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PHYSICAL AND MECHANICAL PROPERTIES OF WOOD PLASTIC COMPOSITES PRODUCED FROM SAWDUST OF *Ceiba pentandra* (L.) Gaertn. AND PLASTIC WASTES

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Abstract

The study was conducted to investigate effect of some process variables on the physical and mechanical properties of wood/plastic composites (WPCs) produced from plastic wastes and sawdust. The sawdust of *Ceiba pentandra* and plastic wastes from relatively thick waste plastics comprised of plastic waste from kegs and buckets (PWT), plastic wastes from water sachets (PWS) and plastic wastes from bottled water (PWB) were employed in the study. The experimental wood plastic composites were prepared at wood/plastic ratio of 40:60, 50:50 and 60:40 (percentage by weight) and particle size classes of =0.5, 0.5 - 1.0 and 1.0 - 2.0 mm. The WPC for each study variable combination was prepared in 3 replicates. The physical properties tested include: water absorption, linear expansion and thickness swelling while the mechanical properties tested were Modulus of Elasticity (MOE), Modulus of Ruptures (MOR) and Compression strength. The experiment was carried out at nominal density of WPC. The study was laid in 3 x 3 x 3 factorial experiment in Completely Randomized Design (CRD) and data was analysed using ANOVA at 5% probability level. The result of physical properties tested showed that WPC made using plastic wastes from bottled water and water sachets were more dimensionally stable than WPC made using plastic wastes from thick plastics. For particle size, WPC made with particles sizes class of = 0.5 mm and 0.5 – 1.0 mm had better dimensional stability than WPC made using particle size class of 1.0 – 2.0 mm. In terms of combination ratio, WPC made with wood/plastic ratio of 40:60 was the highest in dimensional stability while wood/plastic ratio of 60:40 was the lowest. On mechanical properties, the result showed that WPC made using plastic wastes from bottled water and water sachets were the highest in strength properties while the lowest were WPCs made using plastic wastes from thick plastics. With regards to particle size, WPC produced from particle size class of 0.5 – 1.0 mm were the highest in strength properties compared to WPC produced from particle size class of 1.0 – 2.0 mm. On combination ratio, WPC made using wood/plastic ratio of 40:50 was the highest in strength properties followed by wood/plastic ratio of 50:50 while WPC made using wood/plastic ratio of 60:40 was the lowest. Hence, possibility dimensionally stable board has been achieved in this study using several wastes generated in the environment. This can resultantly enhanced cleaner and friendlier environment if concerted efforts are put in place in producing the board on commercial scale.

Keywords: Physical, mechanical, plastic waste, sawdust, *Ceiba pentadra.*

Introduction

Wood Plastic Composites(WPCs) are composite materials made from a combination of wood particles in the form of flour, tiny particles, sawdust and fibres and thermoplastic materials using heat and pressure. The thermoplastic materials include Polyethylene (PE), Polypropylene (PP), and Polyvinylchloride (PVC) which also serves as binding agent. Heat is applied to melt the plastic material which enables easy mixing of the wood flour with the plastic. After a thorough mixing, pressure is then applied to consolidate the product formed. The product formed can be made into any form, shape, size, design or quality depending on the concept of the producer and the intended end use. Extrusion methods are often employed; where the mixed paste is extruded into a mould or a die; the product (WPC) takes the shape of the mould and solidifies as such under pressure. The mould is then dismantled to obtain the product. Additives may be added to further improve the products' quality.

In addition to wood fibre and plastic, WPCs can also contain other lignocellulosic and/or inorganic filler materials. WPCs are a subset of a larger category of materials called natural fibre plastic composites (NFPCs), which may contain non cellulose-based fibre fillers such as pulp fibres, peanut hulls, bamboo, straw, digestate, and so on.

There are many types of wood/plastic composites which are differentiated based on certain considerations such as materials combined, variation of the components like mixing ratio and particle size of the combining materials, application, trademarks or patents. Types of WPC developed also depend on innovations done to it and these innovations in turn depend on what has been included in the composition of such composites. A few examples includes Wood dust/Plastic Composite (WPC), Natural fibre plastic composites (NFPCs), Foam - Wood/Plastic Composite (FWPC), Wood Plastic Sandwich Boards (WPSB), Wood - Clay/Plastic Composite, Agric wastes/Plastic Composites and Wood Fibre/Plastic Composites and so on. (TRG, 2016 and Wikipedia, 2010).

