PRINT ISSN 1119-8362
Electronic ISSN 2659-1502

Full-text Available Online at
https://www.ajol.info/index.php/jasem
http://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 26 (7) 1219-1224 July 2022

Effect of Thermal Treatment on Chemical, Biological and Mechanical Properties of African Whitewood (*Triplochiton scleroxylon* K. SCHUM)

***[1]ADEBAWO, FG; [1]ADEGOKE, OA; [1]ADELUSI, EA; [2]ADEKUNLE, EA; [1]ODEYALE, OC**

**[1]Federal College of Forestry Ibadan, P.M.B 5087, Ibadan, Nigeria.*
[2]Forestry Research Institute of Nigeria, P.M.B 5054, Dugbe, Ibadan, Nigeria
**Corresponding Author Email: adebawofunke@yahoo.com*
Other Authors Email: aolaoluwa.adegoke@gmail.com; adelusi_ade@yahoo.com; adekunleea@gmail.com; jumoceline81@gmail.com

ABSTRACT: The thermal modification of wood is a potential alternative method for improving wood properties. This paper evaluates the effect of thermal treatment on the chemical, biological and mechanical properties of African Whitewood (*Triplochiton scleroxylon* K. Schum) by subjecting the wood to three temperature (200, 170, 140 ℃) at three different time (3, 6, 12 h). Fourier Transformed infrared (FT-IR) spectrometer was used to ascertain the effect of heat treatment on the chemical constituent of the wood while mechanical properties were determined by Modulus of Elasticity (MOE) and Modulus of Rupture (MOR). Durability of heat-treated wood against subterranean termites using field test was also investigated. FTIR results provided information on the chemical constituents after heat treatment revealing the cellulose and hemicelluloses of *Triplochiton scleroxylon* wood samples. The decreasing intensity of hydroxyl groups stretching at 3341 cm-1 indicated that heat-treated samples have lost some of their hydroxyl groups. The results showed that the MOR of heated-treated wood at 200 ℃ was significantly higher than the untreated samples. There was also a 26% increase in the MOE of the 170 ℃ heat-treated wood relative to untreated samples. Wood samples thermally treated at 170 ℃ and 200 ℃ as well as untreated wood samples were strongly degraded in term of weight loss (WL) by termite though the degree of degradation varied based on temperature and time in which the wood was modified. However, heat-treated wood at 140 ℃ gave the lowest WL of 20.41% compared to other treated and untreated wood samples. Therefore, strength properties and termites' resistance of African whitewood also known as Obeche wood in Nigeria could be improved when thermally modified at 170 ℃ and 140 ℃ respectively.

DOI: https://dx.doi.org/10.4314/jasem.v26i7.5

Impact factor: http://sjifactor.com/passport.php?id=21082

Google Analytics: https://www.ajol.info/stats/bdf07303d34706088ffffbc8a92c9c1491b12470

Dates: Received: 01 June 2022; Revised: 10 July 2022; Accepted: 13 July 2022

Keyword: Modulus of elasticity; Modulus of rupture; thermal modification; termite resistance; weight loss

Forest wealth is depleting at a rapid rate because of the rapid industrialization and increasing population, thus, it has become imperative to make use of wood species for various timber applications. However, certain wood species are less durable and often characterized by certain problems such as low dimensional stability, low mechanical properties and poor decay resistance against bio-deteriorating agents. These are mostly accepted as undesirable features for many timber applications of wood. Selection of decay resistant and dimensionally stable wood species for a specific use, therefore, plays an important role in achieving its most economic utilization. In order to overcome one or more limitations, wood material is generally modified by thermal or chemical techniques so as to improve certain quality parameters specific to various end-use requirements (Rep and Pohleven, 2001; Hill, 2006; Gerardin, 2016). Thermal modification known as heat treatment causes the number of hydroxyl groups of cellulose and hemicelluloses to decrease thereby resulting in the decrease of the adsorption of water (Mitsui *et al.* 2008). Enhancement of the dimensional stability of wood occurs because volume swelling caused by water absorption is under control in consequence for the reduction in the number of water accessible hydroxyl sites and unknown mechanisms. Heat treatment of wood has been suggested to cause irreversible creation of new hydrogen bonds in the amorphous regions of cellulose and hemicelluloses (Kato and Cameron, 1999); a phenomenon known as

