Design, Fabrication, and Performance Evaluation of Shredding Machines for Shredding Plastic Bottles and Cups Waste

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Keywords: Shredding Machine, Plastic Waste, Plastic Bottle, Plastic Cups.

Abstract: Plastic's function in human lifestyles is expanding. This boom is because of the truth that plastic is light-weight, realistic, and reasonably priced and can replace other objects features. Plastic use is hastily increasing in East Nusa Tenggara Province, especially in Kupang town, as evidenced by the enormous use of plastic gadget. Some people in Kupang town see this problem as a possibility and opportunity to create jobs and a generate of income by gathering plastic waste to be sold and despatched to some other island to be recycled. Therefore, this study focused on designing and fabricating a low-cost plastic shredding machine that will assist plastics collectors as small and medium-scale entrepreneurs in the city of Kupang in chopping plastic waste i.e. bottles and cups into small fragments, making it easy to pack and ship it. The plastic shredder machine is made up of four major parts: the hopper, the shredding unit, the power unit, and the machine frame. The design parameters, such as hopper capacity, shaft diameter, reducer ratio, and required power, have been calculated. The result of the calculated design parameters was being used for fabrication. The uniqueness of this plastic shredder machine lies in the uniqueness of its design where at the bottom of the shredding unit there are a metal sieve with the geometric shape of arc that allows the recirculation of crushed plastic not conforming to the appropriate size to reintegrate it in the shredding process. This metal sieve will ensure the chopped plastic are uniform in size. The performance evaluation of the machines was determined in terms of the machine efficiency and the production rate. Following the successful completion of the fabrication, the shredder machine is tested using 4500 gr of the plastic bottle and 2600 gr of plastic cups as a sample, with the succeeding results obtained: At a machine speed of 135 rpm, the plastic bottle was shredded to an average particle size of 30 mm^2 in 840 sec, and plastic cups was shredded to an average particle size of 28 mm^2 in 400 sec. The average machine efficiency was 98% for plastic cups, and 94% for plastic bottle.

1 INTRODUCTION

Plastic's use in human existence is expanding by the day. Plastic is being used more because it is light, practical, and affordable, and it may replace the function of other goods. Because of their practical and affordable character, plastics are frequently utilized as disposable objects, increasing plastic waste as more equipment made of plastic materials is used. This is what causes the amount of plastic waste to continue to rise, causing major environmental issues. Plastic trash is an environmental issue that the people of Indonesia and the rest of the globe face. The use of non-environmentally friendly plastic products generates a variety of major environmental issues. Plastic garbage is one sort of waste that is extremely difficult to degrade in the soil, taking decades or even hundreds of years to completely decompose in nature. Plastic garbage dumped directly into the final disposal site will cause complications if not properly managed (L. Habib, et all, 2018). The dumping of plastic waste is one of the sources of environmental damage that remains a significant concern for the Indonesian people. The plastic trash takes tens. However, the negative impact of plastic waste is proportionate to its usefulness. Thus, if the trash is not eliminated, it will pose a major hazard

In the city of Kupang, particularly in the sub-district of Kelapa Lima, the usage of plastic is fast increasing, as seen by the prevalence of plastic-made equipment. This is exacerbated by the public's lack of awareness regarding proper waste disposal, so in several locations along the coast in Kupang City, such

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as Pasir Panjang beach and Oesapa Beach, there is a great deal of plastic waste that pollutes the environment and will undoubtedly have further repercussions if not addressed immediately.

The issue of plastic trash is not just an environmental concern, but also an opportunity for commercial growth. Therefore, several residents of Kupang city view this opportunity as a source of income-generating employment opportunities. The scavengers will begin to collect and sell plastic waste to plastic collectors, who will subsequently ship and sell the plastic waste to the island of Java to be converted into plastic raw materials.

Based on the preliminary study conducted by the author in Kupang Regency of East Nusa Tenggara Province, at various plastic collection sites run by local citizens in the Kupang City, the collected plastic was sent directly to the main island of java in Surabaya without further processing. If the plastic has been treated (crushed into shreds), it will be significantly easier to pack and ship. In addition, the selling price will be more than that of plastic garbage sold in its entirety.