According to Maine (2004), the use of wood fibre with plastic to make composite started a few years ago when Mobil undertook research efforts to find a way to recycle polyethylene grocery bags. Mobil team used recycled polyethylene (PE) and cellulose fibres, such as obtained from sawdust or newspaper, to make a composite that was formed into deck boards. The story did not end there according to Maine (2004); the group that developed this technology organized a management buyout in 1996 and formed a company called Trex, which based in Winchester, Virginia. Today this technology has grown, improved, expanded and adopted in many parts of the World.

Polymer–wood composites have attracted increasing attention in the past decade owing to the reinforcing potential of lignocellulosic fibres and the economic advantage of using the fibres as fillers for thermoplastics. The wood fillers are environmentally advantageous because they originate from renewable resources and may increase the rate of degradability to plastics (Li and Wolcott, 2003). The commercial markets for wood filled thermoplastics are most frequently termed wood plastic composites (WPC) in North America. The production of these materials has grown four-fold between the year 1997 and 2000 (Li and Wolcott, 2003). The future will bring improved forms of these renewable and environmentally friendly products; technological advancement may lead to reduced costs, improved performance, new products, material recycling and more environmental sensitivity (OSU, 2010). In Nigeria WPC is not widely known, a vast majority of Nigerians are not yet aware of this product despite its importance. At the moment, greater percentage of WPCs and its products are imported, a few industries exist that produce WPC one of such industry is Compowood Industry, located along Akure/Owo Road, Akure, Ondo State. The market potential for WPC in Nigeria is enormous considering the quality, aesthetics and many other excellent attributes; it has the potential to flourish in Nigerian market as long as it can be made available and affordable.

MATERIALS AND METHODS

Sawdust processing

The sawdust of the *Ceiba pentandra* was sieved in turn with 2.0 mm, 1.0 mm and 0.5 mm mesh screen (Plate 1). The portions of sawdust particles retrieved on the 2.0 mm screen were considered oversize and were discarded. The portion that passed through 2.0 mm screen but was retained on 1.0 mm sieve was classified as 1-2 mm particle size. The portion of the sawdust that passed through 1.0 mm mesh screen but was retained on 0.5 mm screen was designated as 0.5 - 1 mm particle size, while that which passed through 0.5 mm mesh screen was designated as = 0.5 mm class. This procedure gave three particle sizes as follows: = 0.5 mm, 0.5-1 mm and 1-2 mm wood particle sizes.

Processing of Plastic Materials

After procurement the plastic wastes thereafter were washed and dried, labels and other unwanted materials removed. The plastic wastes were then converted into particles with a grinding machine. The comminute wastes plastics obtained from the grinder are shown in plate 2

Plate 1: Wood sawdust screened to three particle size classes using: (a) 2.0 mm, (b) 1.0 mm and (c) 0.5 mm mesh screens

Plates 2: Comminuted plastic wastes from: (a) relatively thick plastic containers; plastic kegs, buckets and plates (b), bottled water and (c) water sachets

The required amount of sawdust and plastic materials for each combination were compounded into homogenous mixture and heated to form WPC using the following procedures. Each plastic type was first heated to appropriate temperature to melt bearing in mind standard melting temperatures of plastics. The melting temperature for low density polyethylene (LDPE), high density polyethylene (HDPE) and polyethylene terphthalate (PETE) are 110 - 150^{o}C, 130 - 170^{o}C and 250 - 260^{o}C respectively. The molten plastic was allowed to cool down to a wood-tolerable temperature between 130^{o}C and 160^{o}C before mixing the wood dusts to avoid burning of wood. The mixture was stirred thoroughly to form homogenous mixture. The molten mixture was extruded with pressure into a mould of size 40 x 80 x 200 mm attached to the machine. The samples were stripped from the mould and allowed to cool for about 30 min at room temperature. The bond get stronger and further consolidate as it cools. The samples were then trimmed with a carbide-toothed machine saw and cut into samples of size; 4 x 8 x 130 mm for flexural/mechanical test and 20 x 20 x 60 mm for physical properties test.

