

Design and Fabrication of a PET Plastic Shredder

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Abstract

Plastic waste management has become a serious environmental concern due to the rapid increase in the use of polyethylene terephthalate (PET) bottles. Mechanical recycling through shredding is one of the most effective methods to reduce plastic waste volume and facilitate reuse. This paper presents the design and fabrication of a low-cost PET plastic shredder suitable for small-scale recycling applications. Design calculations were carried out for the shaft, blades, bearings, and power transmission system. The machine was fabricated using locally available materials and tested for performance. Experimental results show that the shredder efficiently converts PET bottles into uniform flakes with stable operation and low power consumption, making it suitable for community-level recycling.

Keywords: PET; plastic recycling; shredder; mechanical design; fabrication

1. Introduction

The excessive use of PET bottles has led to significant environmental pollution due to improper disposal. Recycling of PET plastics helps in conserving resources and reducing landfill waste. Shredding is a key process in mechanical recycling, as it reduces the size of plastic waste into reusable flakes that can be more easily transported, stored, and reprocessed. This study aims to design and fabricate an affordable PET plastic shredder that can be easily manufactured, operated, and maintained using local resources, thereby supporting community-level and small-enterprise recycling initiatives.

2. Literature Review

Several researchers have studied the design and performance of plastic shredding machines. Previous studies emphasize the importance of blade design, material selection, and energy efficiency in achieving reliable and economical shredding performance (Singh, n.d.). Recycling more broadly remains one of the principal strategies for reducing the environmental burden of plastics, alongside material reduction, reuse, and energy recovery (Hopewell et al., 2009). Most existing shredders described in the literature are either costly or unsuitable for small-scale recycling operations, highlighting the need for a low-cost and efficient alternative designed specifically for community-level use.

3. Methodology

The methodology involved conceptual design, selection of materials, mechanical design calculations, CAD modeling, fabrication, and experimental testing. Standard mechanical engineering equations were used to determine shaft diameter, blade dimensions, and motor power requirements, following established design procedures for machine elements (Callister & Rethwisch, n.d.). The design process proceeded from concept generation and selection, through detailed sizing of the shaft, blades, bearings, and transmission system, to fabrication and functional testing of the assembled prototype.

4. Design and Fabrication

The PET plastic shredder consists of a mild steel frame, rotating cutting blades mounted on a shaft, bearings, a belt-pulley transmission system, and an electric motor. Fabrication was carried out using conventional machining and welding processes. The design prioritizes safety, durability, and ease of maintenance, using standard and locally sourced components to keep manufacturing and repair costs low.

4.1 Detail Design

4.1.1 Shredder Blade

The design of shredder blades is done in such a way that it can shred the PET bottles optimally with available power and feed speed. A blade with three cutting edges is designed as shown below in figure 4.1. The thickness of blade is 6mm. Mild steel plate is used to fabricate the blade using CNC plasma cutter.

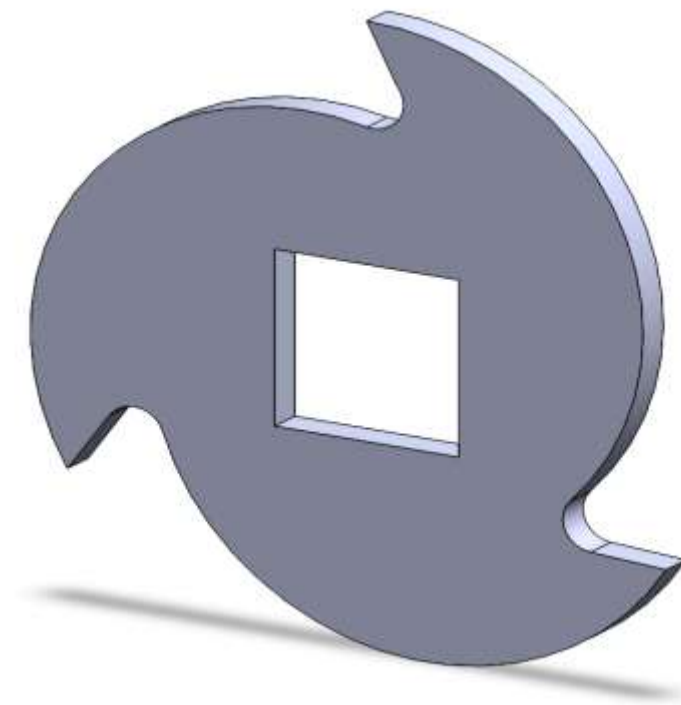


Figure 4.1.1: Model of Shredder Blade

ANSYS Structural Analysis of Shredder Blade

Input values used for the Structural analysis of the shredder blade are:

- a. Material used – Mild Steel
- b. Meshing – 3mm (Number of nodes- 13609 & elements- 2342)
- c. Applied force – 3840 N
- d. Fixed point – Faces of the hexagonal hole.

