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PHYSICO-MECHANICAL PROPERTIES OF SELECTED SPECIES SUBJECTED TO THERMO-OIL TREATMENT

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ABSTRACT

This research examined the effect of thermal modification on the physical and mechanical properties of Gmelina arborea, Triplochiton scleroxylon, and Hevea brasiliensis using palm kernel oil. Colour change, density, compression strength, Modulus of rupture, and modulus of elasticity were measured. Results showed that at temperatures between 170°C and 190 °C, average density values varied from 375.83 kg/m^3 to 431.70 kg/m^3 for obeche, 470.56 kg/m^3 to 474.59 kg/m^3 for Gmelina arborea and rubber from 539.17 kg/m^3 to 510.47 kg/m^3. The Average Compression strength values varied from 25.38 N/mm^2 at 27.50 N/mm^2 for obeche, 42.87 N/mm^2 to 45.16 N/mm^2 for Gmelina arborea, and rubber from 28.83 N/mm^2 to 25.37 N/mm^2. The Average Modulus of Elasticity values varied from 4264.63 N/mm^2 at 170°C to 4891.66 N/mm^2 for obeche, 8496.72 N/mm^2 to 7405.64 N/mm^2 for Gmelina arborea, and rubber from 5159.17 N/mm^2 to 4613.07 N/mm^2. The Average Modulus of Rupture values varied from 67.32 N/mm^2 to 60.45 N/mm^2 for obeche, 78.54 N/mm^2 to 74.52 N/mm^2 for Gmelina arborea, and rubber from 63.83 N/mm^2 to 58.16 N/mm^2. It was observed that dimensional stability was enhanced when thermally modified. The colour of wood samples became darker after treatment therefore, thermal modification is recommended for applications where the appearance and high strength of wood are not paramount.
Keywords: *Gmelina***;** *Triplochiton; Hevea brasiliensis;* thermal modification.

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INTRODUCTION

Thermal modification was developed as an alternative to traditional wood treatments such as impregnation with chemical products (toxic products) that aims to improve wood properties. Thermal treatment is a process of modification of different materials at high temperatures. Studies have shown that this process can be performed between 140 and 160°C (Pincelli, 2012; Bal, 2013) and between 180°C and 260°C (Hill, 2006).

The physical and mechanical properties of wood can be used to define its strength and suitability for structural or construction purposes. However, these properties can vary with respect to the wood species (Jamala *et al*., 2013). Hence, (Qiaofang *et al* 2019) stated that some wood species possess low physico-mechanical properties. Nevertheless, some studies have shown that the physico-mechanical properties of wood can be improved through immersion in organic matter impregnation and thermal treatments among others.

In a study, Bal (2013) determined the effects of heat treatment on the physical properties of heartwood and sapwood of *Cedrus libani*, and found a clear difference in the physical properties between the heartwood and sapwood at 220ºC. Also, Esteves and Pereira (2009) reported increasing dimensional stability in heat-treated wood. However, these studies only subject the wood species to direct temperature without the consideration of suitable pre-treatment to optimize the thermal process.

Over time, the use of chemicals in wood modification has been adopted, but its contribution to environmental pollution is an issue of concern. Unlike conventional chemicals, palm kernel oil is an edible plant oil produced from the kernel of oil palm produced by palm trees scientifically referred to as *Elaeis guineensis* which is environmentally friendly. Palm oil is processed from the pulp of oil palm fruit. It is semi-solid at room temperature and more saturated than palm oil and coconut oil (Boateng *et al*., 2016). More importantly, palm kernel oil is considered a good material useful in wood modification (Yiin *et al*., 2014).

We aim to pretreat wood from selected hardwood species (*Gmelina arborea, Triplochiton scleroxylon,* and *Hevea brasiliensi*) with palm kernel oil and subject same to thermal modification with the view of improving their strength properties. Thus, this study assessed the physico-mechanical properties of thermally pretreated selected hardwood species.

MATERIAL AND METHODS

Sample collection

The study samples (*Gmelina arborea, Triplochiton scleroxylon,* and *Hevea brasiliensis*) were bought in a Timber market at Oke-aro in Akure South Local Government area, Ondo State, Nigeria while the palm kernel oil was processed in Ede, Osun State.