Plate 3: Wood/Plastic composites produced from three plastic waste types; A - Relatively thick plastics (PWT), B - Water sachets (PWS) and C - Bottled water (PWB).

Physical properties determination

Water absorption (WA), thickness swelling (TS) and linear expansion (LE) Determination**:** WPC specimens 20 x 20 x 150 mm in dimension were weighed, the thickness and length were also measured and then immediately soaked in water for 24 hrs, at the expiration of 24 hours the specimens were removed and mopped with clean cloth to remove excess surface water, thereafter the specimens were weighed; the thickness and length were measured. Water absorption (WA), thickness swelling (TS) and linear expansion (LE) were calculated as follows:

$$WA = \frac{W_2 - W_1}{W_1} X100 \quad (1)$$

Where:

WA= Water absorption (%)

W_1 = Initial weight of the sample (g)

W_2 = Final weight of the sample (g)

$$TS = \frac{T_2 - T_1}{T_1} X100 \quad (2)$$

Where:

TS= Thickness swelling (%)

T_1= Initial thickness of the sample (mm)

T_2= Final thickness of the sample (mm)

$$LE = \frac{L_1 - L_2}{L_1} X100 \text{--} (3)$$

Where:

LE= Linear Expansion (%)

L_1= Initial length of the sample (mm)

L_2= Final length of the sample (mm)

Mechanical properties determination

Flexural determination: The flexural test was carried out using the Universal Testing Machine model M and capacity 25KN according to ASTM C1225 (2005). The test specimens 4 x 8 x 130 mm in dimension were mounted one by one on the machine. Load was applied at the centre with the aid of an electro-mechanical motor till the point when failure occurred. The ultimate load (P) and the deflection for each test specimen were recorded. From the data obtained, the modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated using the following formula:

$$MOE = \frac{PL^3}{4BD^3 \Delta S} (N / mm^2) ----------------------------- (4)$$

Where:

L = Span between center of support (mm)

B = Width of test sample (mm)

ΔS = Increase in deflection

P = Ultimate failure load (N)

D = Thickness of the sample

$$MOR = \frac{3PL}{2BD^2}(N/mm^2) ------------------------------ (5)$$

Where:

L = Span between centre of support (mm)

B = Width of test sample (mm)

D = Thickness of test sample (mm)

P = Ultimate failure load (N)

Compression strength determination: Compressive properties of the composite board samples (4 x 8 x 130) mm were determined by subjecting the samples to test using Universal Testing Machine as specified by the American Society for Testing and Materials (ASTM C1225, 2005). Test samples (4 x 8 x 130) mm in dimension were mounted one by one on the machine. Load was applied at both ends of the sample along the grain of the wood with the aid of an electro-mechanical motor till the point when failure occurred and the compression results recorded.

Statistical Analysis

The experiment was laid in 3 x 3 x 3 factorial experiment in Completely Randomized Design (CRD) and data was analysed using ANOVA at 5% probability level. Variables that are significantly different were subjected to follow-up test using Duncan Multiple Range Test (DMRT)

Results and Discussion

Physical Properties

Water absorption (WA)

The mean values of water absorption of WPC produced from sawdust of *C. pentandra* ranged from 1.82 - 34.04 % (Table 1). The highest mean values were observed for WPC made using plastic wastes from thick plastics at 0.1 - 2.0 mm particle size and 60% wood with a value of 34.04%, while the lowest were WPC produced using plastic wastes from water sachets and bottled water both at = 0.5 mm particle and 40% wood. WPCs made with plastic wastes from thick plastics were higher in water absorption than those made with plastic wastes from bottled water and water sachets.

