

Development of a Wood Plastic Composite Extruder

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Abstract

Wood plastic composites (WPC) is the recycling of wood flour and plastic into new products like particle boards, floor tiles and other structural building applications. An extruding machine is developed at the workshop of Agricultural and Environmental Engineering Department of The Federal University of Technology, Akure, Ondo State to handle the production of these products. The major components of the machine include the melting/mixing chamber, the extruding chamber, the frame and the discharging chamber. The working principle of the machine is by allowing the recycled shredded plastic to melt at 200°C before adding the wood flour and mixed thoroughly. This is now fed into the extruding chamber at same temperature which further kneads the mixture into slurry before discharging it into a mould of dimension 150 mm × 80 mm × 70 mm. The machine is powered by 10 Hp three phase electric motor. Specimen produced is now hot-pressed at 120°C to a thickness of 13mm and allowed to cool before removal. The machine had a throughput of 0.78 kg/hr and functional efficiency of 86%. The total production cost as at the time of fabrication is Three Hundred and Fifteen Thousand Naira Only (N 315,000). It is recommended for small and medium scale entrepreneurs.

Keywords: Development; Plastic; Wood; Extruder; Machine; Waste; Cost

Introduction

Wood plastic composite (WPC) are materials made from a combination of saw dust, thermoplastic resin and chemical additives [1]. WPCs are relatively new products as compared to the long history of natural lumber or traditional wood composites such as particleboard or fibreboard [2]. Wood in form of flour/particles/fibres/sawdust is combined with thermoplastic materials under specific heat and pressure for producing WPCs where additives are added for improved quality. Many researchers have been working on WPCs by flat-pressed method at various wood-plastic ratio which typically ranges between 20% to 80% of saw dust or fibre either as filler or reinforcements [1,3-8]. The two main adopted techniques in the production of WPCs are extrusion and injection moulding. The extrusion process produces continuous linear profiles via forcing a melted thermoplastic through a die; on the other hand, the injection moulding process produces three-dimensional items with minimizing the stages of post-manufacturing [9]. The manufacturing techniques adopted by Bengtsson and Oksman [10] were based on drying wood flour at 100°C to reach a moisture content of 0.3%. The dried wood and plastic granules were then fed to the co-rotating twin-screw extruder at temperatures varying from 165°C to 200°C. A rectangular die was used at the extruder end and the extrudates were then cooled at ambient temperature [10]. Yeh et al. [11] divided the WPC manufacturing process into two main parts. The first part consisted of compounding the material; using a twin-screw extruder. The second part was to obtain profiles via single-screw extruder or use injection moulding to obtain a product resembling the wood in look and properties. Migneault et al. [9], conducted a comparison between extrusion and injection moulding for producing WPC, common steps found in both include melting, shaping, and cooling; in addition, they both use screws to convey, pump, and blend the mixed component and concluded that pressure and shearing in injection moulding are higher than an extrusion regardless the process parameters mentioned. Winandy et al. [12], compared WPC samples; composed from 50% wood flour and HDPE, obtained from extrusion and injection moulding and found that they gave the same flexural modulus; however, the flexural strength and density of injected parts were higher. The authors justified that this could be resulted from

the better interfacial contact in injection moulding between wood and polymer; totally encapsulated wood particles within polymer matrix, resulting in higher density and therefore more strength. However, Bledzki and Faruk [13], have shown that WPC made from 30% hardwood particles and polyethylene resulted in similar specific bending modulus of elasticity and density for both injection moulding and extrusion techniques. Concerning physical properties, Clemons and Ibach [14], conducted sorption behaviour comparison for WPC; composed from 50% of 40-mesh pine flour and HDPE, and concluded that water-soaked extruded samples absorbed and swelled more water than injection moulded samples. Recycled plastics can also be considered for manufacturing of WPCs depending on their melting temperature [15]. Additives can also be added to improve the quality of the composites by eliminating the off-putting properties. However, the utilization of recycled plastic in WPC manufacturing is still limited, and a major portion of global municipal solid waste (MSW) includes post consumer plastic materials like HDPE, LDPE, PVC, and PET which have the potentiality for being used in the WPCs [16].

