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PHYSICAL AND MECHANICAL PROPERTIES OF SELECTED NIGERIAN WOOD SPECIES AFTER THERMO-OIL MODIFICATION

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Abstract:
The influence of thermo-oil treatment on the physical and mechanical properties of Terminalia superba, Triplochiton scelrozylon, and Alstonia boonei wood was investigated. Pre-dried sawn timber of the selected wood and the required standard sizes were thermo-treated with native Neem seed oil and palm kernel oil and their maleinized derivatives at different temperatures (140°C, 160°C and 180°C) and duration (30, 45, and 60 min). The results revealed density increment in wood treated with the maleinized oils compared to the t use of unmaleinized oil. The wood sample treated with maleinized oil and native oil has improved volumetric shrinkage and swelling when compared with the control sample without oil treatment. There were slight improvements in the bending strength of the thermo-oil-modified samples, but since the oil is not expected to contribute to strength properties, this improvement may be similar to the initial increase in strength properties in thermally modified wood. The outcome of this investigation has shown that maleinization of neem oil and palm kernel oil has contributed to improvement in dimensional stability of the thermo-oil modified wood, but with a slight increase for bending properties despite an increase in density for samples treated with maleinized oils. This suggests that the maleinized samples may be more applicable for use in moisture-prone environments.

Key words: *Physical properties; Mechanical properties, Thermo-oil, Modification.*

INTRODUCTION

Wood has some disadvantages compared to other competitors such as steel, plastic, and concrete because it is dimensionally unstable under changing moisture and temperature conditions. Also, it is bio-degradable, weatherable, and flammable; the water absorption and volumetric swelling are more pronounced in the presence of moisture (Aina *et al*. 2020). The challenges facing wood industries in Nigeria are not limited to the aforementioned disadvantages alone, but also that of over-exploitation and deforestation (Owoyemi *et al*. 2017; Adekunle *et al*. 2013). Over-exploitation and deforestation have left Nigerian forests with young and small-diameter trees which are mostly composed of a high proportion of juvenile wood as well as lesser-known (Fabiyi 2014; Owoyemi and Akinwamide 2023). Therefore, construction industries and wood end-users are faced with finding solutions to the problem of degradation and instability associated with the use of commonly available less durable wood species (Fabiyi 2014). Improvement in these inherent properties of wood polymers and their structures is achieved through various wood modification techniques like thermal, hydrothermal, chemical, mechanical (densification), and plasma modifications (Hills 2006; Liu *et al.* 2022; Owoyemi and Akinwamide 2023). The exposure of wood to a

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controlled elevated temperature has been known to modify its properties since the mid-twentieth century (Lahtela and Kärki 2016).

The thermal modification of wood reduces its hygroscopicity (Borrega and Kärenlampi 2010, Hill *et al*. 2021), thus improving its dimensional stability (Lahtela and Kärki 2016). This research was carried out to improve the properties of three selected wood species (*Terminalia superba, Triplochiton scleroxylon,* and *Alstonia boonei*) because they are commonly used but are not dimensionally stable and durable; hence there is a restriction in the area of usage, and this call for a need to expand the areas of utilization. Vegetable oils are good heating mediums due to their ability to transfer heat to wood more readily and equally. Moreover, oil can separate oxygen from wood during the treatment process and prevent the occurrence of an oxidative process that leads to strength reduction in the treated samples (Dubey *et al.* 2011). Oil heat treatment of wood is a process used to improve the properties of wood by subjecting it to high temperatures in the presence of different types of oils. This treatment alters the wood's structure and enhances its durability, stability, and resistance to decay and insects.

MATERIALS AND METHOD

Terminalia superba Engl. & Diels*, Triplochiton scleroxylon* K. Schum, and *Alstonia boonei* De Wild sawn timber were obtained from freshly converted boards and further processed. The sawn timber was machined into the required dimensions with a circular saw; twenty-seven specimens were cut into 20×20x60mm for physical properties test while samples or mechanical tests were dimensions 20×20x300mm were prepared.

Determination of Physical Properties

The basic density (N/mm^3) of the samples was determined according to British standard specification, BS 375 (1989) using Equation 1.

$$\text{Density} = \frac{\text{Oven dry weight}}{\text{Oven dry volume}} \ (\text{N/mm}^3) \qquad 1$$

Oil Modification

Maleinization of oil was carried out by pouring oil and maleic anhydride into a three-bottle neck round flask with a capacity of 500mL in a ratio of 2:1 to form a slurry and heated at 80^{0}C with continuous stirring for complete mixing. The temperature was raised to 100°C for 1h, and after increasing the temperature up to 120°C for 1h, the darkening and thickening (i.e., viscosity) of treated oil was observed periodically. The reaction was terminated when sufficient viscous mass was observed indicating almost complete reaction of maleic anhydride with oil.

