



Influence of Thermal and Chemical Modification on the Physical and Mechanical Properties of *Leucaena leucocephala* Wood

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Authors' contributions

This work was carried out in collaboration between all authors. Authors designed the study, performed the statistical analysis and wrote the protocol and first draft of the manuscript. Author EAI modified the first draft while author BO supervised the study and edited the final draft. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJARR/2018/v2i229744

Editor(s):

(1) Dr. Abhinandan Surgonda Patil, Institute of Postharvest & Food Sciences, Agricultural Research Organization (ARO)–Volcani Center, State of Israel / Ministry of Agriculture & Rural Development, Israel.

Reviewers:

(1) Chong Leong, Gan, Malaysia.

(2) Rahim Foroughbakhch, Universidad Autónoma de Nuevo León, Mexico.

(3) Diene Ndiaye, University Gaston Berger of Saint Louis, Senegal.

Complete Peer review History: <http://www.sciencedomain.org/review-history/27078>

Original Research Article

Received 17 August 2018

Accepted 01 November 2018

Published 06 November 2018

ABSTRACT

This study examined the physical and mechanical properties of thermally and chemically modified *Leucaena leucocephala* wood. Sample planks were obtained from Akure and reduced to defect-free samples of 20 mm × 20 mm × 60 mm. Wood samples were oven dried to a constant weight at 103 ± 2°C and cooled in a desiccator before the thermal treatment. Heat treatment of wood was Carried out in a muffle furnace at 140, 160 and 180°C for 1hr and 2 hrs. Butyl Acetate was used for the chemical treatment. The dimensional stability, weight gain of the samples was measured with parameters such as volumetric swelling, percentage weight gain and water absorption. The result of WA showed that there was a decrease with increased temperature and treatment time. At a treatment time of 2 hr, lower values of WA were obtained as compared to the control samples which are 22.65% at 160°C and 17.15% for 180°C. Volumetric swelling values of 5.87 and 5.56 at 160°C and 180°C were obtained during the experiment. The result of the experiment showed that the water absorption of the wood decreases at increasing temperature and treatment time but after

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prolonged soaking of wood in water thermally treated wood showed lower resistance to biodeterioration as compared to chemically treated wood.

Chemically modified wood showed increased MOR at 2 hrs treatment time (109.75 N/mm^2) than thermally treated wood with MOR of 99.14 N/mm^2 at 160°C and 48.76 N/mm^2 at 180°C which makes them be more durable and can therefore be used for constructional purposes.

Keywords: *Modification; acetylation; butyl acetate; thermal treatment; physical properties; mechanical properties; Leucaena leucocephala.*

1. INTRODUCTION

The excellent properties of wood are widely recognised because it has been used in the manufacture of structures and shelters from the earliest ages of man. As the population and the needs of today's civilisation grow, the demand for forest and forest products keeps on increasing as the forest estate is drastically reducing. The annual demand for wood as a construction material exceeds the quantity of round log extracted from the forest reserves and forest plantations per annum. Out of about 10 million cubic meter of wood Nigeria requires for her major constructions, 0.62 million cubic meters can only be provided by the Forest reserves and existing plantations [1,2,3].

Another area that has been of interest to scientists recently is the area of modifying wood properties of lesser-used species to solve the problems of availability resulting from wood supply deficiency due to increasing population and slow growth rate of indigenous species. The wood modification is the process of improving the properties of wood to produce a new material that when disposed at the end of product life cycle doesn't present an environmental hazard greater than that of unmodified wood [4,5,6]. The thermal modification has long been known to increase the dimensional stability of wood by reducing its hygroscopicity and increasing the wood resistance to biodegradation [7,8,9]. It has been established that when wood is heated at a high temperature above 160°C , the chemical and physical properties of the wood undergo permanent changes and its structure is transformed [10,11,12].

The modification of wood will improve such properties such as decay resistance, dimensional stability, water repellency, strength properties and Ultra- Violet resistance [13,14,15]

This research focused on investigating the influence of thermal treatment and chemical modification on *Leucaena leucocephala* wood to improve the suitability of the wood species for

different applications since there is no such report on this particular wood species.