Materials and Methods

Material selection for machine components

The following were considered in selecting materials for the fabrication of the wood plastic extruding machine;

- Availability of the fabrication materials
- Durability of selected materials

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- c. Strength of the selected materials to withstand and conduct heat
- d. Cost of the materials selected
- e. Ease of fabrication of the machine

Design analysis of wood plastic extruding machine

The melting/mixing chamber: Galvanized mild steel sheet of 2 mm thickness was selected because of its strength and ability to withstand and conduct heat. It was designed as a cylindrical chamber of 280 mm × 200 mm diameter with slanted base for easy flow of the mixture of the waste plastic and sawdust after mixing together under gravitational force. It has a stopper at the exit end to regulate the inflow of the mixture into the extruding chamber.

The shaft: This is a screw-augered shaft made of mild steel of 1015 mm length and 35 mm diameter. The screw auger pitch distance is 40 mm and covers a length of 810 mm of the shaft. Mild steel was chosen due to its ability to withstand heat and pressure.

The barrel: This is hollowed mild steel of 2 mm thickness selected because of its ruggedness and ability to conduct and withstand heat and pressure without deformity. The barrel has outer and inner diameter of 75 mm and 36.5 mm respectively and the total length is 780 mm.

Bearing: A single row deep groove ball bearing of 35 mm diameter was used on either sides of the shaft for the design of the machine.

Heaters: There are seven heat bands of 1.5 kw used to heat up the melting and mixing chamber and the extruder barrel and has the adaptation for regulation between 0°C to 500°C.

Control panel: This is a board where all the electrical fittings are assembled to give power to the electric motor and regulate the heat supplied by the heat bands to the extruder and the melting/mixing chamber.

The frame: This is the unit of the machine on which all other components are mounted. It is made up of angle iron of 46 mm × 27 mm dimension and 5 mm thickness.

The mould: The mould is a rectangular shaped galvanized steel of thickness 13 mm and dimension of 150 × 80 × 70 mm. Galvanized steel was selected because of its hardness and non-adhesive character which gives the mould easy removal after compression.

The hydraulic press: The hydraulic press is designed using angular iron of thickness 2 mm as the frame to support the hydraulic pump for the compression of the extrudate.

Test procedure

1. Weight based three ratios of wood – plastic were chosen; 40:60, 30:70 and 20:80 (SD-PET). The sawdust (SD) was sieved to size 2.00 mm and air dried to a moisture content of 12% while the plastic were already shredded into smaller pieces (Figure 1).
2. The melting and extruding chambers of the WPC extruding machine were heated to 200°C by 7.5 kw heat bands and this heat was maintained throughout the production.
3. The shredded waste plastic water bottle (PET) was allowed to melt at 200°C inside the melting chamber of the extruding machine before adding the sawdust (SD) according to the ratios selected.
4. The mixture were mixed together and fed directly into the extruder through its discharge point as shown in Figure 2. The extruder further kneaded the mixture together and the sample was collected at

the discharge outlet of the extruder into a mould of 150 mm × 80 mm × 70 mm dimension.

5. The sample was hot pressed at 120°C to a thickness of 13 mm with hydraulic press and allowed to cool down before removal. Figure 3 shows the picture of sample produced.

6. The time taken to melt the plastic, the time taken to mix the composites and the time taken to extrude were recorded for the three ratio used.