Table 2 showed the ANOVA carried out at 5 % probability level which indicated that all the production variables; particle size, mixing ratio and plastic types had significant effect on the water absorption properties of WPCs produced. There were significant differences in all the interactions except interaction between the particle size and plastic type at 5 % probability level. The result of ANOVA showed that effect of plastic wastes from relatively thick plastics was significant on WPCs made. In terms of particle size, the particle size class of 1.0 – 2.0 mm had significant effect on WPCs produced while wood/plastic ratio of 60:40 had significant effect on WPCs produced.

The result showed that water absorption increased with increase in particle size and increased with increase in the proportion of wood in wood/plastic ratio. WPCs with 60% wood showed the highest response to water absorption while 40% wood were the lowest, also where particle size used was = 0.5 mm water absorption was reduced to the lowest level. This could be due to the fact that wood has more affinity for water being hydrophilic, therefore increase in the particle size and the proportion of wood in wood/plastic ratio implies higher chances for more water uptake corroborated by Gozdecki*et al.*, (2015) and Izekor*et al.*, (2013). In terms of plastic types, WPC made using plastic waste from bottled water and water sachets had high resistance to water absorption which could be attributed to the low meltrheology which leads to the formation of stronger bond with wood particles compared to the use plastic wastes from thick plastics which had high meltrheology due to strong intermolecular bonding of the plastic polymer, corroborated by Aina*et al.*, (2014).Again, this resulted in poor board formation and eventually high level of water intake observed for WPC produced using plastic wastes from thick plastics. Generally similar trend was observed for linear expansion and thickness swelling therefore the same reasons advanced for the behaviour of WPC in water absorption can apply to linear expansion and thickness swelling. More so the tests were carried under similar condition (water soaked test) and that water absorption has direct impact on dimensional stability.

Table 1: Mean Values for Physical Properties of WPC made from sawdust of *Ceiba pentandra* and plastic wastes as influenced by plastic types, variation in particle size and wood/plastic ratio

Waste Plastic Types	Part. Size class(mm)	Wood/Plast. ratio (% by weight)	Water absorption (%)	Linear Expansion (%)	Thickness swelling (%)
PWT	= 0.5	40	9.40 ± 0.45	0.18 ± 0.20	0.12 ± 0.05
PWS			4.69 ± 0.10	0.12 ± 0.13	0.13 ± 0.01
PWB			1.82 ± 0.05	0.29 ± 0.33	0.13 ± 0.21

PWT		50	5.06 ± 0.30	0.83 ± 0.19	0.88 ± 0.30
PWS			5.51 ± 0.49	0.84 ± 0.03	0.84 ± 0.47
PWB			2.95 ± 0.77	0.33 ± 0.05	0.33 ± 0.03
PWT		60	13.90 ± 2.97	0.42 ± 0.11	1.49 ± 0.47
PWS			6.27 ± 0.96	0.58 ± 0.07	0.58 ± 0.02
PWB			2.50 ± 0.15	0.39 ± 0.12	0.93 ± 0.46
PWT	0.5 – 1	40	7.54 ± 0.86	0.41 ± 0.07	1.41 ± 0.02
PWS			7.49 ± 0.48	0.71 ± 0.05	0.23 ± 0.29
PWB			2.79 ± 0.45	0.54 ± 0.12	0.54 ± 0.26
PWT		50	10.04 ± 0.33	0.12 ± 0.07	2.12 ± 0.13
PWS			7.73 ± 0.16	0.71 ± 0.08	0.71 ± 0.87
PWB			4.27 ± 0.15	0.23 ± 0.21	0.23 ± 0.32
PWT		60	12.17± 0.11	0.69 ± 0.13	1.96 ± 0.32
PWS			5.19 ± 0.45	0.18 ± 0.56	0.98 ± 0.56
PWB			5.61± 0.40	0.50 ± 0.06	0.50 ± 0.26
PWT	1 – 2	40	18.60 ± 0.24	0.17 ± 0.03	1.17 ± 0.45
PWS			3.86 ± 0.13	0.35 ± 0.13	0.35 ± 0.54
PWB					
			11.83 ± 0.43	0.28 ± 0.19	0.28 ± 0.39
PWT		50	16.54 ± 0.31	0.19 ± 0.40	0.78 ± 0.15

PWS		8.08 ± 0.30	0.82 ± 0.01	0.71 ± 0.19
PWB		3.05 ± 0.15	0.56 ± 0.35	0.56 ± 0.08
PWT	60	34.04 ± 0.35	0.94 ± 0.28	4.05 ± 0.05
PWS		10.60 ± 0.14	0.14 ± 0.17	0.22 ± 0.12
PWB		6.59 ± 0.12	0.43 ± 0.09	0.68 ± 0.11

Number before "±" denotes mean values of three replicate and the number after "±" denotes standard deviation. PWT - plastic wastes from thick plastics, PWB - plastic wastes from bottled water and PWS – plastic wastes from water sachets.