Sample Preparation

The conversion of the wood samples of 20 mm × 20 mm × 60 mm and 20 mm × 20 mm × 300 mm for physical and mechanical properties, respectively were done at the Federal University of Technology Akure. All of the samples were oven-dried before treatment with palm kernel oil. The wood samples were heated in palm oil using a pressure cooker to allow deep penetration of palm kernel oil into the wood samples while the untreated samples represent the control. The thermal modification of the wood samples in palm kernel oil was done at varying temperatures (170° and 190°C) and time intervals (30 and 45 minutes) at the Federal University of Technology Akure. The wood samples were oven dried after treatment. A total of 150 samples were prepared for the experiment. Further tests were carried out at the Forestry Research Institute of Nigeria, Jericho, Ibadan, Oyo State.

Experimental design

Each sample was replicated five (5) times for all experiments, and laid out as a 3 x 2 x 2 factorial experiment (3 wood samples: *Gmelina arborea, Triplochiton scleroxylon,* and *Hevea brasiliensis*), two-time interval and two temperature readings). Data Analysis: Data generated were analyzed using Statistical Package for Social Science. Data on the physical and mechanical properties were analyzed, mean and standard deviation of each property were determined. Analysis of Variance (ANOVA), Duncan Multiple Range Test was carried out on the data set to assess if there are significant differences between the time interval and temperature range.

RESULTS

The density of treated wood samples

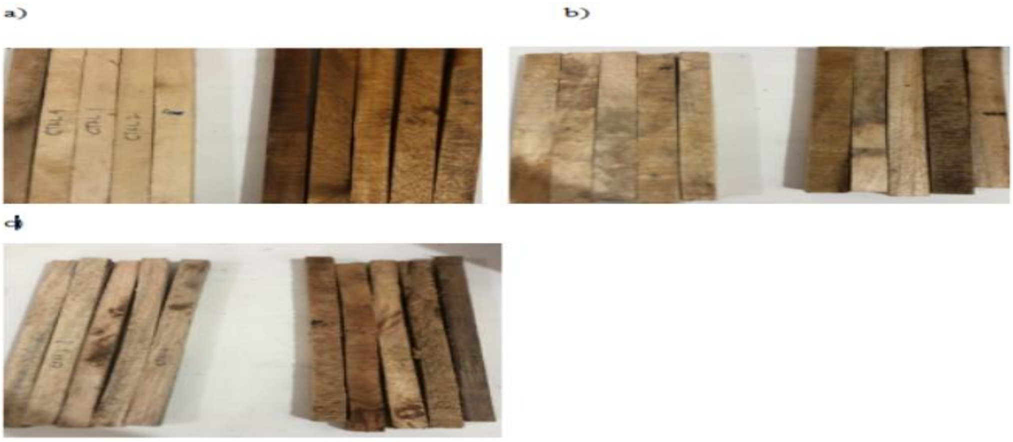
The relationship between Density among the wood Species, Temperature, and Time is shown in Table 1. The samples obtained from the *Gmelina arborea* had a mean density of 470.56g/m^3 at 170ºC while at 190ºC the mean density was 474.59 kg/m^3, both values were lesser than that of the control samples with a mean density of 476.55 kg/m^3. *Hevea brasiliensis* had a mean density of 539.17kg/m^3 at 170ºC, and at 190ºC, the mean density was 510.73kg/m3; both values obtained were lesser than the mean density of the untreated samples of *Hevea brasiliensis* which was 606.47kg/m^3. Wood obtained from the *Triplochiton scleroxylon* had the least mean density among the three wood species. At 170ºC, the mean density was 375.83kg/m^3, while at 190ºC, the mean density recorded was 431.70kg/m^3, the values obtained at temperatures 170ºC and 190ºC were higher than those from the untreated samples of obeche with mean density of 345.65kg/m^3. From the data obtained, it can be observed that as temperature increased with an increase in time, the density of *Gmelina arborea* and *Triplochiton scleroxylon* density decreased, and on the other hand Rubber wood at 170ºC increased as time duration increased.

Table 1: Density of *Triplochiton scleroxylon*, *G. arborea*, and *Hevea brasiliensis* Against Species, Temperature, and Time.

