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Recycling of Plastic Waste Using Mini Shredder

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Abstract

In the current situation, plastic use is expanding daily, leading to a significant environmental problem. Plastics can negatively affect soil organisms in a variety of ways through complex interactions. For example, it has been found that microplastics seep into the soil and change its physical makeup, which lowers the soil's ability to hold water. Particularly in India, people generate 26,000 tons of plastic waste every day which is equivalent to 26,000 small cars(approximately). Ineffective waste management, such as incorrect waste collection and recycling, is the main cause of concern when it comes to plastic waste in India, not the quantity of waste generated. So, the purpose of our project is to design and build a small plastic shredder that can shred plastic PET bottles into tiny pieces that may be used to generate 3D printing filament (future work). Although they currently exist, they are prohibitively expensive. Therefore, the primary goal of this project is to design and build a mini shredder at a reasonable cost using Solid Works. The components of this shredder machine include a 0.25 HP motor, grate, collection system, hopper, and cutting chamber (frame) with rotating and fixed blades. This paper explains the design requirements for every component of the shredder machine.

Keywords: Plastic PET bottles, shredder machine, cost-effective, blade analysis, 3D printing

INTRODUCTION

The production of plastics is attracting the attention of industries, and plastics are used to make a wide range of goods[1]. Plastics are low-cost, lightweight, robust, corrosion-resistant, and have excellent electrical and thermal insulating qualities. Numerous products that improve technology and medicine, save energy and benefit society in many other ways are made possible by the diversity of polymers and the adaptability of their qualities[2].

Various amounts of additional chemicals, such as catalysts, accelerators, stabilizers, hardeners, pigments, and so on, are added to synthetic plastic materials in addition to the polymer to help regulate polymerization or to affect the final material's qualities, such as color and flexibility[3]. Despite having so many benefits, the substance is not biodegradable, which allows it to persist in nature without significantly losing weight. The environment is under long-term risk due to the low rates of degradation[4].

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Plastic stays in our environment for a very long time since it does not biodegrade. Plastic can cause birth defects, reduced immunity, cancer, and other health problems in humans. The use of plastic attracts many kinds of impurities. Eliminating plastic costs billions of dollars and more [5]. Rainwater enters the dump through the spaces between the plastics and other debris, accumulating compounds that are soluble in water, some of which are extremely toxic[6].

Shredders are devices that reduce a wide range of materials, including paper, plastic, and metal, into

tiny bits. To make the materials easier to dispose of, they are employed to reduce them into smaller, more uniform shapes [7]. The shredding actions are not a proper case of shear failure, it's more of a combination of bending, compressive, and shear failure [8]. The primary function of the shredder set up with a single axle shaft is to cut material based on its impact and shear strengths. The machines that are available for recycling are more expensive and need a lot of setups. To address these issues, we created plastic shredder machines, which allow anyone to start the recycling setup without any expertise [9].

COMPONENTS OF SHREDDER

Five main subassemblies make up the machine. The machine frame, which consists of the machine stand, hopper feeder unit, and cutting unit housing; the cutting unit, which consists of the shaft and cutting blades; the drive mechanism, which consists of a gear mesh drive and a v-belt drive; and the prime mover[10].