**Corresponding Author Email: adebawofunke@yahoo.com*

hornification in which a decrease of water retention value of fibres occurs due to structural changes in the cell wall during drying (Laivins and Scallan, 1993). Meanwhile, wood thermal modification has been the subject of increasing interest over the last decades and is currently considered one of the most promising non biocide alternatives to improving the performance of low durability wood species (Militz, 2002; Pereira, 2009). However, even if wood decay resistance and dimensional stability are improved, termite resistance is not sufficient to permit its use in termite-infested areas (Mburu et al. 2007, Shi et al. 2007, Surini et al. 2012, Sivrikaya et al. 2015). On the contrary, there are reports that thermally modified wood is generally more susceptible to termite attacks than untreated wood (Sivrikaya et al. 2015, Salman et al. 2016). Termite resistance improvements to thermally modified wood is crucial for future development of thermo-modified materials. This study therefore evaluates the effect of thermal treatment on the chemical, biological and mechanical properties of African Whitewood Timber (*Triplochiton scleroxylon* K. Schum) by subjecting the wood to varying temperatures and time.

MATERIALS AND METHODS

Wood preparation: Wood bolts were obtained from a 22-year-old Obeche tree and sectioned to 20 x 20 x 300 mm (radial x tangential x longitudinal) coupons. The resultant coupons were further converted to specimens with dimensions of 20 x 20 x 60 mm (radial x tangential x longitudinal) of which thirty samples with no defects were selected. The samples were weighed, and their masses recorded, oven dried at 105±2 °C, cooled over silica gel in a desiccator, and then weighed again to determine their moisture content before heat treatment.

Thermal modification: Muffle furnace with a temperature-controlled heating unit was used for the thermal modification of the Obeche wood. The samples were conditioned at 12% moisture content and they were subjected to modification at varying temperatures of 140, 170 and 200 °C for 3, 6 and 12 h. Meanwhile, the furnace was adjusted to the actual temperature at which the treatment would occur before the introduction of the wood samples and this was done for each treatment. At the end of each treatment period, heat treated samples were withdrawn from the furnace and cooled in a desiccator over a silica gel and weighed.

Fourier Transform Infrared (FT- IR) Spectroscopy: Heat-treated and untreated wood samples were ground in a Wiley mill to a homogeneous meal. The powdered wood samples were used for Fourier Transform Infrared (FT-IR) spectroscopy measurement. The IR spectra of the heat-treated, and untreated samples were recorded in the absorption mode in the range of 4000 - 600 cm^{-1} using a Perkin-Elmer FT-IR Frontier spectrophotometer by the accumulation of 64 scans with a resolution of 4 cm^{-1}.

Modulus of elasticity (MOE) and Modulus of Rupture (MOR): MOE and MOR of the wood samples (dimension: 20 mm x 20 mm x 60 mm) were determined according to the BS373:1987 method. The strength properties were determined using a 4kN computer-controlled MTS- SANS CMT 5000 Universal testing machine. Four replicates of each treatment for the heat-treated and untreated wood samples were used and samples were tested at a cross-head speed of 0.635 mm/min.

Termite resistance test: The heat-treated samples and untreated (control) *T. scleroxylon* (Obeche) wood were exposed to graveyard at 0.5m apart for the period of 12 weeks following the methods of Lenz *et al.*, 2003; Emerhi, *et al.*, 2015 to evaluate termite's degradation resistance. At the end of the exposure, the exposed samples were removed and was cleaned properly form sands. The samples were then dried at 30 °C to constant weight. Finally, weights of the samples were recorded to determine the weight loss (WL) caused by the termite attack.

$$WL\ (\%) = \frac{W_i - W_t}{W_i} x100 \qquad 1$$

Where: $\mathbf{W_i}$ - weight of wood block before test (g) $\mathbf{W_t}$- weight of dried block after test (g).

