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Shredding Machine Development for Recycling Process of Waste Plastic Bottles

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Review Article

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ABSTRACT

Plastic is one of the most available materials in the world today, but its waste is bedevil with serious environmental pollution and landfill space exhaustion. Waste plastic recycling is a process of recovering material that are useful making new plastic products such as plastic lumber, containers and particle boards. In accomplishing this task waste plastic is require to be shred first into smaller pieces, facilitating the movement for subsequent processing. A shredder was designed and constructed with locally sourced materials to reduce the volume of commercially used plastic bottles into smaller pieces or for further processing into useful products. The shredder has a feeding unit, a shredder unit, a power transmission unit (2 HP) with single phase. The performance evaluation of the machine showed that the machine has efficiency of 34%. The machine is suitable for the control of waste plastics in the environment.

INTRODUCTION

Plastic commonly refer to as 'Plastikos,' is a Greek word that means a shapeable or moldable substance, such as wax, clay, asphalt, or amber. The introduction of plastics over a century, plastic has become an indispensable part of our daily lives. It is now one of the most sourt materials for bottling liquid product in all the continents. Polyethylene Terephthalate (PET), High-density Polyethylene (HDPE), Polyvinylchloride (PVC), Polypropylene (PP), and Low-density Polyethylene (LDPE) are the five major types (LDPE). Most of these plastic categories are currently being marketed and will eventually end as landfill waste. This is causing a waste product problem due to the large amount of waste generated, non-biodegradability, and other factors. Plastic bottles account for 11% of waste content and landfill, resulting in serious environmental challenges. Over 60% of the Municipal solid waste is consisting of plastic waste where 22% is recycle and 78% disposed of locally [1,2]. In United State, the waste of plastic in 2005 was calculated as 11.8% of the 246 million tons of MSW generated. Some states in the United States, such as Michigan, have recycling rates close to 100 percent, and in Brazil, some recycling potential has been raised, with around 15 percent of all plastic consumed recycled and returned to industry. Some states in the developed nation, have recycling rates close to 100 percent, and in Brazil, some recycling potential has been raised, with around 15 percent of all plastic consumed and recycled. Research has been carried out locally to ascertain the challenges of solid wastes in Euro nation and continent, but works on plastic wastes in Nigerian cities and towns are still limited [3,4]. Developing countries like Nigeria is importing virgin plastic at exorbitant price because of limited recycling activities are usually low in these countries. Recycling machinery in under developed countries is typically very expensive and bulky, and as a result, recycling activities in these countries are limited. To overcome these challenges, it is necessary to develop a low-cost shredding machine using local materials that can be easily operated without much skill by low and middle-income earners. This will serve as a precursor for recycling the waste plastic in manufacturing of new products [5,6]. Plastic recycling involve the following process such as collection, separation, processing and returning of use plastic waste material that would otherwise become solid waste. A shredder machine shreds used plastic bottles into smaller particles to improve their portability and ease of use for producing other new product. The design technique of this machine was inspired by the ancient method of scissors application in the cutting of materials for size reduction and rabbits scratching technique of digging or tearing. The highlighted methods were incorporated into the machine's design by fabricating a cutting blade to cut the waste plastic, with the cutting blades having sharply curved edges to draw the plastic into the cutting blade teeth. The waste plastic shredder is made up of four major parts: the feed part, the shred part, the power unit, and the machined frame [7,8].

