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ORIGINAL RESEARCH ARTICLE

STRENGTH, SORPTION AND CHEMICAL PROPERTIES OF CEIBA PENTANDRA AND TECTONA GRANDIS WOOD COMPOSITE

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ABSTRACT

The enormous quantities of wood wastes in Nigerian sawmills and disused polystyrene from packaging can be converted to value added composite products thus curtailing their indiscriminate disposal; enhancing greener environment. This work examined the strength, sorption and chemical properties of wood composites made from Ceiba pentandra and Tectona grandis. Ceiba pentandra (Araba) and Tectona grandis (Teak) composite boards were made from polystyrene glue and a conventional water-based adhesive used in the wood industries. The fabricated boards were tested for strength and sorption properties while the functional groups of the composites were determined using the Fourier Transformed Infrared Radioscopy technique. The results obtained revealed that the composites had low strength, poor sorption properties and can only be utilized as insulating components in building construction. Polystyrene based composites possessed higher strength (Modulus of Rupture: 2.2 – 4.9 N/mm^2) and enhanced sorption properties (Water Absorption: 14.2 - 98.5 %; Thickness Swelling: 0.61 - 3.45%) in comparison with those of the water-based adhesives (Modulus of Rupture: 1.6 – 2.8 N/mm^2; Water Absorption: 33.4 – 158.4 % and Thickness Swelling: 1.80 – 7.41%) possibly due to preponderance of aromatic compounds which enhanced interfacial bonding. Increase in glue content significantly enhanced the strength and sorption properties of the wood composites

1.0 Introduction

Enormous quantities of waste estimated as 1.8 million tons per annum is generated by the wood industries in Nigeria in the form of off-cuts, plain shavings, wood rejects and sawdusts. This is as a result of lack of expertise of the machine operators, utilization of obsolete equipment and saw kerf. (Ogunbode et al., 2013; Ogunwusi, 2014). These items are injurious to the wood mill, mill workers and the wood products. Oftentimes, wood waste results in flammability, fungi and insect infestations. Also, polystyrene, a polymer of styrene used for packaging and insulation is a non-biodegradable product that is majorly discarded into the environment. The presence of these items in the society cause environmental pollution, health hazards and blockage of water ways (Kwon et al., 2009; Kan and Demirboga, 2009; Ricky et al., 2010)

Conversion of these wastes into value added products could be a means of curtailing this menace thus enhancing greener environment which consequently can help in reducing the existing pressures of over exploitation of the dwindling timber resource in Nigeria. One of the advantages of polystyrene based composites is that polystyrene is impervious to water and has closed cell characteristics which might enhance the mechanical properties of the resultant products (Adefisan, 2018). Composite products made from polystyrene and wood waste have been found to have moderate strength (4.9 – 32.0 N/mm^2) and can be integrated into low cost building components adapted for interior and exterior uses (Voulgardis, et al., 2003; Poletto, 2016; Adefisan, 2018). However, there is still paucity of information on properties of polystyrene based composites made from Nigerian grown hardwood. The knowledge of certain properties of polystyrene based composites such as the strength and sorption properties, is imperative to foment wider utilization and commercialization of the products. Therefore, this study was aimed at investigating the strength and sorption properties of polystyrene based composites made from Ceiba pentandra (Araba) and Tectona grandis (Teak) woods in comparison with those of conventional water-based adhesives commonly used in the wood industries. The functional groups of the fabricated composites using the Fourier Transformed Infrared Radioscopy (FTIR) technique were also evaluated.

2. Materials and Methods

Particles of C. pentandra and T. grandis woods were collected from a local mill in Ibadan, Oyo state while disused polystyrene (PS) were locally sourced within the Ibadan metropolis. The wood particles were air dried for 14 days to a moisture content of 10% and later sieved using 4.75 mm sieve. The particles that passed through the 4.75 mm sieve were collected and used for board formation.