Table 2: Analysis of Variance for Physical and Mechanical properties

	Source of variation	df	Sum of squares	Mean square	F
WA	Particle size	2	159.895	79.948	8.330*
	Mixing ratio	2	1518.766	759.383	79.123*
	Plastic type	2	6338.498	3169.249	330.217*
	Particle size*Mixing ratio	4	304.843	76.211	7.941*
	Particle size*Plastic type	4	72.131	18.033	1.879 ns
	Mixing ratio*Plastic type	4	463.389	115.847	12.071*
	Particle size*Mixing ratio*Plastic type	8	548.696	68.587	7.146*
	Error	162	1554.791	9.597	
	Total	188	10961.009		
LE	Particle size	2	1.269	0.635	8.233*
	Mixing ratio	2	1.880	0.940	12.177*
	Plastic type	2	4.237	2.119	27.446*
	Particle size*Mixing ratio	4	0.521	0.130	1.687 ns
	Particle size*Plastic type	4	1.063	0.266	3.442*
	Mixing ratio*Plastic type	4	0.417	0.104	1.350 ns
	Particle size*Mixing ratio*Plastic type	8	0.912	0.114	1.476 ns
	Error	162	12.545	0.077	
	Total	188	22.804		
TS	Particle size	2	22.924	11.462	6.662*
	Mixing ratio	2	6.545	3.272	1.902 ns
	Plastic type	2	30.854	15.427	8.967*
	Particle size*Mixing ratio	4	2.419	0.605	0.352ns
	Particle size*Plastic type	4	6.034	1.509	0.877 ns
	Mixing ratio*Plastic type	4	11.135	2.784	1.618 ns
	Particle size*Mixing ratio*Plastic type	8	12.954	1.619	0.941 ns
	Error	162	278.701	1.720	

Total	188	371.566		
MOE Particle size	2	1200926.449	600463.224	6.741*
Mixing ratio	2	976395.896	488197.948	5.481*
Plastic type	2	1183473.948	591736.666	6.643*
Particle size*Mixing ratio	4	391949.597	97987.399	1.100 ns
Particle size*Plastic type	4	607040.193	151760.048	1.704 ns
Mixing ratio*Plastic type	4	960560.684	240140.171	2.696*
Particle size*Mixing ratio*Plastic type	8	1937668.049	242208.506	2.719*
Error	162	14430396.312	89076.520	
Total	188	38819771.606		
MOR Particle size	2	42.506	21.253	6.534*
Mixing ratio	2	156.652	78.326	24.081*
Plastic type	2	1871.408	935.704	287.679*
Particle size*Mixing ratio	4	67.317	16.829	5.174*
Particle size*Plastic type	4	108.227	27.057	8.319*
Mixing ratio*Plastic type	4	106.422	26.605	8.180*
Particle size*Mixing ratio*Plastic type	8	101.53	12.692	3.902*
Error	162	526.921	3.253	
Total	188	3992.100		
CMP Particle size	2	8,027	4.013	3.843*
Mixing ratio	2	15.227	7.613	7.291*
Plastic type	2	103.786	51.893	49.693*
Particle size*Mixing ratio	4	35.767	8.942	8.563*
Particle size*Plastic type	4	39.716	9.929	9.508*
Mixing ratio*Plastic type	4	16.309	4.077	3.904*
Particle size*Mixing ratio*Plastic type	8	7.362	0.920	0.881 ns
Error	162	169.172	1.044	
Total	188	747.848		