Thermal oil Treatment

The thermo-oil treatment was conducted in a heating chamber with a regulated temperature of 140, 160, and 180°C for 30, 45, and 60 min. At the end of each treatment period, the samples were removed from the chamber, and their weights and dimensions were measured and thereafter cooled in a desiccator.

Volumetric Shrinkage (%) of the samples was determined according to BS 373 (1989) using Equation 2.

$$VS = \frac{D_i - D_o}{D_o} \ [\%] \qquad 2$$

where: *VS* = volumetric shrinkage (%), D_i = Initial (wet) volume of the wood and D_o = Final (thermally dry) volume of the wood (cm^3)

The volumetric swelling at various time intervals was calculated using:

$$VS = \frac{T_2 - T_1}{T_1} \times 100 \ [\%] \qquad 3$$

where: *VS* = Volumetric Swelling in %, T_1 = Volume of samples after soaking and T_2 = Volume of samples before soaking in cm^3.

Mechanical properties

The following static bending tests were carried out according to ASTM D143-09 standard, using a three-point bending apparatus.

Modulus of Elasticity (MOE): The modulus of elasticity (N/mm^3) was calculated using Equation 4.

$$\text{MOE} = \frac{PL^3}{4x\Delta xbxd^3} \quad 4$$

where: P is the Maximum load (KN); L is the Span of the test specimen (mm); Δ is Increment in deflection (mm) corresponding to the maximum load (P); b is the breadth of the test specimen (mm) while d is the depth or thickness of the test specimen (mm).

Modulus of Rupture (MOR): The modulus (N/mm^3) of rupture was calculated using Equation 5.

$$\text{MOR} = \frac{3PL}{2xbxd^2} \quad 5$$

where: P is the Maximum load (KN); L is the Span of the test specimen (mm); b is the breadth of the test specimen (mm); d is the depth or thickness of the test specimen (mm).

Statistical analysis

All multiple comparisons were analyzed with multivariate analysis of variance. Significant at ($\alpha \leq 0.05$) differences between values of the untreated and treated samples were determined using Duncan's Multiple Range Test. All statistics were performed using SPSS version 26.

RESULT AND DISCUSSION

Density of thermo-oil-treated wood

The results of the density before and after thermo oil treatment in Fig. 1, 2, and 3 show that for *T. superba*, the mean density value ranged from 310-642kg/m^3; *A. boonei* had a range value of 302-469kg/m^3 while for *T. scleroxylon* ranged from 361-642kg/m^3. This is an indication that the wood density increases because of the amount of oil that the wood absorbs. The amount of oil absorbed could be due to the anatomical property of the wood species like the porosity of the wood and also the rate of flow of the oil. The wood with high porosity would absorb more oil and this will increase the density. Owoyemi (2010) and Dubey *et al*. (2011) also stated that the viscosity of a liquid increases as temperature rises. Owoyemi *et al*. (2017) observed an increase in specimen weight due to oil absorption during heat treatment and a weight decrease with increasing temperature and time (Dubey *et al*. 2011). The thermo-oil treatment influenced the wood density only to a small extent as can be seen in Fig. 1, 2, and 3. *T. superba* wood showed the smallest increase in wood density after the treatment when compared to *T. scleroxylon* and *A. boonei.* The analysis of variance carried out at a 95% probability level showed that thermo-oil treatment had a significant effect on the density of the wood species.

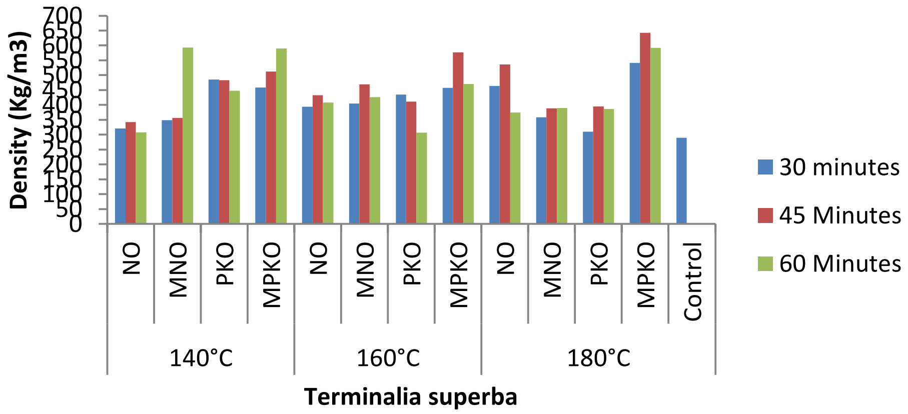

Fig. 1a.
Density of Wood species before and after treatment for T. superba.
KEY: NO = Neem seed oil, MNO = maleinized neem seed oil, PKO = Palm kernel oil, MPKO = Maleinized Palm kernel oil.