2.1 Board Formation

The PS were cleaned, cut into smaller sizes of about 2 x 2 x 7 cm^3 and then dissolved in premium motor spirit (PMS) in the PS: PMS ratio of 1:2 (w/v) in accordance with the procedures of Adefisan (2018) until homogeneous slurry was formed. Particles of the wood species were mixed with PS-PMS slurry in the ratios 2:1 and 3:1, and formed into a mat in a wooden deckle measuring 30 x 30 x 10 cm^3. The mat was cold-pressed with a pressure of 3 MPa for 30 minutes and conditioned in a room at temperature (25 ± 2°) and at relative humidity of 72% for 14 days. This procedure was also carried out for boards formed with conventional water-soluble adhesive used in the wood industry as comparison.

2.2 Fourier Transform Infrared Radioscopy (FTIR) of the Polystyrene Glue

The functional groups of the composites were determined using the Fourier transform infrared (FTIR) machine (PerkinElmer FT-IR system spectrum BX) in accordance with the procedure adapted by Fabiyi et al. (2009). 2 mg of the dried samples was homogenized with 200 mg of Potassium bromated (KBR) salt. With the aid of hydraulic press, the powdered mixtures were pelletized into disc forms and inserted into the FTIR machine. Spectrum was taken as an average of 64 scans at a resolution of 4 cm^{-1}.

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2.3 Physical Property and Flexural Test

The de-moulded boards were cut to samples sizes according to American society for testing and materials (ASTM) standard D1037-96 and the densities of the composites were evaluated. Flexural test was conducted on a 600kN Okhard Universal Testing Machine (UTM) at cross head speed of 2mm/min from which the mechanical properties such as moduli of rupture (MOR) and elasticity (MOE) were evaluated.

2.4 Water Absorption (WA) and Thickness Swelling (TS) Tests

Samples of the C. pentandra and T. grandis bonded boards (five replicates) were initially weighed and then soaked in water at room temperature for 61 days and periodically measured in accordance with procedures adapted by Fabiyi et al., (2011). The WA and TS of the wood species were determined as expressions of the initial weights and thicknesses.

2.5 Statistical Analysis

The data obtained from the flexural and sorption tests were subjected to analysis of variance (ANOVA) at $P \leq 0.05$. Significant means were separated using Duncan's Multiple Range Test.

3. Results and Discussion

3.1 Results of the Fourier Transformed Infrared Radioscopy

Tables 1- 4 and Figures 1 and 2 show the band wave numbers of the functional groups present in the conventional water-soluble and polystyrene bonded composites. The composites had hydrogen bonded O-H stretching vibrations at 3412.65 – 3441.80 cm^{-1}, aliphatic C-H methylene stretching vibration at 2916.88 – 2930.97 cm^{-1}, Aromatic C-C stretching vibration at 1597.62 – 1605.62 cm^{-1}, C-C bending vibrations at 1441.83 – 1446.57 cm^{-1} and C-O stretching vibrations at 1031.02 - 1033.17 cm^{-1}. As shown in Tables 1- 4 and Figures 1 and 2, the polystyrene bonded composites had preponderance of aromatic compounds suggesting better interfacial bonding in comparison with those bonded with the water-soluble adhesives (Lampman et al., 2010; Osemeahon and Dimas, 2014). As shown, C=O carboxylic stretching band at 1731.14 cm^{-1} (Table 3) and aromatic C-H stretching band at 3027.45 cm^{-1} (Table 4) were observed in T. grandis bonded composites. These functional groups enhance interfacial bonding and induce strength in the composites (Lampman et al., 2010)

Table 1: Infrared Bands of Polystyrene based C. pentandra Composites

S/N	Wave number (cm^{-1})	Peak Assignment
1	3421.85	O-H Stretch (Hydrogen Bonded)
2	3027.94	Aromatic C-H Stretching Vibration
3	2916.88	Aliphatic C-H Stretching Vibration
4	1600.64	Aromatic C=C Stretching Vibration
5	1446.05	C-C Bending Vibration
6	1366.35	C-H Rocking Vibration
7	1031.55	C-O Stretching Vibration
8	754.3	Aromatic C-H Stretching Vibration
9	688.15	