2. MATERIALS AND METHODS

2.1 Sample Size and Collection of Samples

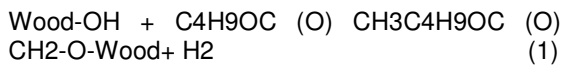
Samples of *Leucaena leucocephala* planks were obtained from The Federal University of Technology Akure plantation, Ondo State in dimensions of $900 \times 1200 \times 3600 \text{ mm}$, air-dried to approximately 20% moisture content. The beams were further processed to required dimensions with a circular saw in the wood workshop of the Department of Forestry and Wood Technology, the Federal University of Technology, Akure.

2.2 Material Preparation

Forty defect free specimens of dimensions $20\text{mm} \times 20 \text{ mm} \times 10 \text{ mm}$ were prepared for the physical test and samples were also prepared for the mechanical test in dimension $20 \text{ mm} \times 20 \text{ mm} \times 300 \text{ mm}$. Test samples were properly labelled and oven-dried at 105°C , cooled in a desiccator over a silica gel. Initial weights and dimensions of the samples were measured before thermal and chemical treatment. Control samples were also prepared to compare the effect of the modification techniques on the physical (thickness swelling, shrinkage, percentage weight gain, weight loss) and mechanical properties (MOE, MOR) of the chemical and heat treated wood. The heat treatment of the samples was carried out in a Muffle furnace with a temperature controlling unit for the regulation of the temperature. The samples were thermally treated at 140 , 160 and 180°C for 1 hr and 2 hrs. The temperature of the furnace was regulated to the temperature at which heat treatment of the samples should occur before the samples were introduced into the furnace. The samples were withdrawn at the end of each treatment period and cooled in a desiccator containing silica gel before subjecting them to further measurements.

Chemically treated *Leucaena leucocephala* was conducted in a closed stainless steel container placed in an oven at 80°C for 3 hrs in a pre-heated butyl acetate solution. Acetylation takes place under atmospheric pressure in the presence of air. A vacuum was pulled for an additional 1 hr at 80°C to remove excess untreated anhydride solution. The samples were then oven dried at 105°C for 24 hrs, cooled in a desiccator and weighed.

The acetylation reaction equation is as shown below;



(Wood) (Butyric acetate) (Butylated wood)
(Hydrogen gas)

Acetylation changes the free hydroxyl in the wood to acetyl group by chemical reaction and this reduces the ability of wood to absorb moisture.

2.3 Measurement of Samples

The acetylated samples of the wood were then measured for percentage weight gain, weight loss, volumetric swelling, water absorption. Vernier calliper and weighing balance were used to examine the effect of chemical modification on the wood samples. Ten samples of *Leucaena leucocephala* were subjected to treatment for 1 hr and 2 hr in comparison with the control samples. The samples were then removed after treatment, dried and cooled in a desiccator. From the measurements, volumetric swelling, water absorption, percentage weight gain, percentage weight loss was estimated with equations 1, 2, 3, 4 and 5.

The thickness swelling was calculated with the formula;

$$S (\%) = \frac{V_{wet} - V_{dry}}{V_{dry}} \times 100 \quad (2)$$

Where,

S = Volumetric Swelling
Vwet = Volume of samples after soaking in water
Vdry = Volume of the sample after oven drying

WATER ABSORPTION (WA)

$$WA (\%) = \left(\frac{W_1 - W_0}{W_0} \times 100 \right) \quad (3)$$

Where,

WA= Water Absorption
W1= Weight of wood after water absorption
W0= Weight of oven dried wood

$$PWL (\%) = \left(\frac{W_0 - W_t}{W_0} \times 100 \right) \quad (4)$$

Where,

PWL=Percentage weight loss
W0 =Oven dry weight before treatment
Wt =Weight after thermal and acetylation treatment

$$PWG (\%) = \left(\frac{W_t - W_0}{W_0} \times 100 \right) \quad (5)$$

Wo = Oven dry weight before treatment
Wt = Weight after thermal and acetylation

2.4 Statistical Analysis of Data

The data obtained from this research was used to analyse statistically to know if there is a significant difference in the properties of the wood being tested. The analysis of variance of the data collected was used to determine the influence of thermo-chemical modification on the physical and mechanical properties of *Leucaena leucocephala* wood at various levels.

The data obtained from this research was analysed using analysis of variance (ANOVA) with Factorial Experiment where the Temperature regime was Factor A, Duration of treatment was Factor B.