Statistical analysis: Variation in the weight loss of treated and untreated wood were compared and analyzed by 4^3 factorial experiment in complete randomized design in which three temperature (200, 170, 140 ℃) and period of heating (12, 6, 3 h). A comparison of the means was conducted employing Duncan Multiple Range Test (DMRT) to identify which groups were significantly different at $\alpha_{0.05}$ when the ANOVA indicated a significant difference among temperature and period of heating.

RESULTS AND DISCUSSION

FT-IR: FT-IR spectra of untreated and heat treated *Triplochiton scleroxylon* wood is given in Figure 1. The IR-spectra were recorded for treated samples at 140, 170, and 200ºC for 3, 6 and 12 h for each of the treatment temperature and for the control sample. For *T. scleroxylon* wood samples, the intensities of the wavenumber between 3302-3342 cm^{-1} is associated with hydroxyl groups originating from cellulose and hemicellulose (Bodirlau *et al.*, 2012). There was a decrease in the peak at this region for heat treated samples at 140-12h, 170- 6h, 170-12h and 200-12h compare with the untreated samples. A reduction in the peak at wavenumber 1738 cm^{-1} which is related to the unconjugated C=O stretch vibration were observed in all the heat-treated samples compared to the untreated samples. The the magnitude of the band at 1595 cm^{-1} relating to CH2 bending for cellulose increased with heat treatment relative to the untreated samples. However, there was no distinct increase of the band at 1595cm-1 for 140-3h and 140-6h heat treated samples compared to their counterparts. Other heat-treated samples at 140-12h and all other samples treated at 170 and 200 ^{0}C had a distinct increase at this peak. The peak exhibited at 1167 cm^{-1} (C=C stretching) for samples did not give an obvious change as a result of heat treatment. The band at 1176 cm^{-1} (Asym. Bridge C–O–C stretching for cellulose) did not change to an obvious visible extent in samples as a result of heat treatment at 140 °C and 170 °C relative to the control wood sample. However, the band at 1176 cm^{-1} moved up markedly at 200-6h and 200-12h (Fig. 1). Results similar to this were reported by Akgül *et al.* (2006). The bands at 1029 cm and 1504 cm^{-1} (C=O valance vibration of COOH group) had almost the same absorbance value for all samples.

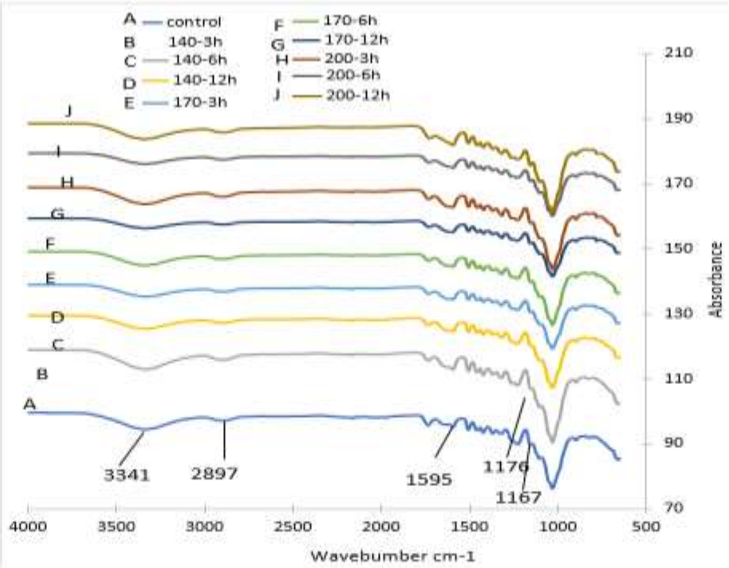

Fig 1: FT-IR Spectra of untreated and heat-treated *Triplochiton scleroxylon. Absorbance scale is not provided in the figure because they are shifted parallel to the wavenumber axis*

The FT-IR results provided information on the effect of heat treatment on the cellulose and hemicelluloses of *Triplochiton scleroxylon* wood samples. The decreasing intensity of hydroxyl groups stretching at 3341cm-1 indicated that some the heat-treated samples have lost their hydroxyl group sites. This is similar to the result of Fabiyi and Ogunleye (2015). The increase in the magnitude of the band at 1595cm^{-1} could be due to increased lignin contents with increasing treatment temperature. The increase in lignin content could be as a result of thermal stability of lignin and increase in degradation of the hemicelluloses (de Moura *et al.* 2012).

