Evaluation of the Strength and Sorption Properties of Injection-moulded Plastic Composites of Teak (Tectona grandis) and Ọ̀mọ̀ (Cordia millenii) Woods

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Abstract

Wood and plastic wastes are sources of environmental pollution. Conversion of these items into value added moisture resistance products can curtail this menace. This work examined the strength and sorption properties of injection-moulded wood plastic composites of teak (*Tectona grandis*) and *ọ̀mọ̀* (*Cordia millenii*) woods using disused automobile battery cases and virgin polypropylene plastics. Milled particles of teak (*Tectona grandis*) and *ọ̀mọ̀* (*Cordia millenii*) woods were injected in an injection moulder with disused automobile battery cases and virgin polypropylene plastics and fabricated into plastic composites. The fabricated boards were cut to specimen sizes in accordance with ASTM D 790-07 and D 570-98, tested on a universal testing machine for flexural properties while sorption properties were determined after soaking in water for 2 and then 144 hours. The results obtained indicated that the composites possessed adequate strength (modulus of rupture: 18.2 – 28.1 N/mm^2) applicable for structural purposes and were dimensionally stable with low sorption and swelling rates (water absorption: 0.0 -1.07%; thickness swelling 0.0 - 0.67%).

Keywords: Wood plastic composites, Injection moulding, *Tectona grandis* and *Cordia millenii*

Introduction

Wood, like other bio-materials, is susceptible to biodegradation when subjected to fluctuating cycles of moisture content, which is a major setback in its utilisation for furniture and construction works (Clemons, 2002). The incorporation of an impervious material such as plastic can however reduce the moisture ingress, thereby enhancing serviceability (Stark and Rowlands, 2003). The deployment of plastics in wood, known as wood plastic composites (WPCs) is not new but has been used in many developed countries such as the United States of America and the United Kingdom in diverse building applications such as decking, fencing, window and door frames, park benches, indoor and outdoor furniture. The advantageous properties of WPCs in building construction include enhanced dimensional stability due to reduction in water absorption and swelling, which often results in the eradication of biodegrading organisms (Fabiyi and Mcdonald, 2010). Wood plastic products also exhibit improved durability against checking, decay, termites, and marine organisms (Kuo et al., 2009; Fabiyi and McDonald, 2010).

In Nigeria, enormous waste is generated in most sawmills due to the use of obsolete equipment, improper sawing methods and lack of expertise (Ogunbode et al., 2013). Also, disused plastics such as automobile battery cases are not biodegradable and impervious. These items are indiscriminately disposed through land filling, open air incineration, dumping in waterways, etc. They however, constitute environmental nuisance and oftentimes result in health hazards (Adefisan, 2018). The utilisation of these wastes in composite production can enhance a greener environment and also promote the development of low-cost building components which could alleviate the dependence on expensive components used in housing construction. Properties of plastic composites fabricated from these items are scarce in literature and need to be investigated. This work therefore examined the strength and sorption properties of injection-moulded plastic composites made from particles of teak (*Tectona grandis*) and *ọ̀mọ̀* (*Cordia millenii*) woods in combination with waste plastic from disused car battery cases and virgin polypropylene plastic.

Materials and Methods

Wood flours (0.7mm) of teak (*Tectona grandis) and ọ̀mọ̀ (Cordia millenii)* obtained from a local sawmill were dried to 0.5% moisture content and sieved with a 0.25mm wire mesh. Locally-sourced shredded waste battery cases (WBC), virgin polypropylene (PP) and 2% calcium carbonate ($CaCO_3$) (based on the mass of the wood flour) used as additive were mixed with the sieved wood flours in ratios 1: 40: 0.02; 1.5: 40: 0.03; 2: 40: 0.04, and fed into the heating barrel of a Woo Sung BSE-180 injection moulder at a temperature range of 150°C to 170°C. The molten mixtures were then injected through the injection cylinder into 200mm × 100mm × 6mm moulds. Samples of the wood plastic composites produced were prepared for flexural and sorption tests in accordance with ASTM D790-07 and D570-98 standards and the densities of the WPCs evaluated.