Required outputs of the static analysis of the shredder blade are:

- a. Total deformation.
- b. Equivalent stress (von-mises).

The designed blade is analyzed by the help of the Ansys software. The blade is analyzed by the static structural method. The blade is meshed and then the parameters such as friction coefficient of the blade, feed ratio, dynamic coefficient, motor power and specific cutting force are applied. The properties of the material of the blade are preselected. The static structural method gives the stress, strain acting on the body and the total deformation of the body when it comes in contact with the material that is to be shredded.

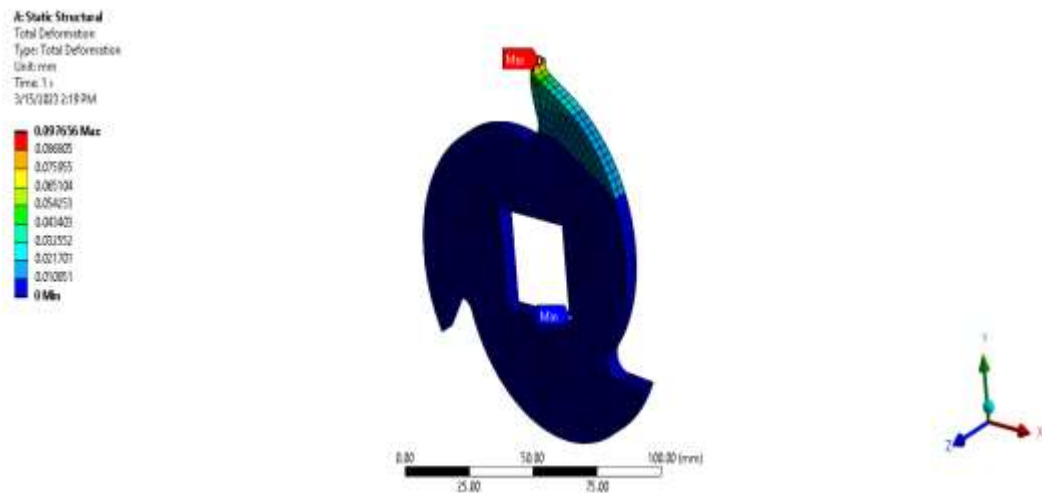


Figure 4.1.2: Total Deformation in Blade

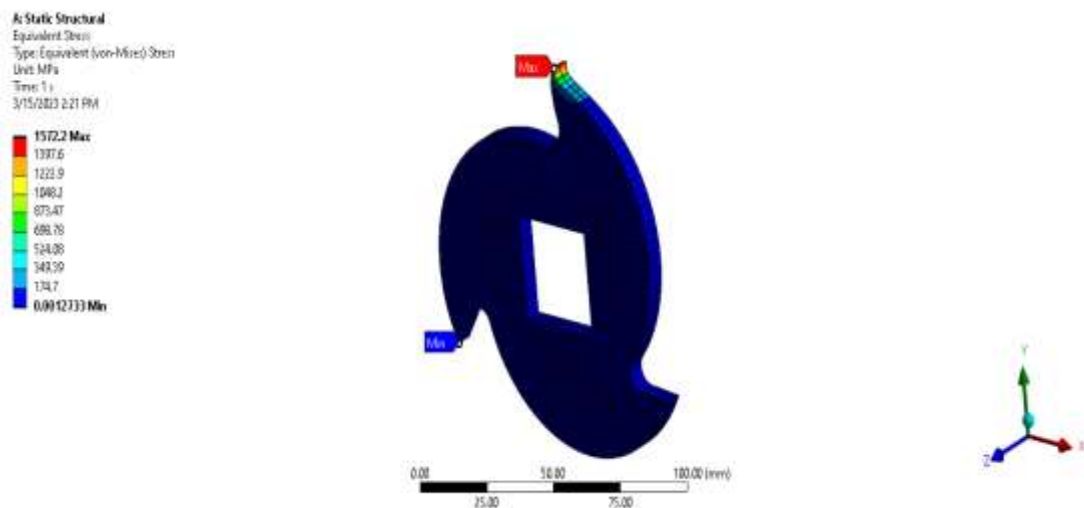


Figure 4.1.3: Equivalent Stress in Blade

Total deformation analysis of the shredder blade is done as in figure 4.1.2, using a mild steel material and maximum deformation in blade is 0.0976 mm which is within the safe limits of the blade design.