According to the findings of interviews with a number of plastic collectors, there is hope that the community will process the plastic waste into small pieces before sending it to Java for recycling, but due to the high cost of the chopper machine and technological limitations, all plastics collector in Kupang city continue to operate under the current conditions. Seeing the data and the reality on the ground, the author attempts to design and fabricate a Shredding Machines for Shredding Plastic Bottles and plastics cups with a simple cutting process so that it can be more effective in packing and shipping plastic waste than shipping plastic waste in its intact form, which is deemed inefficient.

The objective of this research is to design a Plastic Shredding Machine to obtain small plastic waste in such a way that it enables recycling industry professionals to obtain waste automatically and is also very useful for reducing plastic pollution in the environment.

2 RELATED WORKS

Plastic waste shredding machines are extremely important, as a number of studies have demonstrated as follows;

(A. Waleola Ayo, et all, 2017) recognized that when disposable plastic is shredded, the small pieces can be used to create new plastic products. Accordingly, they proposed the development of a plastic waste shredding machine. The machine's performance is 27.3 kg/h and its efficiency is 53% for all types of plastic and 95% for polyvinyl chloride plastic, concluding that the machine could be very useful in situations where large quantities of plastics need to be crushed and is also effective in crushing large sizes.

(Nuri Aryani et al., 2019) conducted a study to design and fabricate a plastic shredder machine using the Pahl and Beitz method, which consists of designing and describing the job, designing the product concept, constructing the machine, and designing the details. The plastic shredder machine consists of blades or a cutter, a spur gear-shaped transmission element, an electric motor, and a machine body. The types of plastic waste to be shredded are LDPE, HDPE, PP, and PS Based on its design, a plastic shredder machine can produce small flakes measuring approximately 10 mm in length and 1 mm in width.

(Witman Alvarado-Diaz, 2021), conducted a study to design a plastic shredding machine to obtain small plastic waste to assist people in being dedicated to the recycling industry in an automated way, it would also generate jobs because it requires a staff in charge of the machine, and it will also be extremely useful in reducing plastic pollution in the environment, which is increasing due to COVID-19 The plastic will be selected by color and type of plastic composition, whether it is Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE), Polychloride vinyl (PVC), or Others (Plastic Mix), then it will go through the shredding process to become small plastic waste, which could be turned into filament for 3D printers, using the design of the plastic waste shredding machine.

Jaypalsinh Rana, (2020), Conduct a study to design and construct a lightweight and inexpensive plastic shredder machine. So, the goal of this project is to process plastic garbage as cheaply as possible by cutting where it is made to reduce labour work, which results in cost savings. This project describes the trial with plastic bottle cutting machines as well as the examination of the machine's mechanism. A plastic bottle cutter is a machine that cuts plastic into little pieces to facilitate waste management. We are developing this project model to be used for the recycling of plastic waste in the home, industries, and scrap collectors. This machine is a solution to the space problem.

Adepo, S. O, and Obanoyen, N. O. (2017), conducted a study to design and construct a plastic shredding machine, which is an integral part of plastic recycling process. By crushing used plastic bottles, the plastic bottle crushing device assists in the management and disposal of municipal waste. Due to the use of readily available local raw materials during construction, the machine requires little upkeep and maintenance. The performance test analysis, which shows that the machine operates effectively and efficiently to complete its task at a high level of finished shredding efficiency of 97% at a speed of 11.5 m/s, defines the characteristics of the machine.

3 MATERIAL AND METHODS

During the design and material selection process, the following elements were considered: locally available, safety, strength, reliability, stability, size and shape, power consumption, ease of maintenance, and ease of operation. The shredding machine represented in figure 1 was made up of the following components: a hopper, a shredding unit, a power unit, a machine frame, and a discharge chute. The uniqueness of this plastic shredder machine lies in its design, which includes a metal sieve with the geometric shape of an arc at the bottom of the shredding unit, allowing the recirculation of crushed plastic that does not conform to the appropriate size to be reintegrated in the shredding process. This metal filter ensures that the chopped plastic is uniform in size.