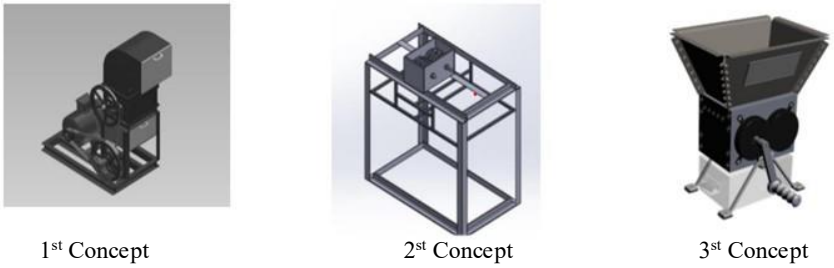
Hopper

The machine has a hopper that plastic must go through to be fed into the plastic shredder. The pusher has more leverage to enter the hopper and descend to the bottom because of the box-shaped hopper structure[11]. So the top of the hopper breath is large and the bottom of the hopper breath is less when compared to the top side. Typically, hoppers are constructed from durable materials such as steel, stainless steel, or heavy-duty plastic to endure the forces involved in feeding. Depending on how the shredder is designed, hoppers might be rectangular, conical, or cylindrical. Depending on the shredder's capability, the hopper's size can change considerably. It might be as small as a desktop shredder's hopper or as huge as an industrial hopper. Hoppers can feed material into the shredder using a variety of techniques, including automatic feeding mechanisms, conveyor systems, and hand feeding. Certain hoppers are equipped with safety mechanisms, such as interlocks, which shield the operator from harm by preventing action when the hopper is open. The amount of stuff that a hopper can contain at once is determined by its capacity, which can be expressed in weight or volume units like liters or cubic feet (e.g., kilograms or pounds). Hoppers may include lids or covers to improve safety and keep dust and debris from escaping while being shredded in Figure 1.

Cutting Chamber

Cutting chambers are typically made of high-strength steel or alloy materials to withstand the forces generated during shredding. Shredder machines can have different cutting mechanisms, such as rotary blades, counter-rotating blades, or single-shaft shredding. Milling machines fitted with end mills and slot drills can be used to create the outside surfaces, cutting angles, and hexagonal holes required for the shredder blades[12]. The major and important part of the shredder machine is blade design which affects the cut size of pieces[13]. In previous blade designs, multiple cutting edges were used to shred scrap at high speeds. However, these blades had drawbacks: when striking a surface harder than their hardness range, they neither cut nor ignored the scrap. Instead, they reversed direction and struck the same surface again, causing delays and potential damage. To address these issues, an upgraded shredding blade design features only two cutting edges These larger cutting edges apply greater force to the scrap, resulting in improved shredding efficiency. The increased surface area enhances the grabbing force, leading to better overall performance compared to other blades currently in use[14].

Figure 1. Mini-shredder



1st Concept 2st Concept 3st Concept

Figure 2. Three different concepts of mini-shredder [15]

The second concept shown in Figure 2 does not have a more complex design compared to the other two concepts. The moveableness of components used in this concept is also better than other concepts[15]. The shredder of size 210mm x 149mm x 135mm is enough to shred up to 4 plastic bottles at a time. However, we use the shredder size of 120mm x 88mm x 150mm to shred at least two bottles at a time[16]. The number of blades in the cutting chamber affects the shredding efficiency and speed. More blades can lead to finer and faster shredding. The shape and arrangement of blades can vary, impacting the cutting process. Some shredders have special blades for specific materials, like paper or plastics. The width of the cutting chamber determines how wide the material can be fed into the shredder. A wider chamber can handle larger sheets or items. The cutting chamber's size and the type of materials it can shred often depend on the power of the shredder's motor. More powerful motors can handle tougher materials. The ease of access and maintenance for the cutting chamber, including blade replacement and cleaning, is an important consideration. Some shredders are designed with noise reduction features to minimize the sound generated during shredding. The speed at which the cutting chamber operates can vary, affecting the overall throughput of the shredder. The cutting chamber's design and settings can determine the size of the shredded particles, which is important for specific applications.

Motor and Drive System

Typically, a drive system and an electric motor make up a shredding machine. The drive system consists of parts like belts, gears, or chains to transfer the engine's power to the blades so they may cut and shred materials. The motor we have used is a 3-phase Motor (shown in Figure 3) of 1HP with 1500rpm. But the 1500 rpm is very high for the plastic crusher, so we have attached the gearbox to reduce the rpm. By attaching the gearbox, they get around 60-70 rpm[17]. Table 1 shows the specifications of the motor which we use.

Figure 3. Three phase motor.

