Applied Tropical Agriculture
Volume 21, No.1, 190-195, 2016.

Effects of Thermal Treatment on Selected Physical and Mechanical Properties of Rubber (*Hevea brasiliensis*) Wood

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ABSTRACT

One of the major problems of wood in service is dimensional stability caused by absorption of moisture from humid environment. Recent effort has been on using non-chemical treatment to enhance wood serviceable life. Therefore, this study examined the influence of thermal treatment on the physical and mechanical properties of Hevea braziliensis wood. The wood samples were selected from the top, middle and base of rubber trees, oven-dried to a moisture content of 12% before thermal modification in a muffle furnace at varying temperature of 160 ºC, 180 ºC and 200ºC for 30, 60 and 90 minutes duration. Mean values for water absorption ranged from 54.55% (160°C for 30 min) to 49.34% (200°C for 90 min). The Modulus of Rupture values varied from 87.22N/mm^2 at 160°C to 66.87N/mm^2 at 200°C. Increase in treatment time from 30 minutes to 60 minutes caused a decrease in the MOR from 86.98N/mm^2 at 30 minutes to 73.23N/mm^2 at 60 minutes. There were significant difference in the results obtained with thermally treated wood at 200 ºC and 90 minutes with improvement in resistance of rubber wood to moisture and decrease in mechanical properties especially the modulus of rupture. The result showed that thermal treatment could improve the resistance of the wood to moisture absorption and enhanced mechanical properties of the treated wood.

Keywords: Hygroscopicity, Moisture content, Anti swelling efficiency, bending strength, Density.

INTRODUCTION

From prehistoric times, man depended on wood for his various construction purposes because of its structural, economic, environmental and aesthetic benefits. Even though other structural materials are currently available in the market, wood retains its position as the most acceptable material because of its versatility. Its usage is playing an important role in the world economy and it is the fifth most important product of the world trade as reported by (Christophe and Gregoire, 2001). The inherent properties and availability of wood have made it a natural material for building structures, furniture, tools, vehicles and decorative objects. Worldwide it is used more than metal or plastic. Wood is a natural product that is sustainable when used responsibly is a sustainable resource when used responsibly. In Nigeria, more than 80% of the timber products are used for construction purposes such as building, furniture, railway sleepers, and transmission poles as reported by Akanbi and Ashiru, (2002).

Woody and herbaceous biomasses are referred to as lignocellulose biomasses, as their major organic mass fraction consists of cellulose, hemicellulose and lignin. These components are responsible for the structural strength of such biomasses. Biomass also contains some non-structural organic compounds referred to as extractives. These materials are soluble in either water or ethanol, and are thus known as water soluble extractives and ethanol soluble extractives (Sluiter *et al*, 2005). Due to its poor dimensional stability under varying atmospheric conditions, researches on stabilization treatment are carried out to minimize the moisture absorption by reducing the number of hydroxyl groups of the wood with heat treatment. This type of alteration is known as thermal modification.

Thermal modification has long been known to increase the dimensional stability of wood by reducing its hygroscopicity and increasing its resistance to biodegradation. When wood is heated, its chemical and physical properties undergo permanent changes and its structure is also transformed (Boonstra *et al.*, 2007). The observed changes in the properties are mainly due to degradation of hemicelluloses. The changes continue as temperature is increased during heating process. As a result, swelling due to its moisture absorption decrease, biological durability improves, colour darkens, and some extractives flow from inside of the wood to the surface, pH decrease, thermal insulation properties improve, and the density of the wood decreases (Gunduz *et al*., 2009). The general objective of this study is to investigate the effects of thermal modification on physical and mechanical properties of Rubber (*Hevea brasiliensis*) wood.

