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Full Length Research Paper

Effect of Age on the Strength and Durability Properties of *Gmelina arborea* (Roxb.) Wood Treated with Lactic Acid

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Abstract

The maturity of wood is one of the determining factors for utilization. *Gmelina arborea* wood samples were obtained from two different age plantation trees of 15 and 10 years in Akure, Nigeria. Oven-dried samples were impregnated with a 60% solution concentration of Lactic acid in a vacuum-pressure impregnation chamber. Impregnated samples were cured for a complete modification process in the oven. The strength property using the 3-point loading apparatus and biological durability assessment was carried out to examine the effect of age and lactic acid treatment according to the American Society of Testing Materials standard. Durability specimens were subjected to termites' attack at the timber graveyard for the duration of 16 weeks and the gravimetric weight loss was obtained after the exposure. On average, density, modulus of elasticity and Modulus of rupture of the 10- and 15-year *G. arborea* treated with lactic acid were 421.83kg/m^3 and 469.24kg/m^3, 14646.99N/mm^2 and 12127.63N/mm^2, and 103.46N/mm^2 and 90.10 N/mm^2 respectively. The results showed that there is a significant improvement in the property's enhancement of *G. arborea* impregnated with lactic acid which varies with the curing time.

Keywords: Durability; less-durable; Modification; strength properties; and enhancement.

INTRODUCTION

The demand for wood and its products coupled with the increase in world population has led to deforestation of the forest land and overexploitation of durable trees species which has left wood users with the use of less durable wood species and fast-growing plantation trees such as *Gmelina arborea* to meet the ever-increasing demand (Zhang *et al.,* 2022). Most of these commonly available species were neglected for their low strength properties and durability resistance which call for improvement to achieve the desirable properties, especially for consideration in construction applications where the carrying of loads or exposure to biodeteriorating agents is required (Wang *et al.,* 2020; Jiang *et al.,* 2022). Traditionally, these limitations have been addressed through drying, good design, chemical treatments, and the use of naturally resistant wood species (Spear *et al.,* 2021).

The strength and durability properties of the wood are its factors in fitness and ability to resist applied forces and attacks against biodeteriorating agents. It is largely properties that determine the use of wood for structural and building purposes and innumerable other uses of which furniture, vehicles, implements, and tools handles are a few common examples (Owoyemi *et al.,* 2015). Wood modification systems have been known to enhance wood properties by restricting dimensional change, improving

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strength and reducing susceptibility to decay (Ormondroyd *et al.,* 2015; Sandberg *et al.,* 2017; Jones and Sandberg, 2020; Ali *et al.,* 2021).

The significant developments in the area of wood modification for properties enhancement can be attributed to an increase in environmental concerns, the escalating demand for high and quality wood products; the rising prices of durable tropical timber, and its limited availability, heightened by illegal logging activities. The inherent problem of these most commonly less durable wood has made it imperative to find solutions to achieve the desirable properties. Therefore, increasing the range of efficient wood treatments using eco-friendly compounds like the lactic acid-based treatment has been recently reported by Grosse *et al.* (2019) to offer an improvement on the strength and durability properties of wood. Lactic acid ($CH_3CH(OH)COOH$) is an organic acid miscible with water in a white solid state and can be produced with both synthetic and natural resources (Wikipedia, 2023). Lactic acid is used as a synthetic intermediate in many organic synthesis industries and various biochemical industries. This study, therefore, assessed the mechanical and durability properties of *G. arborea* wood treated with Lactic Acid to improve its strength and durability properties.

MATERIALS AND METHOD

Study Area

This study was carried out at the Federal University of Technology, Akure (FUTA), Department of Forestry and Wood Technology in Akure, Ondo State, Nigeria (Figure 1), which is located between latitudes 07^o 16 and 07^o 18N and longitudes 05^o 09 and 05^o 11E. The region has a tropical climate with two distinct seasons: the wet season (March to November) with an average rainfall of 400 mm, and the dry season (December to February), with an average rainfall of 25 mm. However, there are minute differences from year to year. The mean annual temperature ranges from 26 to 28 ^{o}C with an average daily humidity of 80% (Ibitolu and Ogunjobi, 2016). The yearly rainfall varies from 1,150 mm in the northern regions to 2,000 mm in the southern area.

Preparation of wood samples

Gmelina arborea trees of 15 and 10 years with a diameter at breast height of 46 cm and 41.5 cm respectively were harvested and processed into three (3) billets 3m long at 25 %, 50 %, and 75 % of the total height. The samples were dimensioned to 20 x 20 x 60 mm, 20 x 20 x 300 mm, and 35 x 35 x 350 mm according to the required sizes for basic physical, mechanical and durability assessment for the American Society for Testing and Materials (ASTM). The processed defect-free samples were oven-dried at 103 ±2 °C for 24 hours till constant weight was achieved before chemical treatment.

Treatment of wood samples

The defect-free oven-dried samples of *G. arborea* wood were loaded into a vacuum-pressure impregnation chamber filled with a 60% solution concentration of Lactic acid for chemical modification (Plate 1). The impregnation cycle starts with a 5-min initial vacuum of 2 KPa in an impregnation chamber, followed by the chamber being filled with the prepared lactic acid solution until all the samples were submerged. Next, the pressure was applied at 4 bars for 30 minutes to ensure the best penetration, and the stage ended with the samples being removed from the chamber. To finish the wood sample modification procedure, the withdrawn samples were wrapped in aluminum foil (Plate 2a) and placed in a controlled oven (Plate 2b) to cure at a temperature of 140 ^{o}C for varied amounts of time (3 hours, 6 hours, and 9 hours). The untreated samples (Plate 3a) were dried at 100 ^{o}C till a constant weight was recorded for comparison. All the modified samples (Plate 3b) were conditioned at atmospheric room conditions for 24 hours before testing.