4 DESIGN CALCULATIONS

The design parameters, such as shredder hopper, Shredder cutter, blade cutting force, required power, shaft diameter, shredder machine capacity, supporting frame have been calculated. The result of the calculated design parameters was being used for fabrication

4.1 Shredder Hopper

The shredder hopper is a pyramid with a truncated rectangular base that is positioned on the shredder chamber. The volume of the shredder hopper (VH) through which recyclable plastics are fed is determined by the equation (1).

$$VH = (\frac{1}{3})(BH - bh) \quad (1)$$

Where: B = the area of the rectangular base for the big pyramid (mm), H = the height of the big pyramid (mm), b = the area of the rectangular base for the small truncated pyramid (mm), and h = is the height of the small truncated pyramid. It is hoped that 75 percent of the hopper's volume will be occupied by recyclable PET/PET plastic due to the spacing between individual plastic elements.

Volume of PET bottle (Aqua Botle) in the shredding chamber: Area × height = = (πd4/4) × h; No of bottle to fill the hopper = volume of hopper/ volume of PET Bottle

4.2 Shredder Cutter

The cutting system of the plastic shredder machine employs two shafts with chopping blades placed alternately and moving in opposite directions to work by chopping, squeezing, and crushing the plastic trash. Each shredder knife is made up of 5 cutting blades with the design depicted in figure 1. The following is the shredder blade design data: blade diameter (B_d)= 100 mm, inner blade diameter (B_i) = 80 mm, blade thickness (B_t) = 3 mm, blade length (B_l) = 10 mm, blade material = SC45 Carbon Steel, blade cross-sectional area = 30 mm², total number of blades = 72, modulus elasticity of plastic (PPT) = 2,76 GPA = 281,4 Kgf/mm², planned knife rotation (n): 135 rpm, the initial rotation of the electrical motor: 3600 rpm

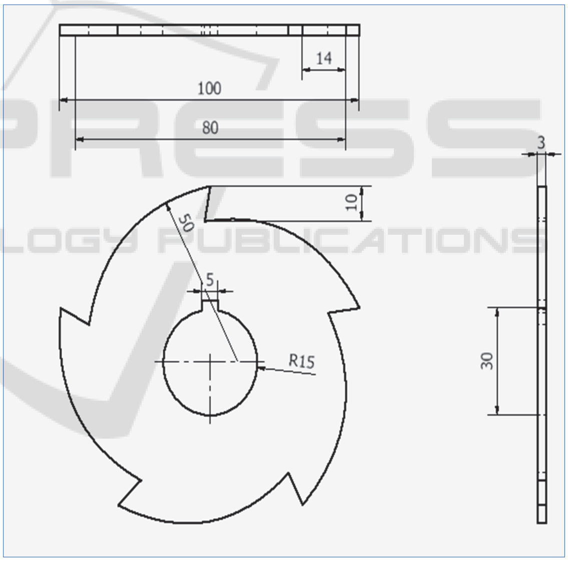

Figure 1: Blade Geometric.

4.3 Finding Blade Cutting Force (F_{blade})

The blade cutting force (F_{blade}) can be found using the equation:

$$Fblade = A \cdot F_t \quad (2)$$

Where: A = blade cross-sectional area, F_t = modulus elasticity of plastic. By getting the cutting force, the Torque (T) on the blade can be found using the equation:

$$T = F_{blade} \cdot r \quad (3)$$

Where: r = The blade diameter, T = Torque

4.4 Required Motor Driver Power

The driver motor or provides power to the machine. There are two types of motor driver can be used to provides the rotational motion and power needed to rotate the shaft through belt and pulley which is the electrical motor, or gasoline motor. The horsepower of the motor driver needed can be calculated as follow [7].