LITERATURE REVIEW

According to reports, plastic waste is a silent threat to the environment, and its disposal is a serious issue for waste managers. Nowadays, society has no viable alternative to plastic products such as plastic bags, plastic bottles, plastic sheets, and so on. Despite all efforts to limit its use, its utility is increasing day by day. Many efforts were made in the past to avoid this problem by reusing plastic waste, but no significant results were obtained. The experimentation with a can or plastic bottle shredder machine and the mechanism used in the machine. This machine involves processes such as design, fabrication, analysis, and the assembly of various components, among others. This will increase knowledge of all parameters such as design, fabrication, analysis, and so on, but most importantly knowledge of analysis. Ming and Taipei, worked on Blade of Paper Shredder, whose cutting edges were in contact with the shredded paper when the amount of shredded paper increased, the paper shredder stopped working normally because multiple cutting edges engaged with the paper to be shredded paper stuck in the shredder at the same time. This issue was resolved by employing a rotary cutter with multiple blades with numbered cutting edges [9,10]. The noise of the shredding was also greatly reduced with the arrangement described here. Worked on the design and development of a coconut fiber extraction machine for small-scale industries In this machine, a 14 HP single-phase AC motor, heavy-duty, is attached at the base, and a smaller pulley at the motor end provides drive with the help of a V-belt to the bigger pulley at the other end of the driven shaft gear are connected, so one gear provides drive to the other gear, and the barrel rotates in the opposite direction at 240 rpm.

Nithyananth, worked on the design of the waste shredder machine the waste shredder machine is an attachment, similar to a plowing attachment. A shredder can be used with a tractor Power Take-Off Shaft (PTO). The tractor's power 35 HP and above is transmitted to the shredder assembly. The Assembly is made up of one fixed blade and five circular blades. The shredded organic matter will be in small pieces, allowing the farmer to use it to prepare vermin compost. Work on the effect of blending waste thermoplastic polymers, specifically High-Density Polyethylene (HDPE) and Polypropylene (PP), in conventional AC-20 graded bitumen at various plastic compositions. The properties of the unmodified bitumen were found to be improved as a result of the changes observed in the rheological properties of the Polymer-Modified Bitumen (PMB).It was discovered that polypropylene polymer had a profound effect on homogeneity and compatibility, with a slight linear increase in viscosity, softening, and penetration values compared to relatively high changes for HDPE modified bitumen. Plastic waste in Municipal Solid Waste (MSW) has been reported to be increasing as a result of increased population, urbanization, development activities, and lifestyle changes, resulting in widespread littering on the landscape. As a result of their non-biodegradability and unattractive appearance, waste plastic disposal is a hazard and has become a serious global problem [10]. Bitumen is used as a binder in traditional road construction. Such bitumen can be modified with waste plastic pieces to create a bitumen mix that can be used as a top layer coat of flexible pavement. This waste plastic modified bitumen mix has a better binding property, stability, density, and water resistance. Waste plastic materials, such as Low-Density Polyethylene (LDPE) grocery bags, are disposed of in landfills, posing environmental pollution due to the difficulty in degrading polymeric materials by environmental factors. Described waste disposal, including waste plastic bags, which has become a serious problem, and waste plastics are burnt for obvious disposal, causing environmental pollution. The use of waste plastic bags in bituminous mixes has shown that they improve the properties of the mix while also solving disposal issues [11]. The addition of rubber pieces in the mixture can improve the mixture's ability to pave flexibility. Waste disposal, including waste plastic bags, has become a serious issue, and waste plastics are burned for obvious disposal, causing environmental pollution. The use of waste plastic bags in bituminous mixes has demonstrated that they improve the properties of the mix while also solving disposal issues. Using a shredding machine, cleaned plastic waste is cut into pieces small enough to pass through a 2-3 mm sieve. After heating the aggregate mix, the plastic is effectively coated over the aggregate. This plastic waste-coated aggregate is combined with hot bitumen and used in road construction. The plastic shredding machine in this study is designed to apply a sufficient amount of shredding force to the plastic waste material to be shredded *via* cyclic impact loading. This generates enough energy in the plastic material to cause its molecules to separate or deform relative to one another. This machine has five major components: a prime mover, a hopper, a shredding chamber, a shredding shaft, and a collector bin. The prime mover is an electric motor that produces the torque required to turn the shredding shaft [12]. The hopper is the machine component that empties the plastic waste into the shredding chamber. A chute on the hopper's side directs the plastic waste into the hopper. To prevent popping/flying plastic waste from escaping during operation, the top of the hopper is covered. The shredding chamber consists of a pair of static blades connected by the length of the inner wall and a mesh screen at the bottom [13,14]. Only shredded plastic particles smaller than the mesh size are allowed to pass through to the collecting bin thanks to the mesh screen. The shredding shaft is housed in the shredding chamber; as it rotates, it shreds plastic waste caught between the shaft's blades and the static blades by the walls in Figures 1-5. This process is repeated until the plastic waste in the shredding chamber has shrunk significantly and is no longer trapped between the shredding blades [15-18]. The summary of components and materials used in the production of the machine is presented in Table 1.