4.1.2 Fixed Blade

The optimal fixed blade design with optimal is also done as shown below in figure 4.1.4. The thickness of this blade is also 6mm. Mild steel plate is used to fabricate the fixed blade using CNC plasma cutter.



Figure 4.1.4: Model of Fixed Blade

4.1.3 Shaft

A 32mm square shaft is designed with circular ends of diameter 25mm for adding gears and connecting to the worm gear. The shaft is made of mild steel and made in Lathe machine. As shown in figure 4.1.5, key slots of 3mm depth by 6mm width is made using milling operation at both the circular ends.

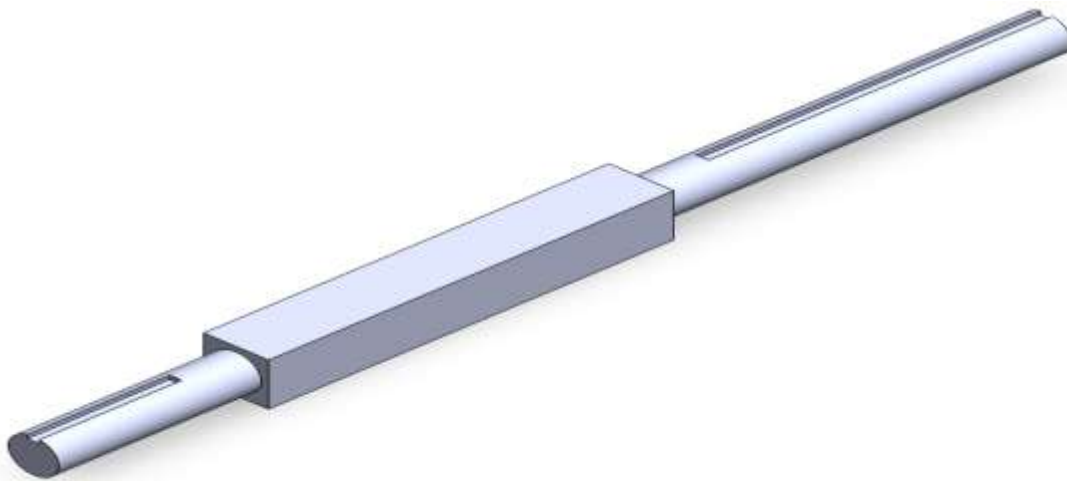


Figure 4.1.5: Model of Shaft

ANSYS Structural Analysis of Shredder Shaft

Input values used for the Structural analysis of the shredder shaft are:

- Material used – Mild Steel
- Meshing – 10 mm (Number of nodes- 5800 & elements- 3316)
- Applied moment – 795.6 N.m
- Fixed point – left end face of the shaft

Required outputs of the static analysis of the shredder shaft are:

- Total deformation
- Equivalent stress (von-mises)

It is expected that the rotating shredder shaft is subjected to torque due to the power delivered from the gearbox. The torque applied to the shredder shaft is obtained from the design calculation as 795.6 N.m. The behavior of the rotating shredder shaft under the torque is analyzed in the FE domain of the ANSYS application software. The SOLIDWORK model of the shredder shaft was discretized into a solid mesh. One end of the shaft was fixed while the other end was subjected to torque. The torque experienced by the shaft is expected to result from the plastic materials to be shredded in the shredding chamber, since the shaft is mounted on bearings at both ends and freely rotating.

