

MECHANICAL AND SORPTION PROPERTIES OF MAHOGANY (*Khaya Ivorensis*) AND TEAK (*Tectona Grandis*) WOOD COMPOSITES

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Abstract: The rate of waste generation in the wood industries in Nigeria is alarming. Production of wood composites from wood wastes could be a means of curtailing the enormous wood waste generated in the wood industry. This work examined the properties of wood composites from particles of Mahogany (*Khaya ivorensis*) and Teak (*Tectona grandis*) bonded with conventional water soluble adhesive used in the wood industry. The fabricated composites were tested for strength and sorption properties in accordance with ASTM standard. The results obtained revealed that the composites made at low mixing ratios had moderate strength and high sorption properties and thus can be utilised as indoor insulating components such as panelling while those of higher mixing ratio could be deployed for structural purposes. The properties of the boards were affected by the wood species and the mixing ratios used. The functional groups present in the adhesives were the hydroxyl, alkanes and alkenes.

Keywords: Wood waste, wood composites, Mahogany, Teak

Introduction

Enormous wood waste of about 45-50% is generated during timber processing operations. These items constitute environmental nuisance, pollution and are oftentimes disposed of by incineration, along the bank of streams and rivers or left to rot. As the demand for wood and wood products increase, the volume of waste being generated in the mill will also increase. Wood wastes however, are potential hazard to the wood mill, the wood and the mill workers especially in terms flammability and fungi and insects infestation (Oluoti *et al.*, 2014). Accumulation of wood wastes can also affect work rate negatively and result in reduced productivity (Oluoti *et al.*, 2014; Obaidi and Ajaj, 2015). A means of curtailing this deleterious effect could be in the production of value added composite products by bonding these wastes with the adhesives commonly used in the mill. The wood composites thus produced are known low-cost building components that can be adapted for panelling, ceiling, shuttering (Badejo, 1989,1998) which can augment the development of non-conventional construction materials in view of the escalating price of building components. Evaluation of the properties of these composites products will portend their suitability as low-cost building components either for exterior or interior applications. In this regard, this work therefore examined the properties of Mahogany (*Khaya ivorensis*) and Teak (*Tectona grandis*) wood composites bonded with conventional water soluble adhesives used in the wood industry in Nigeria.

Materials and Methods

Wood particles of Teak (*Tectona grandis*) and Mahogany (*khaya ivorensis*) were obtained from a local sawmill and air-dried for 2-weeks until 10% moisture content was attained. The dried particles were then sieved with a sieve of size 4.76mm. Particles that passed through the 4.76mm sieve were collected, mixed with conventional water soluble adhesive in the ratio 1:1, 2:1,1:2 and 3:1, and formed into a board in a wooden deckle measuring 30 x 30 x 10 cm³. The mat was cold pressed with a pressure of 3MPa for 30 minutes and then conditioned at room temperature (27 ± 2°) and at relative humidity of 72%. After conditioning, the densities of the composites were evaluated. Also, samples of the adhesive were dried and subjected to Fourier Transformed Infrared Radioscopy (FTIR) to determine the functional groups.

Flexural Test

The de-moulded boards were cut to samples sizes according to ASTM standard (D-4761 and D-6109) and tested on a Universal Testing Machine (UTM) cross head of 2mm/min from which the mechanical properties i.e. moduli of rupture (MOR) and elasticity (MOE) were evaluated

$$\text{MOR} = \frac{3PL}{2bh^2} \text{-----} (1)$$

$$\text{MOE} = \frac{PL^3}{4bh^3Y} \text{-----} (2)$$

Where P is the maximum load (N),

P is the load at the proportional limit (N),

Y is the deflection corresponding to P (mm),

b is the width of the specimen (mm),

h is the thickness of the specimen (mm), and

L is the span (mm), respectively.

