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## Research Article

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## Test Performance of Plastic Waste Shredder Machine and Analyze the Quality of the Shredded Plastic Product Using the Taguchi Method

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## A B S T R A C T

The food and beverage industry contributes 65% to the total plastic packaging demand and also produces plastic waste. This causes problems for the environment, humans, and others, especially in the waste treatment process. Cause plastic is difficult to recycle by the soil or the environment. Consumption of plastic packaging also reaches 65% of the total national plastic consumption. To overcome this plastic processing, a plastic Waste processing machine is made that can process and change the form of plastic waste into other derivative products. The important thing in plastic processing machines is the ability of plastic processing machines to produce products according to consumer desires. The purpose of this research is to get the maximum capacity of plastic Waste shredding, and to know the production capacity of plastic waste in one process of enumeration. The experiment method is used in this research to get the performance of the machine like voltage, power, cutting force of tool, and cutting speed. Also Taguchi method are used to analyze of quality product by varying shape of product waste plastic such as Cup 0.22l, Bottle 0.65l, and Cap Bottle 19l. In this test, a maximum capacity of 20Kg/hour was obtained by using the plastic Cap Bottle 19l test material. By calculate of cutting force for Cap Bottle 19l is obtained voltage 231.5 Volts and power 555.4 Watts at shaft rotation 24.96 rpm. Cutting force of tool is 25.92 N and torque 1.68Nm with cutting speed of 1.986 m/min. For Cup plastic 0,22l obtained the results on voltage are 238.9 Volt and power 585.96 Watts by a shaft rotation of 25.1 rpm. The cutting force of the tool is 54 N and torque 3.36 Nm with a cutting speed of 2.025m/min. For the plastic Bottle 0.65l, the Voltage is 238.86 Volt and the power of 595.9 Watts at the shaft rotation is 24.8rpm. Cutting force of tool is 119.23 N and torque is 7.75 Nm at the cutting speed is 1.97m/min.

## 1. INTRODUCTION

A plastic shredder machine is a plastic waste processing tool that is made to cut plastic waste into small flakes or granules with a certain mass so that it can be used or recycled. Plastic shredder machines currently have various forms starting from the shape of the shredder, machine capacity, type of cutting edge, drive type mechanism, construction of shredder machine and others where the function is the same namely to treat plastic waste through the process of shredding or cutting [1-9].

The minimal waste management [10-11] level is the main cause of difficulties in processing plastic waste. Plastic waste takes 20 years to decompose completely and for plastic bottles even take 450 years to decompose. Plastic consumption increases with the increasing population, so the volume of waste generated also increases. Waste processing currently uses the 4R concept, namely reduce, reuse, recycle, and replace item with the potential for plastic bottle waste to other materials [12-22]. As much as 45% of plastic waste is not well managed of the total plastic waste of around 65

million tons annually. Most plastic waste is processed by the traditional process of burning in an open space. This causes damage to the environment, both the gas produced and the final product of combustion that cannot be used anymore. To overcome this traditional plastic processing, a plastic waste processing machine was made that can process and convert plastic waste into derivative products such as plywood boards, floors, fuel, household goods, and others. In this paper, plastic processing machines are only used to shredder plastic waste. Plastic waste are used in the shape of Cups 0,22 l, Bottles 0,65 l, Cap Bottles 19 l and others. Where this plastic waste material is made of PET/PETE.

Plastic waste is processed by cutting using a plastic shredding machine into flakes and the resulting of flakes are processed into other products using injection molding machine. Plastic waste shredder machine consists of several components, namely the holder frame, motor, plastic crushing chamber, plastic crushing machine cutting bits, shafts, gears, bearings and others.

The objective of plastic waste shredder machine is get the size of the flakes cutting, shape of cutting, voltage, and time to cutting processing. From testing of plastic waste shredding machine is obtained the performance of the plastic waste shredding machine such as size and shape of cutting, voltage and time for cutting processing. Taguchi method are used to analysis of performance of plastic waste shredding machine.

## 2. METHOD

In this study, experimental methods are used to determine the capacity of the plastic waste shredder. Requirement of product quality is dimension of plastic waste shredder is smaller (less than 20 mm), shape of cutting like rectangular, oval, round, and random. Product quality analysis was carried out by cutting process in shredder machine and using the Taguchi method. By using Taguchi method type of plastic waste, weight of plastic waste, dimension and shape of plastic waste shredding is variable for

dependent data. Independent data to analysis performance of plastic are force cutting, torque, time, voltage and electric power so that the maximum capability of the plastic machine is obtained [23-25]. Plastic waste of shredder machine used plastic waste such as Cup 0,22 l, Bottle 0,65 l and Cap Bottle 19 l.