Basic Physical Properties of *G. arborea* Wood

- **Moisture Content (MC%) Determination**

The MC% of *G. arborea* wood was determined according to ASTM D4442-16 using the:

$$\mathbf{MC}\,(\%) = \frac{Wg-Wo}{Wo} X\,100 \text{ …………………….. Equation (1)}$$

Where: W_g is the Weight of green samples (g); W_o is the Weight of oven-dried samples (g).

- **Wood Density Determination**

The density of *G. arborea* wood was calculated according to ASTM D2395-14e1 using:

$$\textbf{Density=}\left(\frac{M}{V}\right)\text{kg/m}^3\text{…..............................Equation (2)}$$

Where: M is the mass of the oven-dried sample (g); V is the volume of the oven-dried samples (mm^3).

Mechanical properties:

Static Bending Tests

The static bending tests were carried out according to ASTM D143-09 standard, using a three-point bending apparatus as shown in Plate 4. The load was applied in the tangential direction and the mechanical strength properties are estimated as follows:

- **Modulus of Elasticity (MOE)**

The modulus of elasticity which measures the stiffness of

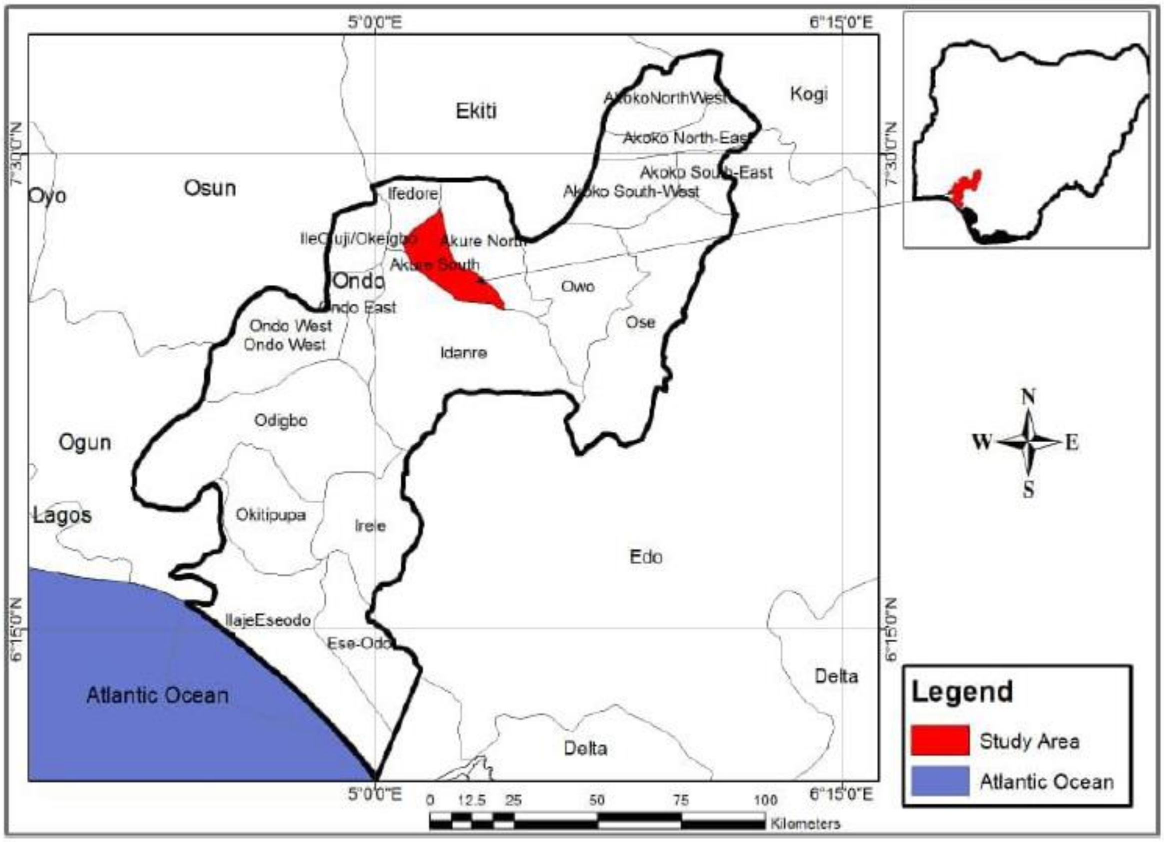

Figure 1: Map of Ondo State showing Akure South Study Area (Ogungbade *et al.,* 2020).

wood was calculated using:

$$MOE = \left(\frac{PL^3}{4x\,\Delta\,xbxd^3}\right) \text{ .... Equation (3)}$$

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 depth or thickness of the test specimen (mm)

- **Modulus of Rupture (MOR)**

The modulus of rupture of the treated and control samples was calculated using;

$$MOR = \left(\frac{3PL}{2XbXd^2}\right) \text{ .... Equation (4)}$$

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).