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Table 2: Infrared Bands of Conventional Water Soluble based C. pentandra Composites

S/N	Wave number (cm^{-1})	Peak Assignment
1	3441.8	O-H Stretch (Hydrogen Bonded)
2	2930.97	Aliphatic C-H Stretching Vibration
3	1605.62	Aromatic C=C Stretching Vibration
4	1439.72	C-C Bending Vibration
5	1033.17	C-O Stretching Vibration

Table 3: Infrared Bands of Polystyrene based T. grandis Composites

S/N	Wave number (cm^{-1})	Peak Assignment
1	3424.68	O-H Stretch (Hydrogen Bonded)
2	3027.61	Aromatic C-H Stretching Vibration
3	2917.26	Aliphatic C-H Stretching Vibration
4	1731.14	C=O Stretching Vibration
5	1599.1	Aromatic C=C Stretching Vibration
6	1446.57	C-C Bending Vibration
7	1031.73	C-O Stretching Vibration
8	754.23	Aromatic C-H Stretching Vibration
9	688.71	

Table 4: Infrared Bands of Conventional Water Soluble based T. grandis Composites

S/N	Wave number (cm^{-1})	Peak Assignment
1	3412.65	O-H Stretch (Hydrogen Bonded)
2	3027.45	Aromatic C-H Stretching Vibration
3	2921.76	Aliphatic C-H Stretching Vibration
4	1597.62	Aromatic C=C Stretching Vibration
5	1441.83	C-C Bending Vibration
6	1031.02	C-O Stretching Vibration