MATERIALS AND METHODS

Preparation of Wood Samples

The wood samples for this study were obtained from Akinjoye Farm, Legbogbo Village at Ode-Irele, Ondo State, Nigeria located on an area of 963 square kilometers (372 sq mi) and coordinates of 6º29′0″N 4º52′0″E. Samples from three *H. Brasiliensis* trees were selected from three sampling heights of 25%, 50% and 75% (the top, middle and the basal parts). The selected logs were flitched for easy transportation and later re-processed at the Wood Workshop of the Department of Forestry and Wood Technology, Federal University of Technology Akure. They were then machined into the required dimensions of 20 mm × 20 mm x 60 mm for the evaluation of dimensional stability (ASTM 2009). For static bending tests (modulus of rupture and modulus of elasticity), dimensioned samples of 20 mm × 20 mm x 300 mm were prepared (ASTM 2009). Provision was made for untreated samples used as control. The specimens were oven dried at 103±2ºC and leave in the oven for 24 hours after which it was removed from the oven and allowed to cool immediately in a desiccator over a silica gel. The samples were then reweighed and put in oven again for another 30 minutes. Cool in a desiccators and then reweigh until constant weight was achieved; then cooled in a desiccator over silica gel. Thereafter, the weights and dimensions of the specimens were taken before the thermal treatment.

Thermal Treatment Process

The heat treatment was conducted in a closed Muffle furnace; a temperature controlled heating chamber. The conditioned specimens (at constant M.C. of 12% of the wood samples ramped in a cellophane nylon to avoid moisture absorption before thermal treatment) were thermally treated at temperatures of 160ºC, 180ºC and 200ºC for 30, 60 and 90 minutes durations respectively. The temperature of the furnace was set to the temperature at which the actual heat treatment occurred before introducing the wood samples. At the end of each treatment period, the samples were removed from the furnace, and their weights and dimensions taken after cooling in a desiccator to determine the weight loss. The percentage weight loss (PWL) was estimated using.

$\text{PWL}(\%) = \left(\frac{W_o - W_t}{W_o}\right) \times 100$…..(equation 1). Where W_o (g) is the oven-dry weight of specimens before the treatment and W_t (g) is the oven-dry weight of specimens after the treatment

Mechanical Properties Test

For evaluation of static bending strength, three -points' flexural test was performed on both control and modified samples in accordance with ASTM 143 standard (2009). An Instron 5500R-1137 Universal Test Machine was used to generate data from which MOR and MOE were calculated using equations 5 and 6 for MOR and MOE respectively.

$$MOR = \frac{3PL}{2BH^2} \text{ (N/mm}^2\text{)} \quad \text{----------} \quad (5)$$

Where: MOR = Modulus of Rupture; L = Span between centre of support (mm); B = Width of test specimen (mm) H = Thickness of test specimen (mm); P = Ultimate failure load (N)

Physical Properties Test

Dimensional Stability Tests

Thermally treated and untreated wood samples were submerged in distilled water in a stainless steel container. Water absorption was assessed after 24 and 48 hours of complete immersion in water. Mass and volume measurements (Length x Breadth x Width) were recorded. From the measurement of the weights of specimens, the water absorption (WA) was calculated using the equation 2 while volumetric swelling was estimated using equation 3.

$\text{. WA } (\%) = \left(\frac{W_{Wet} - W_{dry}}{W_{dry}}\right) \times 100$….(equation 2)

where WA = Water Absorption; W_{wet} = weight of the samples after soaking in water; V_{dry} = Weight of the oven dried samples.

$S\ (\%) = \left(\frac{V_{Wet} - V_{dry}}{V_{dry}}\right) \times 100$…..equation (3)

where S%= Volumetric swelling; V_{wet} = Volume of the samples after soaking in water; V_{dry} = Volume of the same sample after oven drying. Also the anti-swelling efficiency (anti-shrink efficiency), ASE, is determined using the equation (4):

$\text{ASE } (\%) = \left(\frac{S_{unmod} - S_{mod}}{S_{unmod}}\right) \times 100$….(equation 4)

where $S_{unmod.}$ = Volumetric swelling coefficient of modified sample; $S_{mod.}$ = Volumetric swelling coefficient of control specimen

$$MOE = \frac{PL^3}{4BHD^3} \text{ (N/mm}^2\text{)} \quad \text{----------} \quad (6)$$

Where: L = Span between centre of support (mm); B = Width of test specimen (mm); H = Increase in deflection; P = Ultimate failure load (N); D = Thickness of the specimen

RESULTS

Physical properties of thermally treated *Hevea brasiliensis* (Rubber wood)

The mean values for the water absorption (WA) and anti-shrinkage efficiencies (ASE) of thermally treated *Heavea brasiliensis* wood are presented in Table 1.

