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Development of Processing Equipment for Souvenir Production from Wood and Plastics Wastes

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Abstract: Wood wastes and consumer waste plastic wastes are abundant and constitute menace in the environment. The present means of disposing these wastes are ineffective and the machines for processing wood plastic composite are expensive, high energy consumption, required high technical know-how and are not readily available. This work was therefore designed to develop a processing equipment from locally available materials, that are cheap, energy efficient, and effective for the production of souvenirs from wood and consumer waste plastic bottles. The machines consist of melting and mixing chamber, temperature control unit, heating unit, the stirrer, the moulding unit, discharge chute and the support frame unit. A batch production takes 2hrs 45minutes with a throughput of 7.2kg/hr and machine efficiency of 72.5%. the properties of wood plastic composite produced were sorption properties (water absorption and thickness swelling), density, flexural and tensile. These were found suitable for non-structural applications and were used for souvenir productions such as broom base, picture frame, flower pots and office accessories.

Keywords: Wood Plastic Composite, Souvenir Production, Processing Equipment, Melting and Mixing Chamber, Sorption Properties.

INTRODUCTION

Wood plastic composite (WPC) is a product obtained from plastic and wood. It is a composite with a rapid growing usage consisting of a mixture of wood waste and polymeric material (Soury, *et. al*., 2009). Several worldwide attempts have been adopted; especially in the developing countries, to take advantage of these types of waste especially with the increased The main applications of WPCs are in products such as rails, decking, door and window profiles, decorative trims, roof tiles, sheathing etc. New applications and end uses of wood plastics composites include decking, flooring and outdoor facilities, window frames etc. with improved thermal and creep performance compared with unfilled plastics (Balma et. al 2001). need for alternatives to virgin materials (Winandy, *et. al.*, 2004). Wood products and furniture manufacturers generate large quantities of sawdust from wood processing (sawing, cutting, drilling, milling and sanding) operations. On average, 48 million m^3 of timber is being consumed annually in the UK and the wood processing resulting in 5-10% sawdust and wood wastes (Magin, 2001). Wood plastic composites (WPCs) are materials that combined the properties of wood and matrix polymer. They contain varying contents of wood, plastics and additives and are processed using the same techniques as thermoplastic polymers. Its applications has been growing since the 90s and presently, the major markets for wood polymer composites have been North America and Asia, although its use is also on the increase in Europe (Maiju *et. al.*, 2011). Its application has gained little or no grounds in Africa and its main use is in building construction to replace impregnated wood in outdoor applications due to its durability, low maintenance, no painting, insect and decay resistance, it will not warp, splinter, crack, it is denser and thus holds screw better and can be manufactured to be resistant to ultraviolet light (Douglas *et. al.*, 2002).

Sawdust, wood and plastic wastes are major under-utilised by-products from sawmilling operations and packaging industries and because they contribute a great deal of waste to the environment, their utilization for the production of other value-added products is highly desirable. Hence this research was designed to process wood and plastic wastes to valuable products such as souvenirs

MATERIALS AND METHOD

Material Collection and Preparation

Saw dust

Sawdust were collected at university of Ibadan sawmill. The species of wood from which the samples were collected is *Gmelina arborea*. The sample was oven-dried to reduce the moisture content to less than 4%.

Consumer waste plastic bottles

The consumer water bottles were collected locally around the University of Ibadan. Consumer plastic bottles were washed, hammer milled to smaller chips (2mm-5mm). The plastic chips were screened to remove the oversized chips. The chips were then sun dried in order to remove additional moisture absorbed by the chips during grinding processes.

Wood Plastic Composite (WPC) Processing Equipment

The main purpose of the machine is to melt, mix and mould the mixed materials into the desired sizes and shape. The major components of the machine include the melting and mixing chamber, the stirrer, the heating unit, the support frame and the discharge chute.

The Working Principle of WPC Processing Equipment
The shredded plastics are fed into the melting chamber, the heating unit supplied heat and melt the plastic at 195℃. It was a batch process. Wood flour was then added and thoroughly mixed together to form a homogenous mixture.