Figure 1 shows the plastic shredder machine used in this study. A plastic shredder machine consists of frame components, electric motors, and shredder blades. Hopper to accommodate the chopped results, motors, gears, shafts and others.

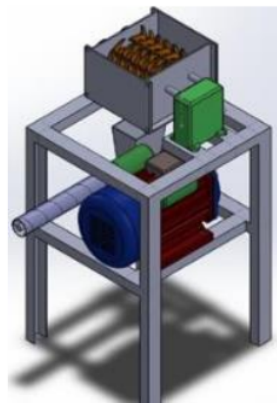
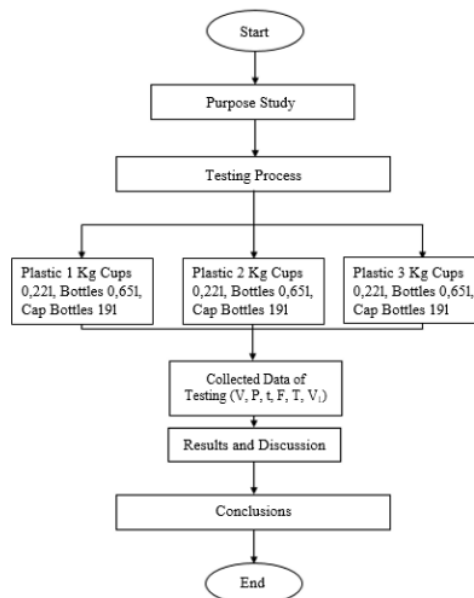


Figure 1. Shredder Plastic Machine



### Figure 2. Stage of research

The stages of research in this study can be seen in Figure 2 which includes observations of the traditional plastic waste treatment process, preparation of research equipment, testing with variations in plastic mass, and analysis of research results and conclusions.

#### 2.1. Equipment and Materials

The equipment and materials used in this research are:

1. Plastic Shredder Machine
2. Electric Motor. An electric motor with a power specification of 1100 W, a voltage of 220 V and a current of 9.8 A. The average engine speed is 1480 rpm and a mass of 22.5 Kg.
3. Digital Scales. Digital scales are used to weigh mass of plastic waste.
4. Multi meter. A digital multi meter is used to measure the electrical voltage obtained on a plastic chopper. The specifications of the digital multi meter are:  
Brand: A830  
Power: 9V Battery  
Maximum Voltage between Terminal and Earth Ground: 1000VDC or 700VAC
5. Power meter. Power meter is used to measure the output power of a plastic shredder machine. The specifications are:  
Brand: Taff Ware  
Operating Voltage: 230V  
Rated Power: 3680W
6. Tachometer. Tachometer is used to measure the rotation of the shaft on a plastic chopping machine.  
Brand: DT  
Test distance: 2.5 up to 99.999rpm  
Accuracy:  $\pm (0.05\% + a \text{ digit})$
7. Stop Watch
8. Plastic Waste

#### 2.2. Step of Research

This research uses an experimental method by measuring the voltage and output power of a plastic shredder machine, weighting the mass of shredded/cut plastic waste and the Taguchi method is used to optimize production capacity.

The dimensions of the shredder plastic are 285mm, 245mm, 180mm, with a motor rotation of 1480 rpm and an induction motor power of 1 HP, and 2 blades with a diameter of 130mm in the shape of a disc.

#### 2.3. Step of Collected of Experimental Data

The data collection procedure is:

1. Prepare of plastic shredder machine and turn on the plastic shredder machine for 30 minute (idle).
2. Select of plastic waste and weighing the mass of plastic waste to be chopped.
3. Put in plastic waste into the plastic shredder machine.
4. Measure the voltage and power when the plastic chopper is cutting the plastic waste.
5. Measuring the time the process of cutting plastic waste.
6. Measuring the mass of the results of the plastic waste cutting process.
7. Repeat testing with variations in plastic load and type of plastic.