Biological Durability (Termites In-Ground Test)

The resistance of treated and untreated wood of two different age groups of *G. arborea* wood was carried out using 35 x 35 x 350 mm stakes subjected to termites' attack at the timber graveyard (Plate 5) for the duration of 16 weeks. The visual rating and weight loss assessment was carried out according to ASTM D3345-2017 as shown:

Attacking Grade	Description
10	No attack or few nibbles present
9	less than 3% of the cross-sectional area affected at any location
7	Termite attack affects 10-25% of the cross-sectional area at any location
4	Termites affect more than 50% of the cross-sectional area at one location
0	over 50% of the wood cross-section was eaten up by termites

Gravimetric Weight Loss Assessment

At the end of the exposure (plate 6), the infested wood samples were withdrawn and oven-dried until a constant weight was attained. The gravimetric weight loss was calculated using:

Plate 1: Wood-impregnating machine.

Plate 2: A: Withdrawn Wood samples placed on aluminium foil; B: Curing Processing in Oven.

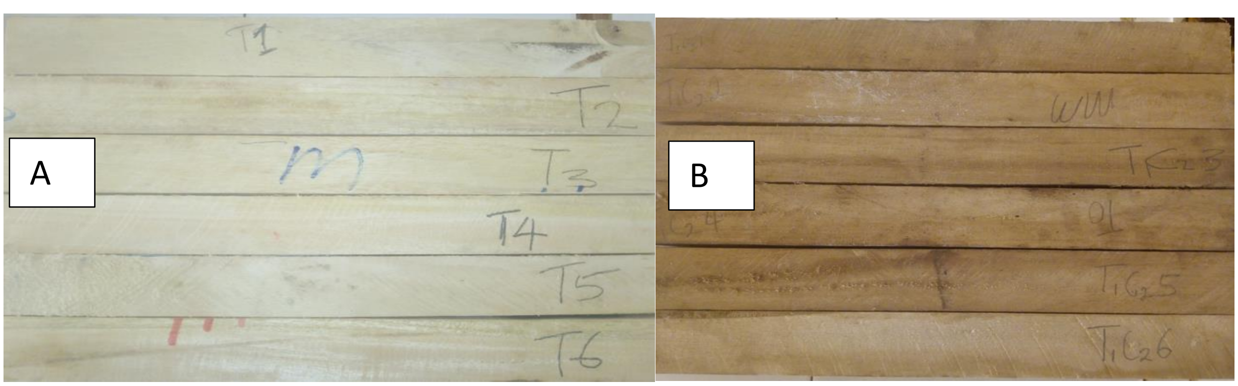

Plate 3: A: Untreated Samples B: Treated Samples

Plate 4: Universal Testing Machine.

Plate 5: Samples set out on the timber graveyard of the Department of Forestry and Wood Technology, FUTA.

Plate 6: Wood samples during exposure to termite attack at different levels at the timber graveyard.

Gravimetric Weight Loss (%) = $\frac{W_i - W_f}{W_i} \times 100$

………Equation (5)

Where; W_i is the oven-dried weight (g) before exposure; W_f is the oven-dried weight (g) after exposure.

RESULTS

Basic Physical Properties

The descriptive statistics of the mean separation results of the percentage moisture content of two different age groups of *G. arborea* wood (Figure 2) showed that the 10-year-old wood had a mean percentage moisture content of 57.32%, higher than that obtained from the 15-year-old with the value of 48.39 %. This recorded the variations in moisture content distribution of the two selected age groups G. arborea wood.

The density distribution of two different age groups *Gmelina arborea* wood (Figure 2), revealed that the 10 years old wood had a mean density value of 421.83 kg/m^3, lower than that obtained from the 15 years old with the value of 469.24 kg/m^3. The results showed that there was a strong relationship between the age of the tree, density and moisture content distribution of the two selected age groups *Gmelina arborea* wood: as the density increases with age, the wood moisture content reduces. The Analysis of variance ($\alpha = 0.05$) for the basic properties of the two different ages of *G. arborea* wood in Table 1, showed that there was no significant difference in the value obtained for the MC% of the two

