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DEVELOPMENT AND PERFORMANCE EVALUATION OF A PLASTIC WASTE REDUCTION MACHINE (SHREDDER) FOR EFFECTIVE PLASIC WASTE MANAGEMENT

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Abstract
This study presents the design, fabrication, and performance evaluation of a plastic waste reduction machine developed to address the growing challenges of plastic waste management. The machine employs a rotary cutting mechanism powered by an electric motor to reduce plastic waste into smaller fragments suitable for recycling processes. Performance tests conducted using polyethylene terephthalate (PET) bottles, high-density polyethylene (HDPE) containers, and low-density polyethylene (LDPE) materials demonstrated a throughput capacity of 18-25 kg/hr with particle size reduction ranging from 15-40 mm. The machine achieved an average efficiency of 78.5% with minimal power consumption of 2.2 kW. The developed shredder offers a practical solution for plastic waste management in resource-limited settings.

Keywords: plastic waste reduction, shredder design, waste management, recycling technology, mechanical size reduction, sustainability

Introduction

Plastic waste has emerged as one of the most pressing environmental challenges of the 21st century (Mishra *et al*., 2024). Global plastic production has increased exponentially from 2 million tonnes in 1950 to over 380 million tonnes annually, with only 9% being recycled effectively (Gautam *et al*., 2024). The accumulation of plastic waste in landfills and aquatic ecosystems poses severe threats to environmental sustainability and public health. In developing nations, inadequate waste management infrastructure compounds this problem, necessitating affordable and efficient waste processing technologies (Kumari and Raghubanshi, 2023).

Mechanical size reduction represents a critical preprocessing stage in plastic waste recycling, facilitating subsequent operations such as washing, separation, and reprocessing. Shredders reduce plastic waste volume, increase surface area for chemical processing, and enable easier transportation and storage (Jeyalakshmi *et al*., 2022). However, commercial shredding equipment remains prohibitively expensive for small-scale operations, particularly in emerging economies. The development of cost-effective alternatives using locally available materials and components addresses a critical gap in the waste management value chain (Kurniawan *et al.*, 2025).

Several researchers have explored various approaches to plastic waste reduction technology. Singh and Sharma (2016) developed a dual shaft shredder achieving throughput rates of 30-40 kg/hr with particle sizes between 10-30 mm, while Okonkwo et al. (2018) fabricated a single-shaft alternative with lower throughput (12-18 kg/hr) but significantly reduced production costs. Research indicates that cutting mechanism design, material selection, and power transmission systems significantly influence shredder performance and economic viability (Bala *et a*l., 2017; Adeyemi and Thompson, 2020). However, limited research exists on comprehensive performance evaluation protocols and designs specifically optimized for resource constrained environments.

This research addresses the need for accessible plastic waste reduction technology by developing a locally fabricated shredder targeting common plastic waste types including PET bottles, HDPE containers, and LDPE films. The study aims to design and fabricate a functional machine, evaluate its performance characteristics including throughput capacity and energy consumption, assess economic viability for small to medium-scale operations, and provide replicable technical specifications for resource limited settings. By demonstrating the feasibility of low-cost shredder fabrication, this research provides a practical model for waste management initiatives while promoting skill development and employment opportunities within local metalworking and recycling sectors.

METHODOLOGY

Design Specifications

The plastic waste reduction machine was designed based on the following specifications:

- Target throughput: 20-30 kg/hr
- Input material: PET bottles, HDPE containers, LDPE films
- Maximum input size: 500 mm × 300 mm
- Target output size: 15-40 mm fragments
- 13 HP Gasoling Engine

Machine Components

The shredder consists of the following major components:

Hopper Assembly: A trapezoidal feeding hopper fabricated from 2 mm mild steel sheet, dimensions 400 mm × 350 mm × 450 mm, with a 30-degree inclination to facilitate gravity feeding.

Cutting Chamber: Housing fabricated from 4 mm mild steel plate, containing the rotor assembly and stationary bed knife. Internal dimensions: 350 mm width × 250 mm depth.

Rotor Assembly: Shaft diameter of 40 mm with four cutting blades mounted at 90-degree intervals. Blades fabricated from spring steel (thickness 8 mm, length 300 mm, cutting edge angle 35 degrees).

Bed Knife: Stationary blade mounted on the chamber floor with adjustable clearance gap (2-5 mm) from rotor blades, fabricated from high-carbon steel.

Power Transmission: V-belt drive system with 1:2 speed reduction, driving pulley diameter 150 mm, driven pulley diameter 300 mm, achieving rotor speed of 1440 rpm.

Frame Structure: Base frame constructed from 50 mm × 50 mm angle iron with bracing for stability and vibration dampening.

Table 1: Design Calculations:

Type of Design	Design Formula	Result
Cutting Force	$F = \sigma \times A$. Where: $\sigma = 50$ MPa (PET shear strength). $A = t \times L = 0.5\times10^{-3} \times 0.3\ m^2$	F = 7,500 N. A = 0.00015 m^2
Torque Requirement	$T = F \times r$. Where: r = 0.15 m (rotor radius)	T = 1,125 N·m
Theoretical Power	$P = (2\pi NT)/60$. Where: N = 1440 rpm	P = 170 kW (peak)
Practical Power	P actual = P theoretical × 0.15 (with safety	P = 25.5 kW. (2-3 kW continuous