Strength Properties of the heat-treated wood of Triplochiton scleroxylon wood Modulus of Rupture (MOR): The modulus of rupture (MOR) of untreated and heat-treated *T. scleroxylon* wood is shown in Figure 2. The results showed that there is an increase in the MOR of the heat-treated wood compared with untreated wood. For wood samples treated at 140 °C and 170 °C, there was an increase in MOR for samples treated for 3h and 12h while the treated samples at 6 h gave a lower MOR than the untreated samples. However, MOR of all the heat-treated samples at 200 °C for all the periods was significantly higher than the untreated samples.

This result is similar to the findings of Solange et al. 2016, who reported an increase in the MOR of *Aspidosperma populifolium* from 97 MPa for untreated wood to 109 MPa for the heat-treated wood at 220 °C. However, a lower MOR was also reported for heat-treated samples *Mimosa scabrella* than the untreated samples i.e. 96 MPa for heat-treated and 105 MPa for the untreated samples (Solange et al. 2016). Moreover, an average strength loss of 5% to 18% was also reported for heat-treated of pine wood (Militz and Tjeerdsma, 2001).

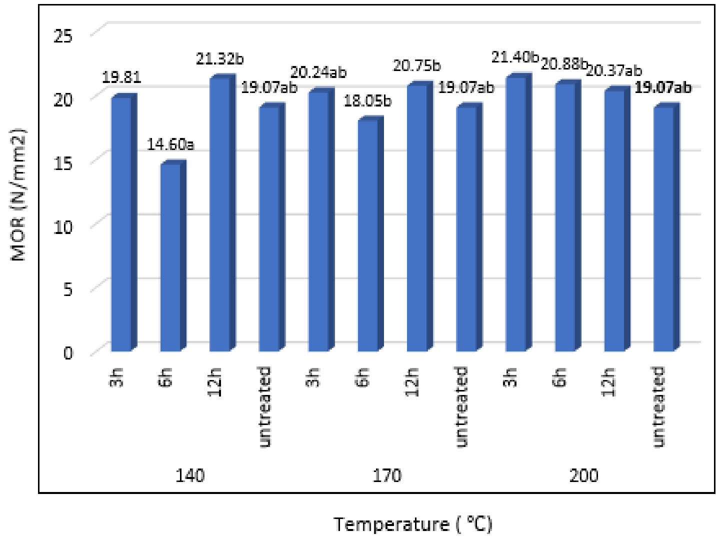

Fig 2: Effect of different temperature and time on MOR of heat treated *Triplochiton scleroxylon* wood

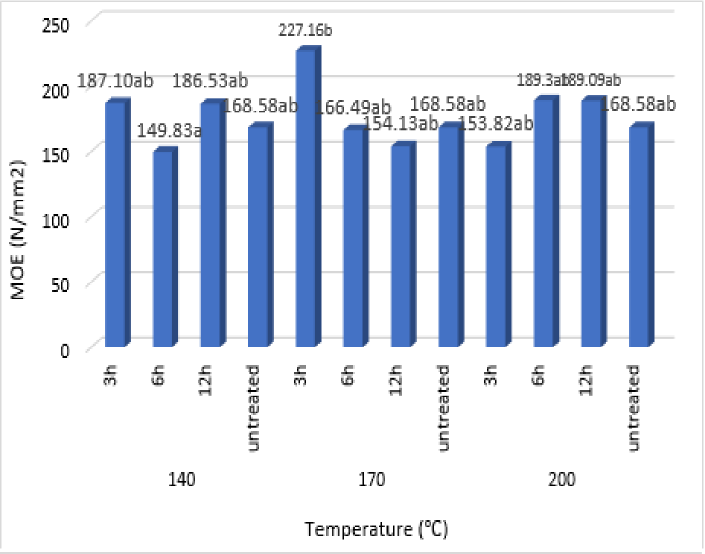

Fig 3: Effect of different temperature and time on MOE of heat treated *Triplochiton scleroxylon* wood