7. The throughput and efficiency of the machine were calculated from Equations (1) and (2) [17].

$$\text{Throughput (TP)} = \frac{\text{Output mass of recycled waste plastic (Q)}}{\text{Time taken for recycling (t)}} \quad (1)$$

$$\text{Recycling Efficiency (RE)} = \frac{\text{Output mass of recycled waste plastic (Q)} \times 100}{\text{Input mass of waste plastic (I)}} \quad (2)$$

Results and Discussion

Table 1 shows the results obtained from the machine during the performance test where SD was the saw dust content (%) in

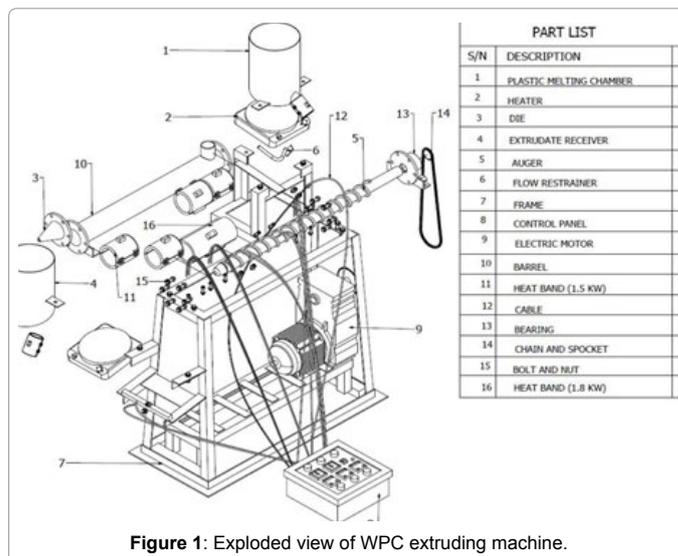


Figure 1: Exploded view of WPC extruding machine.

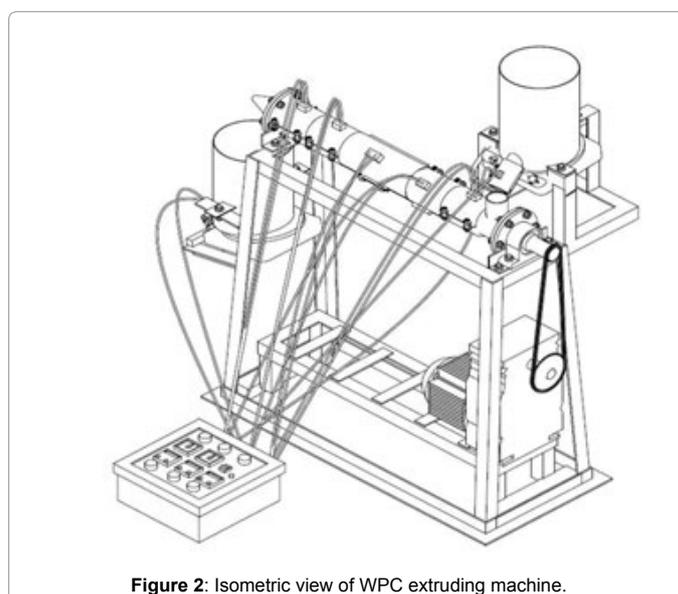


Figure 2: Isometric view of WPC extruding machine.



Figure 3: Samples of wood-plastic composite produced.

the composites formulation. W1 was the initial weight (kg) of the composites before extruding while W2 was the final weight (kg) of the composites after extrusion. The time taken for the plastic to melt, the composites to thoroughly mixed and extrusion process were taken. From these information, the throughput and the efficiency of the WPC extruding machine were calculated for each of the SD-PET ratio.

Figure 4, shows a linear trend maintained for the three ratios input and output results. For 40% -SD, 0.21 kg of the composites were fed into the extruder while 0.18 kg of the composites was collected. For 30% SD, 0.20 kg of the composites were fed into the machine while 0.16 kg were collected and the same goes for 20% -SD, where 0.18 kg composites were fed into the machine and 0.16 kg were collected. The reduction in the mass of the composite extruded was due to the quantity that sticks to the extruder barrel during the process due to the adhesive nature of plastics. It was also observed from Figure 5 that the lesser the mass of the sawdust in the composites, the lesser the time taken to mix them together. This is due to the nature of the melted plastic to encapsulate the sawdust during their mixing together. It took 7 mins to mix 40% -SD, 5mins for 30% -SD and 3mins for 20% -SD. As the quantity of the sawdust reduces so is the time used in mixing them together.