Water Absorption [WA] and Thickness Swelling [TS] Test

Samples of the Teak and Mahogany bonded boards were initially weighed and then soaked in water at room temperature for 2 hours and then 24, 48 and 72 hours. At the end of the soaking period the samples were withdrawn from water and allowed to drain before the final weights and thicknesses were determined. The WA and TS of the wood species were determined following the expressions:

$$WA (\%) = \frac{W_t - W_i}{W_i} * 100 \text{-----} (3)$$

Where WA is the amount of absorbed water at time t,
Wt is the weights of the samples at time t and
Wi is initial weight of the samples, respectively.

$$TS (\%) = \frac{T_t - T_i}{T_i} * 100 \text{-----} (4)$$

Where TS is the thickness swelling after time t,
Tt is the thickness of the samples at time t and
Ti is the initial thickness of the samples, respectively

Results and Discussion

Density

The densities of the Mahogany (*K. ivorensis*) and Teak (*T. grandis*) composites were between 360.7 and 670.8 kg/m³ and 299.6 and 666.5 kg/m³ respectively (Tables 1 and 2). These values indicate that the composites are lightweight products. Statistical analyses (Duncan's multiple range test) revealed that the mixing ratio and wood species significantly ($P \leq 0.05$) affected the densities of the composites. Also, boards bonded with higher mixing ratios generally recorded significantly higher densities (Tables 1 - 3). This indicates that increasing the adhesive content during board production improved the interfacial bonding of the wood particles. Composites bonded with Mahogany particles had significantly higher densities than those of Teak.

Mechanical Properties

The results of the flexural tests are shown in Tables 1 and 2. As shown, the MORs of the Mahogany and Teak composites ranged from 9.6 to 63.8 N/mm² and 10.9 to 52.2 N/mm² respectively. The respective MOEs were between 3759.0 and 71,715.0 N/mm² and 787.0 and 7746.0 N/mm². These values are comparable to those obtained by Voulgardis *et al.*, (2003) and Osemeahon and Dimas (2014). The flexural test revealed that composites fabricated with lower mixing ratio generally had moderate strength values which can only be used as insulating components such as ceiling boards and panel products while those made of higher

Table 1: Physical and Flexural Properties of Mahogany Composites

Mahogany Wood			
Mixing Ratio	Density	MOR (N/mm ²)	MOE (N/mm ²)
1: 1	390.5 ^d (8.92)	9.9 ^s (0.01)	3759.0 ^{cd} (202.0)
1: 2	360.7 ^d (13.28)	9.6 ^s (0.01)	4596.0 ^{cd} (803.1)
2: 1	592.6 ^b (42.78)	43.0 ^c (0.06)	32,466.0 ^b (1842.3)
3: 1	670.8 ^a (72.76)	63.8 ^a (0.08)	71,715.0 ^a (8980.8)

Means with the same Letters for the same property are not statistically different

- Significant at $P \leq 0.05$ Probability level

Table 2: Physical and Flexural Properties Teak Composites

Teak Wood			
Mixing Ratio	Density	MOR (N/mm ²)	MOE (N/mm ²)
1: 1	330.2 ^{cd} (3.51)	10.9 ^f (0.04)	1816.0 ^{cd} (278.7)
1: 2	299.6 ^e (16.90)	20.7 ^d (0.01)	2193.0 ^{cd} (317.1)
2: 1	490.3 ^c (13.59)	52.2 ^b (1.48)	7746.0 ^c (581.5)
3: 1	666.5 ^a (10.08)	13.4 ^c (0.03)	787.0 ^c (108.3)

Means with the same Letters for the same property are not statistically different

- Significant at $P \leq 0.05$ Probability level

mixing ratios can be deployed for structural uses. Also, boards with higher densities and higher mixing ratio generally recorded higher MORs and MOEs. This may be due to the enhanced interfacial bonding between the wood particles with increasing adhesive content.

