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MECHANICAL RESISTANCE OF ACETYLATED AND DENSIFIED BOMBAX WOOD

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ABSTRACT

The objective of this study was to investigate the influence of acetylation and densification on the mechanical properties Bombax (*Bombax buonopozence)* sawn wood. Samples were randomly selected for the following treatments: compression at 20% and 50% densification (D_1 and D_2) and acetylation (Ac). The density and mechanical properties of treated and untreated wood samples were determined. The mechanical properties evaluated include bending strength, compression strength, Brinell hardness, screw withdrawal and abrasion.The results revealed that density of the wood increased from 316 kg/m^3 for the control to 361kg/m^3 for the acetylated wood, 385 kg/m^3 for the wood densified at 20 % compression and to 525 kg/m^3 for the wood densified at 50% compression. The compression strength increased from 12.63 MPa for the control to 21.57 MPa for the wood densified at 20 % compression and 24.59 MPa for the wood densified at 50% compression and to 27.01 MPa for acetylated samples. There was no significant difference between the different treatments while there were significant differences in the control. The bending strength and modulus of elasticity (MOE) also increased from 32.41 MPa and 57.9 MPa and 96.6 MPa for wood densified at 50 % compression respectively. The treatments were significantly different. The screw withdrawal resistance increased from 47.32 N/mm^2, for control to 55.44 N/mm^2 for acetylated wood, 67.19 N/mm^2 for wood densified at 20 % compression and 71.82 N/mm^2 for wood densified at 50 % compression. The results of the different treatments were not significantly different while the control showsignificant difference. The results of the abrasion test revealed that the control lost 5.60 x 10^{-4} g/cycle, the acetylated samples lost 6.3 x 10^{-4} g/cycle, while the densified samples at 20 % and 50 % lost 5.19 x 10^{-4} and 3.59 x 10^{-4} g/cycle respectively. The results showed that the various treatments conferred some improvements on the mechanical resistance of Bombax wood which was an indication of possible expansion of its area of use.

Keywords: Mechanical resistance, modification, densification, acetylation, bombax wood

INTRODUCTION

Bombax buonoponse is an important economic tree species in the rainforest zone of Nigeria. The tree is generally tall, sometimes reaching over 40 m in height with a diameter up to 100 cm (Ghelmeziu, 1981). It is in the group of fast growing species which according to Horman and Jorissen (2004), tends to deteriorate rapidly under biological and physical influences. Wilkinson (1979) classified the durability of wood into different classes; very durable, durable, moderately durable, non-durable and perishable. It is known that wood species belonging to the perishable class like Bombax are not generally suitable for use in construction works because it has low mechanical resistance and cannot withstand damp environment or last long when in contact with the ground. In practice this wood species is restricted in use to areas of form work,leaving a large proportion to waste (Horman and Jorissen, 2004). Wood is too valuable and versatile to be underutilised especially in viewof the level of advancement in the possibility to improve and add value to wood. Bio-deterioration has been one of the major problems of wood and it is well pronounced with Bombax. Bio-deterioration has been addressed mainly in Nigeria by impregnation with appropriate chemical preservatives depending on the areas of use.

Conventional wood impregnation methods (water or oil-borne preservatives) are based primarily on the use of toxic chemicals (Papadopoulos, 2010). As a result of environmental concerns however, there has been restrictions on the utilization of conventional chemical treatments as a result of their impact on human health (Olufemi and Olanipekun, 2008). According to FPL (2010) wood treated with copper chrome arsenate, creosote oil and pentachlorophenol requires a careful handling during utilization. Frequent or prolonged inhalation of sawdust of chemically treated wood is hazardous. Contact with creosote or pentachlorophenol-treated wood and their use for residential, industrial or commercial interiors are also being restricted. Burning of treated wood in stoves, fire places, and residential boilers have also been restricted as they could also produce toxic chemicals from smoke and ashes (FPL, 2010).

