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THE DESIGN, FABRICATION AND EVALUATION OF A WASTE PLASTICS CRUSHING MACHINE FOR THE COMPANY'S RAW MATERIALS ACCESSIBILITY

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Abstract: A low-cost variable-speed waste plastic crushing machine was designed, constructed, and tested to evaluate its efficiency and throughput. The machine consists of a hopper, a pulley, a crushing compartment with knives, and a 3 HP variable-speed electric motor. This work aimed to construct a machine that shreds waste plastic into smaller sizes at different working speeds for recycling. Also, the machine was constructed from locally available materials; therefore, its cost is very low and affordable. The machine's throughput at 900rpm, 750rpm and 600rpm was 30.57 kg/hr, 23.37 kg/hr and 21.37 kg/hr, respectively, for PVC-type waste plastic. The Specific energy consumption of the machine at 900rpm, 750rpm and 600rpm was 134.88 kJ/kg, 176.37 kJ/kg and 192.89 kJ/kg, respectively, for PVC-type waste plastic. The average particle size of the machine products at 900rpm, 750rpm and 600rpm was 2.54mm, 2.42mm and 2.21mm, respectively, for PVC waste plastic. The machine's efficiency at 900rpm, 750rpm and 600rpm was 87.45%, 88.95% and 90.24%, respectively, for PVC waste plastic. The optimal operating speed depended on the parameter considered paramount; the best crushed waste plastic, based on average size and crushing percentage, was obtained at 600rpm. Considering the throughput, the optimal result was obtained at an operating speed of 900 rpm.

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Also, considering the Specific energy consumption, the optimal result was obtained at an operating speed of 900rpm. The cost of fabricating the machine was 126,850 NGN.

Keywords: *Waste plastics, crushing mill, design and fabrication, engine speed, efficiency.*

INTRODUCTION

Waste has been defined as any material of no value to the owner [15]. Waste management and disposal seem like huge tasks, given the enormous amount of waste generated. Transporting the generated waste to the dump site requires significant time and money, as the waste is clustered and not uniform in shape or size. Waste is also defined as any product or substance that has no further use or value for the person or organization that owns it, and which could or would be discarded. Also, waste is any solid, liquid or gaseous substance or material that is scrapped, refused or rejected and disposed of or required to be disposed of, as unwanted. Waste is usually in three forms: liquid, solid and gaseous. This work focuses on solid plastic waste recycling because they block sewage, contaminates the water supply, occupies the ocean floor and litters our environment [1]. A crushing machine is used to reduce large solid objects into smaller volumes or smaller pieces. Crushing machines are usually used to reduce the size and shape of materials so they can be used efficiently for their intended purpose. The crushing machine parts must have greater strength and toughness than the materials to be crushed. Crushing machines and devices work mainly by holding the material between two parallel or tangent solid surfaces, and in the process, sufficient force is applied to bring the surfaces together, generating enough energy within the material to fracture or realign its molecules [4]. Recycling is the process of treating waste materials to produce new products. Recycling helps reduce waste, consumption of new raw materials, energy use, incineration emissions, water pollution from landfills, and emissions from the production of new goods from raw materials [4]. [16], researched various plastic waste management strategies. The solution to the waste management problem was separating wet and dry solid waste. The conventional technologies for plastic waste management were land filling and incineration.

Recent technologies for plastic waste management include co-processing in cement kilns and co-processing as an alternative fuel. [15], worked on the overview of the recycling of various types of plastics. Generally, there were two types of plastics: recyclable and non-recyclable. In recyclable plastic, PET, HDPE, LDPE and PVC were used, and in non-recyclable plastic, Bakelite and Nylon were used. Sorting, cleaning, shredding, and Extrusion were the general steps involved in their paper. It also includes various plastic recycling processes, such as mechanical recycling, blast-furnace recycling, and gasification. It also involved environmental issues related to plastic disposal. [19] studied the use of PET for packaging materials. PET is widely used as a packaging material due to its low diffusion properties. It means that no contamination can be diffused into the PET. Various tests showed that PET use in food applications was not harmful to humans. PET was generally used for packaging food products, such as bottles, snack wrappers, trays and blisters.