Species	Temperature °C	Time (Minutes)	Density(Kg/M³)	Average
Triplochiton scleroxylon	170	30	413.50±24.66[c]	375.83±51.17 [a]
		45	338.16±41.66[c]	
	190	30	469.45±39.53[c]	431.70±56.61 [a]
		45	393.80±45.33[c]	
	Control		345.70±65.17 [c]	345.70±65.17 [a]
Gmelina arborea	170	30	463.06±27.66[b]	470.56±23.89 [a]
		45	478.06±19.47[b]	
	190	30	472.44±23.19[b]	474.59±17.32 [a]
		45	476.73±11.22[b]	
	Control		476.55±7.06[b]	476.55±7.06 [a]
Hevea brasiliensis	170	30	463.42±99.77[a]	539.17±110.19[a]
		45	614.92±54.95[a]	
	190	30	401.47±29.74[a]	510.47±117.48 [a]
		45	619.47±21.68[a]	
	Control		456.47±55.45a	456.47±55.45 [a]

Change in colour of treated wood samples

The colour of wood samples changed with increased temperature from 170 ºC to 190 ºC. *Gmelina arborea* turned darker as shown in Fig 2a than *Triplochiton scleroxylon* (Fig 2b) and *Hevea brasiliensis* (Fig 2c). Figure 1: a) *Gmelina arborea* before and after treatment, b) *Triplochiton scleroxylon* before and after oven drying. c) *Hevea brasiliensis* before and after treatment



The compression strength of treated wood samples

The relationship between compression against Species, Temperature, and Time is shown in Table 2. Results showed that temperature and time were significantly different from each other with respect to compression strength. *Gmelina arborea* had the highest mean at 170 ºC with a mean compression strength of 42. 87N/mm^2 while at 190 ºC, mean compression was 45.16N/mm^2, which was higher than that of the control samples 42.22 N/mm^2. *Hevea brasiliensis* had a mean compression of 28.83N/m^2 at 170 ºC and at 190 ºC, mean compression was 25.37N/mm^2; both values obtained were lesser than the mean compression of the untreated samples of rubber wood which was 31.52 N/mm^2. Wood obtained from the *Triplochiton scleroxylon* had the least mean compression among the three wood species. At 170 ºC, the mean compression was 25.38 N/mm^2, while at 190 ºC, the mean compression recorded was 27.50 N/mm^2 the values obtained at temperatures 170 ºC and 190 ºC were higher than those from the untreated samples of obeche with a mean density of 23.61Nm/m^2.

Table 2: Compression Strength of *Triplochiton scleroxylon*, *G. arborea*, and *Hevea brasiliensis*Against Species, Temperature, and Time.

Wood Species	Temperature (ºc)	Time (Minutes)	Compression (N/mm^2)	Average
Triplochiton		30	27.21±2.85^b	25.38±12.32^a
scleroxylon	170	45	23.54±2.26^b	
		30	27.50±2.30^b	27.50±2.30^a
	190	45	27.50±2.30^b	
	Control		23.62±6.13^b	23.61±6.13^a
Gmelina		30	39.56±2.36^a	42.87±4.28^a
arborea	170	45	46.20±2.86^a	
		30	40.12±3.55^a	45.16±5.97^a
	190	45	50.20±2.05^a	
	Control		42.22±3.08^a	42.22±3.08^a
Hevea		30	27.31±3.93^b	28.83±3.65^a
brasiliensis	170	45	30.35±2.94^b	
		30	20.02±9.40^b	25.37±8.47^a
	190	45	30.71±1.27^b	
	Control		31.52±2.88^b	31.52±2.88^a

Modulus of Elasticity (MOE)

The relationship between MOE against species, temperature, and time is shown in Table 3. The MOE from the samples obtained from the *Gmelina arborea* had the highest mean MOE at 170 ºC MOE of 8496.72. 87 N/mm^2 with the 190 ºC MOE which was 7405.64 N/mm^2, both values were higher than samples for control with mean MOE of 4870.27 N/mm^2. *Hevea brasiliensis* wood had a mean MOE of 5159.18 N/mm^2 at 170 ºC while at 190 ºC the mean MOE was 4613.07 N/mm^2. However, both values obtained at these temperatures were lower than the mean MOE of the untreated samples of 3718.12N/mm^2. *Triplochiton scleroxylon* wood samples had the least mean MOE of 4264.63N/mm^2 at 170 ºC, and at 190 ºC, the mean MOE was 4891.66N/mm^2. Similarly, both values were higher than the untreated samples of the same wood with a mean MOE of 3046.88N/mm^2. From the result, it can be observed that the temperature increased with an increase in time.