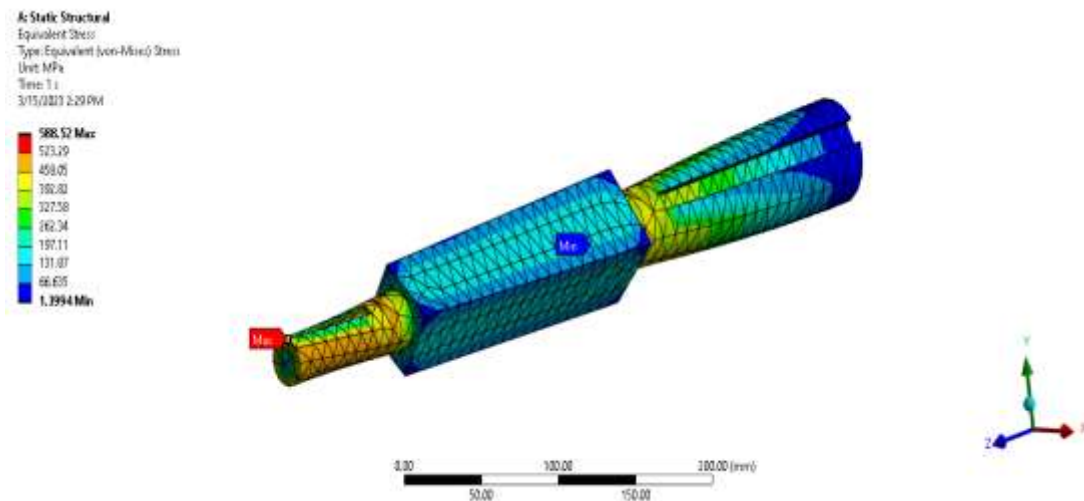


Figure 4.1.6: Equivalent Stress in Shaft

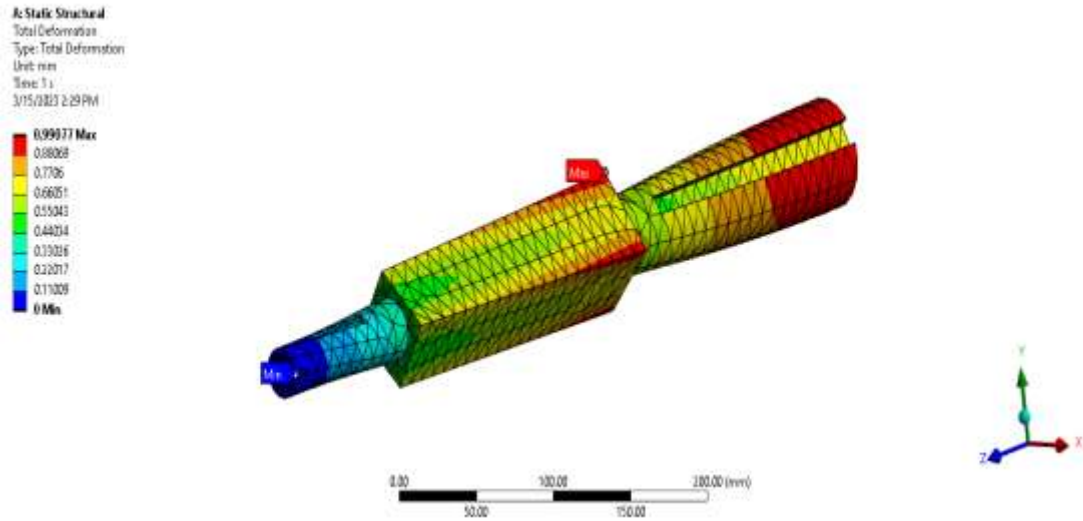


Figure 4.1.7: Total Deformation in Stress

From figure 4.1.7, the total deformation analysis of the shaft the maximum deformation is 0.99 mm which is within the safe limits of the shaft design.

4.1.4 Spacer

Spacer is designed for filling the space between two blades. It stops the blades from moving around. Its thickness is also 6mm. Mild steel plate is used to fabricate this part.

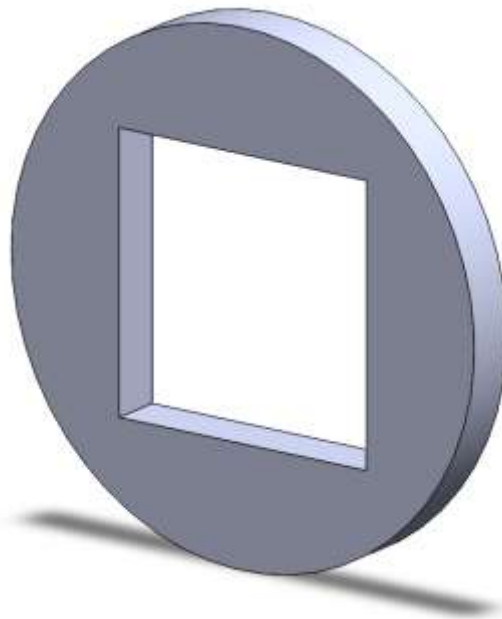


Figure 4.1.8: Model of Spacer

4.2 Design Calculations

Motor Speed = 1440 rpm

Power = 1.5 kW (2 hp)

$$\begin{aligned} \text{Power} &= 2 \times \pi \times N \times \frac{T}{60} \\ 1.5 &= 2 \times \pi \times 1440 \times \frac{T}{60} \end{aligned} \quad \text{Eqn 4.1}$$