Type of Design	Design Formula	Result
	factor and intermittent cutting)	with empirical adjustments)
Speed Ratio	$i = n_1/n_2$. Where: n_1 = 2880 rpm, n_2 = 1440 rpm	i = 2
Pulley Diameters	$d_2 = i \times d_1$. Where: d_1 = 150 mm	d_1 = 150 mm. d_2 = 300 mm
Belt Length	$L = 2C + (\pi/2)(d_1 + d_2) + (d_2 - d_1)^2/4C$. Where: C = 600 mm	L = 1916.3 mm. Standard: B1920 (1920 mm)
Shaft Diameter	$d = \sqrt[3]{[(16T)/(\pi\tau)]}$. Where: T = 1,125 N·m. τ allowable = 42 MPa (mild steel)	d calculated = 51.4 mm. d selected = 40 mm (with safety factor)

Performance Testing
Performance evaluation was conducted using three plastic waste categories:

Test Materials:
- Category A: PET bottles (clean, dry)
- Category B: HDPE containers (various thicknesses)
- Category C: LDPE films and bags

Measured Parameters:
- Throughput capacity (kg/hr)
- Particle size distribution (mm)
- Power consumption (kW)
- Noise level (dB)
- Operational efficiency (%)

Throughput was measured by feeding known quantities of plastic waste and recording processing time. Particle size distribution was determined by sieving shredded output through standard mesh sizes (10 mm, 20 mm, 30 mm, 40 mm). Power consumption was monitored using a digital power meter. Efficiency was calculated as the ratio of theoretical cutting work to actual energy consumed.

RESULTS
Performance Data
The developed plastic waste reduction machine underwent comprehensive testing with the following results:

Table 2: Throughput Capacity and Particle Size Distribution

Plastic Type	Throughput (kg/hr)	Particle Size Range (mm)	Average Particle Size (mm)	Efficiency (%)
PET Bottles	24.8	18-35	26.5	81.2
HDPE Containers	18.3	20-42	31.8	75.6
LDPE Films	22.1	15-38	24.2	78.8
Average	**21.7**	**15-40**	**27.5**	**78.5**

Table 3: Energy Consumption and Operational Parameters

Parameter	Value
Motor Power Rating	2.5 kW
Average Power Consumption	2.2 kW
No-load Power	0.8 kW
Rotational Speed	1440 rpm

Parameter	Value
Noise Level (1m distance)	82 dB
Operating Temperature (motor)	68°C
Blade Clearance Gap	3 mm

7.2 Particle Size Distribution

Sieve analysis revealed the following size distribution:

- 15-20 mm: 28%
- 21-30 mm: 42%
- 31-40 mm: 26%
- 40 mm: 4%

Approximately 96% of shredded material fell within the target size range of 15-40 mm, indicating effective size reduction performance.

8. DISCUSSION

The developed plastic waste reduction machine demonstrated satisfactory performance across multiple evaluation criteria. The average throughput of 21.7 kg/hr falls within the target range for small-scale operations, though slightly below the 30 kg/hr upper specification. This discrepancy primarily stems from feed rate limitations rather than cutting capacity, suggesting that hopper design optimization could improve throughput.

Particle size distribution results indicate effective shredding performance, with 96% of output meeting the 15-40 mm target range. This size range is appropriate for subsequent recycling processes including washing, density separation, and extrusion. The slight variation in performance across plastic types reflects differences in material properties; HDPE's higher thickness and toughness resulted in larger average particle sizes compared to PET and LDPE.

The measured efficiency of 78.5% compares favorably with similar low-cost designs reported in literature. Singh and Sharma (2016) reported 72% efficiency for their dual-shaft system, while Okonkwo et al. (2018) achieved 68% with a single-shaft configuration. The higher efficiency of the present design may be attributed to optimized blade geometry and appropriate clearance gap settings. However, efficiency remains below industrial standards (>85%), indicating opportunities for improvement in cutting mechanics and power transmission.

Energy consumption of 2.2 kW represents economical operation, particularly when compared to commercial units requiring 5-7 kW for similar throughput. This lower power requirement enhances the machine's viability in locations with limited electrical infrastructure or where energy costs constitute a significant operational expense. The no-load power of 0.8 kW suggests moderate bearing friction and belt resistance, within acceptable ranges for belt-driven systems.

Noise levels of 82 dB exceed comfortable hearing thresholds but remain below hazardous exposure limits (85 dB for 8-hour duration). Operators should employ hearing protection during extended use. Noise reduction could be achieved through enclosure panels or rubber vibration dampeners, additions that would minimally impact production costs.

Several limitations warrant consideration. First, the machine's single-shaft design limits processing of thick-walled plastics and multilayer materials. Second, blade wear necessitates periodic sharpening or replacement, introducing maintenance requirements. Third, the absence of automated feeding requires continuous operator attention, limiting throughput optimization. Future iterations could address these limitations through dual-shaft configurations, hardened blade materials, and mechanized feeding systems.

The research demonstrates that functional plastic waste reduction technology can be developed using local fabrication capabilities and modest investment. This finding has significant implications for waste management strategies in resource-limited settings, where technology transfer and local adaptation represent viable alternatives to expensive imported equipment.

9. CONCLUSION

This research successfully developed a plastic waste shredder for small to medium-scale recycling operations, achieving a throughput of 21.7 kg/hr with 78.5% efficiency at 2.2 kW power consumption. The machine effectively processed PET, HDPE, and LDPE plastics into 15-40 mm particles suitable for downstream recycling, with a production cost of ₦610,000 demonstrating economic viability through local fabrication.

The design addresses critical gaps in plastic waste management infrastructure by providing an accessible, replicable solution using readily available materials. Performance data confirms the rotary cutting mechanism's effectiveness and favorable comparison with existing low-cost designs.

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Appendix

Plate 1: The Fabricated Plastic Waste Reduction Machine (Shredder)