The machine employed the principle of melting and mixing. The uniformly mixed materials are then discharged into appropriate moulds to form the required profile. The machine was designed to operate either manually or to be powered by 2Hp electric motor.
The use of local heat source and manual wheel for stirring were considered to avert the problem of power failure and optimize the use of available power supply.

Performance Test for the processing Equipment
The developed WPC processing equipment was tested in terms Recycling efficiency (RE) and Throughput (TP).

$$RE = \frac{Output\ of\ the\ WPC\ sample}{Input\ mass\ of\ the\ WPC\ sample.} \times 100$$

(Ugoamadi *et. al.*, 2011)

$$T = \frac{Output\ \ mass\ of\ the\ WPC\ sample}{Time\ taken\ for\ recycling}$$

(Ugoamadi et al, 2011).

Physical properties test (sorption)
Density
The density of each sample moulded was obtained by dividing its mass by its volume.

$$\text{Density,}\quad \rho = \frac{mass}{volume}$$

(wood handbook, 2010)

Volume (Rectangular composites), $= Lenght \times Breadth \times Thickness$

Water Absorption
This test was carried out in accordance with ASTM D570-98 by which the panel's specimens were immersed in water for 2 hours and 24 hours respectively at a room temperature of 23±1℃. The composite sample were weighed at the respective intervals and the masses were determined using an electronic weighing balance.
Water absorption (WA) was obtained using this equation;

$$Water\ absorption = \frac{m_t - m_o}{m_o} \times 100\%$$

(Wood handbook)
Where; $m_o = initial, \quad and \quad m_t = final$

Thickness Swelling Test
The various samples were soaked in water for 2hrs and 24 hrs and the thickness of the composite at 0hrs, 2hrs and 24hrs were determined using a digital vernier calliper. The thickness swelling (TS) was obtained by using this equation;

$$Thickness\ Swelling\ TS(\%) = \frac{h_t - h_o}{h_o} \times 100\%$$

(Wood handbook)
Where $h_o = initial, \quad and \quad h_t = final\ thickness$ (mm) before and after the water immersion respectively.

Tensile Properties
Specimens with dimensions of 165mm × 19mm × 6.4mm (thickness) were cut and machined from the hot pressed composite panels. The tensile tests were performed in accordance with ASTM D638-99 using a standard Universal Testing machine (UTM-OKH 600 digital display) at a crosshead speed of 0.54 KN/S. Elongation (strain) of the specimen was measured over a 25 mm gage length using an Extensometer. Prior to the tensile test, the specimens were conditioned at 23±2°C and 50% RH for at least 40 h according to the ASTM D638-99.
All measurements were performed at ambient conditions (23±2°C and 50% RH), and five replicates were tested for each composite formulation. The tensile strength was display in the digital screen of the machine.

Flexural Properties
Flexural properties were measured using a standard Universal Testing machine (UTM-OKH 600 digital display) at a crosshead speed of 0.28 KN/S in accordance with ASTM D790. The flexural test specimens were also cut from the composite panels with dimensions of 130 mm × 12.7 mm × 6.4 mm (thickness). The bending measurements were also performed at the ambient conditions of 23±2°C and 50± 5% RH. Five replicates of each composite formulation were tested.

RESULTS AND DISCUSSION
Performance Test for the Machine
Following the design, fabrication and assembly of the processing equipment, the performance of the equipment was evaluated. The machine was prepared for the melting and mixing operation by first switching on the heating element. The heating lasted for 3hrs to enable the melting chamber to attain the temperature of 180-195℃. The processing was done in batches; the sorted samples comprising of both plastic and sawdust at different composition were fed into the processing equipment through the cylinder and the heater was switch on for melting and mixing. The time taken for recycling per batch was monitored and recorded. A circular wheel was used as prime movers at specific

periods of time. The time taken to recycle each quantity of plastic and sawdust was 2hr 45minutes. The average performance of the equipment is estimated to be 72.5% and the average capacity of the machine is estimated as 7.2kg/hr. The tests were replicated four times to obtain the performance of the machine.