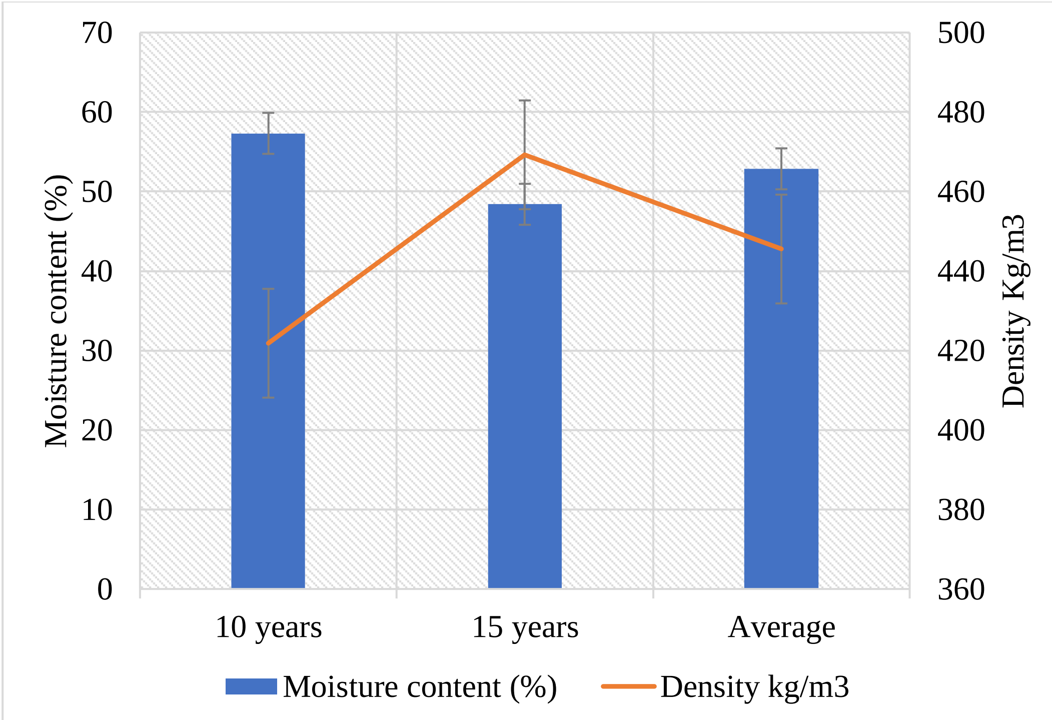

Figure 2: The descriptive statistics of the mean separation for MC% and Density of Two different age groups of *G. arborea* Wood.

Table 1: ANOVA For the Basic Properties of *G. arborea* Wood.

		Sum of Squares	df	Mean Square	F	P	Sig.
	Tree Age	239.056	1	239.056	4.780	0.054	ns
MC (%)	Error	500.134	10	50.013			
	Total	739.190	11				
	Tree Age	6743.124	1	6743.124	9.652	0.011	*
Density kg/m3	Error	6985.992	10	698.599			
	Total	13729.116	11				

** = (P<0.05) are significant, ns = Not significant (P>0.05).*

trees, however, for density, there was a significantly different in the values obtained for the two trees.

Chemical Absorption

The chemical absorption for the two different age classes of *Gmelina arborea* wood treated with lactic acid cured at varying times in Figure 3 showed that on average the 10 years has the highest absorption rate value of 14.25 % higher than the 15 years with an absorption value of 13.17 %. Likewise, the *G. arborea* wood cured for 3 and 6 hours has the highest absorption value of 15.04 % and 13.86 %, while those cured for 6 and 9 hours recorded the lowest value of 13.21 % and 11.98 % for 10- and 15-year trees respectively. The ANOVA for chemical absorption presented in Table 2 revealed that there was no significant difference at P>0.05 in tree age, curing time, and the interaction between the two factors (tree age

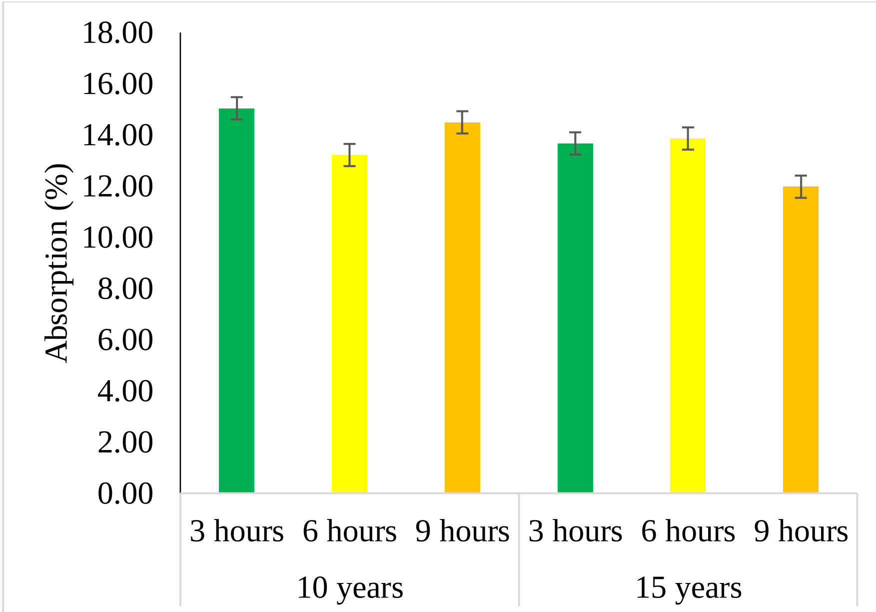

Figure 3: Descriptive summary of absorption rate of two different age groups of *Gmelina arborea* treated with lactic acid at varying curing time.

Table 2: ANOVA Table for absorption of *Gmelina arborea* wood treated with lactic acid.

Source	Type III Sum of Squares	df	Mean Square	F	P	Sig.
Tree	10.520	1	10.520	1.146	0.293	ns
Treatment	8.063	2	4.031	0.439	0.649	ns
Tree * Treatment	15.366	2	7.683	0.837	0.443	ns
Error	275.323	30	9.177			
Total	309.271	35				

ns = Not significant (P>0.05)

and curing time).

Effect of Lactic Acid Treatment on the Mechanical Properties of the two different age *G. arborea* Wood Modulus of Elasticity

The results of the MOE of the two different ages of *G. arborea* wood treated with lactic acid presented in Figure 4 showed that on average the 10 years has the highest MOE value of 14646.99 N/mm^{2}higher than the value obtained for the 15 years with a MOE value of 12127.63 N/mm^2 respectively. The samples cured for 6 and 9 hours had the highest average MOE value of 15734.97 N/mm^2 and the lowest value was recorded for the control samples having 13160.84 and 11402.39 N/mm^2 for 10 and 15 years respectively. The results for Duncan's multiple range tests of MOE of the *G. arborea* wood treated with lactic acid in Table 3 showed that there was a significant difference in the two different age trees and the curing time. The wood cured for 9 hours after impregnation performed best which was not significantly different from the samples cured for 6 and 3 hours but highly significant from the untreated samples.