Generally, the bottles and jars were made by injection stretch blow moulding, and the trays were made by thermoforming. In this paper, it was suggested that there was no legislation governing the use of recycled PET in food applications [14]. Research on reducing plastic waste in the Maldives through mechanical recycling was limited. The 'Male Water and Sewerage Company' (MWSC) established a scheme of mechanical recycling with the 'Buyback Scheme'. Recycled PET was used to produce new PET bottles. Injection moulding was used for pallet making, and blow moulding for bottle making. Various trials were conducted to make bottles with 15%, 25%, and 35% PET using virgin pellets. From the trials, it was shown that 15% PET is beneficial for the new PET bottle-making process. [18] researched on the utilization of waste plastic in the manufacturing of plastic-soil bricks. In mines, laterite stones were excavated. During this process, significant waste was generated from the laterite quarry. So, this quarry could be reused by using recycled plastic waste and binders. Generally, 70% recycled PET by weight of laterite quarry was used to produce bricks measuring 20×10×10 cm. [14] worked on a project involving the utilization of recycled PET in engineering materials. Waste PET was generally used as engineering materials, such as road pavements, asphalt, and building concrete. The main reason to use plastic waste in asphalt road pavements and concrete is its ability to provide a softer binder at low temperature to avoid cracking, a stiffer binder at high temperature to avoid rutting, reduced viscosity and a higher-strength binder. It also reduces material costs. [23] researched on the effect of the use of recycled LDPE, PET and HDPE in structural applications. For these, a UTM test was carried out on a specimen made from the recycled LDPE, PET and HDPE. These waste plastics were palletized by extrusion, and a sample was produced by injection moulding. 7 samples of each material were tested for tensile properties, and various mechanical properties were determined. The samples made from virgin materials were also tested, and the results were compared. From this, it was concluded that although the properties of the recycled plastic sample were reduced, it could still be effectively used as a sustainable building material. [22] researched on the use of PET bottles as a sustainable material in construction. Plastic bottles could be used instead of bricks by filling them with suitable filling materials, such as sand, fly ash and wood particles. As a result, carbon emissions from brick production decreased, and plastic bottle recycling increased. For these plastic bottles, sand, fly ash and wood particles were filled in various proportions, and a compression strength test was carried out. From the test, it was noted that a plastic bottle filled with a 2:1 mixture of fly ash and sand has a high load-sustaining capacity and could be used as a building material. [7] studied the conversion of LDPE plastic into useful liquid fuel. It has been shown that fuel derived from waste LDPE has properties similar to those of conventional fuels. The pyrolysis method converts waste LDPE into useful fuel. It involves heating crushed plastic in the absence of oxygen. The setup ranged from 100°C to 400°C. At 100°C to 250°C, we obtain 20-30% liquid fuel. At 270°C, the plastic slurry starts to vaporize, and the vapor condenses in the condenser. At up to 325°C, 40% of the liquid fuel remained. At 400°C, the process was completed. [19], presented a work on the design and the conversion of waste PET into useful liquid fuel. A simple Catalytic conversion process obtained this fuel. In this experiment, Calcium Hydroxide (CaOH_2) was used as a catalyst. A sample was prepared with 40 g of PET waste and 80 g of catalyst. The 40-gm catalyst was placed in the boiling flask first. Then the PET waste was placed on it, and the remaining 40 gm of catalyst was placed at the last. The mixture was heated to 405°C. After 10 minutes, vapour began to form, but it did not condense immediately.

It travels to the collection flask. After 13 minutes, vapour started to condense, and drops of fuel were collected in the collection flask. After 20 minutes, the mantle temperature was reduced to 315°C, and it was heated for 15 minutes. After that, fuel generation stopped. 603 ml of fuel was produced during the process. [3] designed a mobile crusher that could be used in small and medium industries, and also by full-time homemakers, so that they could enter the recycling business. The parts of this crusher were blades, hopper, pulley, Belt and Driving Motor. For cutting blades, Stainless Steel was used as the cutting material. The blades were circular, mounted on a shaft driven by a motor via a belt. A 1 HP AC motor was used as the driving unit. From this machine, 6 bottles could be crushed at a time, with particle sizes ranging from 1 mm to 20 mm. The overall cost of manufacturing the crusher was up to RM 2000, which is equivalent to RS. 31000. [20] designed a bottle crusher with the advantage of portability. The crusher was designed directly on top of a waste bin. The plastic bottles had to be passed through three rollers. The first rollers had spikes to prevent the water bottles from slipping.

The second-level rollers were designed with numerous flat projections on their surfaces to crush bottles. The final rollers were heating rollers. They heat the crushed pieces to smooth them and to reduce their volume. A 12-volt DC motor was used as the driving motor to reduce the machine's weight. [17] designed and developed a plastic recycling machine by using Finite Element Analysis (FEA). In this study, the manually operated machine was converted to a pneumatically operated machine through appropriate design considerations. The obtained results of each component of the actual machine, which were total deformation, Equivalent stress and equivalent strain, were somewhat the same as those of the FEA results. Hence, the design is safe. The developed machine was very effective to use, with high accuracy. [2] designed a waste plastic shredding machine that could shred PET, HDPE, PVC, and PP into small pieces. The machine consists of a feeding unit, a shredding unit, a power transmission unit and a machine frame. The feeding unit was made from a 2 mm thick galvanized mild steel sheet measuring 200 mm × 550 mm. The shredding unit consists of a 50 mm-long, 30 mm-diameter mild-steel shaft and a 55 mm-long, 200 mm-diameter cylinders. Cutters were made of 12 mm mild steel attached to a shaft. These have nine teeth welded 2 mm apart. The cylinders had the same cutters, equally spaced. The power transmission unit consists of a 10 HP motor with a belt-and-pulley arrangement. [24] worked on the design considerations for an automatic can-plastic bottle crusher machine. This machine was widely used in the beverage industry and by scrap dealers to reduce the volume of new plastics produced from their raw materials, which require significant energy. Since most plastics are non-biodegradable, they often constitute a nuisance to the environment after use. To preserve our environment, we need to develop sustainable means to manage plastic waste generated by our local communities and industries, thereby making the recycling of plastics an important aspect of waste management. For the recycling process to be sustainable, it must be cost-effective (i.e., economical) and able to address the environmental problems caused by waste plastics without creating new ones, such as air, water or land pollution. Thus, an efficient recycling structure needed to be put in place to process some of these waste plastics, which were supposed to be disposed of in landfills or burned in incinerators, into useful materials. The Objective of this study is to design and fabricate a motorized waste plastic crushing machine operating under varying speeds. Secondly, to evaluate the machine's performance and identify its optimal operating speed.