Table 1. Material selection table.

S/N	Component	Material/Specification	Description and functions
1	Hopper	Mild Steel	A hopper is a funnel-shaped from which waste can emptied into the shredding chamber
2	Shredding chamber	Mild steel	It houses the shredding shaft and mesh, also provides the space for shredding of plastic to take place.
3	Shredding shaft	AISI 4340 steel, Normalized (50 mm)	Produces the shredding force needed to shred the plastic waste.
4	Prime mover	AC motor (2 Hp)	Convert electrical energy to rotary mechanical energy needed to cause rotation of the shaft.
5	Bearing	Cast iron (30)	Provide support for the shaft allowing it rotate freely
6	Frame	$2\frac{1}{2}$ Angle bar	Provide a platform where all the components can be mounted on.
7	Sieve	Mild steel	
8	Coupling		
9	Bearing	UCFL 260DI	A mechanical device for transmitting Power from one shaft to another.

Figure 1. Orthographic and isometric drawing of the plastic shredding machine.

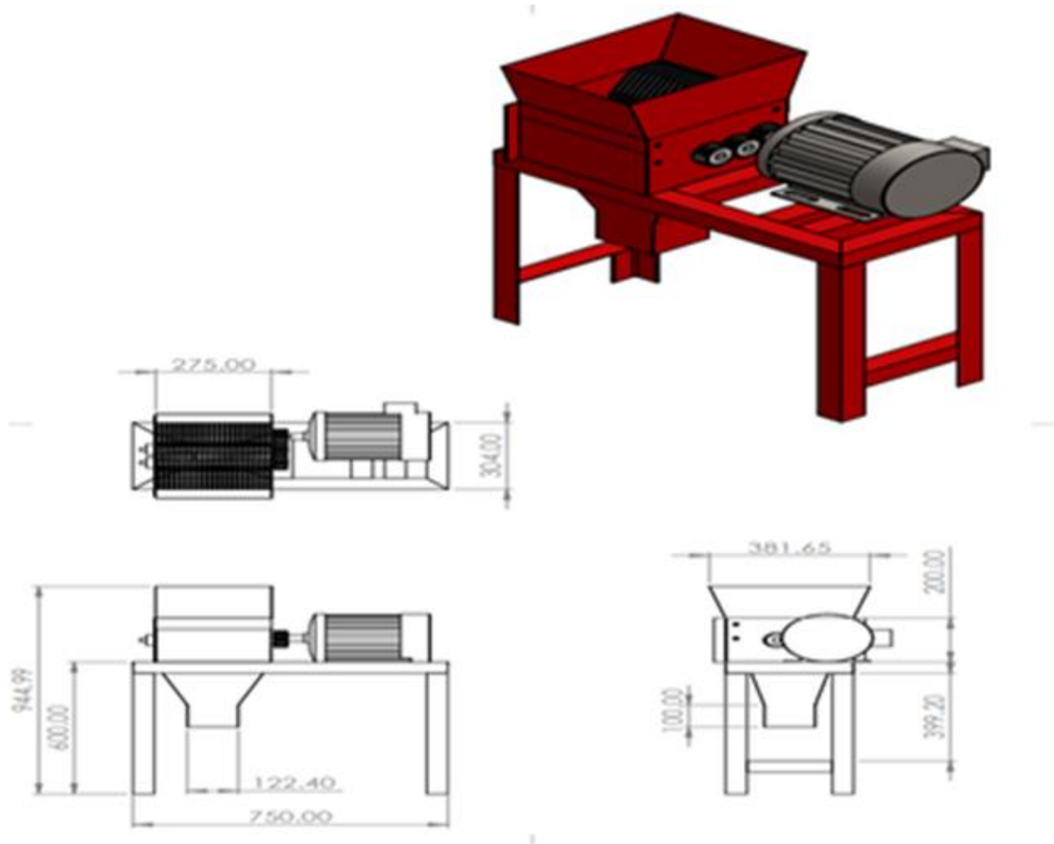
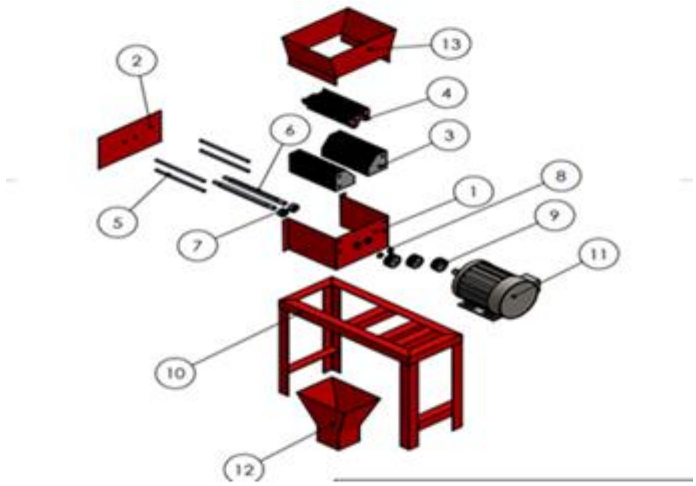