Modulus of Elasticity (MOE): The modulus of Elasticity (MOE) of untreated and heat-treated *T. scleroxylon* wood is shown in Figure 3. The results showed that there were no significant changes among the MOE of the heat-treated wood at different temperature and time except at 140-6h where there was a reduction in the MOE when compared with other heat-treated wood samples. The heat-treated samples at 170 ºC for 3h showed a 26% increase in MOE relative to untreated samples. However, there was a reduction in the MOE of the heat-treated samples when the temperature was increased to 6 h and 12 h. Also, at 200 ºC, there was 11% increase in the MOE of the heat-treated sample for samples treated for 6 h and 12 h when compared with the untreated samples. A similar result of an increase in MOE of heat-treated wood has been reported by Gunduz et al. 2009. This is due to increased lignin cross-linling that makes structure around the cellulose microfibrils and middle lamella more rigid. The increase in MOE could also be explained with increasing crystallinity of the cellulose and moisture content reduction Esteves and Pereira (2009).

Resistance of Triplochiton scleroxylon against termite attack: Thermally modified and unmodified wood has been subject to termite attack in order to test it resistance through weight loss. The termite resistance of heat-treated and untreated obeche wood samples are presented in Table 1. The heated-treated wood and as well as untreated wood at 200 ℃ and 170 ℃ were strongly degraded in term of weight loss (WL) by termite though the degree of degradation varies based on temperature and period in which the blocks were modified. It was observed that the heat-treated woods at high temperature (200 ℃ and 170 ℃) were more susceptible to termite with higher WL of 100% and 99.4% respectively than wood samples at 140 ℃ which had the lowest WL of 20.41%. However, the untreated wood samples are also susceptible to termite attack. This implies that the obeche wood durability against termite attack decreases with the intensity of thermal modification. The results obtained in this study corroborate what Sivrikaya et al., 2015 and Salman et al., 2016 reported that thermally modified wood at higher temperature is more susceptible to termite attacks than untreated wood. Meanwhile, according to Salman et al., 2017, wood durability improvements appear to be due to a synergistic effect between chemical and thermal treatments.

Table 1: Weight loss of Heat treated and untreated *Triplochiton scleroxylon* at different temperatures and time.

Temperature	Period	Weight Loss
200	3	80.50 (7.30) bcd
	6	86.59 (6.65) cd
	12	100 (0) d
170	3	93.06 (4.38) d
	6	89.18 (10.81) cd
	12	99.41(0.59) d
140	3	20.29 (3.41) a
	6	17.01(3.23) a
	12	20.41(2.14) a
Untreated		66.96 (4.05) bc

Standard Error in Parenthesis; number carrying different alphabet are significantly different (P≤0.05)

Table 2: Analysis of variance for resistance to termite attack of heat treated *Triplochiton scleroxylon* wood

Source of variation	df	Sum of Squares	Mean Square	F	Sig.
Temperature	3	21073.98	7024.66	49.62	0.00*
Period (Per)	2	2211.34	1105.67	7.81	0.00*
Temp*Per	6	2048.47	341.41	2.41	0.05*
Error	24	3397.56	141.57		
Total	**35**	**28731.34**			

**significant (P≤0.05)*

Conclusion: The result of this study validates heat treatment as an alternative method to improve mechanical properties and termites' resistance of *Triplochiton scleroxylon* wood. There was an increase in MOE and MOR for wood samples treated at 170 ℃ and 200 ℃ and a decrease for wood treated at 140 ℃. However, the wood treated at 140 ℃ has the lowest weight loss after exposure to termites. Hence, in application where strength is considered, heat treatment at temperature between 170 ℃ and 200 ℃ should be applied while moderate heat treatments at 140 ℃ should be applied to the species when considered for resistance against termite attacks.