MATERIALS AND METHOD

Materials Selection

The selection of materials is very crucial in the design and construction of any machine. Factors such as durability, machinability, availability, reliability and cost were considered in the selection process. Thus, some parts, such as the frame, hopper, knife, rotating shaft, pulleys, belt and prime mover (electric motor), used for the fabrication of the machine were selected, and their descriptions were outlined.

Machine description and operation

The waste plastic crusher comprises three main components: the feeding unit, the crushing unit and the machine frame. The feeding unit is made from a 2mm-thick 16-gauge galvanized mild steel plate measuring 200mm by 550mm, through which waste plastics are fed into the crushing unit. The crushing unit is where the waste plastics are cut into smaller sizes. The crushing unit consists of a 750 mm-long, 25mm-diameter shaft made from mild steel. On the shaft is a crushing knife that helps cut the plastic. Crushing is achieved by converting the electric motor's rotary motion into crushing force through the crushing knives. After the crushed plastics leave the knife chamber, they pass through a mesh before exiting the delivery chute, where they are collected. Oversized materials are sent back to the machine for re-crushing. The machine is powered by a 3HP variable-speed electric motor, which is mounted with a 90mm pulley and operates at 1440rpm.

Design considerations:

The design consideration of the waste plastic crushing machine was based on the following concepts and considerations:

- (1). The availability of materials locally reduces the cost of production and maintenance of the machine.
- (2). The ease of operation of the machine
- (3). The plastic should be well crushed, with no remaining plastic, and the crushed plastic should be properly discharged.
- (4). The waste plastic crushing machine was designed using standard components to allow easy replacement of parts during maintenance.

Design analysis: Volumetric capacity of the machine

The effective volume V_c of the waste plastic crushing machine that the waste plastics can occupy constitutes the volume of the lower channel, where plastics from the hopper meet the crushing knives, and the volume of the hopper [3]. The machine's volume was calculated using equation (1) as 0.0356 m^3 .

$$V_c = (H_L * B_L * L_L) + \left(\frac{1}{2} (L_b + L_c) * L_a * L_d \right) \quad \dots\dots\dots(1)$$

Where,

H_L = Height of the hopper ; B_L = Breadth of the hopper ;

L_L = Length of the hopper

L_a = height of the lower chamber L_b = length of the top base of the hopper lower chamber

L_c = length of the lower base of the lower chamber

L_d = distance between the two trapezoidal ends

$H_L = 0.250\text{m} = 250\text{mm}$, $B_L = 0.150\text{m} = 150\text{mm}$; $L_L = 0.230\text{m} = 230\text{mm}$,
 $L_a = 0.280\text{m} = 280\text{mm}$, $L_B = 0.412\text{m} = 412\text{mm}$
 $L_c = 0.150\text{m} = 150\text{mm}$, $L_d = 0.400\text{m} = 400\text{mm}$

Selection of pulleys and shafts: Selection of pulleys

The machine requires two pulleys. Due to their availability, cost and performance, cast iron pulleys with a groove angle of 38° each were selected. The maximum speed for the crushing design was assumed to be 900 rpm, since the crushing knives require a high speed to crush the plastic. The electric motor is rated at 1440 rpm, and a 90mm diameter pulley is fixed to the variable-speed electric motor shaft [5]. The diameter of the pulley attached to the crushing shaft was determined to be 144mm using equation (2).

$$VR = \frac{N_1}{N_2} = \frac{D_2}{D_1} \quad (2)$$

Where N_1 and N_2 represents the driving (electric motor) and driven (crushing shaft) pulleys' speed while D_1 and D_2 are the pulleys' respective diameters.

C - The Centre distance.

The distance between the adjacent pulleys of the electric motor and the crushing shaft was determined as 207mm according to [10], as presented in eqn. (3).

$$C = \frac{D_1 + D_2}{2} + D_1 \quad (3)$$

Thus, the length of the belts, L , required for crushing the shaft drive was computed from Equation (3) as 784.9mm. Hence, type 'A' V-belts with standard pitch lengths of 823mm were selected for the motor/crushing drive, since the drive transmits less than 3.75 kW of power (IS: 2494-1974; [14]).

$$L = 2C + 1.57(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4C} \quad \dots\dots\dots(4)$$

Determination of the Shaft Diameter.

The shafts were designed to transmit the appropriate load and torque and therefore have ample strength and rigidity.