Figure 2. Exploded views of the shredding machine.



Item NO.	Part Number	Description	QTY.
1	Casing	Mild steel palte	1
2	Casing front cover	Mild steel palte	1
3	Spacer	Mild steel palte	44
4	Cutter	Mild steel palte	44
5	Sapcer holing pipe	Mild steel round pipe	4
6	Shaft	Mild steel square shaft	2
7	Ball bearing	AFBMA 20.1-33-15-8,SI,NC,8_68	2
8	Ball bearing	AFBMA 20.1-47-20-28,SI,NC,28_69	2
9	Gear	Metric-Spur gear 3M 20T 20PA 30FW	3
10	Frame	Mild steel angle iron	1
11	Motor	Geared motor	1
12	Collector	Mild steel plate	1
13	Hopper	Mild steel plate	1

Figure 3. Shaft, cutter and spacer of the plastic shredding machine.

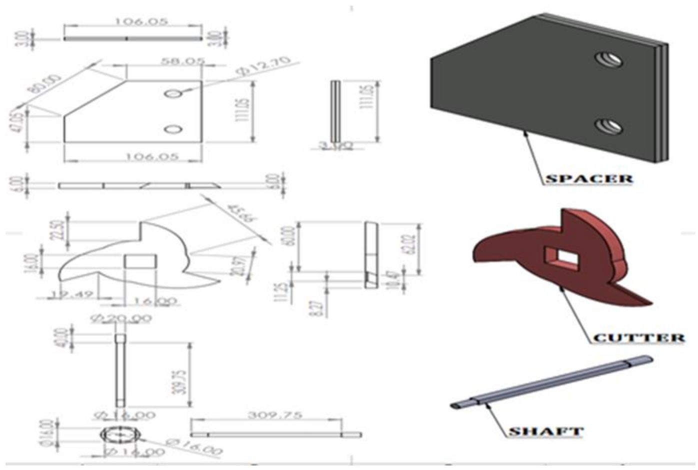


Figure 4. Collector top and collector side cover of the plastic shredding machine.