Density

The volume of each sample was estimated from the nominal dimensions while the mass was determined using weighing balance.

From the results presented in Figure 2.0, it was observed that WPC density tends to decrease as the wood content increases. WPC (50/50) has the highest density of 968.08 Kg/m^3, followed by WPC (40/50) of density 906.23 Kg/m^3, followed by WPC (30/70) of density 812.50 Kg/m^3 and the least is WPC (20/80) of density 691 Kg/m^3. It was also observed that the WPCs are less dense compared to wood weight. Also, it is noted that the difference in the densities of the samples is as a result of variations in the wood content. The affinity for entanglement, together with the bulk density of wood, constitutes also a problem for the feeding of fibres in the extruder (Caulfield, *et* al, 2005). The analysis of variance reveals that the density is significant.

Water Absorption

From the experimental results, it was established that the water absorption increased with increasing wood content in the composites as illustrated in Figure 3.

In addition, the WPC of (50/50) of wood / plastic ratio has water absorption of 1.85% and 4.62% for (2hrs) and (24hrs), followed by WPC (40/60) with 1.05% and 2.62%, WPC (30/70) with 0.42% and 1.05%, while WPC (20/80) has 0.08% and 0.09%.

It was found that the water absorption for 2h immersion varied from 0.08 to 1.85%, and after 24 hrs water immersion, the water absorption increased from 0.09 to 4.62% depending on the composite formulations. Water absorption of composite is an important factor in classifying its durability and composites of low water absorption will afford better protection to reinforcement within it (Taha *et.* al., 2008). The analysis of variance reveals that the water absorption is significant.

Thickness Swelling

Thickness swelling of the wood plastic composites had similar trend as the water absorption, and the composites with high water absorption also exhibited high thickness swelling. From figure 4.0 the thickness swelling for the (2hrs) and (24hrs) immersion for WPC (50/50) has the highest percentage of 0.82% and 2.08, 0.20 to 0.82%, WPC (40/50) has 0.55% and 1.38%, WPC (30:70) with 0.3% and 0.55%, also WPC (20/80) has 0.2% and 0.21%. Samples made with lower content of wood flour had the lowest thickness swelling the same trend as for the water absorption. In general, the composite made of higher wood content has higher thickness swelling.

Tensile

The tensile strength of the wood plastic composites depends on composite formulations. The composites based on WPC (50:50) has 7.3 Mpa, WPC (40/60) has 8.6 Mpa, with WPC (30/70) has 12.9 Mpa, while WPC (20/80) has 14.7 Mpa. From Figure 5.0, the tensile strength increases have the wood content decreases. For example, WPC of (20:80) has the highest tensile properties with a value of 14.7 Mpa. The tensile strength increases with molecular weight due to the effect of better entanglement (Adhikary, 2008).

Flexural properties

The flexural strength showed a similar trend to the tensile strength although small variation was observed in flexural strength with different formulations than the tensile strength. From Figure 6.0, the composites-based WPC (50/50) had a flexural strength of 9.3 Mpa, for WPC (40/60) had 12.2 Mpa, and WPC (30/70) with 19.1 Mpa, while WPC (20/80) had the highest with 21.7Mpa.

Similar observations were reported by (Aina *et. al.*, 2013).

CONCLUSIONS

This study reports on plastic processing equipment designed and fabricated which can be used for recycling waste plastic bottles, sawdust and other recyclable wastes. Wood plastic composites were successfully produced from ratio of wood to plastic of (20/80), (30/70), (40/60) and (50/50). There were observed differences in the physical and mechanical properties of wood plastic composites due to the influence of mixing ratio. The increased sawdust - plastic ratio had a significant effect on the physical and mechanical properties of wood plastic composites.

The equipment is cheap, easy to maintain and also easy to operate. The equipment can be designed and expanded to meet small scale enterprise due to its low cost and little technical know-how.

If the equipment is well maintained, its durability is feasible. It requires a degree of cleaning. The equipment will be useful in developing countries especially for recycling of wood waste and plastic waste, to create an environmentally hygienic condition.