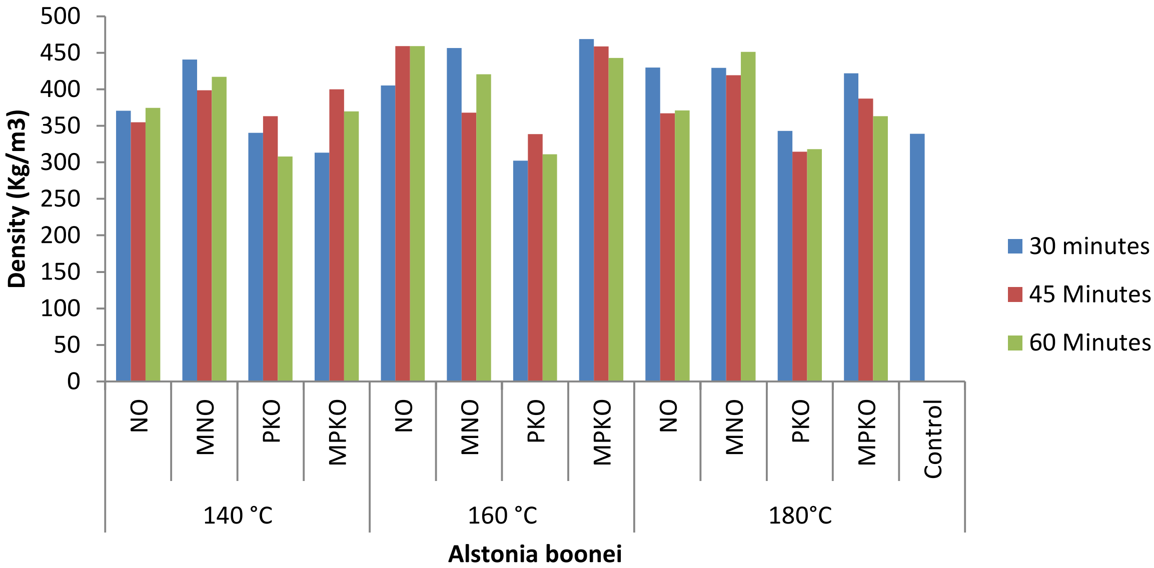

Fig. 1b.
Density of Wood species before and after treatment for A. boonei

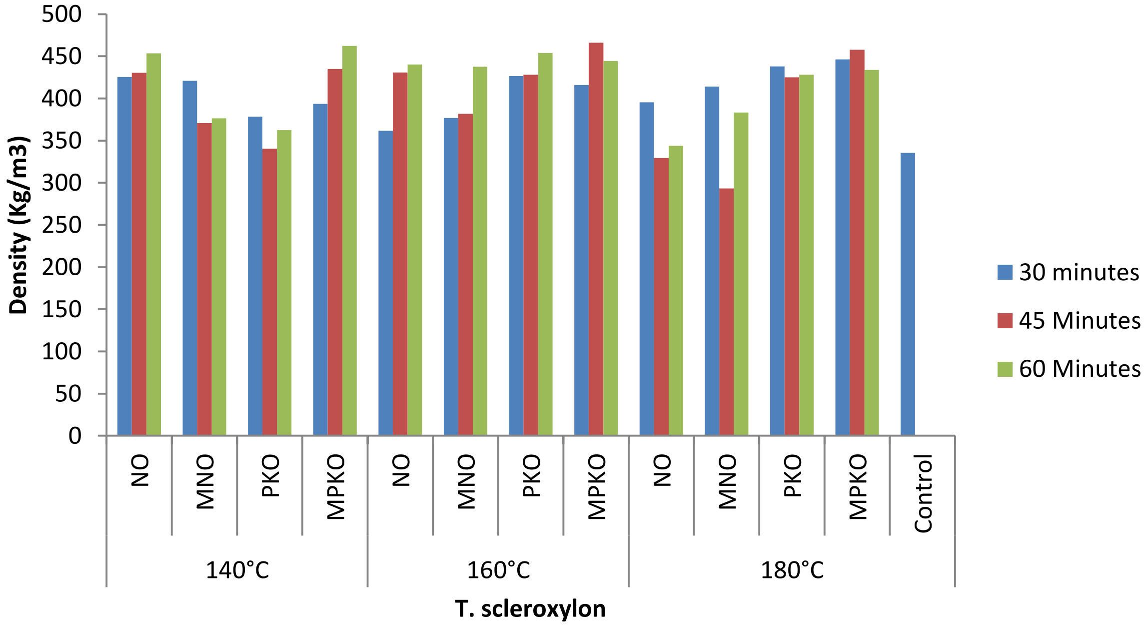

Fig. 1c.
Density of Wood species before and after treatment for T. scleroxylon.