Torque = 9.945 Nm

Gearbox ratio = 1:80

Gearbox output torque = 80×9.945
= 795.6 Nm

Maximum allowable shear strength for shaft,

(Including keyholes) = 40 MPa

$$P = \frac{\pi}{32} \times \tau_{max} \times d^3 \times \frac{N}{1000} \quad \text{Eqn 4.2}$$

$$\begin{aligned} d &= \left(\frac{32 \times P \times 1000}{\pi \times \tau_{max} \times N} \right)^{\frac{1}{3}} \\ &= \left(\frac{32 \times 1.5 \times 1000}{\pi \times 40 \times 1440} \right)^{\frac{1}{3}} \\ &= 28.68 \text{ mm} \end{aligned} \quad \text{Eqn 4.3}$$

The shaft diameter should be approximately 28.68 mm or larger so, 32mm diameter is selected.

$$A = l \times t \quad \text{Eqn 4.4}$$

$$= 16 \times 6 = 96 \text{ mm}^2$$

The shear force to shred the plastic (F_{sh})

S_{ut} (PET plastic) = 55 MPa

$$S_{us} = 0.577 \times S_{ut} \quad \text{Eqn 4.5}$$

$$S_{us} = 0.577 \times 55$$

$$S_{us} = 31.73 \text{ MPa}$$

Assume safety of factor = 2,

$$\begin{aligned} \frac{F_{sh}}{A} &= \frac{S_{us}}{F.O.S} \\ \frac{F_{sh}}{96} &= \frac{31.37}{2} \end{aligned} \quad \text{Eqn 4.6}$$

$$F_{sh} = 1505.76 \text{ N}$$

Cutting force (F_c)

$$S_y = 80 \text{ MPa (For steel material)}$$

$$\frac{Fc}{A} = \frac{Sy}{F.O.S} \quad \text{Eqn 4.7}$$

$$\frac{Fc}{96} = \frac{80}{F.O.S}$$

$$F_c = 3840 \text{ N}$$

Torque (T_{sh})

$$T_{sh} = F_{sh} \times \text{Radius} \quad \text{Eqn 4.8}$$

$$T_{sh} = 1505.76 \times 0.06m$$

$$T_{sh} = 90.345 \text{ N.m}$$

Total torque:

$$T_{total} = 90.345 \times 6 \quad \text{Eqn 4.9}$$

(Let's say 6 blades engage at one time)

$$T_{total} = 542.07 \text{ N.m}$$

Bending moment on the shaft

To determine the bending moment on the shaft first calculate total mass on the shaft which is the mass summation of all blades and spacers.

$$\begin{aligned} \text{Volume of one blade} &= 44277.26 \text{ mm}^3 \\ &= 4.427726 \times 10^{-5} m^3 \end{aligned}$$

$$\begin{aligned} \text{Volume of one spacer} &= 10820.6 \text{ mm}^3 \\ &= 1.08206 \times 10^{-5} m^3 \end{aligned}$$

$$\text{Density of material} = 7850 \text{ Kg/ } m^3$$

$$\text{Mass of one blade} = V_b \times \rho \quad \text{Eqn 4.10}$$

$$\begin{aligned} \text{Mass of one blade} &= (4.427726 \times 10^{-5} m^3) \times 7850 \text{ Kg/ } m^3 \\ &= 0.34979 \text{ Kg} \end{aligned}$$

$$\begin{aligned} \text{Total mass of blade} &= 15 \times 0.34979 \text{ Kg} \\ &= 5.24685 \text{ Kg} \end{aligned}$$

$$\text{Mass of one spacer} = V_s \times \rho \quad \text{Eqn 4.11}$$

$$\begin{aligned} \text{Mass of one spacer} &= (1.08206 \times 10^{-5} m^3) \times 7850 \text{ Kg/ } m^3 \\ &= 0.08548 \text{ Kg} \end{aligned}$$

$$\begin{aligned} \text{Total mass of spacer} &= 15 \times 0.08548 \text{ Kg} \\ &= 1.2822 \text{ Kg} \end{aligned}$$