Considering availability, a mild steel shaft was used for the fabrication, the shaft diameters, The crushing shaft of this machine was determined using equation (5), which is given by

$$d = \left[\frac{16}{\pi \tau} \sqrt{(k_b M_b)^2 + (k_t M_t)^2} \right]^{1/3} \quad (5)$$

Where: $\tau = 42 \text{ N/mm}^2$. The maximum twisting moment acting on the shaft,

M_t = Maximum Twisting Moment on the shafts, Nmm,

M_b = Maximum Bending Moment on the shafts, Nmm,

K_b = Combined shock and fatigue factor for bending, the allowable shear stress for a steel shaft with provision for keyway, τ is given as 42 N/mm^2 [16], while the respective maximum twisting moment on the crushing shaft,

M_t was determined as 11,039 Nmm using this equation (6)

$$M_t = (T_i - T_j) \frac{D_2}{2} \quad (6)$$

The speed of the belt, v . The speed of the electric motor/crushing shaft drive was determined as 6.79 m/s using the relation given in Equation (7) according to [17], as in eqn. (7).

$$v = \frac{\pi D_2 N_2}{60} \quad (7)$$

Tensions are on the tight side, T_i The torque of the belt of the electric motor/crushing shaft was determined as 165.12 N using Equations (8, 9 and 10) [20]. The mass of the belt per meter length, m , coefficient of friction, μ , between the pulleys and the belt, maximum safe stress, σ , and cross-sectional area, a . Some of the belts were also obtained from standard tables, IS: 2494-1974, as 0.108 kg/m, 0.3, 2.1 N/mm², and 81 mm², respectively [1,2,3]. Also, due to availability, cost and performance, cast iron pulleys with groove angle (2β) A temperature of 38° was selected for the drive.

$$T_i = T_{max} - T_c \quad \dots \quad (8)$$

$$T_{max} = \sigma \times a \quad \dots \quad (9)$$

$$T_c = mv^2 \quad \dots \quad (10)$$

Subsequently, the respective belts' slack side tensions,

T_j were determined as 11.80 N using equation (11) (Khurmi & Gupta, 2005)

$$2.3 \log \frac{T_i}{T_j} = \mu \theta \csc \beta \quad \dots \quad (11)$$

Where; T_{max} = Maximum tension on the belts,

T_c = The centrifugal tension on the belts and the belt lap angle (Θ) at the small pulley of the drive were computed from Equation (12) as 164.2° (2.86 rad).

$$\theta = 180 - 2 \left[\sin^{-1} \left(\frac{D_2 - D_1}{2C} \right) \right] \quad (\text{Khurmi and Gupta, 2010}) \quad (12)$$

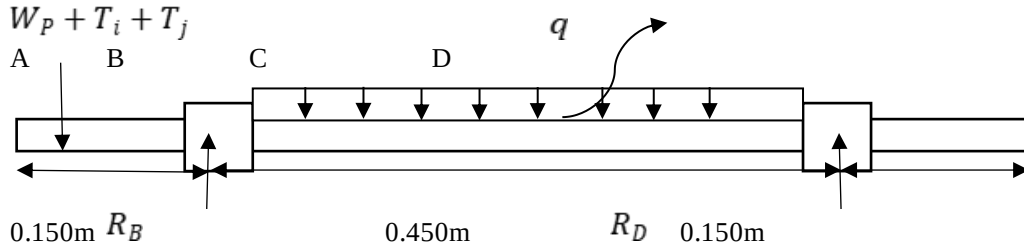
Determination of the shaft's bending moments

Fig. 1. Showing the free-body diagram of the crushing shaft

Where,

W_P = weight of the crushing shaft pulley = 14.76N,

q = uniformly acting weight of the knife crushing compartment = 103N,

T_i = Tension at the tight side of the crushing drive = 165.21N,

T_j = Tension at the slack side of the crushing drive = 11.80N,

Total force at the point A = $W_P + T_i + T_j$ = 191.68N,

Total force at the point C (midpoint between point B and point D) = 23.175N ,

The reactions of bearing R_B and R_D were determined by taking the moment about B.

$$\sum M_B = 0;$$

$$23.175 \times 0.225 = 0.450R_D + 191.68 \times 0.150 \quad \text{.....(13)}$$

$$5.214375 = 0.450R_D + 28.752 \quad \text{.....(14)}$$

$$R_D = -52.31N$$

$$\text{Also } \sum F_y = 0 \quad \text{.....(15)}$$

$$R_B - 52.31 = 191.68 + 23.175 \quad \text{.....(16)}$$

$$R_B - 52.31 = 214.855; R_B = 267.165N \quad \text{.....(17)}$$

Taking downward forces to be negative (-) and upward forces to be positive (+), the shear forces acting on this shaft were computed as follows:

$$F_{A-B} = -191.68N \quad F_{B-C} = -191.68 + 267.166 = 75.486N$$

$$F_{C-D} = -191.68 + 267.166 - 23.175 = -52.31N$$

$$F_{D-E} = -191.68 + 267.166 - 23.175 + (-52.31) = 0N$$

Thus, the bending moments on this shaft are calculated as follows.

$$M_A = 0Nm \quad M_B = -28.752Nm \quad M_C = -13.0717Nm \quad M_D = 0Nm \quad M_E = 0Nm$$

Thus, the maximum bending moment on the crushing unit shaft is $28.752 \text{ N} \cdot \text{m}$ ($28,752 \text{ N} \cdot \text{mm}$). The maximum twisting moment of the shaft is $11,039 \text{ Nmm}$ from equation (5). Since the feeding of the plastic is gradual and steady, $K_b = 1.5$, $K_t = 1.0$ [13,24].