MOTOR SPECIFICATIONS

Sieve

A sieve, also known as a sifter, is a tool used to separate desired components from unwanted material or to determine the sample's particle size distribution. Usually, a woven screen made of metal, mesh, or net is used for this purpose [18]

Collection System

To effectively feed plastic garbage into the shredder, a conveyor belt or hopper is usually integrated into the design of a collection system for a plastic shredder machine. Furthermore, a system—which may consist of containers or bags—should be in place to gather and store shredded plastic particles. Environmental requirements, efficiency, and safety should be given top priority in the design.

PROCESS OF SHREDDING

The goal of the shredding procedure is to break up plastic waste into tiny fragments. Plastic waste is collected from different sources. They are categorized precisely based on the types and densities of plastics. This separation is possible with the use of particular plastic grades. The plastic wastes are then manually cut into tiny bits after these procedures. [20]. These shredded plastics are dumped, and several operations recycle them to make different products [18]. Figure 4 shows the step-by-step process of the mini-shredder machine.

Before Shredding Process

- *Cleaning*: To get rid of any last traces of liquid or debris, wash the bottles and waste products. Maintaining the quality of the final shredded material is crucial.

After Shredding Process

- *Separation*: The plastic shreds subsequently pass through a screen that has a predetermined mesh size. The purpose of this mesh screen is to separate the recycled plastic particles from any other things, such as fluids or dirt [22].
- *Size reduction*: To make the objects fit into the shredder machine, you might need to cut or break them into smaller pieces if they are huge.

Table 1. Motor specifications.

Motor rating (1/4) HP	**0.18kW**
Specific voltage and frequency	230V/400V at 50Hz (or) 460V at 60Hz
Speed	1500RPM & 3000RPM for 50Hz 1800RPM & 3600RPM for 60Hz
Power required	400 Watts (approximately)

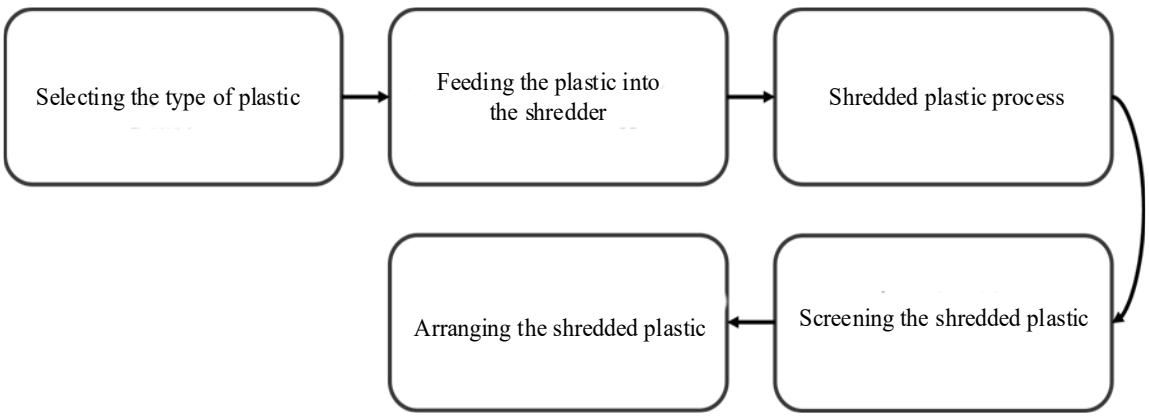


Figure 4. Process of shredding flow chart [19]

COLLECTING WASTE PLASTICS

- In comparison to PE (polyethylene) and HDPE (high-density polyethylene), it is known that the type of PP (polypropylene plastic) is the most ideal plastic for plastic dimensions of 20 cm, which is the most recommended dimension in comparison to the others. The best variation with a plastic weight of 30 g is a thickness of 1 mm [21]. Therefore, PP is easier to shred than PE and HDPE.
- Let's gather the plastic waste from
  - Small businesses to large retailers.
  - Plastics sectors (damaged plastics and wastes)
  - Collecting used water bottles from several meeting rooms and wedding halls
  - Gather the waste plastic from the pipe industry (HDPE)
  - Collect waste and plastic PET bottles from homes, companies, and recycling facilities, among other sources.
- Make sure there are no pollutants present, such as food or other things.