$$\text{Total mass on the shaft} = \text{Total mass of blade} + \text{Total mass of spacer}$$

$$= (5.24685 + 1.2822) \text{ Kg}$$

$$= 6.529 \text{ Kg}$$

Distributed load on the shaft (W_d)

$$W_d = \frac{mg}{\text{total length of shaft}} \quad \text{Eqn 4.12}$$

$$= 6.529 \times \frac{9.81}{515}$$

$$= 0.1243 \text{ N/mm}$$

Concentrated load on the shaft (W_c) at the center

$$W_c = W_d \times \frac{l}{2} \quad \text{Eqn 4.13}$$

$$= 0.1243 \times \frac{515}{2}$$

$$= 32.0247 \text{ N}$$

The bending moment on the shaft due to the concentrated load

$$M = W_c \times \frac{l}{2} \quad \text{Eqn 4.14}$$

$$= 32.0247 \times 515 / 2$$

$$= 8246.37 \text{ Nmm}$$

Twisting moment on the shaft

$$T = W_c \times \frac{\text{Dia blade}}{2} \quad \text{Eqn 4.15}$$

$$= 32.0247 \times 60$$

$$= 1921.482 \text{ Nmm}$$

The equivalent twisting moment

$$T_e = \sqrt{M^2 + T^2} \quad \text{Eqn 4.16}$$

$$= \sqrt{8246.37^2 + 1921.482^2}$$

$$= 8496.71 \text{ Nmm}$$

Gear calculation:

$$\text{Torque (T)} = 795.91$$

$$= 704.59 \text{ N.m}$$

The gear rotates at 18rpm.

Gear available =56 teeth and pitch diameter of 98 mm

Module =1.75

$$\begin{aligned}\text{Power transmitted(P)} &= \text{Torque} \times \text{Angular velocity} \\ &= 1500\text{W}\end{aligned}\quad \text{Eqn 4.17}$$

$$\begin{aligned}\text{Transmitted load} &= 60000 \times \frac{P}{DN\pi} \\ &= 60000 \times \frac{1500}{\pi \times 98 \times 18} \\ &= 16240.3\text{N}\end{aligned}\quad \text{Eqn 4.18}$$

For Moderate shock, we take the overload factor, $K_o=1.75$

$$\begin{aligned}\text{Dynamic factor } K_v &= \left(\frac{A + \sqrt{200V}}{A} \right)^B \\ \text{Where } A &= 50 + 56(1-13) \\ B &= 0.25(12 - Q_v)^{2/3}\end{aligned}\quad \text{Eqn 4.19}$$

Where $Q_v = 7$

So, $B=0.73$ and $A=65.06$

$K_v = 1.611$

Lewis form factor, for gear with 56 teeth is 0.415

$$\begin{aligned}\text{Size factor, } K_s &= 0.904(bm\sqrt{Y})^{0.0535} \\ &= 1.06\end{aligned}\quad \text{Eqn 4.20}$$

$K_H=1$ and $K_B=1$

$$\begin{aligned}\text{Stress} &= W \times K_o \times K_v \times K_s \times K_H \times \frac{K_B}{bm \times Y_J} \\ Y_J &= 0.43\end{aligned}\quad \text{Eqn 4.21}$$

Stress = 32.24 MPa

The safety factor can be calculated as:

$$S_F = \frac{S_t \times Y_n / (K_t \times K_r)}{\text{Stress}}\quad \text{Eqn 4.22}$$

For grade 1 steel,

Allowable bending stress is,

$$S_t = 0.533 H_B + 88.3 \text{ MPa}\quad \text{Eqn 4.23}$$

where $H_B = 70$ (Rockwell Hardness)

$S_t = 125.51 \text{ MPa}$

The stress cycle factor (Y_n) for pinion is 1.19 and the temperature factor (K_t) is 1.

For 0.9999 reliability,

Reliability factor (K_r) = 1.5

$$\text{Safety factor } (S_F) = 125.61 \times \frac{1.19}{1 \times 1.5 \times 32.241} = 3.09 \quad \text{Eqn 4.24}$$

So, it is safe against bending fatigue failure.

5. Results and Discussion

Performance testing indicated that the shredder effectively cuts PET bottles into flakes of acceptable size. The machine operated smoothly, with minimal vibration and stable torque transmission. The results demonstrate that the developed shredder meets the design objectives for small-scale recycling.