The shaft diameter was determined using equation (4) as 17.54 mm . Therefore, a standard 25 mm diameter solid mild steel shaft was selected for the crushing unit.

Selection of the prime mover (electric motor)

The power required for the operation of this machine, according to [19,20,21], was determined from the equation (18).

$$P = (T_i - T_j)V \quad \dots\dots\dots(18)$$

Where T_i = Tension on the tight side of the belt drive

T_j = Tension on the slack side of the belt drive

V = Speed of the belt drive.

Therefore, the required power was found to be 1041.04 W . Considering a 10% power loss due to friction, the theoretical power required to drive the developed waste plastic crushing machine is 1145.14 W . Therefore, a 3HP variable-speed electric motor was used for this machine.

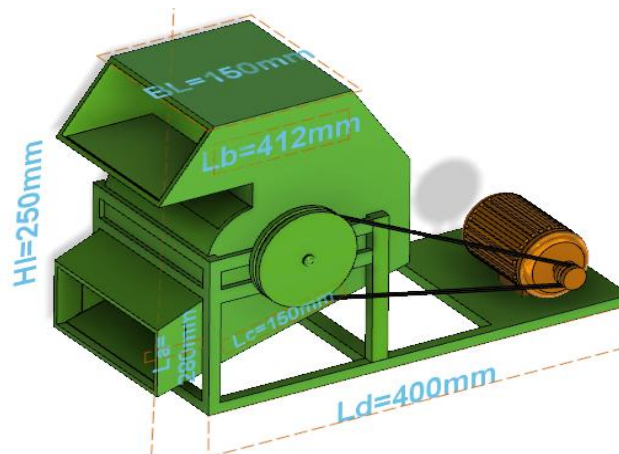


Fig. 2. Diagram of a 3hp waste plastics crushing machine

Experimental procedure used for testing the machine

The experiment was conducted using four different plastic types, each of mass 1Kg, and was crushed at three different speeds. The different plastic types used were polyethylene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC) and polypropylene (PP). The speed of operation was measured with a tachometer and recorded. The waste plastic was crushed, and the crushing time for each plastic type was measured with a stopwatch. The crushed waste plastic was weighed with a weighing balance and recorded. After crushing, the waste plastic was sieved into three size fractions to determine the average particle size and area.

The efficiency of the machine was computed using equation (19) below, the throughput of the machine was also computed using equation (20) below, and the specific energy consumption of the machine was computed using equation (21) below.

$$\text{Efficiency (crushing percentage)} = \frac{\text{mass of crushed plastic}}{\text{mass of loaded plastic}} \times \frac{100}{1} \quad (19)$$

$$\text{Throughput} = \frac{\text{mass of crushed plastic}}{\text{time of crushing of loaded plastic}} \quad (20)$$

$$\text{Specific energy consumption} = \frac{\text{power of operation of the machine} \times \text{crushing time}}{\text{mass of crushed plastic}} \quad (21)$$

RESULT AND DISCUSSION

The results from the experiment for the four types of waste plastic at different speeds are shown in Tables 4.1, 4.2, and 4.3.

Table 1. Results of crushed plastic at an operating speed of 900 rpm

	PET		HDPE		PVC		PP	
No of sieving	Aver. size (mm)	Crushed percent. (%)	Average size (mm)	Crushed percent. (%)	Average size (mm)	Crushed percent. (%)	Average size (mm)	Crushed percent. (%)
1st	1.21	41.43	0.82	52.42	0.42	43.24	1.32	45.33
2nd	3.22	52.21	2.98	61.43	1.48	64.45	3.23	63.32
3rd	4.78	63.33	4.34	75.43	2.54	87.45	5.45	78.43

At the operating speed of 900 rpm reported in Table 1, the machine was found to operate optimally when crushing PVC-type waste plastic, with an average particle size of 2.54 mm and a crushing percentage of 87.45%. Since it takes the machine 103 seconds to crush the waste plastic with an efficiency of 87.45%, the throughput was computed as 30.57 kg/hr from equation (15). Also, the Specific energy consumption was computed as 134.88 kJ/kg from equation (16).

Table 2. Results of crushed plastic at an operating speed of 750 rpm.