COLLECT THE SHREDDED PLASTICS

After being removed from undesired items, the recycled plastic particles are gathered in a special bin. A rotating platform that directs the plastic particles to the collection container makes this collection easier [22]. Check the container occasionally to see if it's filling up. When required, empty it to avoid spills. Move the chopped plastic to a bigger, sealed container if you intend to recycle it or use it for another reason. To avoid infection, make sure the storage environment is dry and clean. Once you've gathered enough chopped plastic, dispose of it according to your community's recycling regulations. Various plastic kinds may require different recycling procedures.

DESIGN & SPECIFICATIONS

Static stress analysis of a specific shredder blade that cuts waste plastic made of polyethylene terephthalate (PET) with three sharp edges Using the papers of M. F. Nasr and K. A. Yehia as a guide, we designed two sharp edge blades [16]. PET bottles are crushed by the design concept's application of a rotating blade working against a fixed blade in the hopper [23]. When designing the plastic recycling machine, the following factors were taken into account:

1. The accessibility of regional raw materials for production
2. Simplicity of use and ease of maintenance
3. Low production costs [17].

Shredder blade (Rotating)

We use stainless steel for rotating blades because it has good corrosive resistance against water shown in Figure 5(b). Table 2 represents the dimensions of the rotating blades and Figure 5(a) shows the solid design of the rotating blade.

Spacer

A spacer keeps the plastic pellets from striking each other which is shown in Figure 6(b). Table 3 shows the diameter and the dimensions of the hexagon cut.

Hex Shaft

The shredder shaft is a revolving component with knife-edged rings that is kept inside the shredder chamber. As it rotates against another stationary shaft in the chamber, these knife-edge rings make it possible to shred the waste plastic materials [17]. Table 4 shows the specification of the hexagon shaft and dimensions of the cuts. Figure 7(b) represents the fabrication of the hex shaft.

Table 2. Specification of the rotary blade.

Description	Dimensions
Blade angle	35 °
Blade width	50mm
Blade length	90mm

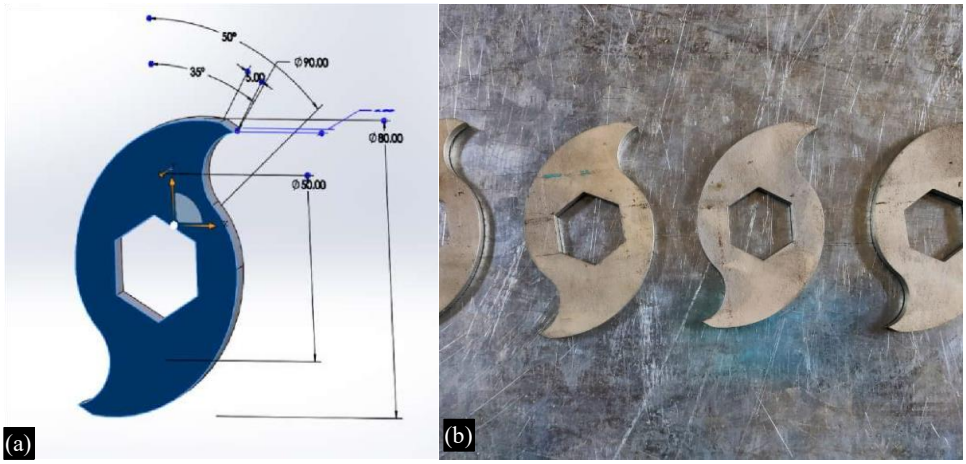


Figure 5. (a) Design of rotary blade; (b) Fabricated rotary blade

Table 3. Specification of spacer.