PET plastic bottles were used to evaluate the machine's performance after it was built. Bottle size of various types was shredded with a single-phase induction motor as the prime mover. The machine's throughput capacity was determined by measuring the output mass and retained mass for various bottle sizes. The data were collected and tabulated as shown in table 5.1.

Table 5.1: Variation in Output Mass with Bottle Sizes

Bottle size(ml)	Input mass(gm)	Output mass(gm)	Retained mass(gm)	Retention %	Shredding efficiency
500	10.3	9.02	1.28	12.43	87.57
	10.3	8.47	1.83	17.77	82.23
	10.3	8.7	1.6	15.53	84.47
1000	19.7	16.4	3.3	16.75	83.25
	19.7	15.4	4.3	21.83	78.17
	19.7	14.68	5.02	25.48	74.52
1500	28.3	23.8	4.5	15.90	84.10
	28.3	22.71	5.59	19.75	80.25
	28.3	22.1	6.2	21.91	78.09

Variation in size of the flakes were observed with the size of the PET plastic bottle. Three different sizes of 500 ml, 1000ml, and 1500 ml bottles were taken into consideration for testing. The flake sizes were observed to increase with increase in the size of bottle. Flake sizes of average 6.7cm were observed for 500ml bottles, sizes of 8.9 cm were observed in 1000 ml and largest average flake sizes of 10.4 cm were observed for 1500 ml bottles.

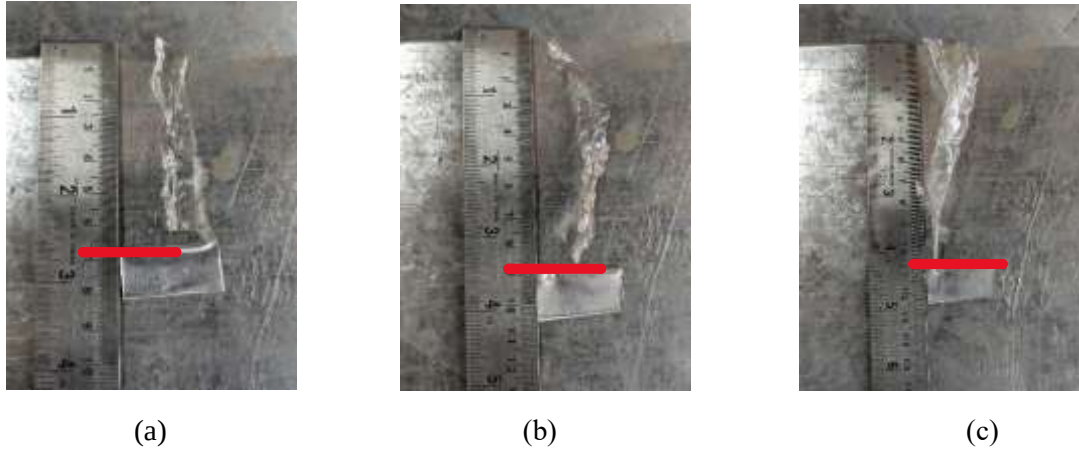


Figure 5.1: Output Flake Sizes During Testing: (a) 500 ml (b) 1000 ml (c) 1500 ml