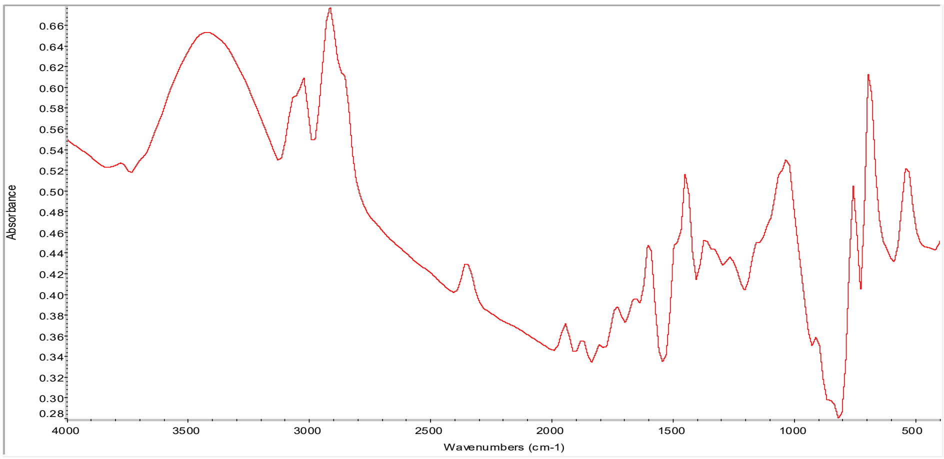

Figure 1: Infrared Bands of Polystyrene based Composites

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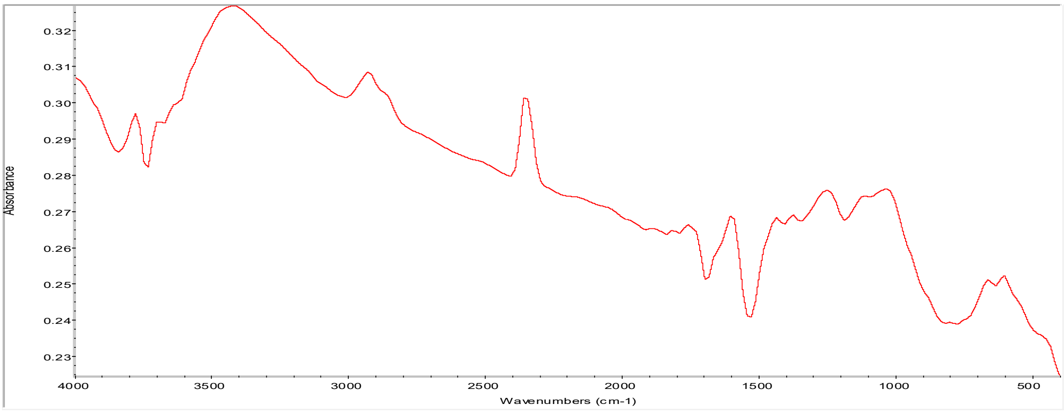

Figure 2: Infrared Bands of the Conventional Water Soluble based Composites

3.2 Physical and Mechanical Properties

3.2.1 Density

The densities of the composites are shown in Table 5. As shown, the density ranged from 441.0 to 686 kg/m^3 and from 467.1 to 687.5 kg/m^3 for the C. pentandra and T. grandis composites respectively. This suggests that the fabricated boards have moderate densities (Olorunnisola et al., 2005). Generally, composites bonded with higher adhesive mixing ratio had significantly ($p < 0.05$) higher densities indicating good interfacial bonding between the wood particles and the adhesive used. Also, composites bonded with disused polystyrene and T. grandis particles recorded significantly higher densities than those fabricated from the conventional adhesive and C. pentandra. This observation could be attributed to the fact that T. grandis belongs to higher strength group (N3 group) while C. pentandra belongs to lower strength (N7) group in accordance with the Nigerian Code of Practice (NCP, 2005; Olorunnisola, 2018). Thus, T. grandis woods may be more durable and stronger in comparison with C. pentandra. Also, the presence of more aromatic compounds in the polystyrene composites enhanced better interfacial bonding and mechanical properties in the composites in comparison with those bonded with the conventional water-soluble adhesives.

Table 5: Physical and Mechanical Properties of T. grandis and C. pentandra Composites

Mixing Ratio	Density (kg/m^3)	MOR (N/mm^2)	MOE (N/mm^2)
Polystyrene Based C. pentandra Composites			
2:1	554.0e (0.0)	2.2e (0.03)	4975cde (806)
3:1	686.0b (0.0)	3.1c (0.01)	7492bcd (2509)
Conventional Water Soluble Adhesive based C. pentandra Composites			
2:1	441.0h (0.0)	1.6h (0.10)	955.0e (73)
3:1	470.8f (0.0)	1.8g (0.01)	1409.0de (207)
Polystyrene Based T. grandis Composites			
2:1	682.0c (0.01)	3.6b (0.07)	13,283b (4833)
3:1	687.5a (0.0)	4.9a (0.10)	20,879a (6935)
Conventional Water Soluble Adhesive based T. grandis Composites			
2:1	467.1g (0.0)	2.0f (0.01)	5405.0cde (1896)
3:1	563.5d (0.0)	2.8d (0.03)	9201.0bc (3208)

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

Significant at 5% level of probability

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3.2.2 Flexural Properties

The result of the flexural tests of the C. pentandra and T. grandis composites are shown in Table 5. The Modulus of Rupture (MOR) of the composites ranged from 1.6 to 3.2 N/mm^2 and from 2.0 to 4.9 N/mm^2 and for the C. pentandra and T. grandis composites respectively. These values are lower than 14.5 – 32.0 N/mm^2 recommended by the Forest Products laboratory (Cai and Ross, 2010), those obtained by Voulgaridis et al., (2003) (14.5 - 25.2N/mm^2) and Adefisan (2018) (4.9 – 12.9 N/mm2). This suggests that the fabricated composites have low strength properties and cannot be used for structural purposes but as insulating components such as paneling. The low MOR can be adduced to be due to the low densities of the fabricated composites (441.0 – 687.5 kg/m3) and this is in line with the report of Olorunnisola et al. (2005). The Modulus of Elasticity (MOE) of the composites were between 955 and 7492.0 N/mm^2 and 5405.0 and 20,879.0 N/mm^2 for the C. pentandra and T. grandis composites respectively.