Description	Dimensions
Hexagon cut length	28.87 mm
Hexagon width	25mm
Diameter	50 mm

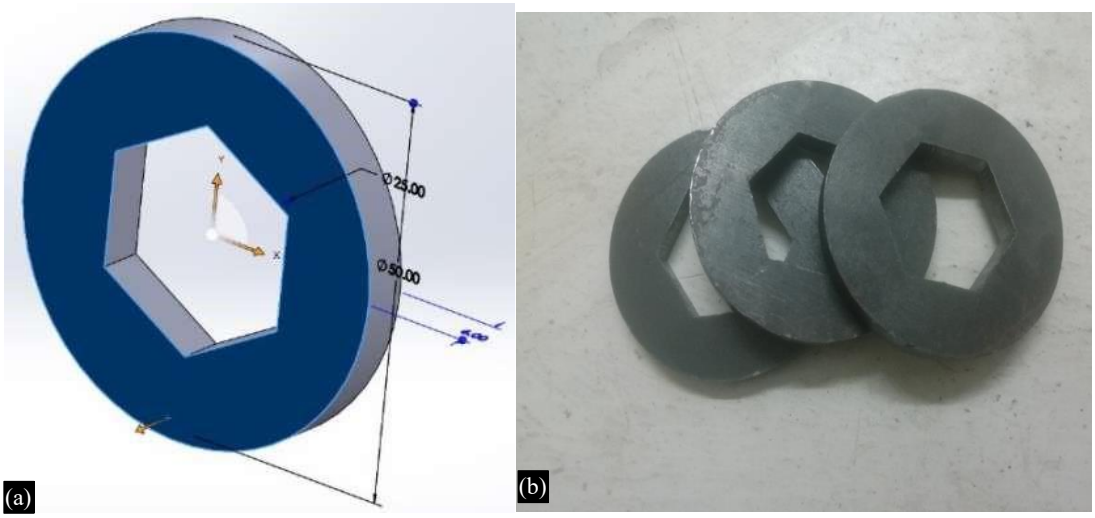


Figure 6. (a) Design of spacer; (b) Fabricated spacer

Table 4. Specification of shaft.

Description	Dimensions
Overall length	180mm
Hex shaft length	78mm
Hex page length	14.43mm
The diameter of the circle inside the Hex	25mm
Circle radius front &back	22mm
Front cut length	56mm
Back cut length	46mm

Shredder Frame

The working machine's frame aligns, supports, and directs all of its moving elements [23]. Figure 8(a) shows the raw design of the frame. The sturdy, thick mild steel that makes up the 5mm plate

shredding chamber. Each of the four plates has a connection that is welded together. It is also designed to make it simple to remove any plastic debris that gets lodged [5]. Figure 8(b) shows the fabrication of the outer frame of the shredder machine. Table 5 shows the specifications of the shredder frame.

Shredder Blade (Fixed)

The fixed blade gives support to the rotating blades. Figure 9(a) shows the design of the fixed blade and Figure 9(b) shows the fabricated fixed blade. Dimensions of fixed blades are shown in Table 6.