Statistical analyses (Duncan's multiple range test) revealed that the mixing ratio and the wood species significantly ($P \leq 0.05$) affected the MORs and MOEs of the fabricated composites (Table 3)

Table 3: Duncan's Test of the effect of Wood Species and Mixing Ratio on the Density, MOR and MOE of Mahogany and Teak Composites

Wood Species	Density (kg/m ³)	MOR (N/mm ²)	MOE (N/mm ²)
Mahogany	497.8 ^a (140.48)	31.5 ^a (24.01)	28,134.0 ^a (29,183.0)
Teak	440.5 ^b (148.60)	24.5 ^b (17.51)	3,136.3 ^b (2850.2)
Mixing Ratio			
1: 1	356.4 ^c (31.61)	10.4 ^d (0.55)	2787.6 ^c (1086.5)
1: 2	325.2 ^c (36.26)	15.2 ^c (6.03)	3394.6 ^c (1425.1)
2: 1	535.6 ^b (61.44)	47.9 ^a (5.47)	20,107.7 ^b (13,529.7)
3: 1	660.2 ^a (46.80)	38.6 ^b (27.43)	36,251.0 ^a (39,261.9)

Means with the same Letters and in the columns are not statistically different

- Significant at $P \leq 0.05$ Probability level

Sorption Properties

The results of the Water Absorption (WA) and Thickness Swelling (TS) are shown in Tables 4 and 5. As shown, the respective WA and TS after 2hrs and then 72hrs soak in water ranged from 28.4 to 164.3% and 1.0 to 13.5% respectively for composites produced from Mahogany. Those of Teak composites were from 13.0 to 192.8% and 1.0 to 12.0% respectively. These values compared favourably with those of Voulgardis *et al.*, (2003) and Osemeahon and Dimas (2014). From the results of the WA and TS, the composites had poor sorption properties and cannot be used in outdoor applications but as insulating indoor component such as panelling. However, composites made with higher mixing ratio generally recorded low sorption properties.

Statistical analyses (Duncan's Test) revealed that the wood species and mixing ratios significantly affected the WA of the composites whereas the soaking time and mixing ratio significantly affected the TS (Table 6). Composites made with higher adhesive mixing ratios and Mahogany had significantly lower WA. This may be attributed again to improved.

Table 4: Water Absorption of Mahogany and Teak Composites

Mixing Ratios	Water Absorption (%)			
	2hrs	24hrs	48hrs	72hrs
Mahogany Composites				
1: 1	112.5 ^{ef} (25.0)	113.0 ^{ef} (28.2)	121.8 ^{def} (4.5)	140.5 ^{def} (10.5)
1: 2	146.8 ^{bcd} (30.55)	164.3 ^{abc} (12.7)	-	-
2: 1	32.6 ^{klj} (3.2)	60.5 ^{hij} (4.8)	60.6 ^{hij} (4.7)	68.5 ^{ijk} (1.4)
3: 1	28.4 ^{kl} (16.1)	48.7 ^{hijk} (10.1)	56.3 ^{hijk} (9.6)	63.2 ^{ijk} (10.0)
Teak Composites				
1: 1	172.4 ^{ab} (5.3)	175.6 ^{ab} (6.3)	182.7 ^a (8.7)	192.8 ^a (9.9)
1: 2	139.6 ^{abcd} (56.7)	158.9 ^{abcd} (30.3)	-	-
2: 1	55.6 ^{hij} (4.0)	80.7 ^{gh} (3.4)	99.6 ^{fg} (10.8)	107.8 ^{fg} (0.5)
3: 1	13.0 ^{ijkl} (0.5)	39.2 ^{ijkl} (1.3)	46.5 ^{ijk} (2.3)	52.5 ^{hijk} (3.0)