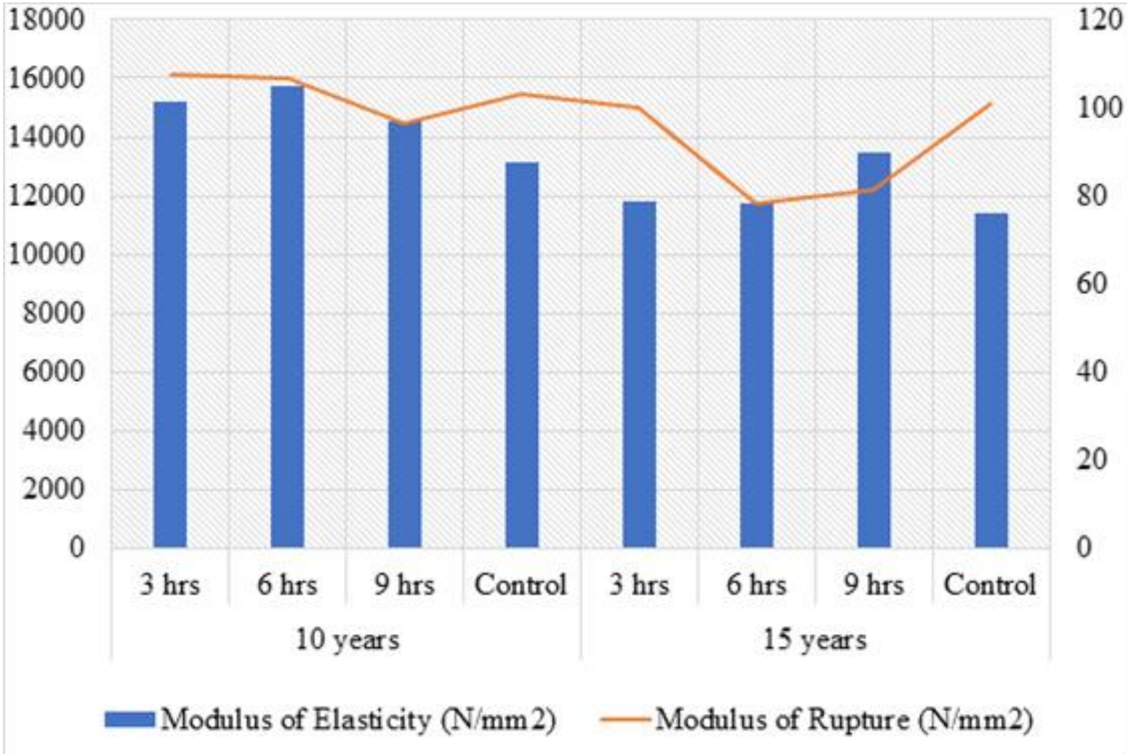

Figure 4: Descriptive for MOE and MOR of G. arborea wood treated with lactic acid.

Table 3: Table 4.21: Duncan's Multiple Range tests for MOE and MOR of G. arborea wood treated with lactic acid.

Curing Time	Modulus of Elasticity (N/mm^2)	Modulus of Rupture (N/mm^2)
9 hours	14004.1493^{a}	88.725^{c}
6 hours	13753.1789^{ab}	92.4094^{bc}
3 hours	13510.2902^{ab}	102.1359^{ab}
Control	12281.6124^{b}	103.8469^{a}

Alphabets with the same letter show that there is no significant difference; Alphabets with different letters show that there is a significant difference.

Modulus of Rupture (MOR)

The results of the MOR for the two different ages of treated *G. arborea* wood (Figure 4) showed that on average the wood obtained from the 10 years old tree has the highest MOR value of 103.46 N/mm^{2}higher than the value obtained for the 15years with MOR value of 90.10 N/mm^2 respectively. The samples cured for 3 hours had the highest average MOR value of 107.70 N/mm^2 and 100.00 N/mm^2, and the lowest value was recorded for those cured for 9 and 6 hours having 96.28 N/mm^2 and 78.23 N/mm^2 for 10 and 15 years respectively. The results for Duncan's multiple range tests of MOR in Table 3 revealed that there was a significant difference in the different age trees and the curing time considered during treatment.

Biological Durability (In-Ground Test)

Resistance of *G. arborea* treated with lactic acid to Termites attack

The resistance of the 10 years *G. arborea* wood to termites in Figure 5 showed that samples from 10-year