Wood modification is an alternative method to conventional wood preservation and its purpose is to change the characteristics of the wood without the attendant environmental hazards associated with wood impregnation (Hill, 2006). There are a range of possible wood modification methods: chemical, thermal, polymerization and enzymatic, with most of the technological advances having been in the first three modification types to date (BRE, 2007). According to Hill (2006) wood modification involves the action of a chemical, biological or physical agent upon the material, resulting in a desired property enhancement during the service life of the modified wood. The modified wood should be non-toxic under service conditions and furthermore, there should be no release of any toxic substances during service, or at the end of its life following disposal or recycling of the modified wood. Wood modification can change important properties of the wood including biological durability, dimensional stability, mechanical resistance such as hardness and UV stability (Ermeydan, *et al,* 2012). Controlling the moisture content of wood is a very effective way to protect timber and increase the mechanical resistance. In many wood applications improving the dimensional stability also helps by reducing structural defects such as the formation of cracks. A secondary effect of dimensional stability is the improved performance of paint coating systems and this can also function as a first objective, especially in applications at lower moisture risk but with high requirements for exact and constant dimensions (Horman and Jorissen, 2004).

The objective of this work was to modify Bombax wood by acetylation and densification and then investigate the effects of these modifications on some mechanical properties of the wood.

MATERIALS AND METHODS

Freshly sawn Bombax wood employed in this study was cut into pieces of 0.5 m length. The wood was conditioned at a room temperature of 20°C at a relative humidity of 65% until equilibrium moisture content was attained. Then, the boards were cut randomly into the different samples for the different treatments: densification at 20% compression (D_1), densification at 50% compression (D_2) and acetylation (Ac). The different treatments were then subjected to the various tests: compression, bending, hardness,screw withdrawal and abrasion.

Densification

Samples for densification were heated in the hot press to attained 70^{o}C and then compressed at 10MPa using metal stopper to achieve the 20% and 50% compression at different times.

Acetylation

Samples of the dry wood were heated in a solution of acetic anhydride containing 50% pyridine as catalyst to allow the diffusion of the mixture into the wood with subsequent acetylation. Acetylation changes the free hydroxyl group to acetyl group by chemical reaction and this reduces the ability of the wood to absorb moisture.

Compression Strength

Compression strength tests were carried out according to the ISO 3132 (1975b) standard. The nominal dimensions of samples were 20 mm x 20 mm(Radial and Tangential) in cross section and40 mm in the longitudinal direction. The loading speed was set such that each test was completed within 90±30 seconds using the Zwick Universal testing machine. The compression strength (σ_c) was calculated for each sample:

$$\sigma_c = \frac{p}{a.l} \quad \text{...} \quad (1)$$

σ_c = the compression strength, MPa (N/mm^2)

p = the load (N)

a = the thickness of the piece(mm)

l = the width of the piece (mm)

Bending Strength and Modulus of Elasticity

The bending strength and modulus of elasticity (MOE) were determined based on ISO 3133 (1975c) using the Zwick Universal testing machine. The nominal dimensions of the samples were 20 × 20× 300 mm, with the longest dimension in the longitudinal direction. The span between the points of suspension was 280 mm. The samples for acetylation were smaller and the bending strength experiments could not be carried out on wood samples. The speed of loading was set such that every test was able to end within 90±30 seconds. The bending strength (σ_B) was calculated for each sample as follows:

$$\sigma_B = \frac{3.p_{max}l}{2.\,b.h^2} \quad \text{...} \quad (2)$$

P_{max} = the load at the point of rupture (N):

l = the span between the points of suspension, (mm);

b = the width of the test piece, (mm);

h = the height of the test piece, (mm)

From the same experiment the modulus of elasticity (MOE) was calculated:

$$MOE = \frac{l^3 . m}{4. b. h^3} \quad \text{...} (3)$$

MOE = the modulus of elasticity, MPa;

m = the gradient of the initial straight-line portion of the load deflection curve;

$$m = \frac{P}{D}, \quad N/mm$$

D = the deflection of the centre of the beam at load P.