Design: (3×2) 2-factor Factorial Experiment in Completely Randomised Design

3. RESULTS AND DISCUSSION

3.1 Color

The result shows the colour changes at different temperatures and duration of thermally modified *Leucaena leucocephala* wood. The colour of thermally modified *Leucaena leucocephala* wood varied from pale creamy to light brown at 140°C at 1 hr, 2 hrs and 160°C at 1 hr to a slightly darker colour at 160°C. At 180°C for 1 hr the thermally treated wood was slightly darker and became darker when treated at 180°C for 2 hrs.

The most pronounced colour change was achieved when wood was thermally modified at 180°C for 1 hr while treatment at 2 hrs became darker and warping/distorting was noticed. The samples treated at 180°C for 2 hrs became darker than other samples and showed evidence of wood defect such as warping, twisting. Heat treatment improved some wood properties such as colour. It is a good approach to improve low market valued tropical woods [16]. The colour change for the chemical treatment was not pronounced as that of the thermal treatment. The penetration of chemical into the wood had little or no effect on the colour.

3.2 Dimensional Stability

The result of this experiment showed improved dimensional stability as indicated by the reduction in water absorption of the wood samples. The result presented in Table 2 shows the mean values of Volumetric swelling, shrinkage and water absorption for the thermally modified samples ranging from 17.15 (180°C for 2 hrs) to 26.26 (140°C for 2 hrs), the water absorption capacity of the samples was reduced relative to the control samples initially. The result showed that there was a significant difference in the temperature range of the treated samples and the control

The crystalline content of wood can be increased due to crystallisation in the quinsi-crystalline region in wood cellulose and even in the hemicelluloses [17,18].

3.3 Hygroscopicity of Wood

This result shows a significant reduction in the hygroscopicity of wood and indicates that heat treatment is a potent way to reduce water absorption in wood, The water absorption of

wood reduced with increased temperature and treatment time. The result of the experiment also shows that the impact of temperature on water absorption is more significant than treatment time.

From the result of volumetric swelling (SW), the mean values were lower for heat treated wood as compared to the control samples. The volumetric swelling ranged from 4.99% (180°C at 1 hr) to 6.59% (140°C at 1 hr). Analysis of the result showed that the volumetric swelling of control samples was slightly higher than of treated samples. Heat treatment has also been noticed to be a good way to reduce volumetric swelling of wood and the maximum decrease was noticed at 180°C for 2 hrs. The decrease in the volumetric swelling is attributed to a reduction in the moisture absorption of the wood.

3.4 Density

The effect of thermal treatment on the density of the thermally treated samples is presented in Table 1. For thermal modification, the increased loss of mass was due to the release of by-products from the wood due to thermal degradation of lignin and as a result of the evacuation of volatile compounds will reduce the density of the wood but for chemical treatment, the reduction of mass loss was due to bulkiness of chemicals into the wood which then occupies all the spaces and increases the density of wood as compared to thermal treatment [7].

3.5 Mechanical Properties

From Table 3, the result of MOR for the chemically treated wood showed that the mean value ranges from 109.75 N/mm²- 115.25 N/mm² while MOE mean value ranges from 16939.0 N/mm²- 22190.5 N/mm². The control samples



Heat treated specimens at different temperatures

mean value ranges from 90.0 N/mm²- 36766.0 N/mm². The ANOVA Table for the MOR shows that both temperature and time significantly affected the MOR and for MOE, there may be many factors that may be responsible for the

different MOR of heat-treated wood and untreated wood such as the atmosphere, temperature, duration of treatment, the rate of heating, weight and dimensions of the samples as listed by Kocafe et al. [17].