	PET		HDPE		PVC		PP	
No of sieving	Aver. size (mm)	Crushed percent. (%)	Average size (mm)	Crushed percent. (%)	Average size (mm)	Crushed percent. (%)	Average size (mm)	Crushed percent. (%)
1st	0.77	42.43	0.72	47.73	0.31	51.45	1.04	54.25
2nd	3.43	54.21	2.48	63.89	1.77	69.45	3.03	67.54
3rd	3.75	75.33	4.04	79.78	2.42	88.95	4.32	85.23

At the operating speed of 750 rpm reported in Table 2, the machine was found to operate optimally when crushing PVC-type waste plastic, with an average particle size of 2.42 mm and a crushing percentage of 88.95%. Since it takes the machine 137 seconds to crush the waste plastic with an efficiency of 88.95%, the throughput was computed as 23.37 kg/hr using equation (15). Also, the Specific energy consumption was 176.37 kJ/kg computed from equation (16).

Table 3. Results of crushed plastic at an operating speed of 600 rpm

	PET		HDPE		PVC		PP	
No of sieving	Aver. size (mm)	Crushed percent. (%)	Average size (mm)	Crushed percent. (%)	Average size (mm)	Crushed percent. (%)	Average size (mm)	Crushed percent. (%)
1st	0.48	52.72	0.72	43.35	0.42	58.54	1.12	56.43
2nd	2.14	58.45	2.67	71.32	1.48	70.23	3.07	73.45
3rd	3.57	85.73	3.44	85.32	2.21	90.24	4.09	88.45

At the operating speed of 600 rpm from Table 4.3, it was deduced that the machine operated optimally when crushing PVC-type waste plastic, with an average particle size of 2.21mm and a crushing percentage of 90.24%. Since it takes the machine 152 seconds to crush the waste plastic with an efficiency of 90.24%, the throughput was computed as 21.37 kg/hr from equation (15).

Also, the Specific energy consumption was 192.89 kJ/kg computed from equation (16).

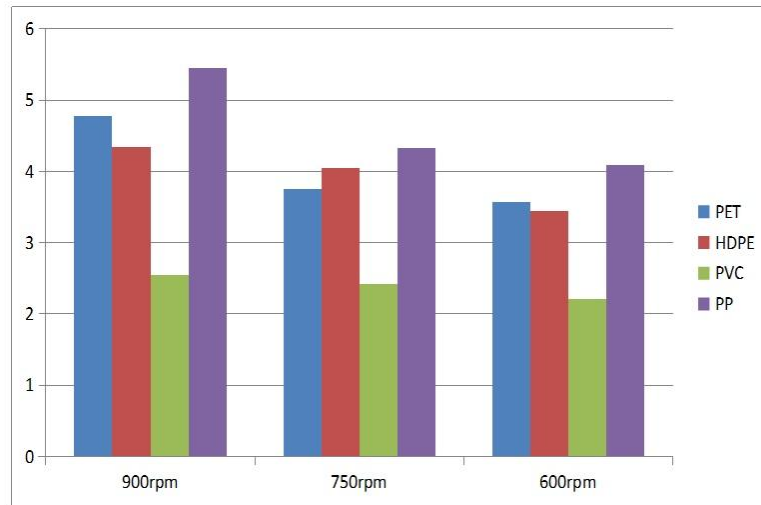


Fig. 3. Average size comparison of the four different waste plastic performances using the three speeds.

Fig. 3 revealed that PP waste plastics had the largest average size at 900rpm, higher than PET, HDPE and PVC at 750 rpm and 600 rpm, respectively.

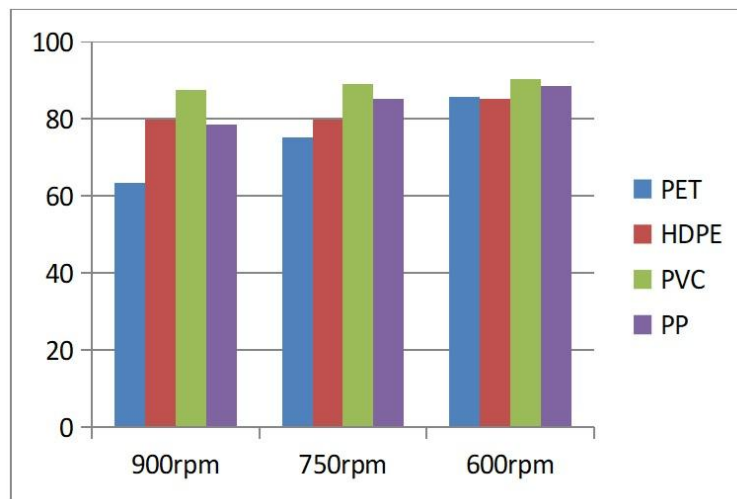


Fig 4. Crushing percentage comparison of the four different waste plastic performances using the three speeds

Fig. 4 showed that PVC waste plastics recorded the highest crushing percentage at 600 rpm, exceeding those of PET, HDPE and PP at 900 rpm and 750 rpm, respectively.