Hardness

The hardness by Brinell method was measured on Zwick Universal testing machine according to EN 1534 (2000). The steel ball 10±0.01 mm in diameter was impressed in the tangential and radial surfaces for tangential and radial hardness respectively with a loading force of 1000 N. The tests were done such that the 1000 N load was reached within 15±3 s and the force was maintained constant for another 25±5 s. The test was repeated five times for each of the surfaces. Brinell hardness was calculated from the depth of the impression of the ball and expressed in N/mm^2:

$$H = \frac{2 . F}{\pi . D [D -(D^2 - d^2)^{1/2}]} \quad \text{...} (4)$$

π = the "pi" factor (3.14);

F = the nominal force, N;

D = the diameter of the ball, mm

d = the diameter of the residual indentation, mm

Abrasion

The abrasion test was carried out on the Teledyne Taber 503 machine where the abrasive head was made to rotate against each of the test piece in 500 cycles. The loss of weight between the initial and final weight of the test piece before and after the test respectively was used to calculate the abrasion.

$$A = \frac{W_i - W_f}{500} \quad \text{.......................................} (5)$$

A= Abrasion (g/cycle)

w_i=initial weight of the test piece, g

w_f=final weight of the test piece, g

Screw Withdrawal

The screw withdrawal tests were carried out on the Zwick universal testing machine using ASTM D1037-78 by pulling the screw fixed on the test pieces until rupture occurred to measure the resistance to the pulling force.

Statistical Analyses

Statistical Package for Social Scientists (SPSS) software was used in the analysis of variance (ANOVA). When the differences that were found between groups were significant, multiple range tests were used to determine the differences between means at 95% confidence level.

RESULTS

The density result of the modified bombax wood samples showed that the control, C is 316 kg/m^3 and increased to 361 kg/m^3 for Acetylated sample A, 385 kg/m^3 for densified sample 1 D_1 and 525 kg/m^3 for densified sample 2, D_2 (Table 1). The mean percentage gain of the acetylated samples is 21.29.

Compression Strength

Results in Table 1 show the compression strength had a mean of 12.63 MPa for the control samples, 21.57 MPa for samples densified at 20 % compression, 24.59 MPa for samples densified at 50 % compression and 27.01 MPa for acetylated samples. The mean modulus of elasticity for the control samples was 3.12 MPa, 5.50 MPa for samples densified at 20 % compression, 7.71 MPa for samples densified at 50 % compression and 8.52 MPa for acetylated samples. The result of analysis of variance showed that there was significant difference in the compression strength of the treated samples. For the compression, MOR, at 20 % densification, 50 % densification and acetylation were not significantly different but were all significantly different from the control. The compression MOE for acetylated samples and 50 % densification was not significantly different but significantly different from the 20 % densification and the control samples.

Bending Strength

The bending strength had a mean of 32.42 MPa for control samples, 39.24 MPa for samples densified at 20 % compression and 43.89 MPa for samples densified at 50 % compression. The mean modulus of elasticity for control samples was 57.9 MPa, 73.1 MPa for samples densified at 20 % compression and 96.7 MPa for samples densified at 50 % compression (Table 1). Samples densified at 50 % compression were significantly different from 20 % compression and control, while 20 % densification was significantly different from the control.

Table 1: Mean values of the density and mechanical properties of *Bombax buonopozence* wood as influenced by densification and acetylation

	Treatments			
Properties	**Control**	**20 % Densification**	**50 % Densification**	**Acetylation**
Density (kg/m^3)	316	385	525	361
Compression (MPa)	12.63^b	21.57^b	24.59^a	27.01^a
Mean MOE (GPa)	5.79^c	7.31^b	9.66^a	
Mean MOR (MPa)	32.41^c	39.23^b	43.89^a	

Mean in the same row followed by the same letter are not significantly different at $\alpha = 0.05$.