Percentage Volumetric Shrinkage (VSH)

The mean value for volumetric shrinkage of *T. superba* ranged from 1.93 – 7.13%; *A. boonei* ranged from 1.73 – 8.24% and *T. scleroxylon* ranged from 2.54 – 7.85%. (Fig. 4, 5 and 6) the highest shrinkage was found in untreated wood samples while the lowest shrinkage was found in *T. superba* treated with Maleinized neem oil at 180^{0}C for 60min. The analysis of variance carried out at a 95% probability level showed that thermo-oil treatment had a significant effect on the volumetric shrinkage for *T. superba* but no significant effect on *A. boonei* and *T. scleroxylon*.

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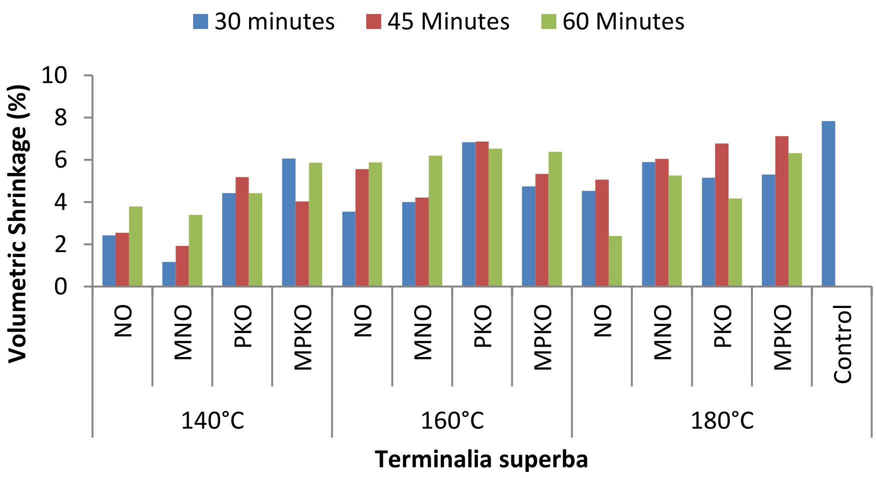

Fig. 2a.
Volumetric Shrinkage of both thermo oil treated and untreated wood species.

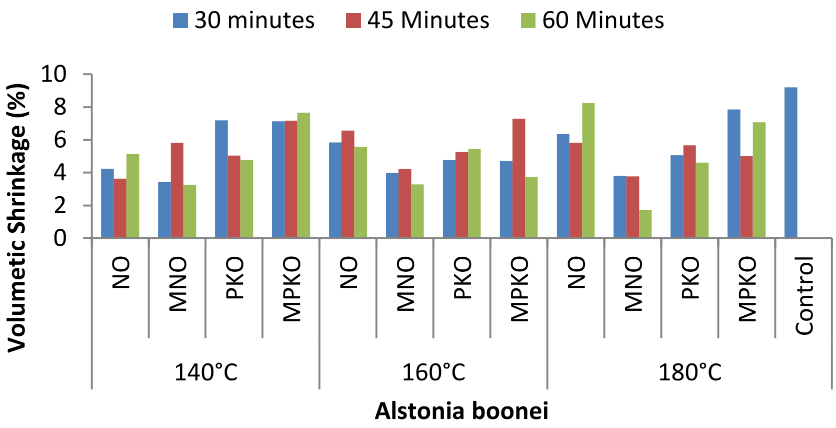

Fig. 2b.
Volumetric Shrinkage of both thermo oil treated and untreated wood species.

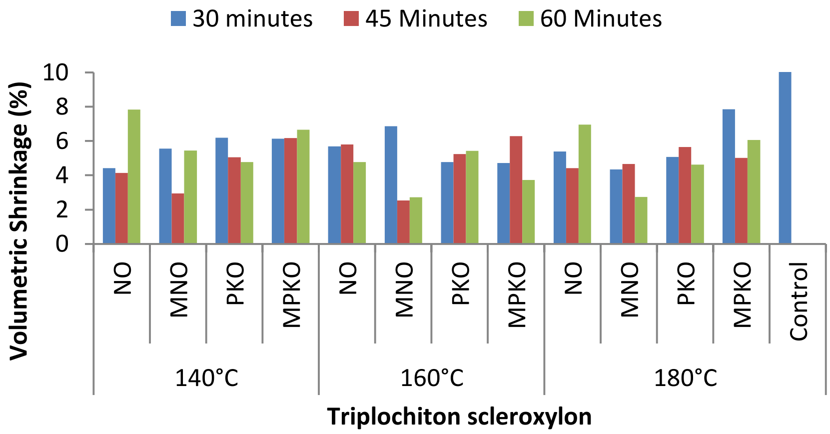

Fig. 2c.
Volumetric Shrinkage of both thermo oil treated and untreated wood species.