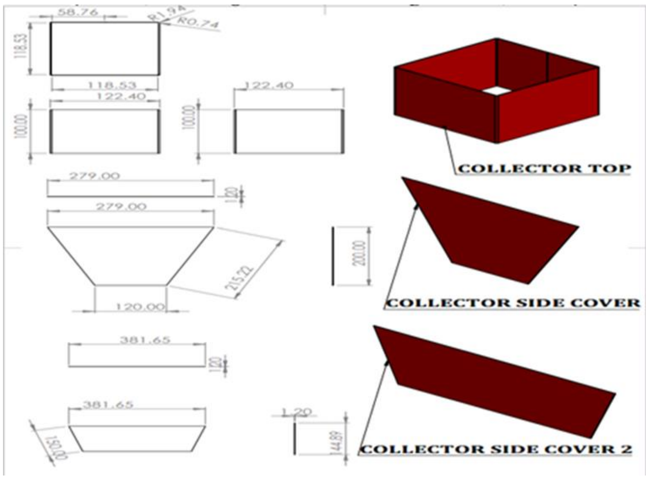
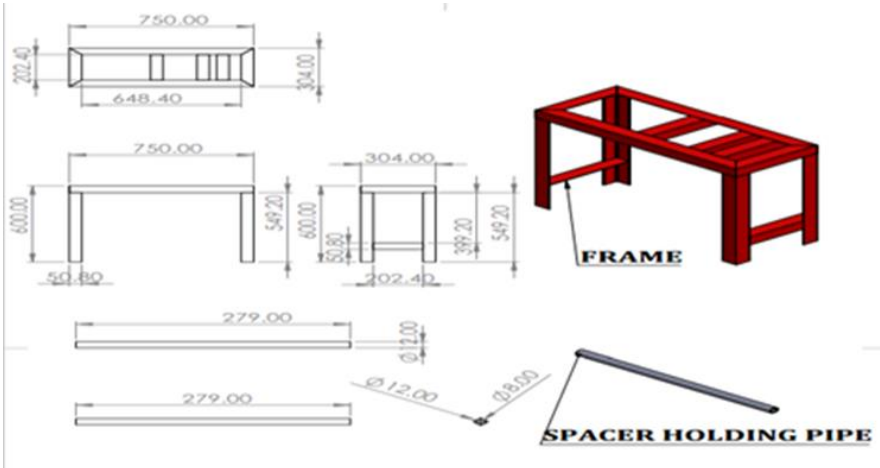


Figure 5. Frame and Spacer holding the pipe.



Design of components

The plastic shredding machine as presented in the working diagram of Figures 1-5 is made up of the hopper, shredding chamber, cutter, shredding shaft, prime mover (Ac motor), coupling, frame and sieve (mild steel) of 5 mm to 10 mm.

Design specification and calculation

Design of hopper: The Hopper as shown in Figure 2 is the collecting container that receives the plastic waste and narrows the waste to the cutter for effective shredding. Equation 1 as given was used to determine the hopper volume.

The volume of the hopper = $\frac{1}{3}\,(A_1{+}A_2\sqrt{}A_1{+}A_2)$ .... (1)

Where, A1 = Area of top base (mm²)

A2 = Area of bottom base (mm²)

h = Height of hopper

A1 = $4500\text{ mm} \times 3000\text{ mm} = 135\times 10^5\text{mm}^2$

A2 = $4000\text{ mm} \times 1500\text{ mm} = 60\text{ mm} \times 10^5\text{mm}^2$

h = 1500 mm

Volume of the hopper = $\frac{1}{3}(135 \times 10^5{+}60 \times 10^5{+}\sqrt{(\,135 \times 10^5 + 60 \times 10^5)}$

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The volume of the hopper = 650 × 10^4 mm^3

Design of hopper: Cutter act as a weapon in a shredder machine used to cut, nurture and tear the plastic. Its density notifies the level of nurturing it can be done to the input.

The outer diameter of cutter=50 mm

Inner diameter of cutter=30 mm

Number of teeth on cutter=3

The thickness of cutter=5 mm

Design of shaft: Shaft design consists primarily of the determination of the correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading conditions. This shaft design is influenced by two main factors; bending and torsion moment as shown in Figures 6-8. The shaft rotates horizontally, which means the design will be based on torsion moment alone.

Figure 6. Bending moment diagram.

