
DEVELOPMENT AND PERFORMANCE EVALUATION OF A WASTE PLASTIC SHREDDER

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ABSTRACT

The increasing use of plastic materials in modern society has led to a significant rise in plastic waste generation. Improper disposal of these materials has created serious environmental challenges, particularly in developing countries where waste management systems are still evolving, hence plastic recycling has therefore become an important approach to reducing environmental pollution and promoting sustainable resource utilization. One of the key processes involved in plastic recycling is the reduction of plastic waste into smaller sizes that can be easily processed and reused. This paper focuses on the design and fabrication of a waste plastic shredding machine suitable for small and medium scale recycling operations. The machine was designed using fundamental principles of mechanical engineering and constructed using locally available materials to ensure affordability, durability, and ease of maintenance while the major components of the machine include the frame, hopper, shredding blades, shaft, drive mechanism, bearings, and a 6.5hp gasoline engine which serves as the power source. The machine operates on the principle of mechanical shearing and cutting, where plastic materials fed through the hopper are reduced into smaller particles by rotating blades mounted on a shaft. Performance evaluation of the fabricated machine was carried out using plastic waste materials and three experimental tests were conducted with an average plastic input weight of 5.37 kg and an average shredding time of 51.67 seconds. The results obtained showed an average shredded plastic output of 4.9 kg, resulting in a shredding efficiency of approximately 91.25 percent. The results indicate that the fabricated plastic shredding machine is capable of effectively reducing plastic waste into smaller particles suitable for recycling processes. The machine therefore provides a practical and cost-effective solution for improving plastic waste management and supporting environmental sustainability, especially in communities where recycling facilities are limited.

Keywords: *Plastics; Environment; Pollution; Shredding; Wastes Management; Machine*

1. INTRODUCTION

The exponential growth of plastic consumption worldwide over recent decades has resulted in the generation of massive quantities of plastic waste, making it one of the most significant environmental and public health challenges of the 2^{1st} century (Thompson *et al.*, 2009; Hopewell *et al.*, 2009) but the indiscriminate disposal of plastic waste in Nigeria has resulted in serious environmental problems, including blocked drainage systems, pollution of water bodies, and threats to human health and biodiversity. Large quantities of plastic waste remain unprocessed due to the lack of appropriate recycling and shredding facilities, particularly at the community and institutional levels.

Many of the plastic shredding machines currently available are imported and expensive, making them inaccessible to small-scale recycling operators and local entrepreneurs. In addition, some existing machines require a reliable electricity supply, which is often unavailable or inconsistent in many parts of Nigeria. As a result, plastic waste is frequently discarded without undergoing size reduction, thereby limiting recycling opportunities.

Plastics are widely used due to their versatility, durability, and low cost, yet their non-biodegradable nature means that, once discarded, they persist in the environment for hundreds of years. Plastic waste accumulates in landfills, rivers, oceans, and terrestrial ecosystems, posing severe threats to wildlife, human health, and overall ecological balance. Microplastics, formed from the breakdown of larger plastic items, have been detected in water sources, soils, and even food chains, raising global concerns about their long-term effects on health and ecosystems. These realities underscore the urgent

need for sustainable, cost-effective, and scalable strategies for plastic waste management, with recycling and reuse emerging as the most viable solutions (Handel and Strazdus, 2021).

Among the critical stages of plastic waste management is size reduction through shredding, a process that enhances recycling efficiency and operational feasibility. Shredding converts bulky, irregular, and difficult-to-handle plastics into smaller, uniform fragments that are easier to transport, sort, and process in subsequent operations such as melting, extrusion, or chemical treatment (Angelo *et al.*, 2022; Wong *et al.*, 2022). Reducing particle size not only increases the surface area for more efficient processing but also lowers storage and transportation costs and reduces hazards associated with manual handling of large plastic items. A well-designed shredding system enhances recycling efficiency, supports circular economy principles, and contributes to resource conservation by enabling plastics to be reintroduced into manufacturing processes. The significance of this research extends beyond technical design but by providing a low-cost, practical, and efficient solution for plastic waste reduction thereby contributing to environmental conservation, promotes sustainable waste management practices, and encourages the adoption of circular economy initiatives at the community and institutional levels (Balasubramanian and Sharma, 2022). It also aims to address local and national plastic waste challenges and also serve as a replicable model that can be adopted by educational institutions, small enterprises, and community-based recycling programs.

Surgude *et al.* (2023) fabricated a plastic shredder designed for small recycling workshops and emphasized the use of locally available materials to reduce manufacturing cost though, the fabricated shredder efficiency was 91.3%, yet their studies demonstrate that locally designed shredding machines can provide effective solutions for plastic waste recycling when appropriate engineering principles are applied.