Percentage Volumetric Swelling

The mean value for volumetric swelling at 24h for *T. superba* ranged from 5.08 – 9.65%; at 48 h 5.71 – 14.73% and at 72 h ranged from 7.57 – 18.2%; for *A. boonei* at 24h ranged from 5.26 – 9.46%, at 48h ranged from 7.38 – 11.68% and at 72h ranged from 9.32 – 15.28%. For *T. scleroxylon* for 24h ranged from 5.57 – 13.29%; at 48h ranged from 8.05 – 14.51% and at 72h ranged from 10.46 – 16.40% (Fig. 4, 5, and 6). The result revealed that *A. boonei* treated with maleinized neem oil had the lowest volumetric swelling at 180^{0}C. The analysis of variance carried out at a 95% probability level showed that thermo-oil treatment had a significant effect on the wood species and the treatment. Lee *et al*. (2018) stated that oil absorption and oil deposits in the cell walls of wood also act as factors, which contribute to the improvement of the dimensional stability of wood. This result contradicts the study of Suril *et al*. (2021) that the swelling values of wood treated with oil-heat treatment decreased with increasing temperature. Some wood species are difficult to impregnate due to occlusions such as the presence of tyloses and other inorganic deposits; making it difficult to achieve maximum penetration in fiber directions and lateral directions (Olaniran *et al*. 2022). The degree of swelling for the wood samples increased with an increase in temperature. Heat treatment lowers water uptake and the wood cell wall absorbs less water because of the decrease of the amount of hydroxyl groups in the wood. As a consequence of the reduced number of hydroxyl groups, the swelling and shrinking were lower (Yildiz 2006). No significant difference at P>0.05 in the treatment, duration, and the interactions between wood species and duration, treatment, and temperature. The results of the volumetric swelling (VS) of thermally modified wood across the different soaking times (24, 48, and 72 hours) highlight several key trends, showing that the choice of wood species and treatment impregnation duration does not have a statistically significant impact on swelling, with P-values above 0.05 for the factors in all cases. In contrast, temperature emerges as a critical factor influencing the swelling properties of the selected wood species after treatment Olaniran (2019). The results showed that across all three soaking times, wood modified with oil treatment at higher temperatures recorded high volumetric swelling as evident in the substantial rise in swelling values observed at 180°C compared to lower temperatures for all wood species and treatment types. This trend suggested that wood treated at low temperatures is more dimensionally stable when compared with those treated at high temperatures. The different oil treatment types yield varying effects on swelling: palm kernel oil (PKO) treatments recorded a higher value of volumetric swelling when compared to the wood samples treated with Maleinized Neem and Neem oil which recorded considerably low values. Thermal deterioration of thermally treated wood was determined to be the cause of mass loss and dimensional instability (Candelier *et al.* 2016). Furthermore, Tenorio and Moya (2013) investigated mass loss during heat treatment and discovered that it is species- and treatment-intensity dependent. This highlights the importance of considering the type of treatment applied when optimizing thermal oil treatment processes for wood products.

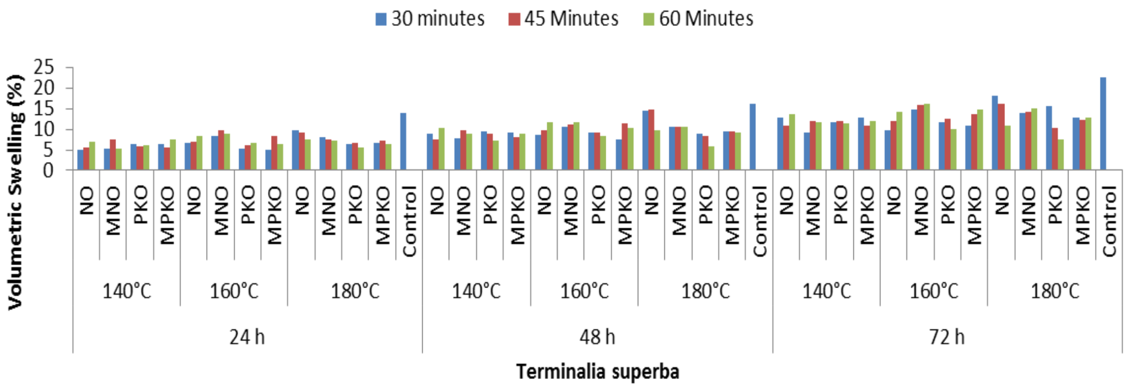

Fig. 3a.
Volumetric Swelling of T. superba.