Table 1. Mean values of density for thermally modified *Leucaena leucocephala* wood

| Temp | Time (min) | PWG (24 hr) | PWL (24 hr) | D (24 hr) |
|---------|------------|-------------|-------------|-----------|
| Control | 0 | - | - | 770 |
| 140 | 1 hr | 8.36 | 7.5 | 760 |
| 140 | 2 hr | 6.22 | 5.47 | 770 |
| 160 | 1 hr | 6.92 | 7.24 | 780 |
| 160 | 2 hr | 8.17 | 7.51 | 790 |
| 180 | 1 hr | 11.75 | 8.56 | 750 |
| 180 | 2 hr | 10.77 | 5.36 | 760 |

Table 2. Mean values of water absorption for thermally modified *Leucaena leucocephala* wood

| Temp | Time (min) | VS (24 hr) | SW (24 hr) | WA (24 hr) |
|---------|------------|------------|------------|------------|
| Control | 0 | 6.03 | 7.76 | 27.72 |
| 140 | 1 hr | 3.55 | 6.59 | 25.6 |
| 140 | 2 hr | 2.77 | 6.94 | 26.26 |
| 160 | 1 hr | 6.49 | 6.45 | 25 |
| 160 | 2 hr | 5.87 | 5.11 | 22.65 |
| 180 | 1 hr | 6.59 | 4.99 | 17.48 |
| 180 | 2 hr | 5.56 | 1.38 | 17.15 |

Table 3. Mean values of MOR and MOE for thermally and chemically modified wood

| Treatment | Temperature | Time | MOR | MOE |
|------------------|-------------|------|----------|----------|
| TC | 140 | 1 hr | 137.415 | 12901.18 |
| | | 2 hr | 130.88 | 13605.78 |
| | 160 | 1 hr | 138.94 | 15165.23 |
| | | 2 hr | 99.14 | 12987.03 |
| | 180 | 1 hr | 123.01 | 13468.25 |
| | | 2 hr | 48.263 | 9271.65 |
| Acetyl | 80 | 1 hr | 115.75 | 16939 |
| | | 2 hr | 109.75 | 22190.5 |
| Control (TC) | | | 137.2817 | 11323.47 |
| Control (Acetyl) | | | 90 | 36766 |

Table 4. Analysis of variance in water absorption in thermally modified wood

| Source | Type III sum of squares | df | Mean square | F | Sig. |
|--------------------|-------------------------|----|-------------|-------|--------------------|
| Temperature | 322.337 | 2 | 161.169 | 3.858 | .040 |
| Time | 2.710 | 1 | 2.710 | .065 | .802 ^{ns} |
| Temperature * time | 9.385 | 2 | 4.693 | .112 | .894 |
| Error | 751.977 | 18 | 41.776 | | |
| Total | 13080.855 | 24 | | | |

Table 5. Analysis of variance for modulus of elasticity (MOE) in thermally modified wood

| Source | Type III sum of squares | Df | Mean square | F | Sig. |
|--------------------|-------------------------|----|--------------|--------|-------|
| Temperature | 30794140.210 | 2 | 15397070.105 | 10.308 | .001* |
| Time | 21434112.027 | 1 | 21434112.027 | 14.350 | .001* |
| Temperature * time | 24270823.893 | 2 | 12135411.947 | 8.124 | .003* |
| Error | 26886885.890 | 18 | 1493715.883 | | |

4. CONCLUSION

The hygroscopic and dimensional stability of *Leucaena leucocephala* was improved as measured by reduced water absorption and volumetric swelling in both thermal and chemical processes.

It was observed that the extent to which the thermal treatment affected the wood samples varied with temperature and the duration of treatment. Temperature range has a significant effect on the wood samples while time has an effect at a longer period of exposure. The colour of the thermally treated wood changed from pale creamy white to dark brown and finally to a darker colour for the temperature at 180 °C for 2 hrs. The hygroscopicity of wood due to thermal treatment was improved. The best temperature for improved physical properties was 180 °C for 1 hr where the colour and other physical properties were improved. The thermally treated *Leucaena leucocephala* wood can be used for polewood, furniture, parquet flooring, gum production among others while the chemically treated *Leucaena leucocephala* wood can be used for constructional purposes where durability and strength properties is desired

ACKNOWLEDGEMENT

I appreciate my creator the God Almighty who has gave me the privilege to make this work a success. My sincere gratitude also goes to my supervisor Prof. B. Olufemi for his encouragement and fatherly advice which helped me throughout the course of this project. I appreciate my parent in person of Mr and Mrs Ayanleye for their financial efforts to complete my education. My profound gratitude goes to my sister who always gave me good advice whenever I lose hope. I appreciate you from the bottom of my heart and say a big thank you my dear sister.

COMPETING INTEREST

Authors have declared that no competing interests exist.

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