Flexural test

Three point flexural tests (modulus of rupture (MOR), modulus of elasticity (MOE)) were performed in accordance with ASTM standard D790-07 in five replicates measuring 20mm × 6mm × 120mm at a crosshead speed of 2 mm/min until failure occurred. The moduli of rupture (MOR) and elasticity (MOE) were evaluated as:

$$MOR = \frac{3Pl}{2bh^2} \quad (1)$$

$$MOE = \frac{Pl^3}{4bh^3y} \quad (2)$$

where :

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)

l is the span (mm)

Water absorption and thickness swelling test

Five replicate specimens measuring 5mm × 5.6mm × 50mm were immersed in water at 25 ± 2°C for 2, 24, 72 and 144 hours in accordance with ASTM D570-98. Weight gain and thickness swell were measured on a total composite basis for determination of water absorption (WA) and thickness swelling (TS) respectively, which were expressed as:

$$WA = \frac{W_2 - W_1}{W_1} \times 100 \quad (3)$$

$$TS = \frac{T_2 - T_1}{T_1} \times 100 \quad (4)$$

where:

W_1 is the initial weight (g)

W_2 is the final weight (g)

T_1 is the initial thickness (mm)

T_2 is the final thickness (mm)

Statistical Analyses

The data obtained from the flexural and sorption tests were analysed using analysis of variance (ANOVA) at $P \leq 0.05$ and significant means were separated using Duncan's multiple range test.

Results and Discussion

Density

The densities of the plastic composites are shown in Table 1. The densities ranged between 2502.4 and 3010.8 kg/m^3 and 2560.3 and 3106.9 kg/m^3 for the *C. millenii* and *T. grandis* composites respectively. These results indicate that the composites are high density products as specified by Olorunnisola et al. (2005). As shown in the table, the densities of the composites generally increased with increasing wood content. Except for the proportion of the wood content used in the study, the densities were not

significantly ($P<0.05$) influenced by the wood species and plastic matrix used in the composite production (see Table 2).

Flexural properties

The flexural properties of the composites are shown in Table 1. The MORs ranged from 18.2 to 28.1 N/mm^2 and 16.7 to 27.6 N/mm^2 for the *C. millenii* and *T. grandis* composites respectively. These values are comparable with 1.72 to 24.4 N/mm^2 reported by Aina et al. (2013, 2016), Izekor and Mordi (2014) and 25.4 – 52.3 N/mm^2 reported by Cai and Ross (2010). The flexural properties of the plastic composites suggest that they have adequate strength and can be deployed as load bearing components in building construction. Generally, the MORs of the composites decreased with increasing wood content, suggesting poor interfacial bonding with increasing wood particles and the plastic matrix. Also, composites manufactured from *C. millenii* generally recorded higher MOR than those of teak. This may imply that the teak particles were not readily compatible with the plastic matrix.

In addition, composites made from waste plastic generally recorded higher MOR than those of virgin plastic. This observation may be due to the fact that automobile battery cases are usually manufactured from combinations of polypropylene and polyethylene terephthalate (Batteryeducation.com, 2018) which could have inherently enhanced its strength (MOR of waste plastic was 23.3 N/mm^2 as against 16.9 N/mm^2 for virgin plastic, Table 1).

Similarly, the MOEs of the composites ranged from 9,106 to 14,960 N/mm^2 and 8,298 to 8943 N/mm^2 for the *C. millenii* and *T. grandis* composites respectively (Table 1). These values are comparable with 341.0 to 15,717 N/mm^2 obtained by Aina et al. (2013, 2016) and Izekor and Mordi (2014). The MOEs of the composites generally increased with increasing wood content suggesting that increasing the wood content increased the elasticity of the composites (Aina et al., 2013). Again, composites made from *C. millenii* generally recorded higher MOEs than those of teak implying poor interfacial bonding between the teak particles and the plastic matrix. Again, composites made from waste plastics generally recorded higher MOEs than those from virgin plastics.

Statistical analyses (Duncan's test) revealed that whereas the species of wood, the wood content and the matrix used significantly influenced the MOR of the composites, the MOE was not affected by these parameters (Table 2).

Table 1: The density, moduli of rupture and elasticity of *C. millenii* and *T. grandis* plastic composites