Means with the same Letters and in the columns are not statistically different

- Significant at $P \leq 0.05$ Probability level

Table 5: Thickness Swelling of Mahogany and Teak Composites

Mixing Ratios	Thickness Swelling (%)			
	2hrs	24hrs	48hrs	72hrs
Mahogany Composites				
1: 1	1.3 ^e (0.9)	8.4 ^{abcd} (4.1)	10.3 ^{ab} (5.9)	12.4 ^{ab} (4.8)
1: 2	6.4 ^{bcd} (3.8)	9.3 ^{abc} (0.4)	-	-
2: 1	2.5 ^{de} (2.1)	5.7 ^{bcd} (1.3)	6.8 ^{bcd} (3.9)	9.1 ^{abc} (2.5)
3: 1	3.0 ^{cde} (1.7)	8.6 ^{bcd} (0.7)	11.6 ^{ab} (2.2)	13.5 ^a (3.2)
Teak Composites				
1: 1	3.4 ^{cde} (4.1)	7.5 ^{bcd} (4.3)	9.2 ^{abc} (1.3)	12.0 ^{ab} (4.1)
1: 2	1.0 ^{bcd} (0.4)	3.3 ^{cde} (1.8)	-	-
2: 1	2.5 ^{de} (1.3)	6.4 ^{bcd} (1.2)	8.4 ^{abcd} (3.0)	10.6 ^{ab} (2.6)
3: 1	3.0 ^{de} (0.7)	6.8 ^{bcd} (1.2)	8.7 ^{abcd}	9.4 ^{abc} (2.1)

Means with the same Letters and in the columns are not statistically different

- Significant at $P \leq 0.05$ Probability level

Table 6: Duncan's Test on the effect of Soaking Time, Mixing ratio and Wood species on the Sorption Properties of Mahogany and Teak Composites

Soaking Time (h)	WA (%)	TS (%)
2	90.3 ^a (66.1)	2.8 ^d (2.5)
24	95.3 ^a (50.4)	7.1 ^c (3.5)
48	98.4 ^a (49.7)	8.8 ^b (3.3)
72	98.7 ^a (49.2)	11.2 ^a (3.4)
Mixing Ratio		
1: 1	147.8 ^a (37.8)	7.8 ^a (5.2)
1: 2	146.0 ^a (33.9)	5.1 ^b (4.0)
2: 1	68.4 ^b (23.5)	6.5 ^{ab} (3.5)
3: 1	43.5 ^c (17.3)	8.1 ^a (3.9)

Wood Species		
Mahogany	84.7 ^b (44.0)	7.8 ^a (4.7)
Teak	106.1 ^a (61.2)	6.5 ^a (3.9)

Means with the same Letters and in the columns are not statistically different

- Significant at $P \leq 0.05$ Probability level

interfacial bonding with increasing adhesive content and the higher density of Mahogany composites in comparison with those of Teak

Fourier Transform Infrared Radioscopy

The spectra of the FTIR of the adhesive (Table7) revealed stretching vibrations of 3409cm^{-1} attributed to strong OH bond. The stretching vibration at 2960cm^{-1} of C-H methyl enhances water resistance and strength properties of the composites. The stretching Olefinic (alkene) C=C at 1643cm^{-1} is prone to oxidation and thus results in low strength properties. The bending vibration of OH at 1373.05cm^{-1} enhances flexibility.

Table 7: Functional Groups of the Conventional Water Soluble Adhesive

S/N	Wave number (cm^{-1})	Functional Groups
1	3409	OH, Hydrogen bonded
2	2960	Methyl C-H stretch (Alkanes)
3	1643.78	Olefinic (Alkene) C=C stretch
4	1373.05	OH bend
5	1241.96	Aliphatic Amines C-N

Conclusions and Recommendations

It is feasible to produce wood composites using the conventional water soluble adhesive used in the wood industry. The fabricated composites possessed moderate strength and high sorption properties and can only be adapted as insulating components in indoor applications. The strength and the sorption properties of the composites were enhanced with increase in density and wood: glue mixing ratios. Mahogany based composites had better strength and sorption properties in comparison with those of Teak possibly due to differences in anatomical structure. It is recommended that the thermal and other physicochemical properties of the composites be evaluated. Also, the possibilities of blending the adhesive used in this study with other adhesives be investigated.

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