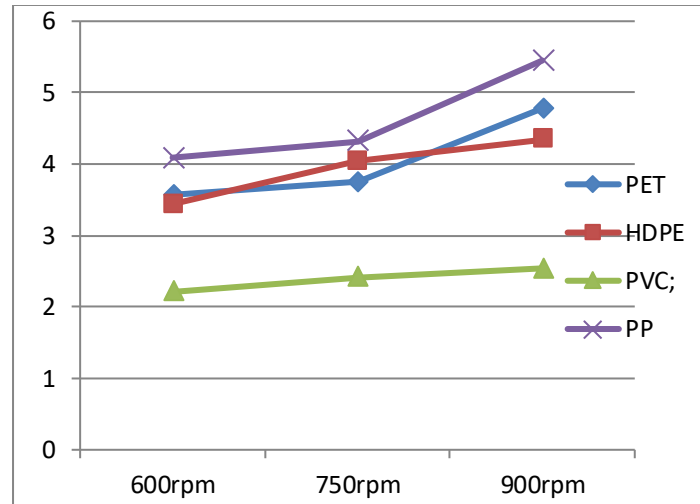


Fig 5. Average size comparison of the four different waste plastic performances showing variation as the speed increases

From Figure 5, it was observed that the four types of waste plastic exhibit the same relationship between average size and operating speed; all average sizes increase as the operating speed increases.

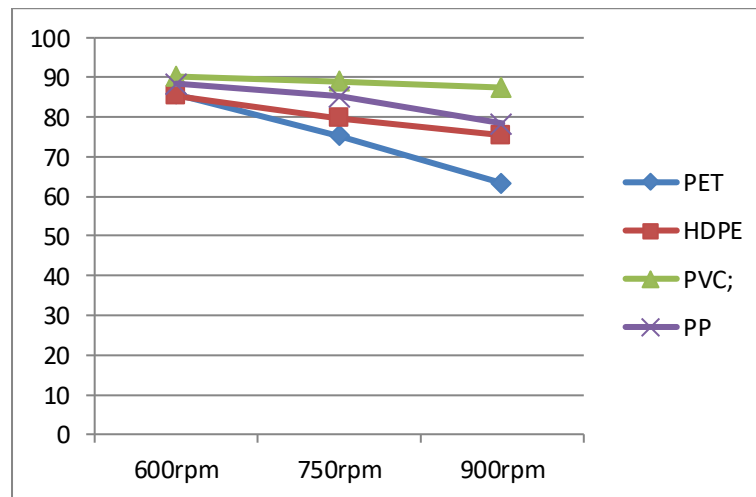


Fig. 6. Crushing percentage comparison of the four different waste plastic performances showing variation as the speed increases

Also, from Figure 6, it was observed that the four types of waste plastic exhibit the same relationship between crushing percentage and operating speed; all crushing percentages decrease as the operating speed increases. Therefore, the best operating speed depends on the parameter considered paramount. The best crushed waste plastic, in terms of average size and crushing percentage, was obtained at an operating speed of 600 rpm. Considering throughput, the optimal result was obtained at 900 rpm; considering specific energy consumption, the optimal result was also achieved at 900 rpm.

CONCLUSIONS

There was a direct relationship between the average size of the four types of waste plastic and both the crushing percentage and the operating speed. The average size of the four types of waste plastic increases with increasing operating speed. Also, the crushing percentage of the four different types of waste plastic decreases as the operating speed increases. The machine's throughput at 900rpm, 750rpm, and 600rpm is 30.57 kg/hr, 23.37 kg/hr, and 21.37 kg/hr, respectively, for PVC waste plastic.

The Specific energy consumption of the machine at 900 rpm, 750 rpm and 600 rpm is 134.88 kJ/kg, 176.37 kJ/kg and 192.89 kJ/kg, respectively, for PVC-type waste plastic. The average particle size of the machine products at 900rpm, 750rpm and 600rpm is 2.54mm, 2.42mm and 2.21mm, respectively, for PVC-type waste plastic. The machine's efficiency at 900rpm, 750rpm and 600rpm is 87.45%, 88.95% and 90.24%, respectively, for PVC waste plastic.

The optimal operating speed depends on the parameter considered paramount. The best crushed waste plastic, in terms of average size and crushing percentage, was obtained at an operating speed of 600rpm. Considering throughput, the optimal result was obtained at an operating speed of 900rpm; considering specific energy consumption, the optimal result was also obtained at 900rpm.

RECOMMENDATIONS

This plastic waste recycling machine should be adopted and commercialized to increase the availability of raw materials for industries, enhancing productivity, and the federal government should investigate waste plastic recycling as an energy source as an alternative to fossil fuels.