Wood content	MOR (N/mm^2)	MOE (N/mm^2)	Density (Kg/m^3)
Waste Plastic + *C. millenii* Particles			
50g	23.3^{b}(0.72)	$9{,}106^{bcd}$(7800.1)	2502.4^{f}(32.5)
75g	22.9^{b}(0.99)	$10{,}429^{bc}$(2655.7)	2937.7^{abcd}(31.3)
100g	28.1^{a}(0.81)	$12{,}887^{ab}$(4076.2)	2816.6^{abcdef}(35.9)
Virgin Plastic + *C. millenii* Particles			
50g	27.7^{a}(0.49)	$14{,}960.0^{a}$(3235.0)	2796.1^{abcdef}(27.1)
75g	21.6^{b}(4.52)	$7{,}789^{cd}$(1279.6)	2870.2^{abcd}(30.7)
100g	18.2^{c}(1.10)	$5{,}230^{d}$(716.2)	3010.8^{abc}(92.8)
Waste Plastic + *T. grandis* Particles			
50g	27.6^{a}(0.64)	$8{,}943^{bcd}$(2114.9)	2560.3^{ef}(29.3)
75g	22.8^{b}(0.20)	$8{,}218^{cd}$(1472.6)	2958.6^{abc}(10.1)
100g	21.6^{b}(1.00)	$8{,}726^{bcd}$(739.0)	2666.3^{def}(29.1)
Virgin Plastic + *T. grandis* Particles			
50g	16.7^{c}(0.57)	$4{,}741^{d}$(1203.2)	2686.8^{cd}(16.8)
75g	22.8^{b}(2.82)	$8{,}082^{cd}$(1057.3)	3144.1^{a}(39.6)
100g	17.2^{c}(0.21)	$6{,}779^{cd}$(1456.6)	3106.9^{ab}(21.3)
Waste Plastic	23.3^{b}(0.25)	$8{,}311^{cd}$(105.8)	2780.0^{bcdef}(25.3)
Virgin Plastic	16.9^{c}(0.15)	$6{,}917^{cd}$(1045.8)	2907.6^{abcd}(41.6)

* Significant at 5% level of probability

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

* Standard deviation in parentheses

Table 2: Duncan's multiple range test of the effect of wood species, wood content and matrix on the moduli of rupture and elasticities of wood plastic composites

Variables	MOR	MOE	Density
Wood Species			
C. millenii	23.6[a](3.93)	9718.2[a](3811)	2822.3[a](201.9)
T. grandis	21.5[b](3.94)	7,930.1[a](3758.4)	2853.8[a](293.0)
Wood Content			
50g	23.8[a](4.66)	9,437[a](5436.2)	2636.4[b](192.5)
75g	22.5[ab](2.50)	8629[a](1890.1)	2977.6[a](174.3)
100g	21.3[b](4.56)	8406[a](3569.0)	2900.1[a](243.4)
Matrix			
Waste Plastic composites	23.3[a](0.25)	8,311[a](1058.4)	2740.3[a](253.1)
Virgin Plastic Composites	16.9[c](0.15)	6917[a](1045.8)	2935.8[a](416.1)

* Significant at 5% level of probability

* Means with the same letters and in the same columns are not statistically sifferent

* Standard deviation in parentheses

Sorption properties

The results of the sorption properties are shown in Tables 3 and 4. The water absorption (WA) of the composites were between 0 and 1.07% and 0 and 0.65% for the *C. millenii* and *T. grandis* composites respectively. The respective thickness swelling (TS) ranged from 0.05 to 0.81% and 0 to 0.67%. These values compare favourably with those of Migneault et al. (2008); San et al. (2008) and Izekor and Mordi (2014). The fabricated composites have low sorption rates and can be utilised for both indoor and outdoor applications. Increase in the wood content significantly increased the WA of the composites due to increase in water residence sites in line with the report of Adefisan and Gbolagade (2017) (Table 5). Teak- based composites recorded significantly higher WA than those made from *C. millenii* suggesting again poor interfacial bonding.