2. METHODOLOGY

The design process for shredding plastic wastes such as PET, HDPE, and polypropylene. involves the identification and configuration of the major machine components, which include: *Hopper; Shredding chamber; Cutting blades; Rotating shaft; Bearings; Structural frame; Power transmission system; Discharge outlet*. Material selection was based on mechanical strength, durability, availability, and ease of fabrication while the engineering drawing provided the dimensional layout used for the design calculations. The overall machine height is 1673 mm, while the frame base dimensions are 730 mm by 914 mm; these dimensions were selected to provide structural stability during operation.

The hopper was designed with a top opening dimension of 580 mm by 956 mm and a vertical depth of 520 mm.; this configuration ensures sufficient feeding capacity while preventing plastic materials from spilling during operation. The machine frame was constructed using mild steel angle bars welded together to form a rigid structure. The shaft was machined using a lathe machine to obtain the required dimensions. Six rows of cutting blades were mounted on the shaft with a spacing of 58 mm between adjacent blades. This spacing allows continuous cutting of plastic materials during rotation. The hopper was fabricated using sheet metal and mounted above the shredding chamber to guide the plastic waste into the cutting region. the machine components were assembled in accordance with the engineering drawing.

The shaft was mounted within the shredding chamber and supported by bearings installed on both sides of the machine frame. The cutting blades were fixed along the shaft at a spacing of 58 mm, forming six rows of shredding elements. The gasoline engine was mounted on the lower frame section, approximately 870 mm below the shredding shaft. This configuration lowers the center of gravity of the machine and improves operational stability. Power transmission from the engine to the shredding shaft was achieved using a V-belt and pulley system. The discharge chute was positioned 197 mm above the ground level to allow easy collection of shredded plastic materials. The material selected are justified in the table and the figure 2 shows the exploded drawing.