Table 3: MOE of *Triplochiton scleroxylon*, *G. arborea*, and *Hevea brasiliensis*Against Species, Temperature, and Time

Species	Temperature (ºC)	Time (Minutes)	MOE (N/mm^2)	Average
Triplochiton		30	3868.24±71.05^b	4264.63±690.93^a
scleroxylon	170	45	4661.02±822.35^b	
		30	5221.21±2713.36^b	4891.66±690.93^a
	190	45	4562.11±308.19^b	
	Control		3046.87±1133.82^b	3046.87±1133.82^b
Gmelina		30	7638.57±1209.99^a	8496.72±1405.80^a
arborea	170	45	9354.87±1068.40^a	
		30	7610.81±1153.66^a	7405.64±913.63^a
	190	45	7200.47±664.82^a	
	Control		4870.27±738.02^a	4870.27±738.02^b
Hevea		30	5497.28±468.06^b	5159.17±728.44^a
brasiliensis	170	45	4821.07±830.09^b	
		30	4292.07±647.74^b	4613.07±806.01^a
	190	45	4934.07±885.74^b	
	Control		3718.12±`1140.06^b	3718.12±`1140.06^b

Modulus of Rupture (MOR)

The relationship between the modulus of rupture and temperature with time is shown in Table 4. *Gmelina arborea* had the highest mean MOR of 78. 54N/mm^2 at 170 ºC. At 190 ºC, the mean MOR was 74.53N/mm^2 compared to the untreated samples with a mean MOR of 45.76±4.97Nm/m^2. Wood obtained from *H. brasiliensis* had a mean MOR of 63.83N/mm^2 at 170 ºC while at 190 ºC, the mean MOR was 58.17N/mm^2. Meanwhile, both values were lower compared to the mean MOR value of untreated samples which was 61.11N/mm^2. Samples obtained from *T. scleroxylon* had the least mean MOR at 170 ºC (67.32 N/mm^2), while it was 45.44N/mm^2 at 190 ºC. Both values were higher than the untreated samples of *T. scleroxylon* with 52.41±18.21 N/mm^2 as the mean.

Table 4: Modulus of Rupture of treated wood samples against Temperature and time

Species	Temperature ^{O}C	Time (Minutes)	MOR (N/mm^2)	Average
Triplochiton		30	58.55±4.83^b	67.32±12.32 ^{a}
scleroxylon	170	45	76.08±11.24^b	
		30	45.45±28.52^b	45.44±19.45 ^{a}
	190	45	45.45±7.16^b	
	Control		52.41±18.21^b	52.41±18.2 ^{b}
Gmelina		30	77.09±10.57^a	78.53±9.90 ^{a}
Arborea	170	45	79.99±10.19^a	
		30	71.91±11.85^a	74.52±10.75 ^{ab}
	190	45	77.14±10.12^a	
	Control		45.76±4.97^a	45.76±4.97 ^{b}
Hevea		30	66.80±4.93^b	63.83±10.52^a
brasiliensis	170	45	62.64±14.88^b	
		30	59.02±13.83^b	58.17±13.74^a
	190	45	57.31±15.23^b	
	Control		61.11±6.63^b	61.11±16.63^a