Table 3: Water absorption of *C. millenii* and *T. grandis* plastic composites

Wood Content	2h	24h	72h	144h
Waste plastic + *C. millenii* particles				
50g	0.06^{cd}(0.03)	0.10^{cd}(0.06)	0.12^{cd}(0.05)	0.13^{cd}(0.1)
75g	0.12^{cd}(0.01)	0.12^{cd}(0.01)	0.22^{cd}(0.21)	0.27^{cd}(0.22)
100g	0.18^{cd}(0.23)	0.20^{cd}(0.13)	0.36^{abcd}((0.15)	0.42^{abcd}(0.26)
Virgin plastic + *C. millenii* particles				
50g	0	0.04^{d}(0.01)	0.06^{d}((0.03)	0.13^{cd}(0.1)
75g	0	0.13^{cd}(0.1)	0.17^{cd}((0.12)	0.30^{bcd}(0.31)
100g	0	0.59^{abcd}(0.1)	0.92^{abcd}(0.89)	1.07^{abcd}(1.12)
Waste plastic + *T. grandis* particles				
50g	0.21^{cd}(0.13)	0.21^{cd}(0.13)	0.26^{cd}(0.14)	0.36^{abcd}(0.16)
75g	0.38^{abcd}(0.19)	0.48^{abcd}(0.32)	0.53^{abcd}(0.37)	0.53^{abcd}(0.37)
100g	0.54^{abcd}	0.56^{abcd}	0.58^{abcd}	0.65^{abcd}
Virgin plastic + *T. grandis* particles				
50g	0	0	0.05^{cd}(0.01)	0.11^{cd}(0.05)
75g	0.18^{cd}(0.11)	0.25^{cd}(0.13)	0.29^{cd}(0.14)	0.3^{cd}(0.18)
100g	0.32^{abcd}(0.30)	0.4^{abcd}(0.32)	0.44^{abcd}(0.36)	0.52^{abcd}(0.38)

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

* Standard deviation in parentheses

Table 4: Thickness swelling of *C. millenii* and *T. grandis* plastic composites

Wood Content	2h	24h	72h	144h
Waste plastic + *C. millenii* particles				
50g	0.08[a](0.03)	0.13[a](0.10)	0.13[a](0.10)	0.13[a](0.10)
75g	0.39[a](0.15)	0.53[a](0.26)	0.53[a](0.26)	0.53[a](0.26)
100g	0.52[a](0.22)	0.55[a](0.28)	0.63[a](0.32)	0.72[a](0.44)
Virgin plastic + *C. millenii* particles				
50g	0.05[a](0.01)	0.07[a](0.05)	0.11[a](0.06)	0.15[a](0.12)
75g	0.22[a](0.16)	0.23[a](0.17)	0.23[a](0.17)	0.32[a](0.31)
100g	0.24[a](0.20)	0.56[a](0.37)	0.81[a](0.52)	0.81[a](0.52)
Waste plastic + *T. grandis* particles				
50g	0	0.14[a](0.06)	0.30[a](0.19)	0.32[a](0.31)
75g	0.19[a](0.03)	0.20[a](0.16)	0.32[a](0.26)	0.32[a](0.26)
100g	0.21[a](0.15)	0.21[a](0.15)	0.45[a](0.50)	0.45[a](0.50)
Virgin Plastic + *T. grandis* particles				
50g	0	0.10[a](0.08)	0.11[a](0.10)	0.16[a](0.14)
75g	0.19[a](0.13)	0.22[a](0.15)	0.28[a](0.27)	0.30[a](0.32)
100g	0.31[a](0.12)	0.44[a](0.51)	0.65[a](0.53)	0.67[a](0.15)

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

* Standard deviation in parentheses

Statistical analyses (Duncan's test) (Table 5) revealed that apart from the plastic matrix used in the study, the WA of the composites were significantly affected by the soaking time, wood species and the wood content. However, the soaking time, wood species, wood content and the plastic matrix used did not have significant effect on the TS of the plastic composites.

Table 5: Duncan's multiple range test of the effect of soaking time, wood species, wood content and matrix on the water absorption and thickness swelling of *C. millenii* and *T. grandis* plastic composites

Variable	WA (%)	TS (%)
Soaking Time(hours)		
2h	0.22^{b}(0.21)	0.2^{b}(0.23)
24h	0.25^{b}(0.28)	0.28^{ab}(0.35)
72h	0.33^{ab}(0.37)	0.39^{a}(0.41)
144h	0.40^{a}(0.37)	0.41^{a}(0.41)
Wood Species		
C. millenii	0.27^{a}(0.37)	0.31^{a}(0.34)
T. grandis	0.34^{b}(0.28)	0.33^{a}(0.38)
Wood Content		
50g	0.21^{b}(0.25)	0.29^{a}(0.21)
75g	0.28^{b}(0.15)	0.31^{a}(0.36)
100g	0.49^{a}(0.43)	0.36^{a}(0.48)
Matrix		
Waste Plastic composites	0.31^{a}(0.25)	0.38^{a}(0.42)
Virgin Plastic Composites	0.30^{a}(0.41)	0.26^{a}(0.28)

* Significant at 5% level of probability

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

Conclusion

Wood plastic composites were produced from virgin polypropylene, disused automobile battery cases and particles of *C. millenii* and *T. grandis*. The fabricated composites possessed adequate strength and low sorption properties which can be adapted for indoor and outdoor applications.

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