Table 1: Mean (± SE) values of Physical properties of thermally treated *Hevea brasiliensis* wood

Source of Variation		WA (%)	ASE (%)
Temperature (℃)	160	53.64^{c} ±1.17	20.31^{c}±0.43
	180	52.42^{b} ±1.18	30.14^{b}±0.34
	200	49.34^{a}±0.86	49.73^{a}±0.69
	Control	54.92^{d}±0.59	-
Treatment time (min.)	30	53.64±1.27c	31.74±1.88b
	60	49.99±0.95a	31.87±2.00b
	90	49.34.±0.96b	36.57±2.36a
	Control	54.92±2.05c	-
Position	Top	45.22±0.16a	33.62±1.98b
	Middle	53.27±1.01b	33.06±2.13a
	Base	57.85±0.58c	33.49±2.26b

Note: Means with the same alphabet are not significantly different ($p \geq 0.05$)

Table 2: Result of analyses of variance (ANOVA) for Water Absorption for thermally treated Rubber wood

Source	Df	Sig.
Temperature	2	.000*
Time	2	.000*
Position	2	.000*
temperature * Time	4	.000*
temperature * position	4	.000*
Time * position	4	.000*
temperature * Time * position	8	.000*
Error	90	
Total	**119**	

*Significant ($p < 0.05$)

The alteration in wood composition caused by thermal modification resulted in a lower hygroscopic property which is the most indicative characteristic of wood with a major influence on both dimensional stability and durability. In this study, the hygroscopicity is expressed as antiswelling efficiency (ASE). ASE is the percentage reduction in the swelling capacity of treated specimens compared with the control samples.

Mechanical Properties of thermally treated *Hevea brasiliensis* (Rubber wood)

The results for MOE and MOR presented in Table 3 showed variation across the temperature and time duration regimes for the top and middle positions of *Hevea brasiliensis.*

DISCUSSION

Physical Properties

The results of the thermally treated samples for water absorption ranged from 49.34% (200°C at 60 min) to 53.64% (160°C at 30 min) compared to control (WA =. 54.92%). This showed that there was reduction in hygroscopicity of the treated wood soaked in water for 24hrs and 48hrs. The results indicated that thermal treatments significantly reduce moisture absorption capacity of the wood. The water absorption of the heat-treated wood samples decreased with increase in temperature and time, compared to the untreated samples. The effect of 160°C at 30 min and 160°C at 60 minutes treatments on WA was not significantly different. However, there were significant differences ($p<0.05$) at the temperatures of 200°C and treatment duration of 60 and 90minutes. With this, increase in treatment temperature has high reductive impact on water absorption of thermally modified wood compared to treatment duration. This report is in consonance with the findings of (Idowu *et al.*, 2015) on effect of thermal and chemical modification on dimensional stability of *Triplochiton sceleroxylon* (Obeche) wood.