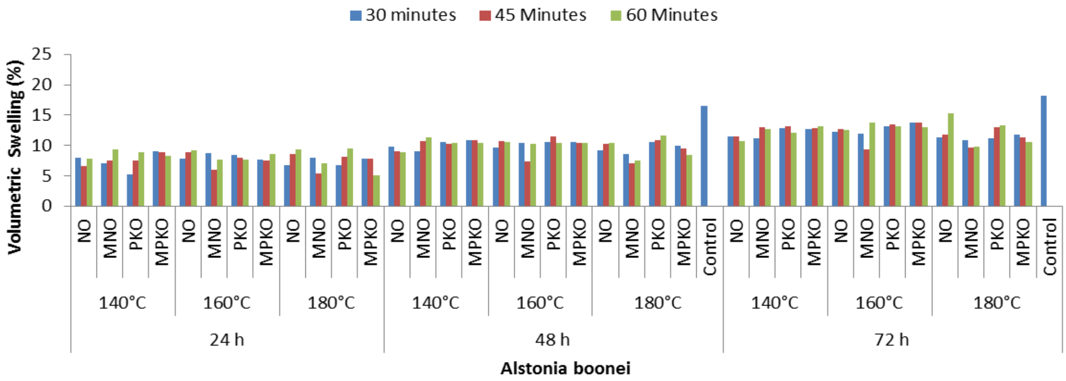

Fig. 3b.
Volumetric Swelling of A. boonei.

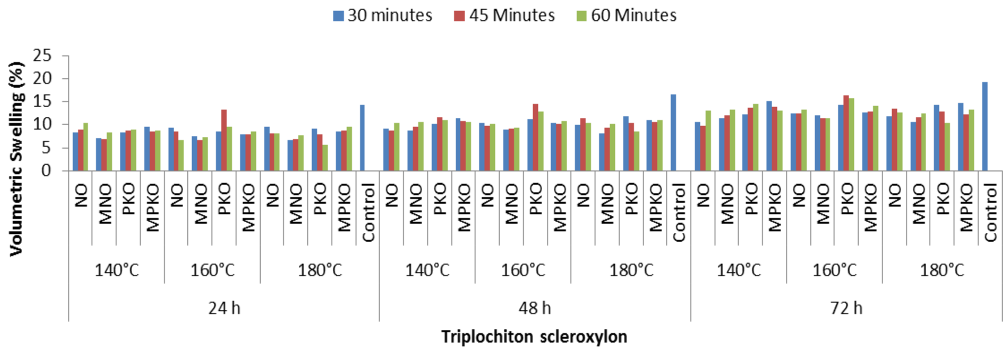

Fig. 3c.
Volumetric Swelling of T. scleroxylon.

Mechanical Properties of Thermal oil treated Wood Species

The mechanical properties are presented in Fig. 7a,b, and c. Neem seed oil had the highest strength MOE for *T superba* treated with Neem recorded 7339.19 N/mm^2 Maleinized neem having 7696.21N/mm^2, PKO (4601.75N/mm^2), and Maleinized PKO recorded value of 4757N/mm^2, for *T. scleroxylon* treated with Neem oil recorded 7181.17N/mm^2, Maleinized neem oil having 6382.71N/mm^2, PKO (6905.94N/mm^2), and Maleinized PKO recorded value of 6075.69N/mm^2, and *A boonei* treated with Neem oil recorded 4399.04N/mm^2 Maleinized neem oil having 3915.57N/mm^2, PKO (6261.45N/mm^2), and Maleinized PKO recorded value of 3986.84N/mm^2. The Analysis of Variance (ANOVA) for MOE of thermal oil-treated wood species revealed that there was no significant difference at P>0.05 in duration, between the wood species and temperature, the interaction between the wood species and duration.

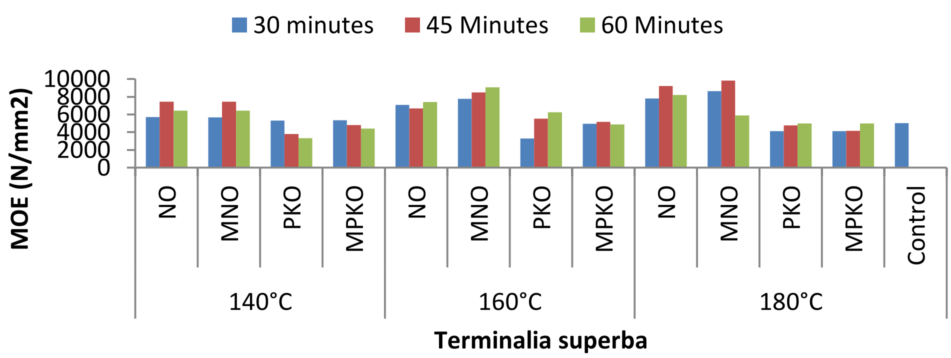

Fig. 7a.
Effect of treatment of Modulus of Elasticity Terminalia superba.