*Significant ($p < 0.05$) probability level, ns = not significant ($p < 0.05$) probability level

WA = Water absorption, LE = Linear expansion, TS = Thickness swelling, MOE = Modulus of elasticity, MOR = Modulus of rupture, CMP = Compression strength

Linear Expansion (LE)

Mean values of linear expansion of WPCs produced from sawdust of *C. pentandra* ranged from 0.11 - 1.76 %; (Table 1). WPCs produced using plastic wastes from thick plastics showed higher linear expansion value of 1.76 %, while boards produced using plastic wastes from water sachets showed least value of linear expansion. Linear expansion was higher in WPCs produced using plastic wastes from thick plastics but lower in WPCs produced using plastic wastes from bottled water and water sachets. In terms of particle size and wood/plastic ratio, linear expansion increased with increase in particle size and increased with increase in wood proportion.

Analysis of variance test carried out showed that there were significant differences in linear expansion of WPCs based on particle size, mixing ratio and plastic type. There were significant differences in the interactions between particle size and plastic type (Table 2). Duncan Multiple Range Test showed the level of significance among the production variable at 5 % level of significance. The level of significance shown in Analysis of variance test was as follows: plastic wastes from thick plastics had significant effect on the linear expansion of WPCs produced. Particle size class of 1.0 - 2.0 mm had significant effect on linear expansion WPCs produced, while wood/plastic ratio 60:40 also had significant effect on linear expansion of WPCs produced.

Thickness Swelling (TS)

Mean values of thickness swelling of WPCs produced from *C. pentandra* ranged from 0.12 – 4.05 % (Table 1). WPC produced using plastic wastes from thick plastics at 1.0 – 2.0 mm particle size and 60 % wood showed higher thickness swelling with a value of 4.05 % while samples produced using plastic wastes from water sachets at = 0.5 mm particle size and 40 % wood showed the lowest value of thickness swelling. Figure 4 indicated that TS of WPCs produced increased with increase in particle size.

Analysis of variance (ANOVA) test carried out at 5 % probability level to test for significant differences among the production variables for thickness swelling are as presented in Table 2. The result showed that there were significant differences regarding particle size and plastic type at 5 % probability level. Duncan Multiple Range Test (DMRT) shows the significant difference of the production variable levels. In plastic type, effect of plastic wastes from thick plastics was significant on thickness swelling of WPCs produced. Similarly, particle size class of 1.0 – 2.0 mm was significant on WPCs produced.

Mechanical Properties test

Modulus of Elasticity (MOE)

Mean values of modulus of elasticity of WPC produced ranged from 458.17 - 1785.90 N/mm^2 (Tables 3). The highest mean value was observed for WPC made with plastic wastes from water sachets at = 0.5 mm particle size and 40 % wood with a value 1785.90 N/mm^2 while the lowest was WPC produced using plastic wastes from thick plastics at = 2.0 mm particle size and 60 % wood having a value of 458.17 N/mm^2. Generally the trend of effect of production variables on WPCs made showed that MOE decreased with increase in particle size and decreased with increase in wood composition. Effect of plastic types showed that WPCs made with plastic wastes from water sachets and bottled water was higher in MOE while those made with plastic wastes from thick plastics were lower.

Analysis of variance carried out at 5 % probability level to test for significant differences among the production variables for MOE are as presented in table 2. The result showed that there were significant differences in the effect of wood particle size, mixing ratio and plastic types at 5 % probability level. There were no significant differences in all the two-level interactions. Duncan Multiple Range Test was used for the separation of mean at 5 % probability level, which showed that plastic wastes from water sachets was significant on MOE of WPCs produced followed by plastic wastes from bottled water, while particle size class of = 0.5 mm was significant on MOE of WPCs produced. Also wood/plastic ratio of 40/60 and 50/50 were significant on MOE of WPCs produced.