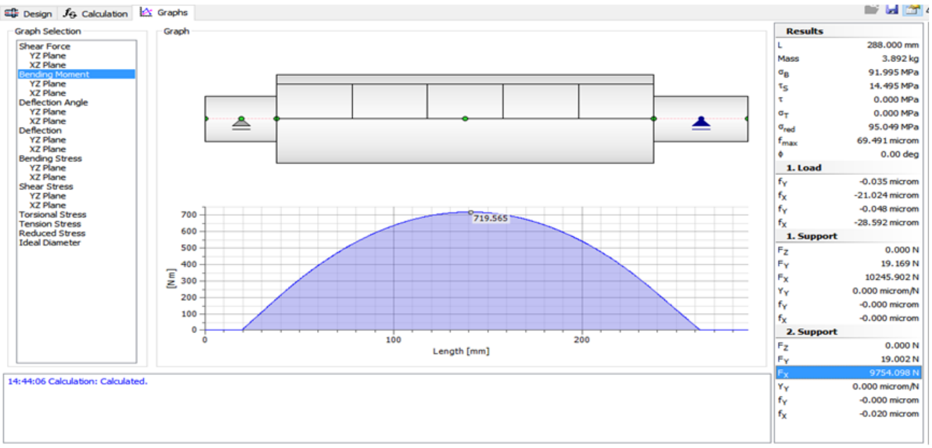


Figure 7. Deflection angle diagram.

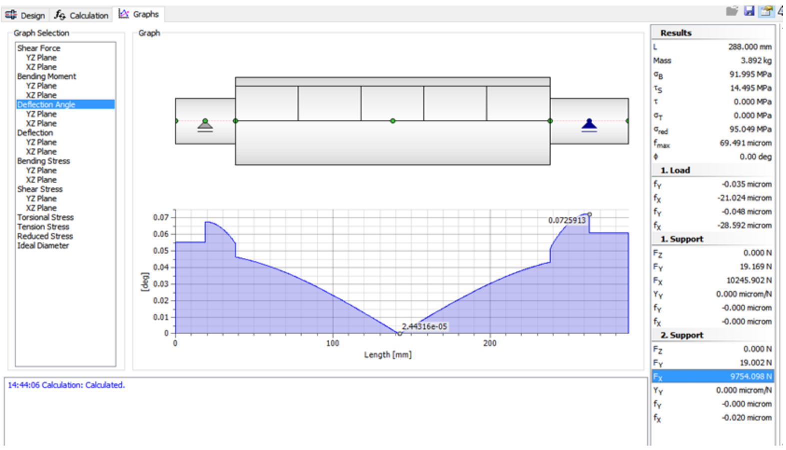
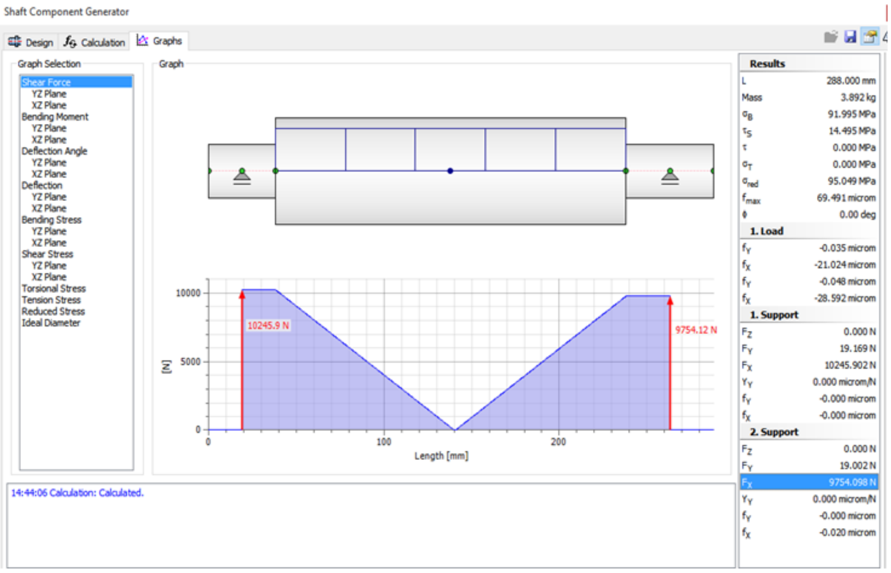


Figure 8. Shear force diagram.