The Screw Withdrawal Resistance

The mean values observed for the screw withdrawal resistance were 1065.55 N for the control samples, 1136.77 N for samples densified at 20 % compression, 1011.25 N for samples densified at 50 % compression and 1145.61 N for acetylated samples (Table 2). The withdrawal tension was 47.32 N/mm for the control samples, 67.19 N/mm for samples densified at 20 % compression, 71.82 N/mm for samples densified at 50 % compression and 55.44 N/mm for acetylated samples. The treatments: 20 % compression, 50 % compression and acetylation were not significantly different but significantly different from the control samples.

Abrasion

The mean abrasion for the control was 5.60 $\times10^{-4}$ g/cycle, 5.19 $\times10^{-4}$ g/cycle for samples densified at 20 % compression, 3.59 $\times 10^{-4}$ g/cycle for samples densified at 50 % compression and 6.30 $\times 10^{-4}$ g/cycle for acetylated samples (Table 2).The result of analysis of variance showed that there was significant difference in the abrasion resistance of the treated samples. The abrasion resistance was not significantly different between acetylated, control and samples densified at 20 % compression but are significantly different from samples densified at 50 % compression.

Hardness

Hardness test was conducted for the treatments and in the two major directions of wood using the Zwick universal testing machine. The mean hardness values for the control samples was 6.74 N/mm^2, 7.21 N/mm^2 for samples densified at 20 % compression and 9.79 N/mm^2 for samples densified at 50 % compression. The samples densified at 50 % compression were significantly different in hardness compared to the 20 % compression and the control. In the different directions of test, a mean of 7.91N/mm^2 was obtained for hardness in the radial direction and 7.92 N/mm^2 for the tangential direction. However, there was no significant difference in the hardness tests in both directions (Table 2).

Table 2: Mean values of Screw withdrawal resistance, withdrawal Tension, abrasion and hardness as influenced by densification and acetylation

	Treatments			
Properties	**Control**	**20 % Densification**	**50 % Densification**	**Acetylation**
Mean withdrawal force (N)	1065.55	1136.77	1011.25	1145.61
Withdrawal Tension (N/mm)	47.32^b	67.19^a	71.82^a	55.44^a
Abrasion (g/cycle) × 10^{-4}	5.60^a	5.19^b	3.59^b	6.30^a
Hardness (N/mm^2)	6.74^c	7.21^b	9.79^a	

Mean in the same row followed by the same letter are not significantly different at $\alpha = 0.05$.

DISCUSSION

The mean density increased with increase in percentage densification as expected. This is an indication of improved mechanical properties (Ghelmeziu, 1981). This was also confirmed by the result of the compressive strength, bending strength and moduli of elasticity, which also increased with the increase in the ratio of compression for densification as found by Wangaard (1981), Rautkari, (2010) and Gong and Lamason (2007). The difference between the mean density of the control samples and mean density of the acetylated samples (21.29 %) showed that the wood had some good retention of the acetic anhydride which was the agent of acetylation.

It was observed that the majority of the densified compression samples did not follow the normal deformation curve or Hooke's law unlike the samples for control and acetylation where majority of the samples followed the normal deformation curve. This trend may be due to collapse and damage done to the wood tissue subjected to compression (Rambu, 1981).

The screw withdrawalresistance increased with increase in the compression ratio of densification. This is an indication of improved resistance (Rowell, 2004). Though there was a slight increase for the acetylated samples compared with the control, the result was lower than that of densification at 20 % compression which was in turn lower than that for 50 % compression. The densified samples resisted abrasion better than the controlled sample while abrasion resistance was better as the densification compression ratio increased. However,acetylation reduced the abrasion resistance this may be due to the chemical reaction between the wood and acetic anhydride that was the agent of acetylation. This means that wood to be used in the areas of pronounced wear should not be acetylated. In the same vein, surfaces of wood exposed to abrasive materials should not be acetylated because it has shown that it may not resist frictional force. The hardness of the wood also increased with increase in densification ratio without any marked difference in the direction of test.

The test results showed that there were improvements in the properties of bombax wood. The density, compression strength, bending strength, modulus of elasticity, hardness and abrasion all increased with increased compression ratio in densification. However, acetylation decreased the abrasion resistance of the wood.

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