$$P = T\left[\frac{2\Pi . n}{60}\right]. \quad (4)$$

Where: n = The rotation of planned knife mounted on the shaft

4.5 Shaft Diameter

The shredder shaft is a revolving component located in the shredder chamber, and it is fitted with rings bearing knife-edged teeth. As it rotates against another stationary shaft in the chamber, this knife-edge ring enables the shredding of waste plastic materials. As its near end is supported by two bearings, the shredder shaft is designed to endure both torsional and bending loads that it is subjected to during operation. Consequently, the shredder shaft diameter (d_s), can be calculated using equation

$$d_s = \left[\frac{5,1}{\tau_a} K_t C_b T\right]^{1/3}. \quad (4)$$

Where: n = The planned knife rotation

ds = shaft diameter, T = Torque, K_t = Torsional moment correction factor vallue 1,0 – 1,5, C_b = flexural factor value 1,2 – 2,3, τ_a = allowed shear stress. The allowed shear stress (τ_a) can be found using equation

$$\tau_a = \frac{\sigma_b}{Sf_1 x Sf_2} \quad (5)$$

Where: σ_b= tensile strength, Sf_1= first safety factor, Sf_2= second safety factor. The tensile strength value for machine construction carbon steel (S45C) is 58 kg/mm2

4.6 Power Transmission

In order to transport power from the electric motor to the shaft of the plastic shredded machine, a V-belt and pulley system is utilized. Principal transmission parameters can be calculated as follows:

$$D_2 = \frac{N_1 \, x \, D_1}{N_2} \quad (6)$$

Where: D_2 = diameter of the pulley connected to the gear box (mm), D_1 = diameter of the pulley connected to the electric motor, N_1 = speed of gasoline motor (Rpm), and N_2 = speed of the pulley connected to the gear box (Rpm).

Equation (7) can be used to determine the length of the belt.

$$t = 2C + 1,257(D_1 + D_2) + \left(\frac{D_1 - D_2}{4C}\right) \quad (7)$$

Where: t = belt length (m), C = centre distance between pulley (m), D_1 = pitch diameter of the pulley connected to the motor (m), D_2 = pitch diameter of the pulley connected to the gear box.

The transmission utilized is a WPA 70 with a 1:20 ratio. The gearbox is linked to the rotation of the electric motor, which has been reduced from N_1 to N_2. In order to calculate the output rotation of the gearbox (N_3), it is determined by the equation as follows.

$$i = \left(\frac{N_2}{N_3}\right);\ i{=}20 \quad (8)$$

Where i=Gear box ratio = 20, N_2 = speed of the pulley connected to the gear box (Rpm), N_3= rotation of the gearbox shaft that connected to the machine shaft.

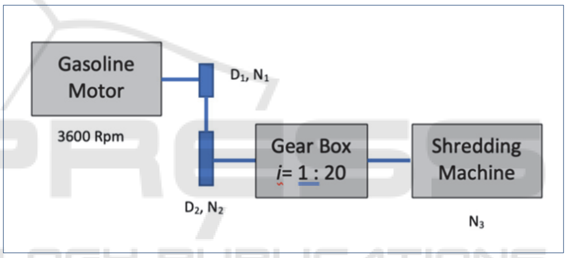

Figure 2: Power Transmission Design.

The belt speed is calculated uses eq. (9)

$$V = \frac{\Pi . D_1 . N_1}{60.000} \quad (9)$$

Where: V = belt speed (m/s), D_1 = diameter of the pulley connected to the electric motor (m), and N_1 = speed of the pulley connected to the shaft (Rpm).

4.7 Supporting Frame

A frame is a freestanding framework designed to hold all of the plastics shredder machine's components. The constructed frame should be capable of bearing the machine's complete weight without collapsing. The most important requirement for the design of the machine frame is that it retains the correct relative position of the units and parts installed on it during an extended period of service. The stand structure should be capable of supporting the machine without

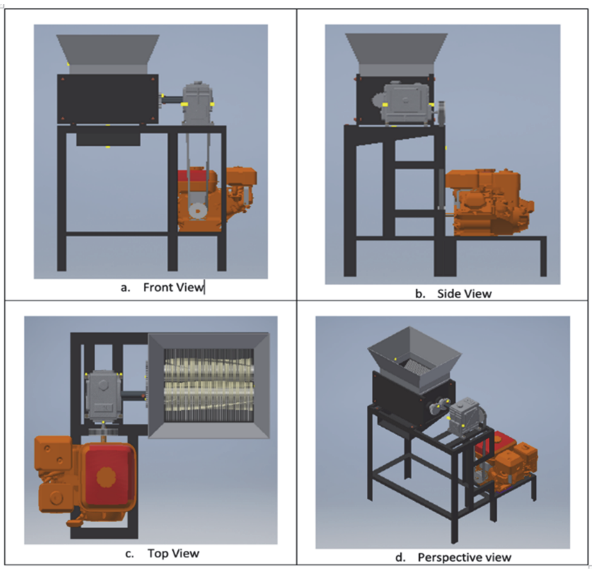

Figure 3: The Design of Shradding Maching.

collapsing. The frame is composed of 75 x 75 x 8 mm angle iron manufactured of low carbon steel.