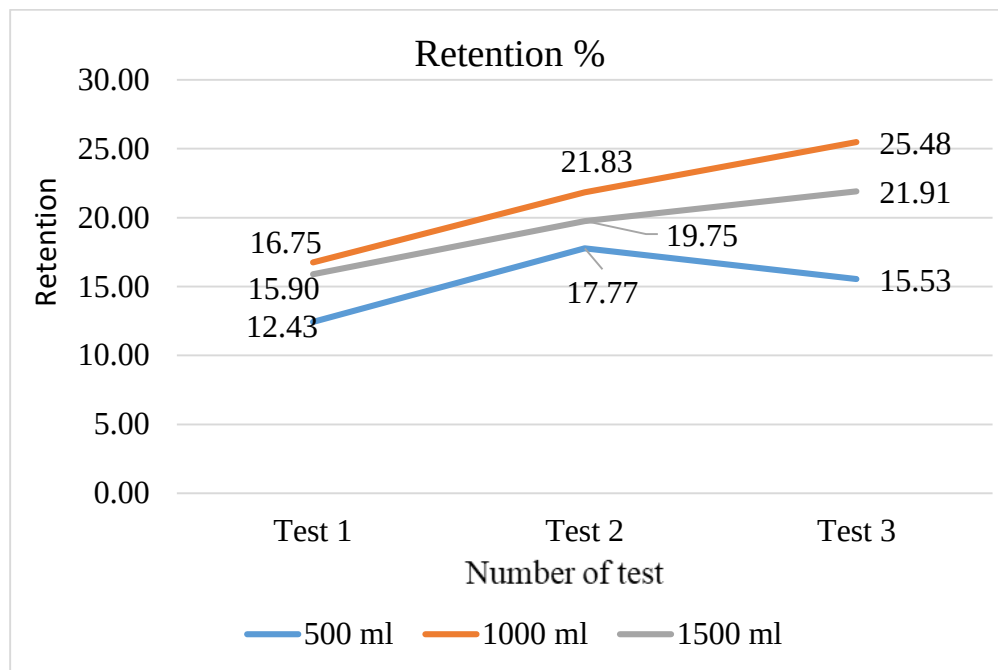


Figure 5.2: Retention % of Different Bottle Sizes

High particle retention in the shredder was observed for 1000 ml bottles, with highest retention percentage of 25.48% at test 3, this is attributed to the clogging of the shredding chamber due to overloading of the input mass. Least retention percentage of 12.43% was recorded at test 1, for 500 ml bottle as shown in figure 5.2.

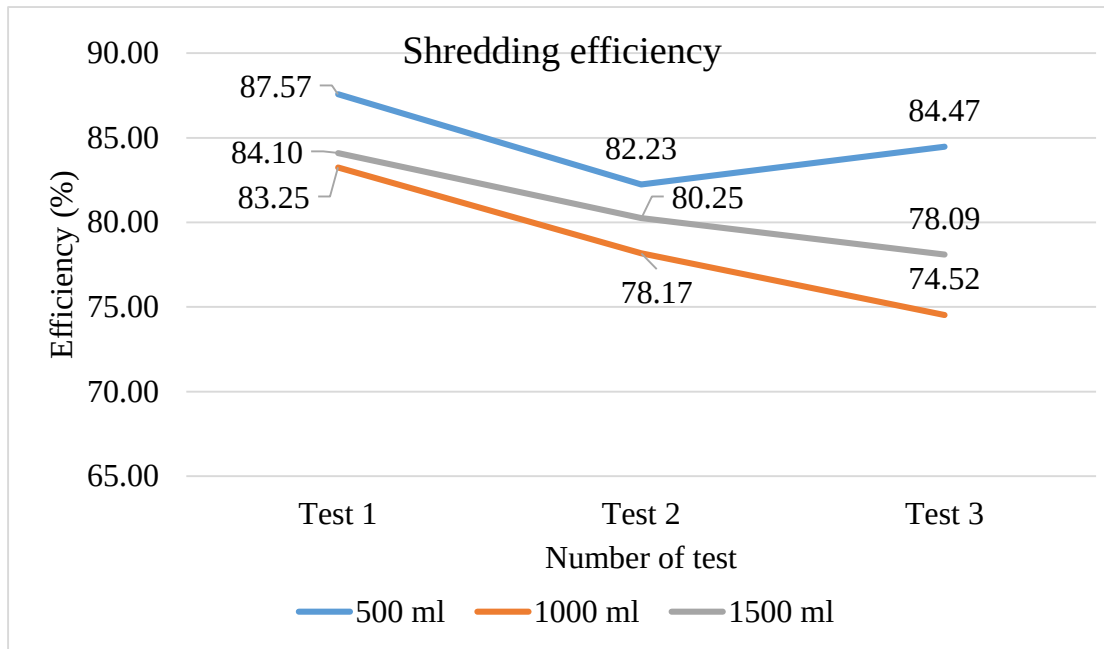


Figure 5.3: Shredding Efficiency of Different Bottle Sizes

As shown in figure 5.3, it was observed that the machine is highly efficient for shredding PET bottles of 500 ml sizes with the highest value of 87.57%. Consequentially, highest value of 84.10% and 83.25% were observed for bottle size of 1500ml and 1000 ml respectively. Shredding efficiency decreases with the increase in number of tests due to clogging of flakes in shredder box. Figure 5.3 shows that PET plastic shredder can achieve minimum shredding efficiency of 74%.

6. Conclusion

A PET plastic shredder was successfully designed and fabricated for recycling applications. The machine is economical, easy to operate, and suitable for small recycling units. Future work may focus on increasing capacity and incorporating automation features such as automatic feeding and speed control.



Figure 6.1: Fabricated PET Plastic Shredder

Acknowledgment

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