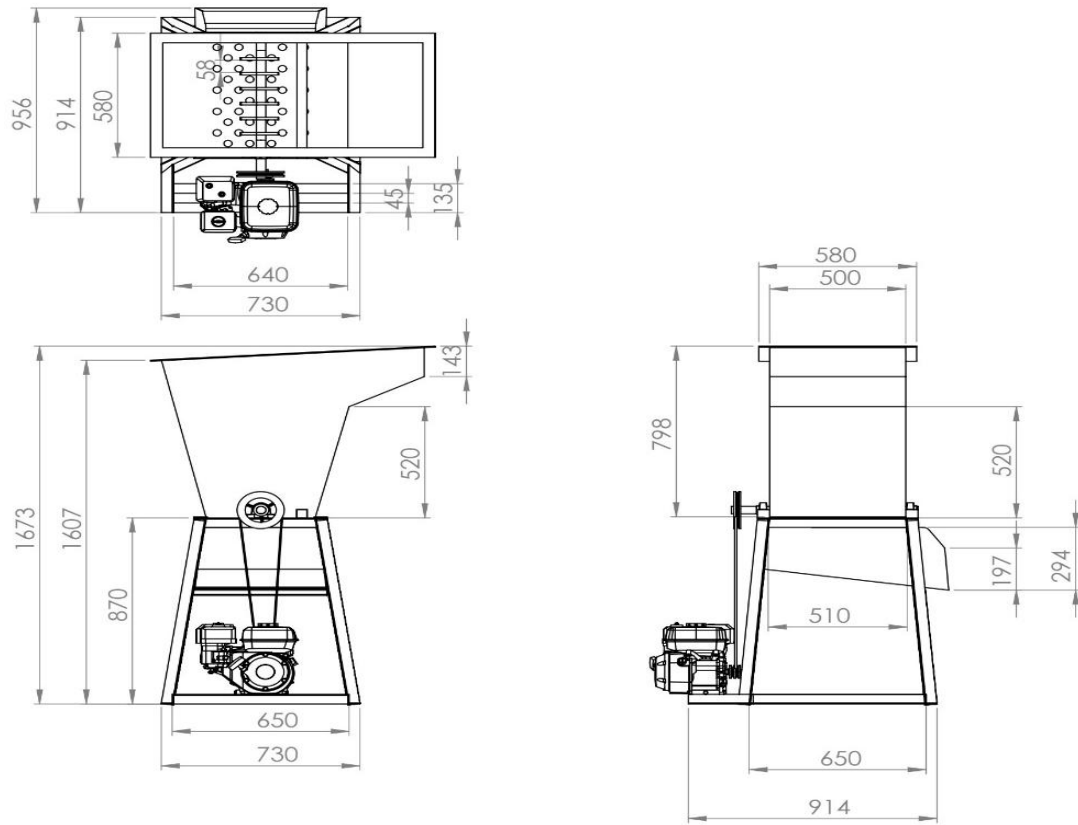


Figure 2: Exploded Drawing

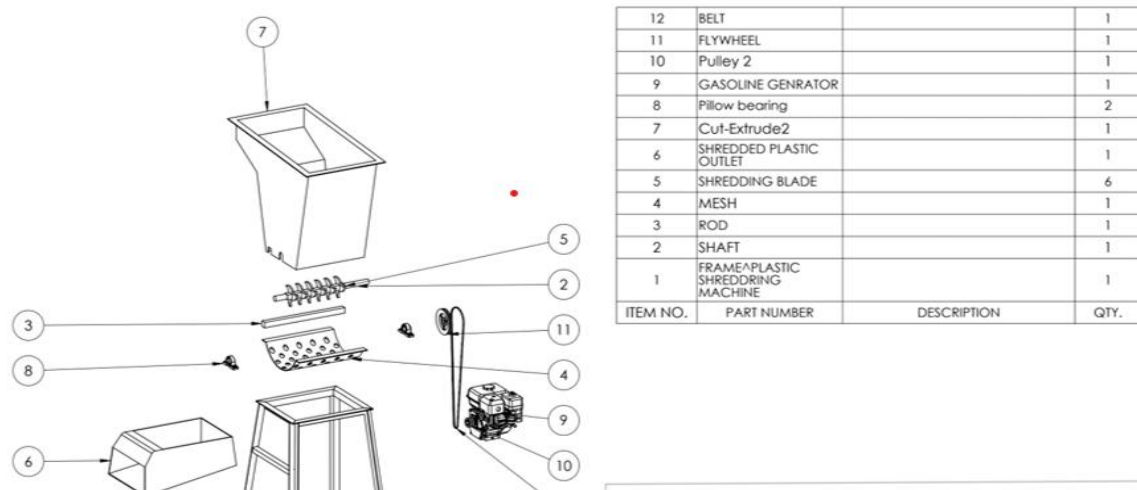


Table 1: Materials used for Machine Fabrication

S/N	Component	Material
1	Frame	Mild steel
2	Shaft	Carbon steel
3	Cutting blades	Hardened steel
4	Hopper	Mild steel sheet
5	Bearings	Ball bearings
6	Bolts and nuts	Mild steel

2.1 Design Parameters

The following parameters were determined:

- Machine throughput capacity
- Shredding efficiency

Shredding efficiency was calculated using the expression:

$$S.E(\%) = \left(\text{Weight of shredded} \frac{\text{output}}{\text{Weight}} \text{ of plastic input} \right) \times 100 \dots\dots\dots$$

equation (2.1)

2.2 Engineering Design Calculations Used

Engineering calculations were performed to determine the power transmission characteristics, shaft torque, and cutting force required for the shredding process.

2.2.1 Engine Power

The machine is powered by a gasoline engine rated at:

Engine power = 6.5 horsepower

Conversion to SI units:

Recall: $1hp = 746$

therefore,

$$P = 6.5 \times 746$$

$$P = 4849W$$

$$P \approx 4.85kw$$

2.3 Torque Transmitted by the Shaft

The torque transmitted by the shaft is determined using:

$$P = \frac{(2\pi NT)}{60} \dots\dots\dots \text{equation (2.3)}$$

Where

$P = \text{power (W)}$

$N = \text{rotational speed (rpm)}$

$T = \text{torque (Nm)}$

Nota Bene: Small gasoline engines typically operate at 3600 rpm.

Substituting the values:

$$4849 = \frac{(2 \times 3.142 \times 3600 \times T)}{60}$$

$$4849 = \frac{22622.4T}{60}$$

Multiplying both sides by 60:

$$290940 = 22622.4T$$

$$T = 12.86Nm$$

Thus, the torque transmitted by the engine shaft is **12.86 Nm**.

2.4 Torque Multiplication through Pulley Ratio

Since the machine uses a speed reduction pulley system, torque increases at the shredding shaft.

If the pulley ratio is approximately 3:1 (large pulley on machine shaft), then

$$T_2 = T_1 \times Ratio \dots\dots\dots \text{equation (2.4)}$$

$$T_2 = 12.86 \times 3$$

$$T_2 \approx 38.58Nm$$

Thus, the shredding shaft receives approximately **38.6 Nm** of torque.

2.5. Blade Arrangement and Cutting Distribution

The machine uses 6 rows of cutting blades spaced 58 mm apart along the shaft.

Total shredding width = 580 mm

Number of blade rows = 6

Average cutting spacing ensures that plastic materials are continuously engaged during rotation, improving shredding efficiency.