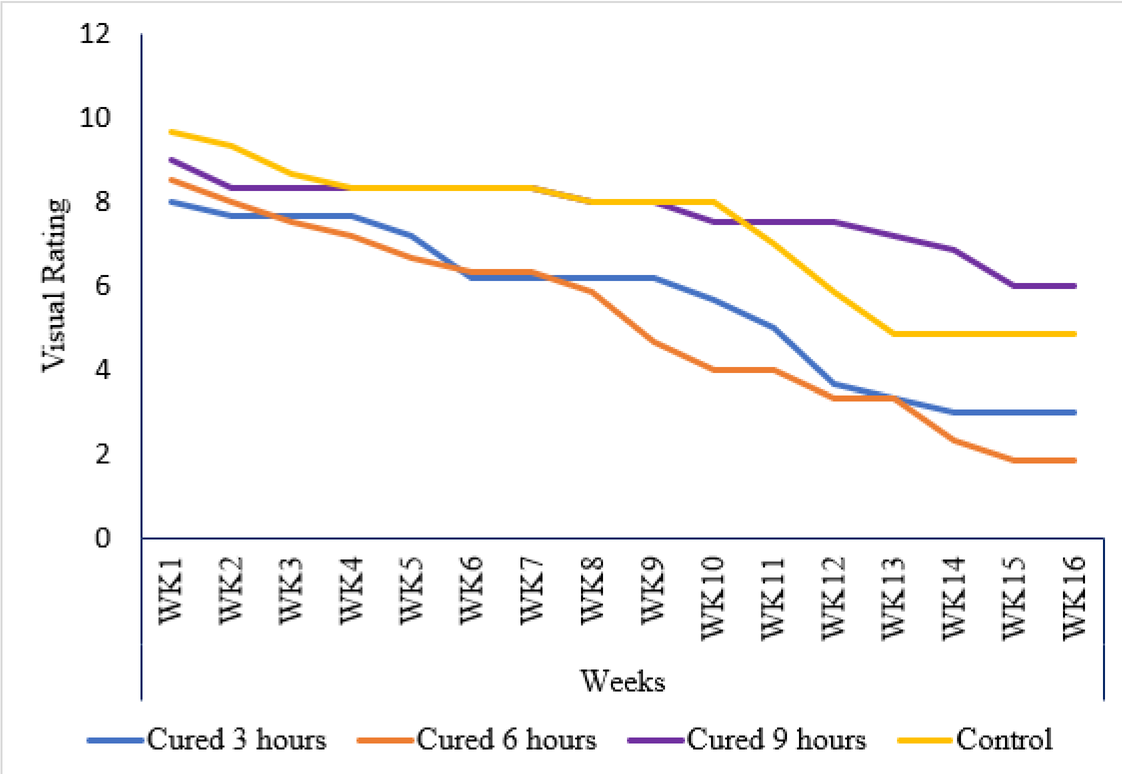

Figure 5: ASTM Visual ratings for 10 years old *G. arborea* wood treated with Lactic acid.

old samples treated with lactic acid cured for 9 hours performed better as they had light attacks for the first eleven weeks of testing after which it remains moderately attacked from week 11 to the end of the exposure. In performance, there is a similarity in the samples treated with lactic acid and cured for 3 and 6 hours as both came under light attack between the 3rd and 4thweeksof exposure to termites which translated to moderate attack between the 4th and 9th weeks and later experienced a heavy attack from 9th to 16th weeks with rapid fall. The results of ASTM visual assessment for a period of 16 weeks of 15-year-old *G. arborea* wood treated with lactic acid (Figure 6) showed that lactic acid treatment for 9 hours curing time performed better as it had a light attack for the first eight weeks and recorded moderate attacks between week 9 and 13, and continued to week 14 and 16 of the field test.

Gravimetric Weight Loss after Exposure to Termite

The weight percentage loss (WPL) after 16 weeks of exposure to termites' attack for the two different age groups of *G. arborea* wood treated with lactic acid cured at varying time schedules in Figure 7 showed that 10 years old *G. arborea* has the highest PWL value of 51.27 % higher than 15 years old with WPL value of 50.11 %. The samples cured for 6 and 3 hours had the highest average PWL value of 67.83 % and 62.28 %and the lowest value was recorded for those cured for 9 hours having PWL values of 31.35 % and 39.61 % for 10 and 15 years respectively. The Duncan multiple ranges presented in Table 4, showed that in terms of the biological durability of the wood species, there was a significant difference at $P<0.05$ between the curing time, samples treated with lactic acid and cured for 9 hours had the best performance which was not highly significant from the control samples, but significant from those samples cured for 3 hours and 6 hours.

DISCUSSION

Basic Physical Properties

Moisture content distribution of *G. arborea* wood exhibited a consistent decrease as the age increased. The variation pattern in the MC% may be influenced by a transitional stage to maturity. This corroborates with the work of Freddy and Roger (2008), that inflexion that occurs in MC % can be influenced by a transitional stage from Juvenile to mature wood. Density is an important parameter contributing to solid wood products' quality, strength, stability, and appearance. The findings from this result showed that *G. arborea* wood belongs to the low-density group as classified by Falemara *et al.,* (2012);