Determination of shaft diameter: The shaft diameter was estimated using equation 2. The basis considered were the maximum bending moment, torsion moment, shear stress, and diameter of the shaft.

$$d^3 = \frac{16}{\pi s_s}\sqrt{((k_b + m_b)^2 + (k_t m_t)^2)} \quad \text{............... (2)}$$

where,

d=diameter of the shaft (mm)

S_s=ultimate tensile strength for steel=56 MPa

M_b=maximum bending moment (16.5 Nmm)

M_t=torsion moment (193.6 Nmm)

K_b=1.5,Kt=1.0 as given in ASME

$$d^3 = \frac{16}{3.142 \times 56 \times 10^6}(\sqrt{(1.5\times193.6)^2 + (1.0\times16.5)^2})$$

d=30 mm

Torque transmitted by shaft

$$T = \frac{P \times 60 \times 1000}{2 \times \pi \times N} \quad \text{...............(3)}$$

Where,

P=Power transmitted by the electric motor

N_2=Revolution of the shaft in rpm

$$\frac{1491 \times 60 \times 1000}{2 \times 3.142 \times 454} = 31.36 \text{ Kw}$$

Speed transmission

The velocity ratio for the belt drive is the ratio between the velocity of the driver and the driven.

$$\frac{N_2}{N_1} = \frac{D_1}{D_2} \text{.............. (4)}$$

Where; N_1 = Speed of the driver (Electric motor) = 1491 r.p.m

N_2 =Speed of the follower (r.p.m)

D_1=Diameter of the driver=100 mm

D_2=Diameter of the follower=200 mm

Therefore,

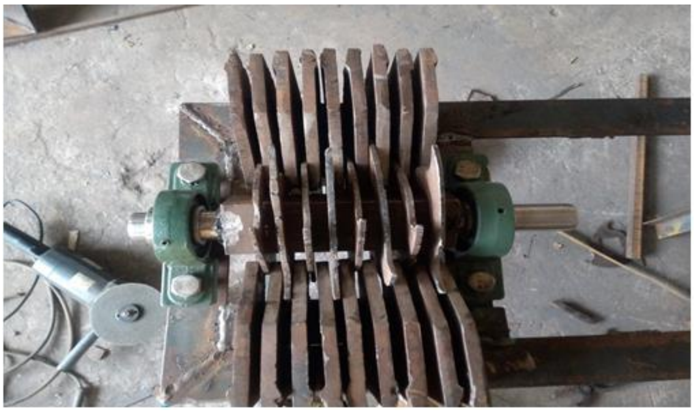
$N_2 = \frac{(1491 \times 100)}{200}$ =746rpm

Coupling

Coupling is a mechanical device used to connect two shafts at their ends to transmit power. Plates 1 and 2 shows the side and plan views of the exact position were the couplings are expected to be used.

Plate 1. Shredder blade and shaft assembly.

Plate 2. Shredder blade and shaft assembly.