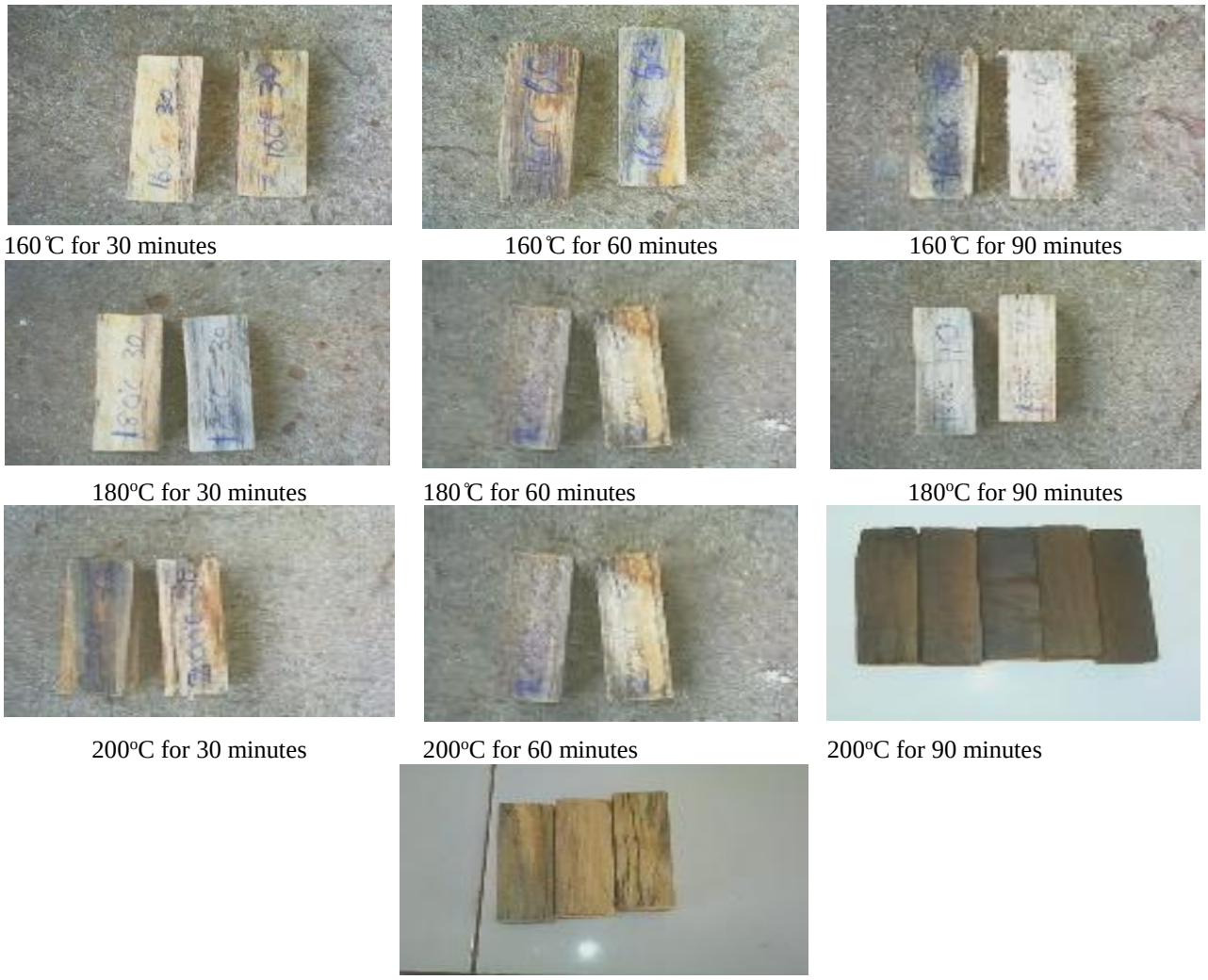

Plate 1: Changes in colour at different temperature/time regime

They reported that heat treatments significantly reduce moisture adsorption in wood and the water absorption of heat-treated wood decreased with increase in treatment temperature and duration.

The reduction in the water absorption of thermally treated *Hevea brasiliensis* wood could be as a result of the reduction in available bonding sites of hydroxyl groups in the hemicelluloses and cellulose (Kocaefe *et al.,* 2008). During heat treatment, the content of hemicellulose, which is relatively easy to hydrolyze at elevated temperature, could have significantly decreased with increase in treatment duration and temperature (Kocaefe *et al.,* 2008). The analysis of variance of water absorption of treated samples and control after immersion in water for 24 hrs indicated that there was significant difference between the treated and the untreated samples. The crystallinity content of wood can be increased due to crystallization in quansi-crystalline region in wood cellulose and even in hemicelluloses (Kocaefe *et al*., 2008). When wood is subjected to heat treatment, lignin softens and blocks the cell pores probably decreasing the radius and number of effective openings on pit membranes (Kocaefe *et al.,* 2008). This could be one of the contributing factors to the reduction in water absorption of heat treated rubber wood.

Colour Changes

It was observed that the colour changes occurred at different temperature and duration of thermally treated of *Hevea brasiliensis* wood. The colour of thermally treated *Heavea brasiliensis wood* varied from pale creamy white to slight brown at 160ºC at 30, 60 and 90 minutes to brown at the 180°C for 30, 60 and 90 minutes. At 200ºC for 90 minutes of treatment, *Hevea brasiliensis* become darker compared to the 200ºC for 30 and 60 minutes (Plate 1). The colour of untreated samples was creamy white to yellowish brown. This colour change in wood can be attributed to some chemical reactions that took place during the heating

Table 3: Mean (± SE) values of Mechanical properties of thermally modified *Hevea brasiliensis* wood