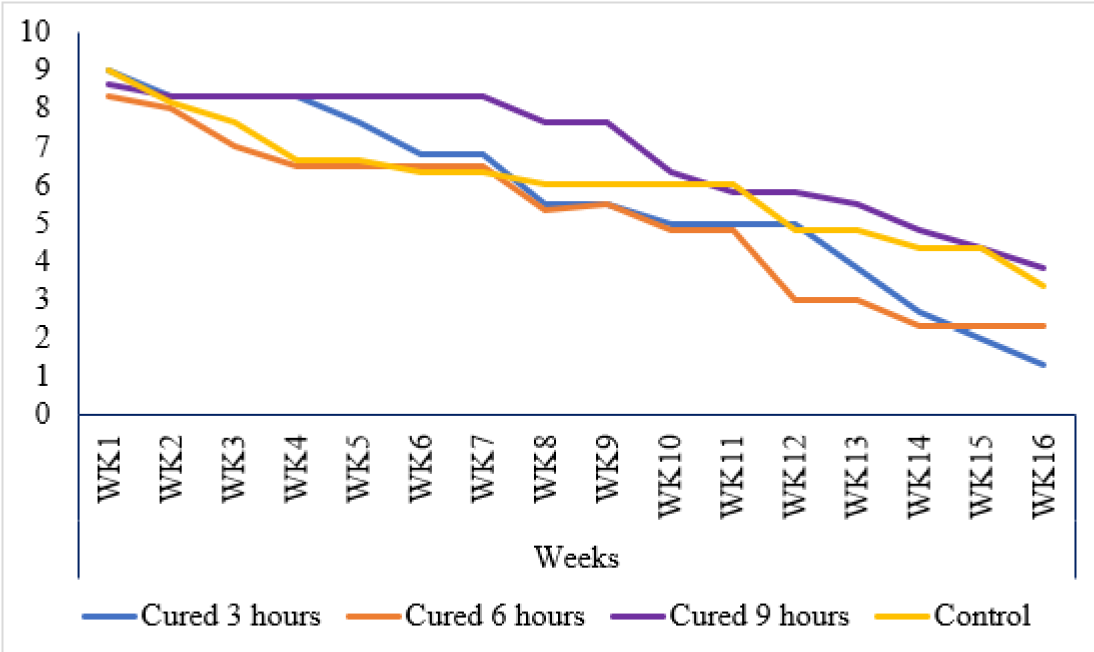

Figure 6: ASTM Visual ratings for 15 years old *G. arborea* wood treated with Lactic acid.

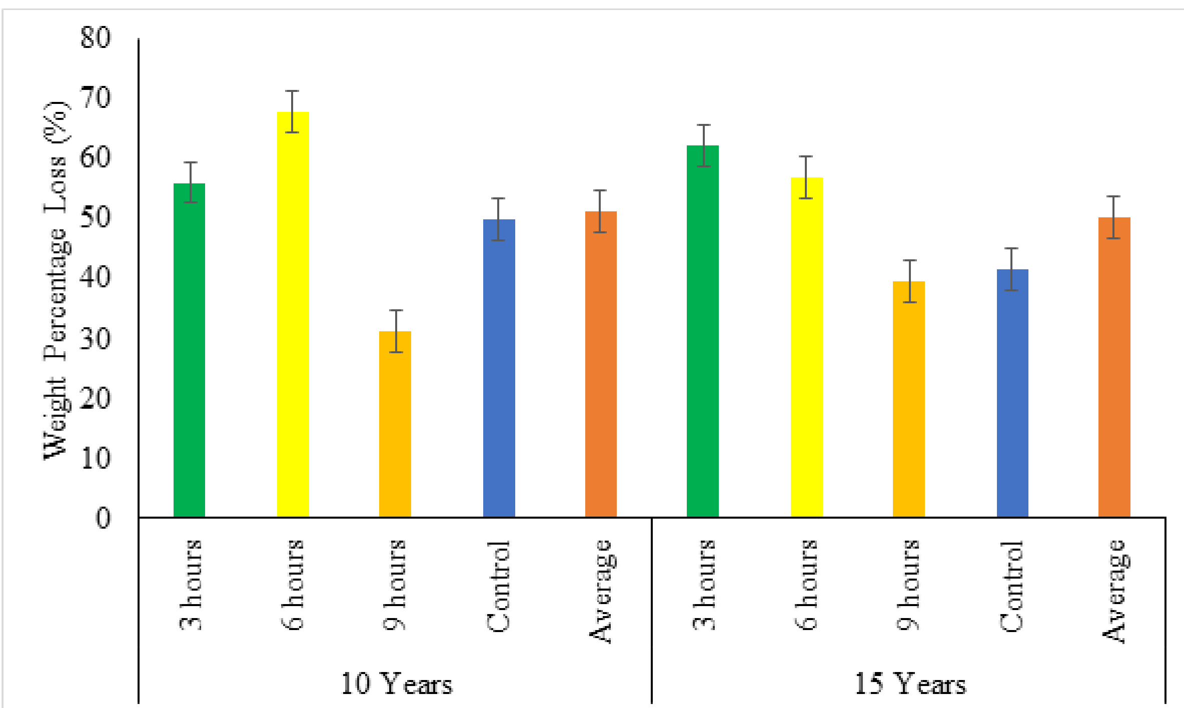

Figure 7: Distribution of weight percentage loss of wood treated with lactic acid after exposure to termite attack.

wood with a density of less than 500 kg/m^3 was classified as low-density. The effect of age on wood density was revealed as two age groups were compared, the older tree has a higher density. This corroborates with Ogunsanwo and Akinlade (2011) work which stated that the effect of age was highly significant on strength properties and variation patterns in *Gmelina arborea* wood and treatment should be included in their conversion

Table 4: Duncan's Multiple Range Tests for the weight percentage loss.

Treatment	**Weight Loss**
9 hours	35.4795[a]
Control	45.7532[ab]
3 hours	58.1370[b]
6 hours	59.6038[b]

Alphabets with the same letter show that there is no significant difference; Alphabets with different letters show that there was a significant difference.

and utilization strategies. Therefore, for material standardization the treatment of *G. arborea* wood is necessary as a result of Owoyemi *et al.* (2016) explained that reduction in the hygroscopic properties of *Gmelina arborea* wood will make it suitable for use in high moisture susceptible areas in construction. Wood modification has long been acknowledged to reduce equilibrium moisture content (EMC), and decay resistance in wood materials (Ringman *et al.,* 2019)

Chemical Uptake

The rate of chemical uptake gradually increased with varying values for the different treatments which potentially predict the chemical and wood fixation. The results indicate that the impregnation solution had a relatively uniform impregnation. The high percentage weight gain recorded for the treated *G. arborea* wood specified that the wood was compatible with the lactic acid after curing. The compatibility of lactic acid treatment and *G. arborea* wood is a critical factor in ensuring the effectiveness and durability of the treatment as incompatible combinations can result in chemical degradation over time, reducing the effectiveness of the treatment (Ringman *et al.,* 2019).