Make statements on the relevance of this to biodiversity conservation e.g. conservation of trees, etc which would have been cut in the absence of recycled materials.

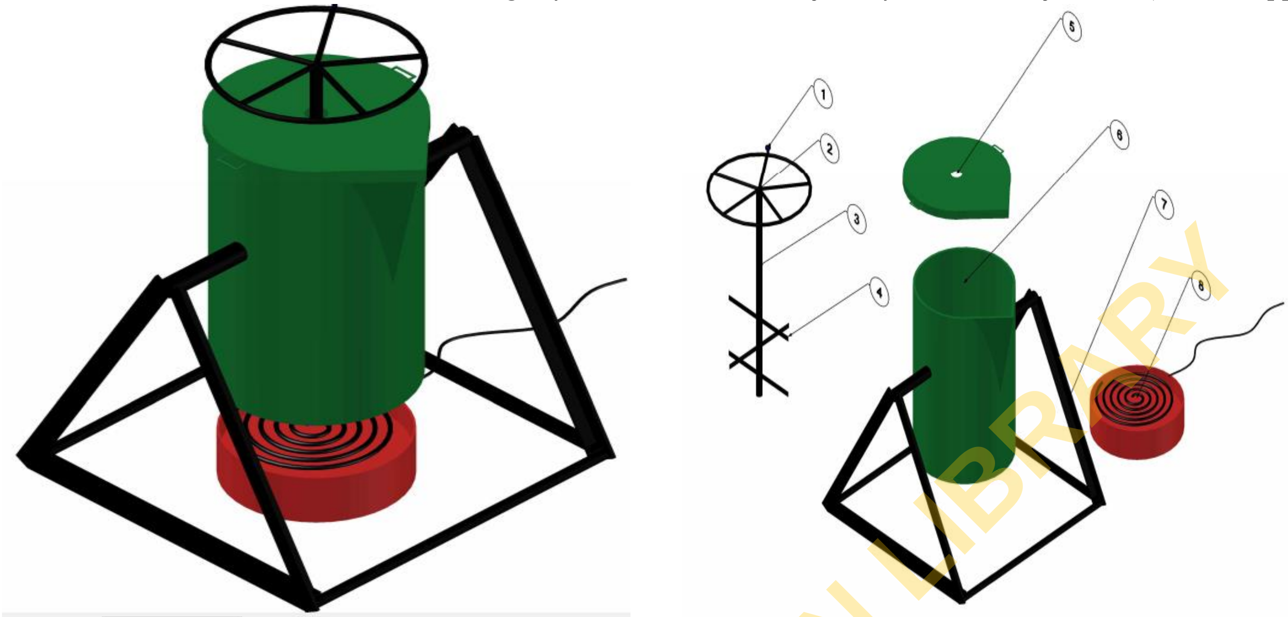

Figure 1.0 The proposed WPC machine**.**

Plate 1.0 The Developed WPC Machine

Plate 2.0 Flower Pots (Souvenir)

Plate 3.0 Penholder (Souvenir)

S/N	Components	Materials
1	Stirrer handle	Wood
2	Stirrer (wheel)	Mild steel bar
3	Shafts	Stainless steel bar
4	Blades	mild steel
5	Lid	Mild steel sheet
6	Cylinder	Stainless Steel
7	Support frame	Angle steel channel
8	Heating element	Ceramic, tungsten wire, plug.

Table 2 Physical and mechanical properties of WPC

Treatments (Composite)	W.A. (2hrs)	W.A. (24hrs)	T.S. (2hrs)	T.S. (24hrs)	Density (kg/m^3)	Tensile (Mpa)	Flexure (Mpa)
WPC (20/80)	0.08	0.09	0.20	0.20	691	14.7	21.7
WPC (30/70)	0.42	1.05	0.30	0.55	812.50	12.9	19.1
WPC (40/60)	1.05	2.62	0.55	1.38	906.23	8.60	12.2
WPC (50/50)	1.85	4.62	0.82	2.08	968.08	7.30	9.30
Mean	**0.85**	**2.10**	**0.47**	**1.05**	**844.5**	**10.9**	**15.6**

Keys: W. A. = water Absorption; **T. S** = Thickness Swelling; WPC = Wood Plastic Composite and Ratio = Wood / Plastic.