Generally, composites bonded with higher adhesive mixing ratio recorded higher MORs and MOEs suggesting enhanced interfacing bonding with increasing adhesive content. Also, composites bonded with polystyrene due to pre-ponderance of aromatic compounds which enhance interfacial bonding recorded higher MORs and MOEs. Likewise, composites bonded with T. grandis particles generally had higher MORs and MOEs than those bonded with C. pentandra. This observation may be attributed to preponderance of strength inducing components, higher density of the T. grandis composites (Table 6) and the variation in strength characteristics of the woods used. While T. grandis belonged to N3, a higher strength class C. pentandra belonged to N7, a lower strength class (NCP, 2005)

Statistical analyses (Duncan's Multiple range Test) (Table 6) revealed that species of wood, the mixing ratios and the glue types employed in the study significantly affected the MORs and MOEs of the fabricated composites.

Table 6: Duncan's Multiple range Test of the Effect of Species, Mixing Ratio and Glue Types on the Moduli of Rupture and Elasticity and Density of Teak and Araba Composites

Variables	Density (kg/m^3)	MOR (N/mm^2)	MOE (N/mm^2)
Species			
C. pentandra	537.9b (99.2)	2.2b (0.61)	3708.0b (3020)
T. grandis	600.0a (95.4)	3.3a (1.11)	12,192.0a (7171)
Mixing Ratio			
2:1	602.0a (95.0)	2.3b (0.78)	6268.0b (5054)
3:1	536.0b (98.3)	3.1a (1.17)	9632.0a (8252)
Glue Types			
Polystyrene	6524a (59.3)	3.4a (1.0)	11,657.0a (7421)
Conventional	485.6b (48.5)	2.0b (0.5)	4242.0b (3840)

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

Significant at 5% level of probability

Sorption Properties

The results of the water absorption (WA) and thickness swelling (TS) of the C. pentandra and T. grandis are shown in Table 7 and Figure 3. Figure 3 shows the WA of the composites reaching a

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pseudo-equilibrium state in accordance with Fickian behaviour (Rangaraj and Smith, 2000). The WA ranged from 14.2 to 158.4% and from 16.9 to 144.1% for the C. pentandra and T. grandis composites respectively. The respective TS ranged from 1.40 to 7.41% and 0.61 to 3.55%. These values (WA: 14.2 to 158.4% and 16.9 to 144.1% , although high and TS: 1.40 to 7.41% and 0.61 to 3.55%) compared favourably with those of Voulgaris et al., (2003) (WA: 11.4 -93.2% for 2 – 24 h, TS: 2.1 – 17.0%) and Adefisan (2018) (WA: 2.2 – 140%; TS: 0.5 – 7.1% for 2 -72 h). As shown in Table 7, the recorded WA and TS indicate that the fabricated boards were generally not dimensionally stable and cannot be used for exterior applications.

Composites made from T. grandis particles with higher mixing ratios and bonded with polystyrene glue generally recorded lower WA and TS and were more dimensionally stable than those of the water-soluble adhesives. This observation may be attributed to higher densities of the Teak composites in comparison with those of C. pentandra, enhanced interfacial bonding with increasing glue content and the pre-ponderance of aromatic compounds in the polystyrene composites which enhanced interfacial bonding than those of water based composites.