As shown in Figure 6, it takes the WPC extruder 15 mins to process 40% SD-PET composites while it takes the machine 12 mins to process that of 20% SD-PET. The lesser the quantity of the saw dust in the composites, the lesser the time used in extruding it. Figure 7 shows the throughput of the WPC extruding machine at ratios 40:60, 30:70 and 20:80 SD-PET composites. The results according to the ratios are 0.72 kg/hr, 0.75 kg/hr and 0.78 kg/hr respectively. The machine has the highest throughput when used to process composites with lesser amount of sawdust, that is, ratio 20:80 SD-PET. Figure 8 shows that the WPC extruder performed efficiently at 86.11% for 20:80 SD-PET ratio, 85.71% and 83.59% for 40:60 and 30:70 SD-PET ratios respectively. The efficiency of the extruder is higher when the sawdust content in the formulation is far lesser than the plastic as we see this in the SD-PET ratio 20:80 where the efficiency was 86.11%.

Conclusion and Recommendation

A small scale wood-plastic composite extruder machine was designed, fabricated and tested at the Agricultural and Environmental Engineering department of The Federal University of Technology, Akure. The extruder is powered by 10Hp three phase electric motor. In this work, the extruder was used to produce particle board with three different wood – plastic ratio based on their weights. The ratios are 40:60, 30:70 and 20:80 SD-PET. The performance of the machine was investigated in terms of the throughput and efficiency on the mixing ratio of the composites. It was observed that the extruder performed optimally when used to process the wood plastic composite of ratio 20:80 SD-PET. It takes the melting chamber 20 minutes to fully melt the plastic and an average of 5 minutes to mix the composites into

SD Content (%)	Input (W ₁) (kg)	Output (W ₂) (kg)	Melting Time (mins)	Mixing Time (mins)	Extruding Time (mins)	Throughput (kg/hr)	Efficiency (%)
40	0.21	0.18	20	7	15	0.72	85.71
30	0.20	0.16	20	5	13	0.75	83.59
20	0.18	0.16	20	3	12	0.78	86.11

Table 1: Results of test procedure of WPC extruding machine.

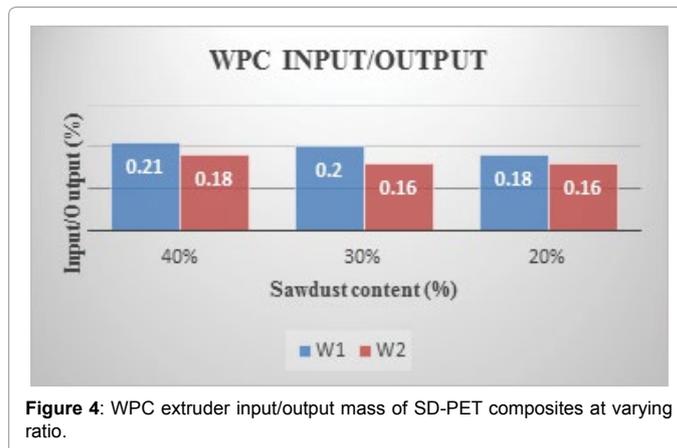


Figure 4: WPC extruder input/output mass of SD-PET composites at varying ratio.