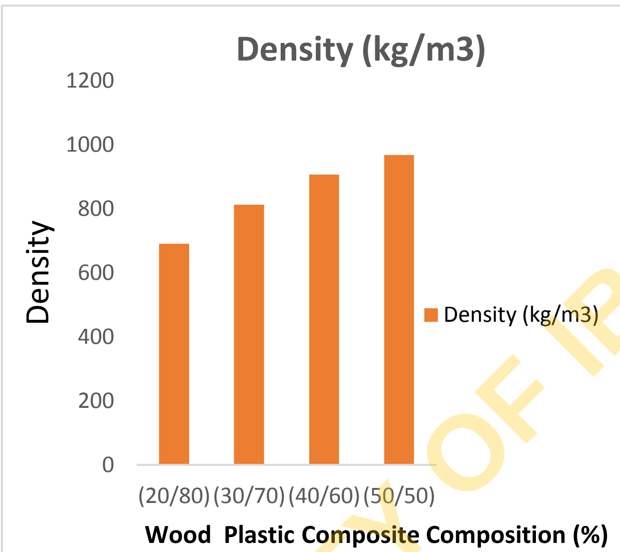

Fig. 2. Density

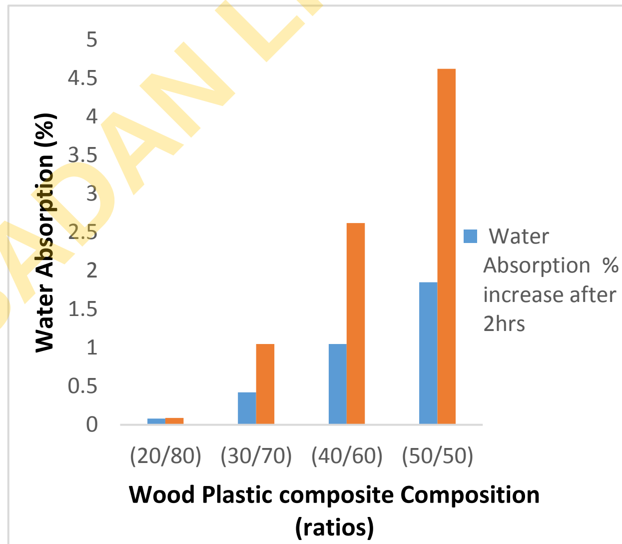

Fig. 3 Water Absorption.