From the result above it could be inferred that smaller wood particles seem to have stronger bond with plastic which may be the reason WPCs with smaller particle size (that is, = 0.5 mm) exhibited high MOE. The trend also showed that MOE decreased with increase in wood proportion in the WPC. WPCs made with 40 % and 50 % wood were higher in modulus of elasticity whereas composites with 60 % wood were the lowest, corroborated byIzekor and Mordi (2015) and Aina *et al*., (2014).WPC with 60 % wood had insufficient polymer to enhance effective bonding thereby affecting strength (Atuanya *et al.*, 2011).It was also observed that WPC made using plastic wastes from bottled water had the highest MOE followed by WPCs made using plastic wastes from water sachets. WPC made using plastic wastes from thick plastic materials was the lowest in MOE. Plastic wastes from water sachets with low melt viscosity and better rheological characteristics had better particles distribution resulting in stronger bond, compact and uniform board formation. This in turn enhanced high modulus of elasticity (MOE) exhibited by WPC made using plastic wastes from bottled water and water sachets (Atuanya *et al.*, 2011). On the other hand, low modulus of elasticity shown by WPC made using plastic wastes from thick plastic materials was as a result of poor board formation because thick plastic polymers has high viscosity, strong intermolecular bond and poor rheological characteristic which posed difficulty in the bond between the plastic and wood particles, corroborated by Aina *et al.*, (2014).

Table 3: Mean Values for Mechanical Properties of WPC made from sawdust of *Ceiba pentandra* and plastic wastes as influenced by plastic types, variation in particle size and wood/plastic ratio (percentage by weight)

Plastic Type	Particle Size class(mm)	wood/plastic (Percentage by weight)	Modulus of elasticity (N/mm^2)	Modulus of rupture (N/mm^2)	Compression (N/mm^2)

PWT	= 0.5	40:60	1326.74 ± 25.55	6.13 ± 1.18	1.51 ± 0.48
PWS			1785.90 ± 31.63	11.68 ± 1.37	5.15 ± 0.52
PWB			1761.48 ± 17.78	13.42 ± 1.12	4.83 ± 0.69
PWT		50:50	1493.56 ± 25.73	8.11 ± 0.25	3.15 ± 0.02
PWS			1646.86 ± 11.27	16.42 ± 0.89	5.00 ± 0.30
PWB			1577.66 ± 23.18	10.19 ± 1.51	4.96 ± 0.70
PWT		60:40	905.33 ± 25.02	2.21 ± 0.32	1.22 ± 0.13
PWS			970.38 ± 16.59	6.33 ± 0.80	2.58 ± 0.96
PWB			1099.07 ± 17.15	5.55 ± 0.75	3.00 ± 0.14
PWT	0.5 – 1	40:60	1705.48 ± 28.23	10.11 ± 1.27	5.05 ± 0.40
PWS			1482.90 ± 26.46	11.74 ± 1.54	5.31 ± 0.81
PWB			1400.42 ± 24.32	15.02 ± 1.16	3.46 ± 0.62
PWT		50:50	1185.71 ± 22.38	7.04 ± 0.59	2.71 ± 0.15
PWS			1397.86 ± 11.83	13.23 ± 1.01	3.72 ± 0.16
PWB			1634.25 ± 11.17	11.18 ± 0.32	5.24 ± 0.12
PWT		60:40	1031.78 ± 28.03	4.49 ± 0.97	1.46 ± 0.33
PWS			974.02 ± 26.12	6.79 ± 0.73	2.32 ± 0.61
PWB			1178.53 ± 23.38	7.14 ± 1.27	2.97 ± 0.36
PWT	1 – 2	40:60	1399.77 ± 18.47	10.10 ± 0.88	2.01 ± 0.74
PWS			1514.24 ± 21.33	12.34 ± 0.31	2.06 ± 0.13
PWB			1294.28 ± 23.99	12.70 ± 0.79	3.99 ± 0.4

PWT	50:50	917.74 ± 24.93	11.38 ± 0.87	2.35 ± 0.15
PWS		1465.96 ± 20.77	11.85 ± 0.92	4.93 ± 0.97
PWB		1212.18 ± 16.74	12.22 ± 1.13	4.32 ± 0.14
PWT	60:40	458.17 ± 12.69	2.74 ± 0.56	0.51 ± 0.12
PWS		880.57 ± 27.58	7.64 ± 0.36	3.97 ± 0.22
PWB		1054.92 ± 23.75	6.75 ± 0.73	3.17 ± 0.66

Number before "±" denotes mean values of three replicate and the number after "±" denotes standard deviation. PWT - plastic wastes from thick plastics, PWB - plastic wastes from bottled water and PWS – plastic wastes from water sachets.