DISCUSSION

Physical properties of treated wood samples

Density of treated wood samples against temperature and time

The density of the selected wood species did not follow a definite pattern as the density of *G. arborea* obtained at both temperature were lower than the untreated samples. Also, *T. scleroxylon and G. arborea* decreased with an increase in temperature while *H. brasiliensis* at 170ºC and 190ºC increased with an increase in time. This corroborates with the work of Borrega and Kärenlampi (2008); Gunduz *et al.* (2019) who confirmed that the density of thermally modified wood at high temperature decreases as noticed in *Triplochiton scleroxylon*. The density of *H. brasiliensis* wood was higher than *G. arborea* while *Triplochiton scleroxylon* had the least mean density value which agrees with the findings of Sulaiman and Lin (1989) who stated that there was an increase in the density of *G. arborea* as temperature increased. This also consulates with Cown (1974) who conducted a test on three batches of *G. arborea*, where batch C increased in density and was fairly uniform from the base to the top of the tree. The density of the *H. brasiliensis* increased as temperature and time increased. This is in line with the statement of Lee *et al*., (2017) who stated that the mean *H. brasiliensis* density of wood treated using a hot press increased in comparison with control samples. The increase in mean *H. brasiliensis* wood density with time may be a result of age which agrees with Izekor *et al*., (2010) that wood density increases with an increase in age. Since the mean density of the three wood species ranges between 300 - 700 kg/m^3. This shows that they were all light wood and therefore will not be able to support heavy structures as density is a good indicator of strength in wood (Izekor *et al.*, 2010).

Mechanical properties of treated wood samples

Compressive strength decreased with increased temperature in *T. scleroxylon* except for *G.*

arborea and *H. brasiliensis* which increased with increased temperature. The compressive strength of *G. arborea* was higher than *T. scleroxylon* while *H. brasiliensis* had the least compressive strength when compared to the control. This aligns with the work of Ma'ruf *et al*. (2019) which explained that compressive strength at all treatment temperature levels in *Cocus nucifera* and *Gmelina arborea* woods decreased when the treatment temperature increased. This could be associated with the variations in some parts of wood used since samples were obtained from planks from various sources. The analysis of variance showed that there was a significant difference between the compressive strength of *T. scleroxylon* and *G. arborea*. *Gmelina arborea* was observed to have high compressive strength when compared to *T. scleroxylon* and *H. brasiliensis*. Compression Strength Parallel grain has been classified according to Farmer, (1972), as very low, low, medium, high, and very high when the strength values are under 20 N/mm^2, ranging from 20- 35N/mm^2, 35-55N/mm^2, 55-85 N/mm^2 and over 85N/mm^2 respectively. Since the three wood species were below 55, it means the wood has a low compression strength

Modulus of Rupture and Modulus of Elasticity of treated wood samples

Modulus of Rupture of *T. scleroxylon* and *H. brasiliensis* decreased in value when compared to the untreated samples. The MOE and MOR of *H. brasiliensis* also decreased with an increase in temperature and cooking time. This corroborates with the work of Owoyemi and Iyiola, (2016); Qiaofang *et al*,(2019) who stated that *H. brasiliensis* decreased with an increase in temperature and time. It was found that the MOR and MOE of *Triplochiton scleroxylon* and *G. arborea* increased with increasing temperature, which is in line with the work of Gennari et al (2020) only discovered an increase in static bending strength in untreated *G. arborea* samples. This 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. According to Farmer (1972), MOR is rated very low when is under 50 N/mm^2, and low if it ranges from 50-85 N/mm^2. Since the MORs for the three species were less than 85 but greater than 50, it can be inferred that they they performed differently after treatment at different temperatures. The modulus of elasticity of *T. scleroxylon* and *G. arborea* decreased as temperature increased which does not agree with the work of Owoyemi et al, (2016) that investigated the MOE of *G. arborea* increased with temperature and duration as *H. brasiliensis* MOE increased. This agreed with the work of Qiaofang, et al, (2019) who revealed an increase in the MOE of *H. brasiliensis* wood as temperature increased with time. Upton and Attah (2003) classified the strength of species based on the MOE at 12% moisture content indicating that MOE below 9,000 N/mm^2 is Low. Therefore, the three wood species used in this study have a low Modulus of Elasticity since all the values were less than 9000 N/mm^2.

CONCLUSION

This study has helped to investigate the impact of thermal modification on *T. scleroxylon, G. arborea*, and *H. brasiliensis* using palm kernel oil. It was observed that there was a comparable improvement in the density of *T. scleroxylon* and *H. brasiliensis* after treatment. The Modulus of Elasticity and Modulus of Rupture improved for all the species when treated at an increased temperature, however, continuous increment in temperature for the treatment of these species did not produce the desired results. Notwithstanding, this study found that the strength of these wood species can be improved by thermally modification. On the other hand, The effect of palm kernel oil treatment negatively impacted the compression strength for *H. brasiliensis*, and MOR for *T. scleroxylon* and *H. brasiliensis* , respectively which made the wood darker when the temperature was increased.

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