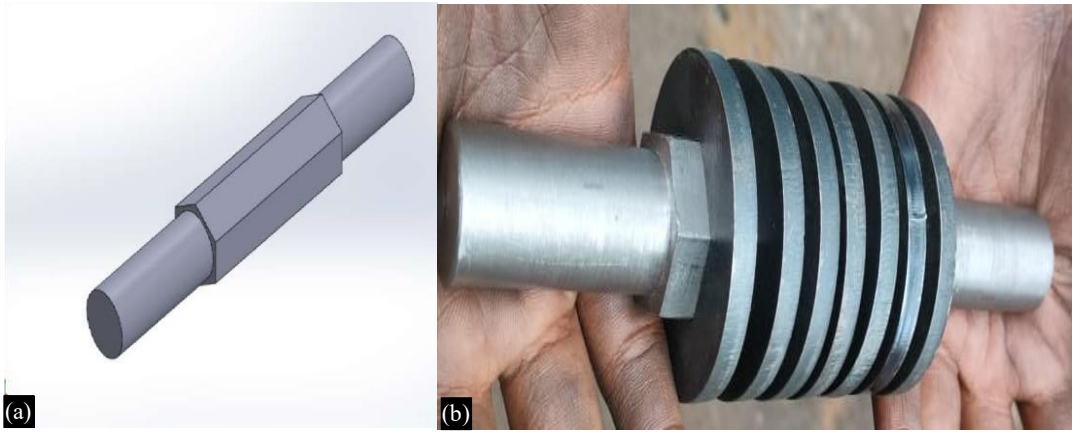


Figure 7. (a) Design of shaft; (b) Fabricated shaft

Table 5. Specification of shredder frame.

Description	Dimensions
Length	120mm
Breadth	100mm
Depth	150mm
Thickness	5mm
Diameter of center hole	20mm
Diameter of corner holes	5mm

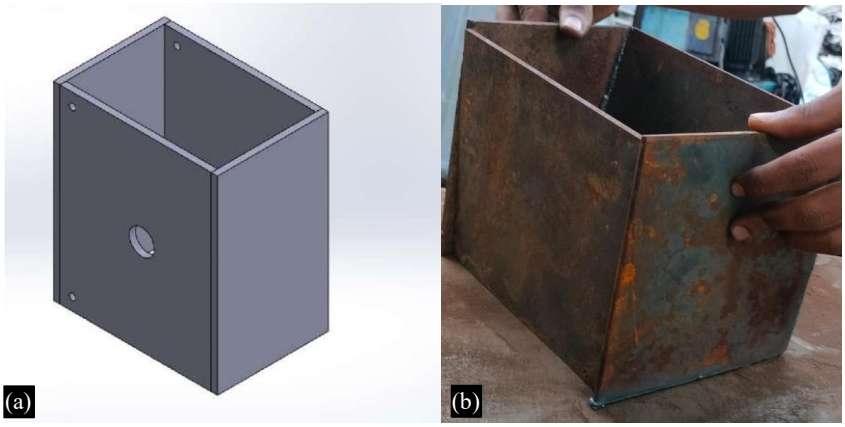


Figure 8. (a) Design of frame; (b) Fabricated frame

Table 6. Specification of fixed blade.

Description	Dimensions
Length	150mm
The radius of the corner cut	42.57mm
The radius of the middle cut	25mm
Diameter of corner holes	5mm

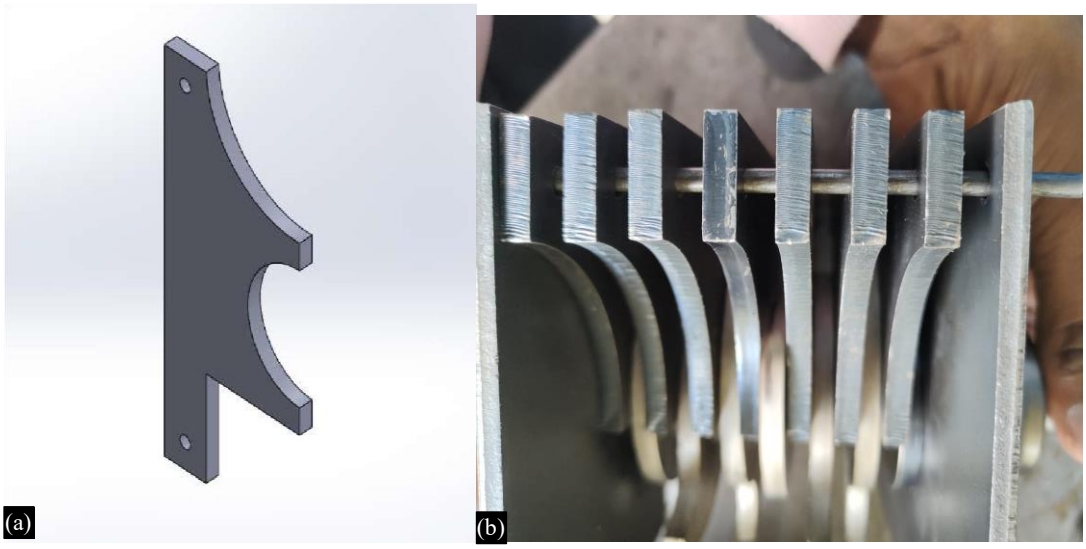


Figure 9. (a) Design of fixed blade; (b) Fabricated fixed blade

Table 7. Specification of bush.