4.8 Finding Machine Capacity

Theoretically the machine capacity is estimated based on the cutting area of each cutter that mounted on the shaft, it is assumed that all cutting tips on each cutter will be cutting perfectly.
The cutting area calculated using equation (10);

$$A = h\,x\,(D_1 - D_1) \quad (10)$$

Where: A = The Cutting Area (m^2), h = Cutting tip height, D_1 = cutter outer diameter (m), D_2 = cutter inner diameter (m)
The cutting volume calculated using equation (11);

$$V_c = A\,x\,L \quad (11)$$

Where: V_c = cutting volume, A = cutting area, L = Tip length.
If each cutter consists of 5 cutting tips; therefore, each cutter will cut 5 x Vc. Since the total number of cutters mounted on the two shafts are 76 cutters; therefore, the volume of plastics chopped by the shredding machine is 5 x V_c x 76 m^3 for each shaft revolution. If the planed shaft revolution is 135 RPM, then the volume of plastics shredded become 135 x 5 x V_c x 76 m^3 per minute = 135 x 5 x V_c x 76 x 60 m^3 per hour. Since the plastic density for PET = 138000 Kg/m3, then the Shredding machine capacity can be calculated as 135 x 5 x V_c x 76 x 60 m^3 x 138000 Kg/hour. This theoretical calculation of machine capacity is an ideal calculation with the assumption that all blades mounted on the shaft are able to chop plastic waste perfectly, which in reality is not possible because during operation there are a number of blades that cannot chop because of the position of plastic waste that enters through the machine. the hopper is still spinning and hasn't had time to touchthe cutting edge

5 PRINCIPAL OPERATION OF THE MACHINE

The plastic garbage to be chopped is gathered in a container and positioned close to the shredder. To start the engine, a gentle press of the on/off button is required. When the drive motor is activated, its rotation and power are sent via pulleys and belts to the gear box, which is then transmitted to two shafts that revolve in opposing directions in the counter space. Due to the movement of the two shafts, the blades connected to the shafts will also revolve. The processed plastic garbage is then put into the machine's hopper with the assistance of an operator. When the waste plastic contacts the chopping knife linked to the two shafts that move in opposing directions, the waste plastic will be severed owing to the sharp edge of the blade tearing and tearing the waste plastic.

The plastic waste fragments will then fall into the half-round filter part and accumulate in the filter. If the chopped plastic granules reach a size smaller than the filter's hole, the results will exit out the outlet. Nevertheless, if the size of the chopped plastic is still greater than the filter hole, the plastic waste will be brought back by the chopping knife and chopped again until its size is smaller than the filter hole. Figure 2. Shows the final design of the Plastics shredding machines

6 DESIGN CALCULATION RESULTS

The outcomes of the calculated procedure are presented in Table 1. All calculations are obtained from equations 1 through 11, as described in the section on design calculations.

Table 1: This caption has one line so it is centered.

Design Parameters	Value obtained
Shredder hopper Volume	0,011m^3
Plastic Bottle Volume (Aqua 600ml)	0,0006 m^3
Number of bottles filled in the hopper for 1 batch (75% of capacity)	13 pcs
Weight of 13 pcs plastic botles	2,6 Kg
Plastic cups volume (aqua 240 ml)	0,00024 m^3
Number of plastic cups filled in the hopper for 1 batch (75% of capacity)	30 pcs
Weight of 30 pcs plastic cups	4,5 Kg
blade cutting force	5148 N
Torque on the blade (T)	257,4 Nm
The horsepower of the motor driver (P)	5 Hp
shaft diameter (d_s)	31 mm
allowed shear stress	
diameter of the pulley connected to the gear box (D_1)	100 mm
diameter of the pulley connected to the electric motor (D_2)	80 mm
belt speed (V)	18,4 m/s
output rotation of the gearbox (N_3)	135 Rpm
speed of gasoline motor (N_1)	3600 Rpm
speed of the pulley connected to the gear box (N_2)	2700
the length of the belt	
cutting area	30 mm^2
Cutting Volume	180 mm^3
Theoretical Machine Capacity	73,4 Kg/Hour