REFERENCES

Akgül, M; Gümüşkaya, E; Korkut, S (2006). "Crystalline structure of heat-treated Scots pine (Pinus sylvestris L.) and Uludağ fir (Abies nordmanniana (Mattf.)) wood." *Wood Sci. Technol.* 41(3), 281-289.

Bodirlau R; Teaca CA; Resmeriţă A; Spiridon I (2012). Investigation of Structural and Thermal Properties of Different Wood Species Treated with Toluene-2,4-Diisocyanate. *Cellulose Chem. Technol.* 46 (5-6), 381-387.

British Standard 373 (1987). Methods of testing small clear specimens of timber. British Standards Institution, London, UK.

Emerhi EA; Adedeji GA; Ogunsanwo OY (2015). Termites' resistance of wood treated with Lagenaria breviflora B. Robert fruit pulp extract. *Nat. Sci.*13 (5):105- 109.

Esteves, B; Marques, AV; Domingos, I; Pereira, H. (2008). Heat induced colour changes of pine (Pinus pinaster) and eucalypt (Eucalyptus globulus) wood. *Wood Sci. Techn.* 42: 369-384.

Gerardin, P (2016). New alternatives for wood preservation based on thermal and chemical modification of wood-a review. *Ann. For. Sci.* 73:559-570.

Gunduz, G; Aydemir, D; Karakas, G (2009). The effects of thermal treatment on the mechanical properties of wild pear (Pyruselaeagnifolia Pall.) wood and changes in physical properties. *Mater. Des.* 30: 4391-4395.

Hill, CAS (2006). Wood Modification: Chemical, Thermal and Other Processes; John Wiley and Sons: Hoboken, NJ, USA, 2006; ISBN 9780470021729.

Kato, KL; Cameron, RE (1999). A Review of the relationship between thermally accelerated ageing of paper and hornification. *Cellulose* 6(1):23-40.

Laivins, V; Scallan, AM (1993). Products of papermaking. Transactions of the 10th fundamental research symposium. Pira International, Oxford, p 1235.

Mburu, F; Dumarçay, S; Huber, F; Petrissans, M; Gerardin, P (2007). Evaluation of thermally modified *Grevillea robusta* heartwood as an alternative to shortage of wood resource in

Kenya: Characterisation of physicochemical properties and improvement of bio-resistance. *Bioresour. Technol.* 98: 3478-3486.

Mitsui, K; Inagaki, T; and Tsuchikawa, S (2008). Monitoring of hydroxyl groups in wood during heat treatment using NIR spectroscopy. *Biomacromolecules* 9: 286–288.

Rep, G; and Pohleven, F (2001). Wood modification-a promising method for wood preservation. *Drvna In-dustrija.* 52 (2): 71-76.

Salman, S; Petrissans, A; Thevenon, MF; Dumarçay, S; Gerardin, P (2016). Decay and termite's resistance of pine blocks impregnated with different additives and subjected to heat treatment. *Eur. J. Wood Prod.* 74:37-42.

Salman, S; Thévenon, MF; Pétrissans, A; Dumarçay, S; Candelier, K; Gérardin, P (2017). Improvement of the durability of heat-treated wood against termites. *Maderas-Cienc. Tecnol.* 19(3):317-328.

Shi, JL; Kocaefe, D; Amburgey, T; Zhang, JL (2007). A comparative study on 345 brown-rot fungus decay and subterranean termite resistance of thermally modified and ACQ346 C-treated wood. *Holz. als Roh und Werstoff. 65*(5): 353-358.

Sivrikaya, H; Can, A; De Troya, T; Conde, M (2015). Comparative biological resistance of differently thermal modified wood species against decay fungi, Reticulitermes grassei and Hylotrupes bajulus. *Maderas-Cienc. Tecnol.* 17(3): 559-570.