Description	Dimensions
Outer diameter	60mm
Inner diameter	20mm
Inner cut diameter	40mm
Inner cut depth	12mm

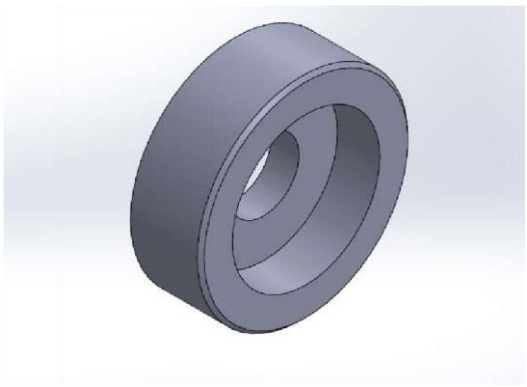


Figure 10. Design of bush

Bush

The thickness of the frame is too small to hold the bearing. The bush helps to hold the bearing. Figure 10 shows the design of the bush and Table 7 represents the dimensions and specifications of the bush.

MACHINING

To make parts like spacers, rotatory blades, and fixed blades, we use laser cutting equipment. Because it is quicker than water jet cutting and allows us to work with intricate structures. Moreover, more precise than plasma and water cutting. Furthermore, operating expenses are low [24].

RESULT AND DISCUSSION

The purpose of this shredding machine is to create PET filaments specifically for use as a feedstock for 3D printers. Therefore, the shredder's compact design significantly lowers the cost of fabrication as compared to domestic shredders. Additionally, this 3D printer shredding machine offers high-volume 3D printed components with time savings, compact spacing, and cost-effectiveness without requiring a

home shredder, which is expensive and requires waiting for the filament to arrive. According to the research paper of Briggs M. Ogunedo and Beneth C. Chukwudi, the market value of a shredder machine is ₦140,750.00(around 15000 in Indian Rupees). The cost of the shredder machine fabricated by his team is ₦109,840.00 (around 12000 in Indian Rupees). He reduces ₹.3000 from the market price which is 21.96 in percentage. He uses mild steel for the hopper and shredding chamber and AISI 4340 Steel for the shredding shaft. We use mild steel for the whole mini shredder (excluding rotating blades). We spend ₹.8000 for our shredder machine (excluding the power system) and if we attach the motor the cost will be ₹.9500. We reduce ₹.5500 from the market price which is 36.5 in percentage[25].

CONCLUSION

Small PET bottles may be efficiently separated and recycled with the help of this machine. Mini shredders can produce shredded paper and cardboard that can be recycled for arts and crafts projects, encouraging creativity and cutting down on waste. Small shredders may recycle cardboard and paper, cutting down on waste and its negative effects on the environment. Mini shredders can be used to illustrate the value of recycling and trash reduction in educational settings. Small PET bottles may be efficiently separated and recycled with the help of this machine. Mini shredders can produce shredded paper and cardboard that can be recycled for arts and crafts projects, encouraging creativity and cutting down on waste. Small shredders may recycle cardboard and paper, cutting down on waste and its negative effects on the environment. Mini shredders can be used to illustrate the value of recycling and trash reduction in educational settings. With the aid of a twin-screw extruder, we collide these tiny plastic fragments that the mini shredder machine produces, and then we send the collision via a nozzle to create a 3D printing filament. In the future, we plan to design and construct a quadcopter utilizing this filament.

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