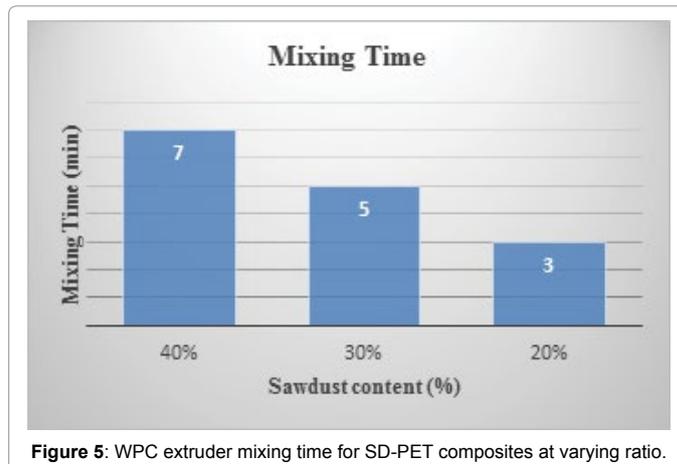


Figure 5: WPC extruder mixing time for SD-PET composites at varying ratio.

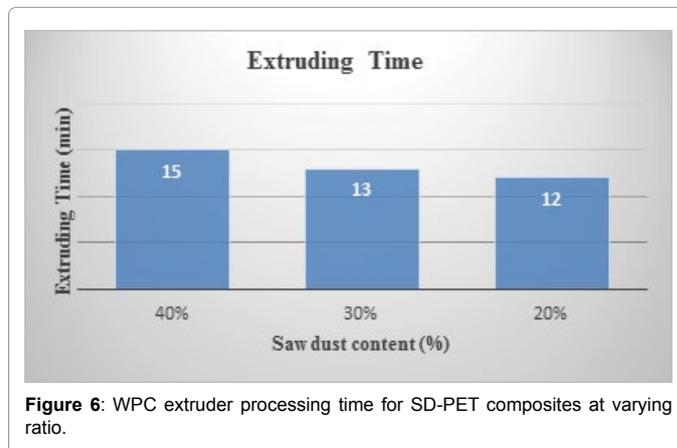


Figure 6: WPC extruder processing time for SD-PET composites at varying ratio.

slurry while the extruder spent an average of 13 minutes to process the mixture and extrudes same. The extruder has a throughput of 0.78 kg/hr and efficiency of 86%. The production cost of the machine

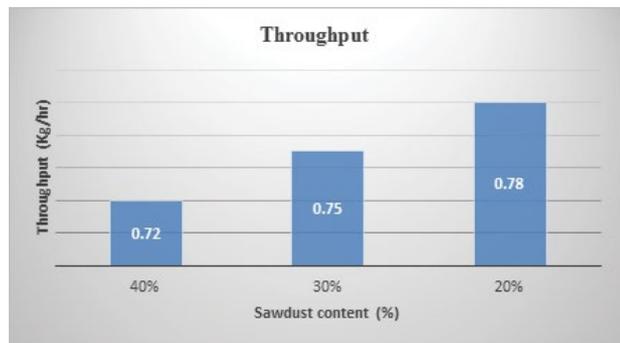


Figure 7: WPC extruder throughput (kg/hr) for SD-PET composites at varying ratio.

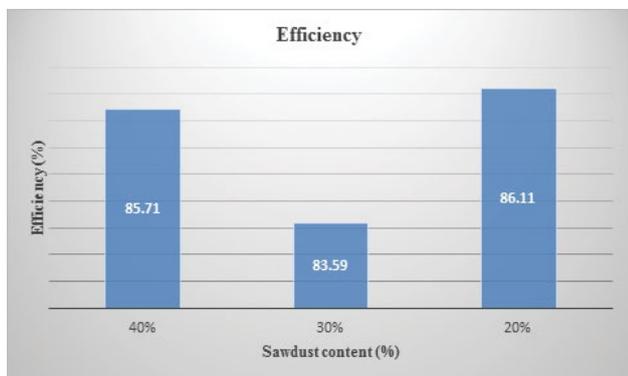


Figure 8: WPC extruder efficiency for SD-PET composites at varying ratio.

was Three Hundred and Fifteen Thousand Naira Only (N315, 000). It is recommended for small and medium scale production of particle boards useful for both indoor and outdoor structural building purposes.

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