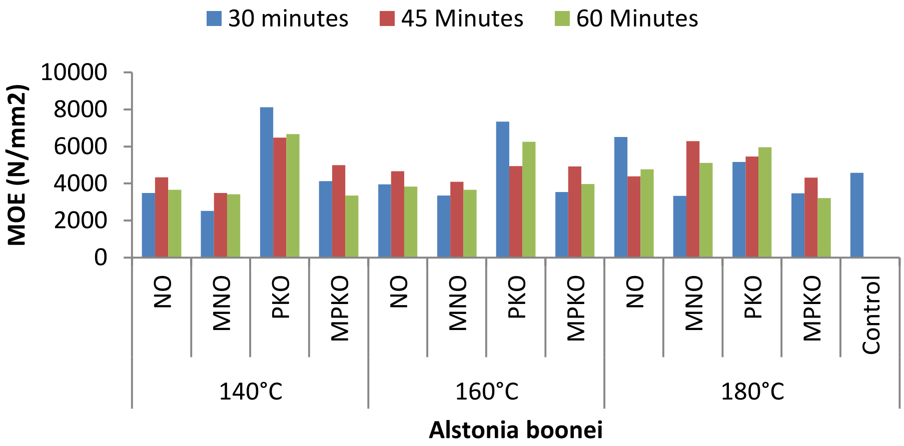

Fig. 7b.
Effect of treatment on Modulus of Elasticity A. boonei.

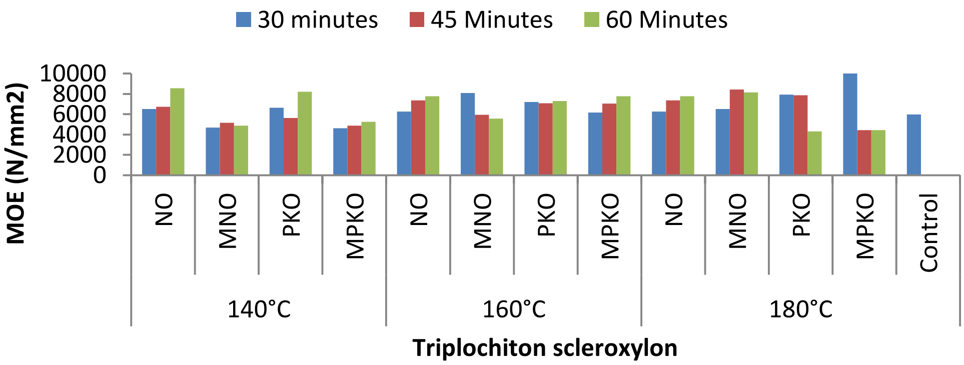

Fig. 7c.
Effect of treatment of Modulus of Elasticity Triplochiton scleroxylon.

Fig. 8a,b and c showed that MOR of *Terminalia superba* treated with Neem seed oil recorded 55.86N/mm^2, Maleinized neem having 53.45N/mm^2, PKO (28.23N/mm^2), and Maleinized PKO recorded value of 42.38N/mm^2, for *T. scleroxylon* treated with Neem oil recorded 66.08N/mm^2, Maleinized neem oil having 60.72N/mm^2, PKO (62.89N/mm^2), and Maleinized PKO recorded value of 52.88N/mm^2, and *Alstonia boonei* treated with Neem oil recorded 42.15N/mm^2, Maleinized neem oil having 36.75N/mm^2, PKO (51.17N/mm^2), and Maleinized PKO recorded value of 40.02N/mm^2. The Analysis of Variance (ANOVA) MOR of thermal oil-treated wood species is presented in Table 2 revealed that there was no significant difference at $P>0.05$ in duration and interaction between temperature and duration while others showed significant differences. The MOE results obtained in this study show an increase in the MOE of wood samples treated with neem seed oil, maleinized neem seed oil, and PKO compared to the control indicating that the presence of oil in the treatments reduced the effect of heat treatment on the elastic properties of those wood species. Maleinized Neem oil treatment resulted in varying MOE values across wood species but generally showed improvements. PKO treatment had varying effects on MOE across wood species and treatment conditions. This can be related to forming new chemical bonds with higher bond energy in comparison to the energy of absent hydrogen bonds according to (Straze *et al*. 2016). It was found from the result that the MOR and MOE of *A. boonei, T. scleroxylon,* and *T. superba* increased with increasing temperature. This also agrees with the work of Owoyemi *et al*. (2016) who observed that as the treatment temperature increased, the MOR of thermally treated *G. arborea* increased in value. Generally, higher temperatures tended to increase MOR values for most wood species. The increase in mechanical properties is probably due to the cross-linking of the lignin network, as well as the rearrangement and crystallization of cellulose, acting as a hardener for the microfibrils and the middle lamina Günduz *et al*. 2009). The results contradict Olaniran *et al*. (2019) who reported that an increase in temperature leads to a decrease in wood strength properties. Previous studies have shown that improvement in strength properties depends on the strength properties of materials involved used as modifying agents (Olaniran *et al.* 2019; Mora Mendez *et al.* 2019). Since the natural oils and their modified forms (maleinized oils) do not possess any appreciable strength properties, they are not expected to contribute to the overall improvement in the strength of the modified wood species.