2.6 Hopper Volume and Feeding Capacity

Hopper dimensions:

Length = 956 mm = 0.956 m

Width = 580 mm = 0.58 m

Depth = 520 mm = 0.52 m

Hopper volume:

$$V = L \times W \times H \dots\dots\dots \text{equation 2.6}$$

$$V = 0.956 \times 0.58 \times 0.52$$

$$V \approx 0.288\text{m}^3$$

Thus, the hopper can accommodate approximately 0.29 cubic meters of plastic material before shredding.

3. RESULTS AND DISCUSSION

An internal testing was conducted to ascertain the performance of the fabricated plastic shredder using plastic waste materials of known weight. During the test, plastic materials were fed into the hopper while the machine was operating, and the shredding time was recorded. After the shredding process, the shredded plastic particles were collected and weighed. Three experimental tests were conducted in order to obtain reliable results and this performance evaluation is based on internal testing of the fabricated plastic wastes shredding machine only. The results obtained from shredding PET, HDPE, and polypropylene wastes are presented in Table 2.

Table 2: Performance Test Results

Test Number	Plastic Input (kg)	Shredded Output (kg)	Shredding Time (s)	Efficiency (%)
1	5.40	4.92	52	91.11
2	5.30	4.85	50	91.51
3	5.41	4.93	53	91.13
Average	5.37	4.90	51.67	91.25

As shown in table 2, the average plastic input used during the experiment was 5.37 kg, while the average shredded output obtained was 4.9 kg. The average shredding time recorded was 51.67 seconds. From table 2, throughput capacity of the machine was calculated as:

$$\text{Capacity} = \frac{\text{Mass}}{\text{Time}}$$

$$\text{Capacity} = \frac{5.37}{51.67} = 0.104\text{kg/s}$$

Converting to kg/hr,

$$0.104 \times 3600 = \mathbf{374\text{kg/hr}}$$

The shredding efficiency was calculated as:

Shredding efficiency is calculated as:

$$Efficiency(\%) = \left(\frac{Output}{Input} \right) \times 100$$

$$Efficiency = \left(\frac{4.9}{5.37} \right) \times 100$$

$$Efficiency \approx \mathbf{91.25\%}$$

The high shredding efficiency obtained in this study is consistent with the findings of *Raji et al. (2020)*, who reported shredding efficiencies above 91.3 percent in their design and development of a plastic waste shredding machine. Their study showed that properly designed blade arrangements and adequate torque transmission significantly improve the efficiency of plastic shredding machines. The results obtained from this study demonstrate that the plastic shredding machine successfully achieved the objectives of the research and addressed the problem of plastic waste size reduction. The design results confirm that a functional plastic shredding machine can be developed using standard mechanical engineering design principles. The arrangement of cutting blades on the rotating shaft produced the necessary shearing force required to reduce plastic materials into smaller particles. This observation agrees with the findings of Groover (2010), who explained that size reduction processes are essential in recycling operations because they improve material handling and processing efficiency. The fabrication results also indicate that the machine can be constructed using locally available materials and conventional workshop tools, which significantly reduces production cost. This supports the argument of *Al-Salem et al. (2009)* that improving recycling technologies at the local level is essential for effective plastic waste management in developing countries. The performance evaluation further showed that the machine achieved an efficiency of 91.25 percent, which indicates effective shredding of plastic materials. This result is comparable with similar studies conducted by *Raji et al. (2020)* and *Surgude et al. (2023)*, who also reported 91.3% high shredding efficiencies in locally fabricated plastic shredding machines. In addition, the throughput capacity of approximately 374 kg per hour demonstrates that the machine can process a significant amount of plastic waste within a relatively short time. This capacity makes the machine suitable for small and medium-scale recycling operations, educational institutions, and community-based waste management initiatives. The use of a gasoline engine as the power source also provides an advantage in environments where electricity supply is unreliable. This feature improves the adaptability of the machine in rural and urban areas where power infrastructure is limited. Overall, the results confirm that the developed plastic shredding machine provides a practical, affordable, and efficient solution for plastic waste size reduction, thereby supporting recycling activities and contributing to improved environmental sustainability.

4. CONCLUSION

1. *Conclusively*, this research successfully achieved the development of a plastic waste shredding machine designed and fabricated using locally available materials and standard mechanical engineering principles. The study was motivated by the growing challenge of plastic waste accumulation and the limited availability of affordable recycling equipment, particularly in developing countries such as Nigeria. Overall, the results of this study confirm that the developed plastic shredding machine provides a practical, cost-effective, and sustainable solution for improving plastic waste management and supporting recycling activities. The machine can contribute to environmental protection, resource recovery, and the development of local recycling

industries however, the study is limited to the shredding of plastic waste materials only and does not include the complete recycling process such as melting, extrusion, or remanufacturing of plastic products hence further research can investigate the use of improved blade materials or heat treatment processes to increase blade durability and reduce wear during continuous operation.

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