7 PERFORMANCE EVALUATION

Performance evaluation is a crucial element in the machine development process. After the design, fabrication, and assembly processes, testing is required to identify the machine's performance, uncovered issues, and improvement opportunities. The intended evaluation was of the machine's production rates and its efficiency.

The following procedures were used for the performance test: (1) the dry plastic waste test materials in the form of plastic bottles and plastic cups packaged of mineral water are weighed; (2) the shredding machine is turned on by turning on the gasoline motor as the prime mover; (3) waste plastic material is fed into the machine's hopper; (4) the time is monitored using a stop watch during the enumeration process; (5) collect and re-weigh the chopped results from the outlet;

7.1 The Production Rates

Equation (12) may be used to calculate the machine's production rate.

$$P_r = \frac{TW_o}{T_o} \tag{12}$$

Where: P_r = production rate (Kg/hour), TWo = weight of waste plastics discharge from the hopper (Kg), T_o = time needed to shredded the plastics (Hour)

7.2 Shredding Machine Efficiency

The efficiency of the shredding machine can be evaluated uses equation (13)

$$\varepsilon = \frac{T_{WI}}{T_{WO}} \tag{13}$$

Whwre: ε = machine efficiency (%), T_{wi} = total weight of plastics fed in to the hopper (Kg), and T_{wo} = total weight of plastics discharge from the cute (Kg).

8 RESULTS AND DISCUSSIONS

Functional test is the latest form of testing of a waste chopper design which aims to determine whether the results of the design can function in accordance with the expected design. If the design is not suitable, modifications must be made to improve its performance. The Test results can be seen in table 2

Table 2: Shredding machine test results.

Types of Plastic Waste	T_{wi} (gr)	T_{wo} (gr)	T_o (sec)	average particle size (mm^2)
PET Glass	2600	2550	400	28
PET Botle	4500	4250	840	30

Remarks: T_{wi} = total weight of plastics fed in to the hopper (Kg), and T_{wo} = total weight of plastics discharge from the cute (Kg); T_o = time needed to shredded the plastics (hour)

The production rates and machine efficiency may be expressed using equations (12) and (13), as shown in table 3.

Table 3: The production rates, and the machine efficiency.

Types of Plastic Waste	Production rates (Kg/Hour)	Machine efficiency (%)
PET Glass	22,95	0,98
PET Botle	18,21	0,94

The trial machine's capacity is 18.21 kg/hr for mineral water bottle packaging and 22.95 kg/hr for plastic glass packaging. When compared to the 73.4 kg/h theoretical engine capacity, the test results appear to be very low. This means that the plastic shredding machine needs to be redesigned, including the blades that cut the plastic, since the knives on the machine tend to break.

9 CONCLUSIONS

The optimization of the machine designed and made capable of shredding mineral water packaging waste in the form of glass up to 22.95 kg/hour, and 18.21 for plastic waste mineral water packaging in the form of bottles. Because the size of the shredded results is an average of 30 $mm^2$for plastic bottle and 28 mm^2 for plastic cups this machine may be more effective and efficient in the process of enumerating plastic glass trash and plastic bottle waste, reducing the requirement for space for packaging rubbish. This machine is ideal for first-level collectors because it is simple to operate with maximum capacity, with a counting efficiency of 0.98% for chopping plastic glass waste and 0.94% for chopping plastic bottle trash. The construction is also quite basic and can be done in small-scale workshops, thus the prices to build it are affordable. This machine design may assist and have a favourable and effective impact on the effectiveness of waste collectors' packaging and shipping activities.

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