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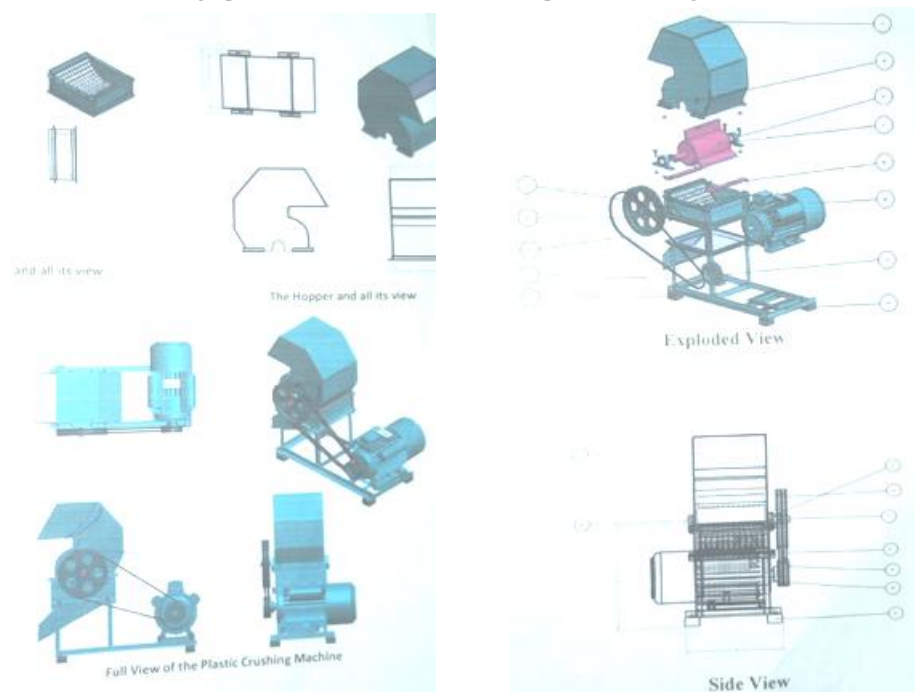
APPENDIX A

Table 4. Engineering cost expenditures of the waste plastics crushing mill.

S/N	DESCRIPTION	SIZE	QUANTITY	AMOUNT(NGN)
1	Variable speed Electric motor	3HP, 3phase	1	50,000
2	Drilling bit	5mm	2	800
3	Rivets	M6(13mm)	1	300
4	Bolt and nut	M10, M12	13, 12 respectively	750
5	Electrode		1 packet	1,550
6	Cutting disc	9"	2	1,800
7	Grinding disc	7"	1	1,300
8	Pointing /screen oxide		1tnk	3,100
9	Flange bearing carrier	4mm thick plate 8."	1	2,100
10	Cellulose			2,300
11	Oil paint and brush		1 tin	4,500
12	Anti-rust paint and brush		1tin	2,200
13	Metal sheets		2	11,500
14	Angle bar		3	7,500
15	Pulley (driven and driving)		2	800
16	Belt drive	v-belt	1	1,200
17	Shaft	25mm diameter	1	1,300
18	Bearing		2	1,000
19	Damping rubber		4	1,400
20	Balancing weight		1	450
21	Screen		1	1,000
22	Labour cost and miscellaneous			30,000
	TOTAL			126,850 NGN

APPENDICES B

Orthographic or multi-view of the waste plastic crushing mill machine



PROJEKTOVANJE, IZRADA I ISPITIVANJE MAŠINE ZA USITNJAVANJE OTPADNE PLASTIKE, ZBOG OBEZBEĐENJA SIROVINSKE OSNOVE PREDUZEĆA

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Abstrakt: Projektovana je, izrađena i eksperimentalno ispitana niskobudžetna mašina sa promenljivom brzinom obrtanja za usitnjavanje otpadne plastike, kako bi se procenili njen stepen efikasnosti i kapacitet rada.

Mašina se sastoji od levka za prihvatanje materijala, remenice, komore za usitnjavanje sa noževima i elektromotora promenljivog broja obrtaja, snage 3 KS (HP).

Cilj istraživanja bio je razvoj mašine koja može da usitnjava otpadnu plastiku na manje čestice pri različitim brzinama rada, radi njene dalje reciklaže. Mašina je izrađena od lokalno dostupnih materijala, zbog čega su troškovi proizvodnje niski i prihvatljivi. Kapacitet mašine pri brzinama od 900, 750 i 600rpm iznosio je 30,57 kg/h, 23,37 kg/h i 21,37 kg/h, respektivno, pri usitnjavanju otpadne plastike tipa PVC.

Specifična potrošnja energije pri istim brzinama iznosila je 134,88 kJ/kg, 176,37 kJ/kg i 192,89 kJ/Kg, respektivno.

Prosečna veličina dobijenih čestica pri brzinama od 900, 750 i 600 rpm iznosila je 2,54 mm, 2,42 mm i 2,21 mm, respektivno.

Efikasnost rada mašine pri navedenim brzinama bila je 87,45 %, 88,95 % i 90,24 %, respektivno.

Optimalna radna brzina zavisi od kriterijuma koji se smatra najvažnijim. Sa aspekta prosečne veličine čestica i procenta usitnjavanja, najbolji rezultati postignuti su pri brzini od 600rpm elektro motora.

Posmatrano prema kapacitetu rada, optimalni rezultati ostvareni su pri brzini od 900 rpm.

Takođe, sa aspekta specifične potrošnje energije, najpovoljniji rezultat postignut je pri brzini od 900 rpm.

Troškovi izrade mašine iznosili su 126.850 NGN (nigerijskih naira).

Ključne reči: Otpadna plastika, mlin za usitnjavanje, projektovanje i izrada, brzina obrtanja, efikasnost.

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