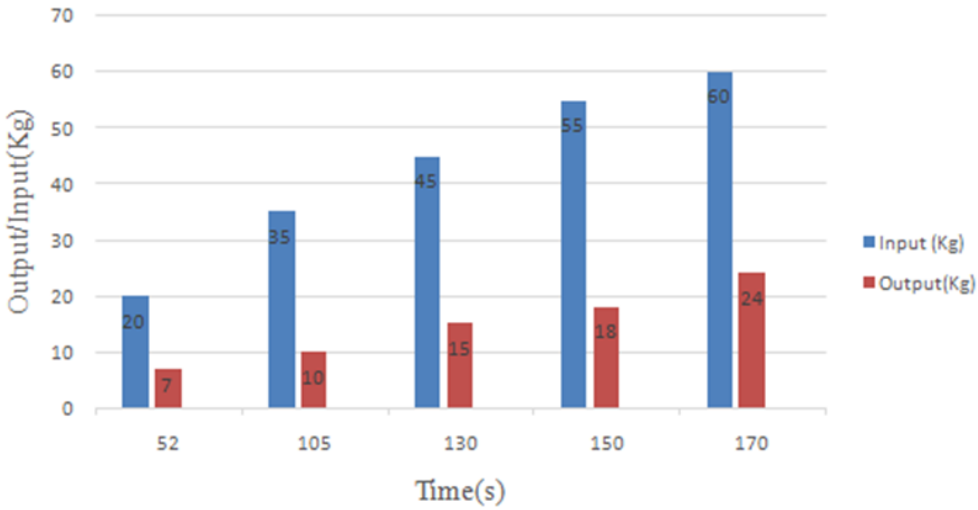
Performance evaluation

Compressed plastic bottles and other plastic waste materials were used to evaluate the machine's performance after it was built. Plastic of various types was shredded with a 2 Hp two-phase electric motor as the prime mover. The machine's throughput capacity was determined by measuring the shredding time with a stopwatch for various input masses. Table 2 shows the mass of input and the time taken to shred the input mass during the performance evaluation. The shredded samples were captured in Plate 3.

Table 2. Mass of input and the time taken to shred.

S/N	Input (kg)	Time (sec)	Output (kg)
1	20	52	7
2	35	105	10
3	45	130	15
4	55	150	18
5	60	170	24

Figure 9. Graph of input and output against time in seconds. Note: (■) Input; (■) Output.



Machine efficiency

Machine efficiency is defined as the ratio of power output to its input multiplied by 100%.

$$\% \text{ efficiency} = \frac{\text{output (kg)}}{\text{Input (kg)}} \times 100 \ldots\ldots\ldots\ldots\ldots \text{(5)}$$

Given that:

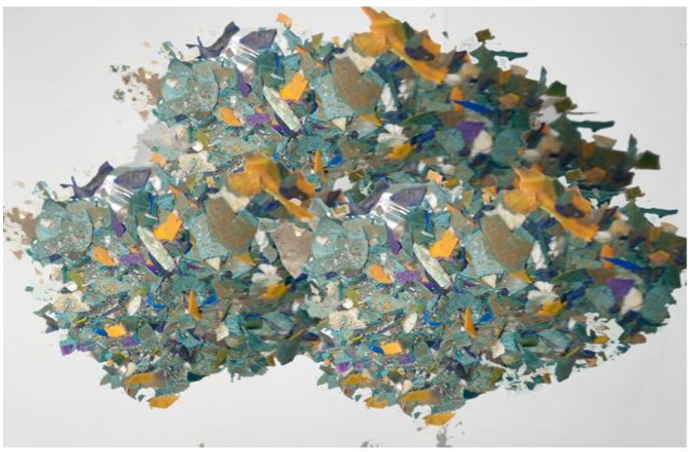
Total output=(7+10+15+18+24) kg=74 kg

Total input=(20+35+45+55+60) kg=215 kg

%efficiency=74/215 × 100

%efficiency=34%

Plate 3. Sample of shredded plastic output 7 kg.



DISCUSSION AND CONCLUSION

Plastic waste management necessitates the use of a plastic shredding machine. The plastic shredding machine was created from scratch. The machine rigidity, strength, stability, and safety of operation are typical design requirements. Shredding input of 20 kg plastic waste gave an output 7 kg within 52 seconds. Plastic recycling involve the following process such as collection, separation, processing and returning of use plastic waste material that would otherwise become solid waste.

A shredder machine shreds used plastic bottles into smaller particles to improve their portability and ease of use for producing other new product. The design technique of this machine was inspired by the ancient method of scissors application in the cutting of materials for size reduction and rabbits scratching technique of digging or tearing. The highlighted methods were incorporated into the machine's design by fabricating a cutting blade to cut the waste plastic, with the cutting blades having sharply curved edges to draw the plastic into the cutting blade teeth. The waste plastic shredder is made up of four major parts: the feed part, the shred part, the power unit, and the machined frame

RECOMMENDATION

During the analysis and construction process, we encountered some challenges that will necessitate future research and development to further improve the efficiency of the machine. The following are hereby recommended for future work on this project to improve the working condition of the machine and its parts: It is recommended that a conveyor be used to transport the plastic waste into the machine. This will improve the flow of plastic waste into the shredding chamber. The electric motor should be changed from 2 Hp to 5 Hp to increase the machine efficiency and the hopper should be changed and designed so that shredded plastic does not escape from the machine.

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