Treatment		MOE	MOR
Temp (°C)	160	18927.90±639.70b	87.22±2.50b
	180	17603.45±520.52b	81.41±1.19b
	200	15368.24±103.36a	66.87±2.23a
	Control	18892.29±1720.83b	100.78±1.15c
Time (min).	30	17963.39±435.39b	86.98±1.51b
	60	17340.50±410.73b	73.23±2.51a
	90	16595.69±117.72a	75.25±2.68a
	Control	18892.29±1720.83b	100.78±1.15c
Position	Top	17390.42±560.06a	80.64±2.35a
	Middle	17429.61±579.32a	80.42±2.46a
	Base	17557.29±570.81a	81.12±2.63a

Table 4: Result of ANOVA for Modulus of Rupture of Thermally treated Rubber wood

Source	**Df**	**Sig.**
Temperature	2	.000*
Time	2	.000*
Position	2	.956ns
temperature * Time	4	.001*
temperature * position	4	.987ns
Time * position	4	.977ns
temperature * Time * position	8	1.000ns
Error	90	
Total	**119**	

*Significant ($p < 0.05$); ns – not significant ($p > 0.05$)

process. During the thermal modification of *Hevea brasiliensis* aldehydes and phenols may have been formed from degraded carbohydrates, and this could be responsible for the formation of coloured compounds after chemical reactions as this observation is similar to the study reported by McDonald *et al*., (2000).

Mechanical Properties

For a given treatment time, the degree of colour change was greater for specimens treated at 200°C than for specimens treated at 160°C. Similarly, specimens treated at a given temperature of 200°C for 90 minutes were darker than those treated at the same temperature for 30 and 60 minutes. However, the treatment temperature has a more profound influence as shown in this study than the treatment time of Mitsui *et al*., (2004).

According to Sundqvist, (2004), the changes in colour of thermally modified wood are attributed to oxidative changes, which predominate over hydrolysis reactions. The effect of extractives in the colour of heat-treated wood showed that unextracted and acetone extracted samples had different/varying colour (Sundqvist, 2004). Sundqvist, 2004 in his work concluded that both extractives and structural components (hemicelluloses and/or lignin) took part in colour change of heat-treated wood. Also, colour of the wood becomes darker due to the thermal degradation of lignin. The MOR of treated rubber wood decreased with increase in temperature from 87.22 at 160 °C to 66.87 at 200°C. Increase in the treatment time from 30 minutes to 60 minutes caused a decrease in the MOR from 86.98 at 30 minutes to 73.23 at 60 minutes. This later increased a bit to 75.25 at 90 minutes. Little variation existed in the MOR due to the position. The ANOVA results of MOR of thermally treated wood samples revealed that the temperature, time and the interaction between temperature and time are significantly different while position, interaction between position and time, position and temperature, and interaction between position, temperature and time were not significant. Factors like temperature, duration, rate of heating, species, weight of the wood samples may be responsible for the different MOR of heat treated and untreated wood as observed by Vernois, (2001) and Kocaefe *et al.*, (2008).

A decrease in MOE of the modified wood samples occurred with increase in temperature and treatment time from 18927.90 N/mm^2 at 160°C to 15368.24 N/mm^2 at 200°C and from 17963.39 N/mm^2 at 30 minutes to 16595.69 N/mm^{2}at 90 minutes. The position (from top to bottom) caused an increase in the MOE of the rubber wood samples. It shows statistically that the temperature, position and interaction between temperature and time was significant to the MOE of treated rubber wood while time, interaction between temperature and position, time and position, and interaction between temperature, time and position are not significant. Statistically, the change in MOE of the treated samples was significantly different to the untreated wood samples (Table 4). The bending strength decreased drastically with the high treatment temperature. Similar observation was made by Rapp and Sailer, (2001) with the oil heat treatment and dry-air heat treatment of pine (*Pinus sylvestris* L.) treated at 180, 200, and 220°C. In the studies on pine wood treated at temperatures of 100, 120, 140, 160, 180, 200, 220, and 240°C, it was reported that heat treatment did not significantly change the MOE.

CONCLUSION

The physical and mechanical properties of *Hevea brasiliensis* wood have been greatly improved through thermal modification. The extent of modification varied with temperature and duration of treatment. Based on the results obtained from this research, it was observed that the heat treated wood had greater dimensional stability than the untreated wood. Therefore, the treated wood is recommended for wall cladding; very light structural works and utensil handles. The colour of the wood changed from creamy white to brown with increased treatment temperature and duration which gave an added value to the physical appearance of the wood which could be finished using clear lacquer without concealing the colour.

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