Table 7: Water Absorption and Thickness Swelling of C. pentandra and T. grandis Composites

Mixing Ratio	Water Absorption		Thickness Swelling	
	1 Day	61 Days	1 Day	61 Days
Polystyrene Based C. pentandra Composites				
2:1	46.6f (0.47)	98.5d (2.80)	1.64cde (0.90)	2.72bcde (0.14)
3:1	14.2h (1.51)	64.3e (6.00)	1.40cde (0.44)	1.74cde (0.93)
Conventional Water Soluble Adhesive based C. pentandra Composites				
2:1	112.3c (9.29)	158.4a (3.70)	1.80cde (0.10)	3.46bc (0.43)
3:1	49.4f (0.78)	100.6d (3.31)	4.23b (2.11)	7.41a (2.24)
Polystyrene Based T. grandis Composites				
2:1	19.7h (2.28)	63.7e (1.51)	1.18ed (0.97)	3.45bc (1.10)
3:1	16.9h (2.30)	61.7e (1.85)	0.61e (0.34)	2.68bcde (0.81)
Conventional Water Soluble Adhesive based T. grandis Composites				
2:1	116.4c (11.43)	144.1b (4.24)	2.97bcd (1.48)	3.55bc (0.72)
3:1	33.4g (3.37)	101.6d (0.46)	2.68bcd (0.39)	3.20bcd (0.09)

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

Significant at 5% level of probability

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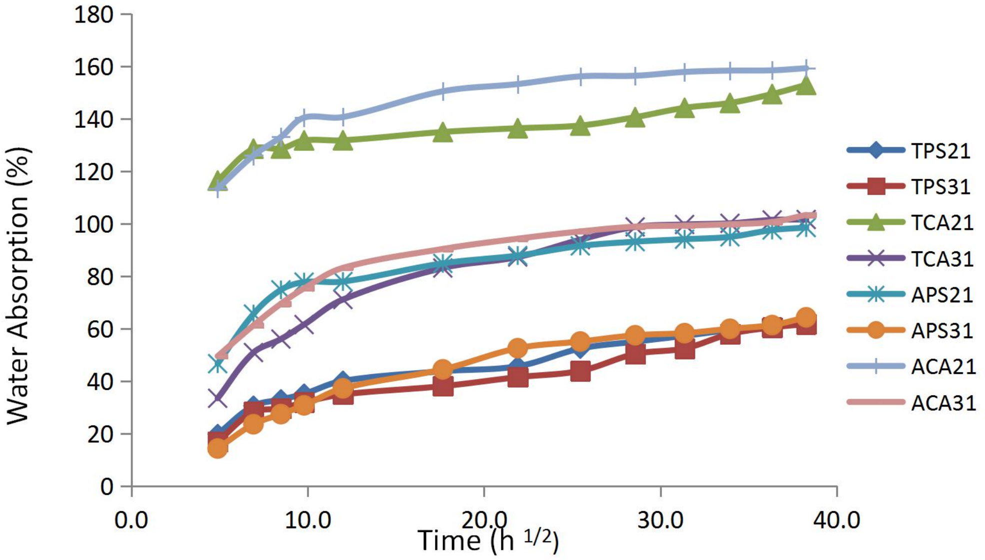

* ACA21- Conventional Water Soluble Adhesive based C. pentandra composites (2:1 Mixing Ratio)

* CPS21- Polystyrene based C. pentandra composites (2:1 Mixing Ratio)

* TCA21- Conventional Water Soluble Adhesive based T. grandis composites (2:1 Mixing Ratio)

* TPS21- Polystyrene based T. grandis composites (2:1 Mixing Ratio)

Fig. 3: Water Absorption of C. pentandra and T. grandis Composites

4.0 Conclusions

Wood composites were produced from disused polystyrene and the common conventional water soluble adhesive used in wood industry. The fabricated composites possessed moderate strength, poor sorption properties and can be used as insulating components such as paneling. The strength and sorption properties of the fabricated composites were influenced by the glue types, mixing ratio and the species of wood used in production. Tectona grandis composites had higher strength and better sorption properties in comparison with those made from Ceiba pentandra possibly due to the structural integrity of the T. grandis wood. Polystyrene bonded composites had better strength and sorption properties than those made from the conventional adhesive due to preponderance of aromatic compounds.

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