Modulus of Rupture (MOR)

Mean values of modulus of rupture of WPCs produced ranged from 2.76 - 16.42 N/mm^2 (Table 3). The highest mean value was observed for WPC made using plastic wastes from water sachets at = 0.5 mm particle size class and 50 % wood with a value of 16.42 N/mm^2 while the lowest mean value of 2.76 N/mm^2 was observed for WPCs made using plastic wastes from thick plastics at 1.0 – 2.0 mm particle size and 60 % wood. The trend showing the effect of plastic types on MOR of WPCs as were influenced by other variables are as shown in Figures 6. The trend showed that MOR of WPCs produced decreased with increase in particle size and decreased with increase in wood composition. WPCs made with plastic wastes from bottled water and water sachets were higher in MOR while those made with plastic wastes from thick plastics were the lowest in MOR.

Analysis of variance carried out at 5 % probability level to test for significant differences among the production variables for modulus of rupture are as presented in Table 2. The result showed that there were significant differences in MOR of WPCs based on particle size, mixing ratio and plastic types. Also there were significant differences in all the interactions between variables. The follow-up test showed that plastic wastes from bottled water followed by plastic wastes from water sachets had significant effect on MOR of WPCs produced. Also wood particle size class of = 0.5 mm followed by 0.5 - 1.0 mm was significant on MOR of WPCs produced, while wood/plastic ratio of 40/60 followed by 50/50 were significant on MOR of WPCs produced.

A similar trend observed for MOE was also observed for MOR and compression strength in the result as was influenced by all the production variables; as such same reasons for the behaviour of WPC in MOE can be advanced for MOR and compression strength.

Compression strength

Mean values of compression strength of WPCs produced from *C. pentandra*, ranged from 0.51 - 5.21 N/mm^2(Tables 3). The highest mean value of 5.21 N/mm^2 was observed for WPC made using plastic wastes from water sachets at 0.5 – 1 mm particle size class and 40 % wood while the lowest mean value of 0.51 N/mm^2 was observe for WPCs made using plastic wastes from thick plastics at 1 – 2 mm particle size class and 60 % wood. The trend showed that compression strength increased slightly with increase in wood composition up to 50 % wood and then drop to the lowest at 60 % wood in wood/plastic ratio. Again compression strength of WPCs increased with decrease in particle size. In terms of plastic types, compression strength was higher in WPCs made using plastic wastes from bottled water and water sachets but generally low in WPCs made with plastic wastes from thick plastics.

Analysis of variance carried out at 5 % probability level to test for significant differences among the production variables for compression are as presented in Table 2. The result showed that there were significant differences in the compression strength of WPCs based on particle size, mixing ratio and plastic type. Also there were significant differences in all the interactions between variables except interactions between particle size, mixing ratio and plastic type which were not significantly different. Duncan Multiple Range Test was used for the separation of mean at 5 % probability level. The result showed that effect of plastic wastes from bottled water was significant on the compression strength of WPCs produced followed by plastic wastes from water sachets; while particle size class of 0.5 – 1 mm followed by = 0.5 mm had significant effect on compression strength of WPCs produced. Also wood/plastic ratio of 50:50 followed by 40:60 had significant effect on the compression strength of WPCs produced.

Conclusion

Strength properties and dimensional stability was higher with WPCs made using plastic wastes from bottled water and plastic wastes from water sachets while the lowest in both strength properties and dimensional stability were WPCs made with plastic wastes from thick plastic materials. Dimensional stability and strength properties were higher in WPCs made with particle sizes classes 0.5 mm and below (= 0.5) mm and 0.5 - 1.0 mm while the lower value of these properties were observed for 2.0 mm (1.0 – 2 mm) size class. In terms of mixing ratio, WPCs made with 40 % wood was higher in dimensional stability and strength properties compared to composites made using wood proportion above 50 %.

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