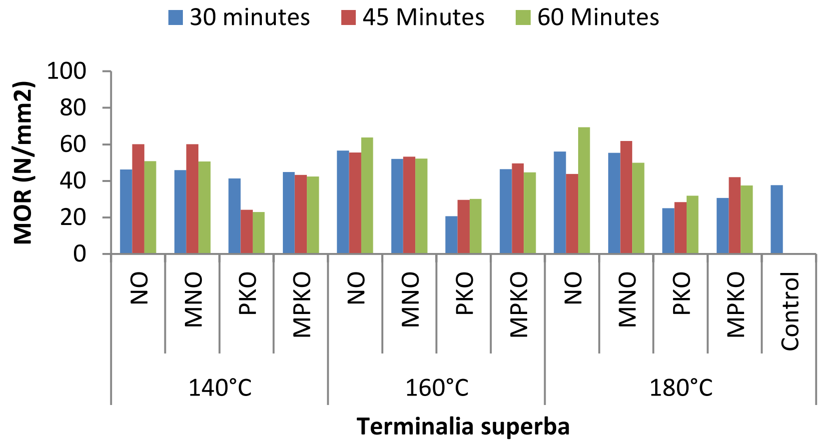

Fig 8a.
Modulus of Rupture of thermal oil treated and untreated wood species.

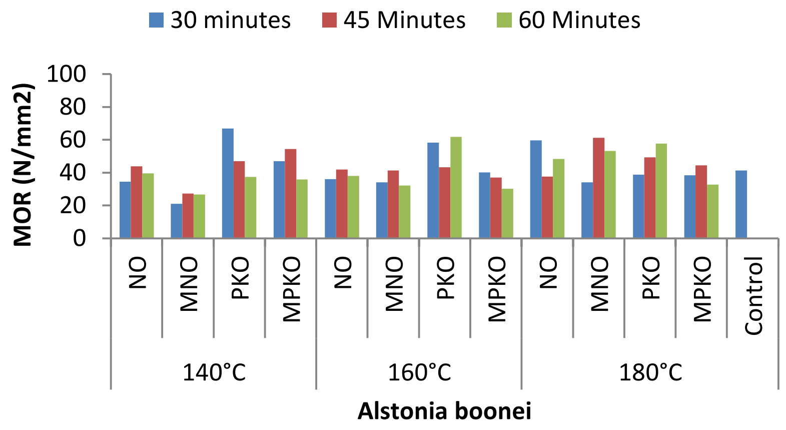

Fig. 8b
Modulus of Rupture of thermal oil treated and untreated wood species.

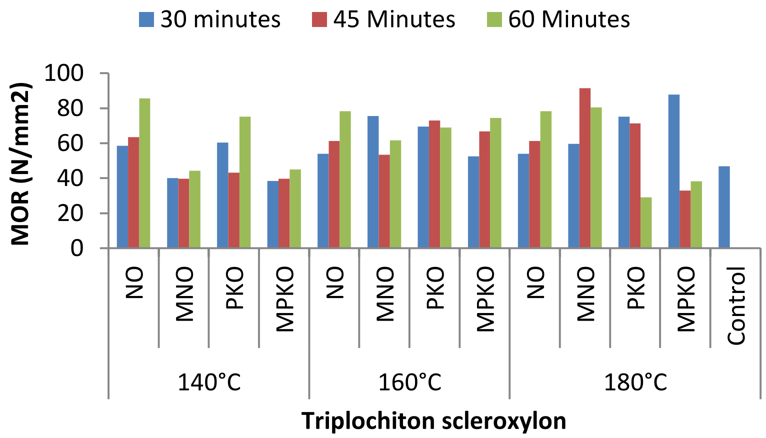

Fig. 8c.
Modulus of Rupture of thermal oil treated and untreated wood species.

CONCLUSIONS

The study showed that the oil and maleinized oil was effective for the thermo oil treatment. There was significant improvement in the physical properties while the mechanical properties showed little improvement on the three wood species. Oil does not impact the strength of wood but rather transfers heat faster into the wood. Oil and the maleinized oil performed well on the wood properties though maleinized oil reacted to the wood species differently.

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