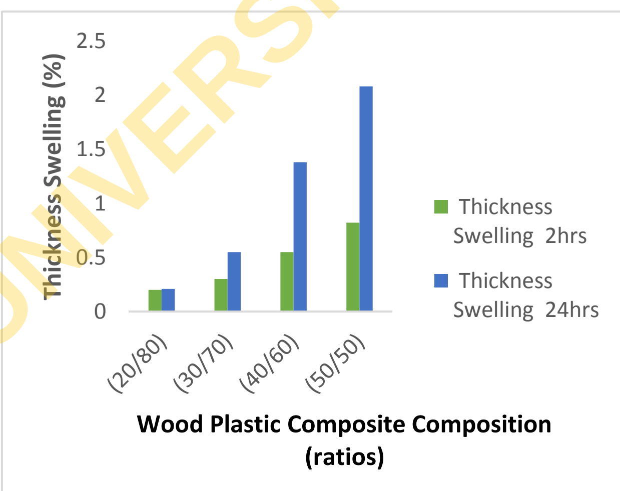

Fig 4. Thickness swelling

Fig. 5 Tensile strength

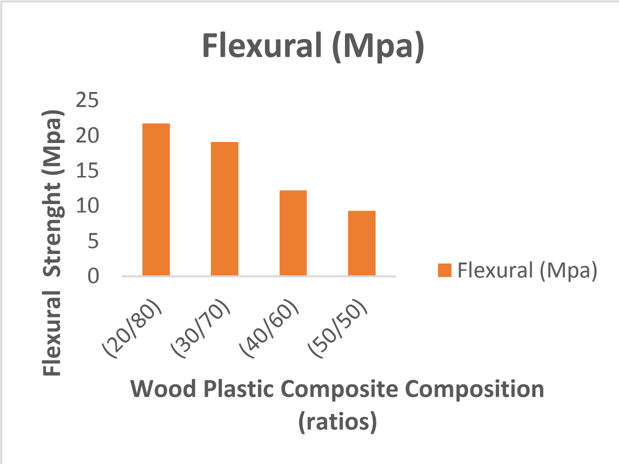

Fig. 6 Flexural strength.

Description of the Components
Melting and mixing chamber

To calculate the density of wood plastic composite

50% plastic Density= $0.96g/cm^3$
$=50/0.96g/cm3=52.08g/cm^3$

30% Wood Density $=1.30g/cm^3$
$=30/1.30g/cm3=23.1g/cm^3$

20% Coupling Agent Density=$2.80g/cm^3$
$=20/2.80g/cm3=7.42g/cm^3$

Density of WPC = $\frac{100}{82.52} = 1.211g/cm^3$

Based on ergonomics and ease of operation, the height of the mixing chamber is assumed to be 410mm.

Hence,

Density = $\frac{Mass}{Volume}$

Volume = $\pi/4 \times d^2 \times h$

$= 0.79 \times 0.254^2 \times 0.410$

$=0.0207m^3$

$=0.0207 \times 1000000 = 20700cm^3$

The diameter (d) is estimated from

$$d = \sqrt{\frac{volume}{h \times \pi / 4}}$$

$d = \sqrt{\frac{20700}{0.410\times0.79}} = 252.80mm$ Let's say 253mm.

Also,

Mass= $Density \times volume$

$=1.211\times 20700$

=25067.7g

=25.0677kg

For the purpose of this design, 6kg of plastic, 3kg of wood flour, and 1kg of additives is recommended, with total of 10kg. Assumed 1.5% waste, $1.5\times 10 = 15kg$

Lid specification

Since there is an opening or manhole in the head, thickness of the plate is given as *Ti*

$$Ti = d\sqrt{\frac{k \times p}{\int t}}$$

d= diameter of cover

p =liquid pressure

∫t= working stress of cylinder.

k = empirical coefficient

K= 0.162

P= is assumed to be 7N/mm2. , ∫t=32N/mm2

Ti= di$\sqrt{k.p/\int t}$

$=250\sqrt{0.162 \times 7/32}$

= 9.89mm, let's say 10mm

The perforated SAE 1086 of high strength and ductility sheet was used for the lid with 10mm thickness.

Stirrer specification

The agitator is the unit of the machine that ensure that wood and plastics wastes are mixed together until homogenous mixture is achieved.

Torque (stress) =assumed to be $32N/m^2$

ks = 1-20 Mpa or N/mm

Torque adopted ranged from 2500 -3000Newton,

$$d = \sqrt[3]{t/0.2 \times ks}$$

$$d = \sqrt[3]{3000/0.2 \times 2}$$

d =19.57mm.

Therefore the diameter of the shafts is 20mm.

Torque $=\frac{\pi d^3}{16} \times \tau$

$= (\pi \times 20^3/16) \times 32$

=50265.4N/mm

To verified the stress in the cylinder

Torque $=\frac{\pi d^3}{16} \times \tau$

$\tau =16\times T/ \pi d^3$

$= 16\times 50265.4/\pi \times 20^3$

= 31.99 N/mm

Length of the shaft = 480mm, Diameter of each blade = 77mm. Number of blade = 6 blades.

Support frame

This is the unit of the machine on which all other components are mounted. It is made up of angle iron bar of 27mm×27mm dimension and 5mm thickness. The height of frame is considered as the height of the heating element plus the average height of the cylinder.

i. Height of support = 460mm
ii. base of support = 460mm

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