Strength Properties

Many low-density species are known for their low load-bearing capacity when subject to constant load (Ramage *et al.,* 2017). This study has proved that chemical modification of *Gmelina arborea* wood with lactic acid is a promising environmentally friendly solution to this disadvantage as the wood seems to hold the future for the construction industry within the tropics (Iwuoha *et al.,* 2021). The mechanical properties recorded show that there is an improvement and that the MOE varies with the difference in the curing time of the samples impregnated with lactic acid, as the strength properties increase as the curing time increases for the two different aged Gmelina wood. This improvement may be attributed to the densification of the wood after impregnation. This finding corroborates the assertion of Grosse *et al*. (2017) that the treatment of dry wood with a lactic acid solution leads to a lower polymerization level but confers good properties.
The treated samples showed considerable improvement in their strength properties with a decrease in age which was highly significantly different from the untreated samples. Ogunsanwo and Akinlade (2011), in their study of the effects of age and sampling position on Gmelina wood property, reported that the strength properties of *Gmelina* improved with age. Also, the treatment of G. arborea wood with lactic acid revealed that the strength properties of the wood increase as the curing time increases. This corroborates the work of Yunianti *et al.* (2019) that the modified densification process increased the bending strength of Pine and Gmelina wood from community forests, but the temperature and duration of treatment must be carefully considered for different wood species. *G. arborea* wood of this age group with this attained improvement in mechanical properties can be considered in the production of indoor furniture, where it is exposed to the elements with less potential damage from insects and fungi, improved mechanical properties make treated wood more durable and furniture made from treated wood will last longer and require less maintenance.

Durability Properties

Samples treated with lactic acid with 3 hours of curing time offered better resistance than the samples cured for 6 hours and the control samples. Many medium-density species are known for their low resistance to degradation (Owoyemi *et al.,* 2013). Consistent with the results obtained for durability assessment of the two different aged *G. arborea* wood presented, generally classified the wood as low durability. It was observed that after 16 weeks

of exposure, *G. arborea* wood treated with lactic acid showed resistance against termite attack with performance at the highest for those cured for 9 hours. This support Yunianti *et al.* (2019) who made an extensive review of the decay resistance of modified wood of various species and described that heat treatment of wood species affects its multiple properties: increases its resistance to decay, and affects its moisture content, among other properties (Kesik *et al*., 2014).
The curing of wood samples has been proven to enhance wood durability (Méndez-Mejía and Moya, 2016). The improvement of resistance to biodegradable agents' attack could attribute to modifications of the chemical components and attribute to both bulking effect and cross-linking reaction or network structure formed in the treated wood (Yan *et al.,* 2014). The drop in the resistance after some weeks of exposure might have been a result of the leaching of the chemical over time (Barbero-López *et al.,* 2021). This calls for further findings on how to ensure maximum fixation of the chemical substance for efficiency of treatment. This further validates the findings of Despot *et al.* (2008) that indicate wood modification with citric acid offered a promising alternative for wood treatment, but further research on optimization of modification parameters is needed to achieve improvement of wood properties. Owoyemi *et al.* (2011) reported that the wood structure of *G. arborea* constituted another barrier to the flow of the preservatives. *G. arborea* wood has a medium-specific gravity between 0.4 – 0. 6g/cm^3. Also, the deposition of extractives in the wood cell walls and the lumens during the biochemical transformation of the sapwood into the heartwood. This assertion corresponds with the report of Owoyemi (2010), that the dry heartwood of Gmelina wood is resistant to penetration by both water-borne and oily preservatives even when treated with vacuum pressure and hot treatment methods.
The percentage weight loss of the two different ages of *G. arborea* wood to termites explains the effect of lactic acid and curing time. It was noticed that wood samples impregnated with lactic acid and cured for 9 hours had the least percentage of weight loss when compared with the control samples. This followed the pattern of variation recorded for the visual rating after exposure to termites' attack for 16 weeks. Concerning this study observation, the extent of weight loss of treatment of *G. arborea* wood with lactic acid indicated the efficacy of using eco-friendly chemicals in the modification of wood for properties enhancement. Durability is a key factor in the selection of construction materials, as it affects the longevity and performance of structures over time, making them more suitable for use in exterior applications, such as decking, siding, and roofing (Mesa *et al.,* 2020; Geetha *et al.,* 2021).

CONCLUSION

The mechanical properties of *Gmelina arborea* treated with lactic acid were found to compare well with those of medium-density species and show good potential for use as a construction material.
The results obtained show that the timber types are hardwoods of higher strength classes when compared. The properties tests carried out on the treated timber types showed that the strength, durability, and density have not much difference in value within the two different ages investigated, however, considerable improvement was noticed as the age increases. To achieve maximum results in terms of mechanical strength it is recommended that tree species of older age should be considered since strength properties improve as the tree ages. However, to satisfy the need for early rotational age, the pressure impregnation of *G. arborea* with lactic acid offers adequate strength properties improvement of the 10 and 15-years wood species. The difference in the age of the wood is a major factor that affects the durability of *Gmelina arborea* wood as 15 years shows comparable improved strength properties when compared with 10 years old wood as the durability properties tend to increase with increased wood density.

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