Swelling			
Sampling Height	2	3.215	0.309ns
Concentration	4	7.372	0.036*
Sampling Height x Concentration	8	0.998	0.932ns
Residual	60	2.685	
Total	74		
Radial Swelling			
Sampling Height	2	0.326	0.864ns
Concentration	4	1.118	0.734ns
Sampling Height x Concentration	8	0.968	0.895ns
Residual	60	2.225	
Total	74		
Volumetric Swelling			
Sampling Height	2	5.306	0.477ns
Concentration	4	13.157	0.13ns
Sampling Height x Concentration	8	3.249	0.880ns
Residual	60	7.087	
Total	74		

Note: * =significant at p<0.05; ns = not significant at p<0.05

3.6 Anti-Swell Efficiency

The ASE result shows that wood samples treated with 30% preservative concentration had the highest ASE value (20.19%), followed by the 10% preservative concentration (18.24%), Kerosene alone (16.54%), while the least was observed for wood samples treated with 20% preservative concentration (11.64%) (Fig. 1.1). The higher ASE value of the 30% preservative concentration implies that higher quantity of the oil was able to penetrate into the cell wall interstices, thereby improving the dimensional stability of the wood, occasioned by the decreased volumetric swelling of the wood in comparison to the control wood samples as explained earlier. The use of oils in improving the dimensional stability of lignocellulosic materials has been documented by several workers [e.g 5, 10]. However, the ASE values obtained in this study are considerably low compared to that reported by Erakhrumen and Ogunsanwo [5] for oil treated bamboo, and Octavia *et al*. [10] for oil treated spruce and beech wood. The higher ASE values reported in these studies are possibly due to the use of hot oil in the treatment of the wood which resulted in chemical alterations in the wood, particularly the degradation of some of the wood sorption sites such as cellulose and hemicellulose [25, 26].

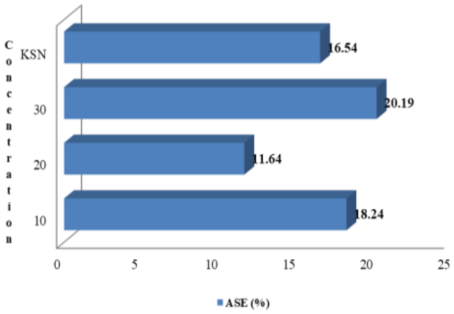

Figure 3.1: Anti-swell efficiency values for the treated woods; N.B: KSN means Kerosene

4. Conclusions

This study has demonstrated the potentials of utilizing castor seed oil in improving the dimensional stability of highly porous *P. caribaea* wood. With its little socio-economic importance in this part of the world, it can be commercially exploited in the wood industry as an oil-borne preservative. Though, treatment of *P. caribaea* wood with castor seed oil insignificantly reduced dimensional swelling along the principal wood axes (with the exception of the tangential axis), the significant reduction in water absorption, high ASE value and percentage improvement in dimensional stability of those treated with the 30% concentration in comparison with the untreated samples clearly shows the influence of utilizing this oil in reducing the hygroscopicity and dimensional instability of the wood. However, the little effectiveness of the oil in improving the wood dimensional stability may be associated with its method of application. While thermal treatment using oils may have improved significantly the dimensional stability of wood as documented by several studies, this may result into significant strength losses in the wood. Thus, further research is suggested on the effect of thermal treatment of *P. caribaea* wood on its dimensional stability and hygroscopicity using castor seed oil, whilst also examining the mechanical properties of the treated wood.

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