#### 2.4. Plastic Waste Shredder Machine Capacity Calculation

The calculation of the capacity of the plastic waste shredder is carried out using equations 1 to 3 [9], namely:

1. Cutting force
 
$$F = A \cdot fs \quad (1)$$

Where:

F: For acting on the cutting edge (N)

A: Cross-sectional area of plastic of cutting (mm).

fs: Shear stress of the material of cutting 10,368  $\frac{N}{m^2}$  for plastic PET (ref. 9).

2. Torque of tool
 
$$T = F \cdot r \quad (2)$$

Where:

T: Torque of cutting edge (Nm)

F: For acting on the cutting edge (N)

r: Length of cutting edge (mm)

3. Cutting speed of cutting edge

$$V1 = \frac{\pi \cdot d \cdot n}{1000 \cdot 60} \quad (3)$$

Where:

$V_1$ : Cutting speed (m/s)  
 d: Diameter shaft (mm)  
 n: Speed (rpm)

### 3. RESULTS DAN DISCUSSION

#### 3.1. Calculation Data and Experimental Results

The research on this plastic shredder machine got the results that for the Plastic Cup 0,22 l test object the value of the electric voltage was 238.9 V and the electric power was 585.96 Watt with a shaft rotation of 25.1 rpm. The cutting force value was 54 N and the torque was 3.36 Nm with rotation cutting speed value 0.0337 m/s and cutting speed value was 2.025 m/min, and capacity of plastic shredder machine 10 Kg/hour or 167 g/minute. The shape of chopped plastic Cup 0,22 l can be seen in Figure 3.



Figure 3. Plastic Cup 0,22 l shredded

In the Plastic Bottle 0,65 l waste test is got the electric voltage value was 238.86 Volts and the electric power was 595.9 Watts with a rotation speed of 24.8 rpm. The cutting force value is 119.23 N and torque is 7.75 Nm with the rotation cutting speed is 0.0328 m/s and the cutting speed is 1.97 m/min. The capacity plastic shredder machine is 8 Kg/hour or 130 g/min. The shape of chopped plastic Bottles 0,65 l can be seen in Figure 4.



Figure 4. Plastic Bottle 0,65l shredded

For testing of the plastic Cap Bottles 19 l is get the electric voltage value was 231.5 Volts and the electric power is 555.4 Watts with a shaft rotation of 24.96 rpm. The cutting force value is 25.92 N, and torque value is 1.68 Nm with rotation speed cutting is 0.0331 m/s and cutting speed is 1.986 m/min. The capacity of plastic shredder machine is 20 Kg/hour or 333 g/min. The shape of the chopped plastic Cap Bottles 19 l can be seen in Figure 5.



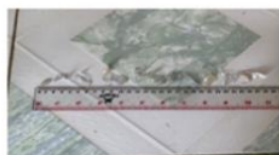
Figure 5. Plastic Cap Bottles 19 l shredded

The average size of shredded plastic obtained is 2 cm, which is still included in the standard of the Minister of Public Works Regulation No.3: 2013 concerning the mass of shredded waste, which is 2 cm as shown in Figure 6.





a. Plastic Cups 0,22l



b. Plastic Bottles 0,65l



c. Plastic Cap Bottles 19l

Figure 6. Size of plastic waste shredded

Table 1. Mean of Experimental Results

Data	Plastic cup 0,22l	Plastic bottles 0,65l	Plastic cap bottles 19l
Voltage	238,9 V	238,86 V	231,5 V
Power	585,96 W	595,9 W	555,4 W
Rotation	25,1 rpm	24,8 rpm	24,96 rpm
Cutting Force Edge	54 N	119,2 N	25,92 N
Torque of Edge	3,36 Nm	7,75 Nm	1,68 Nm
Cutting speed	0,033 m/s	0,032 m/s	0,033 m/s
Result of cutting speed	2,02 m/min	1,97 m/min	1,98 m/min
Capacity	10,02 Kg/h, 167 gr/min	8 Kg/Jam, 133 gr/min	20 Kg/h, 333 gr/min

The overall test results of plastic waste with plastic shredder machine can be seen in Table 1. Furthermore, from the data in Table 1 obtained then data processing is carried out using the Taguchi method. The first step is to determine the Orthogonal Array in which the test matrix is perpendicular and balanced using design variables and levels as shown in Table 2. The design variables include the shape and <sup>20</sup> of plastic waste and the level variable, namely the amount of plastic waste mass according to the shape of plastic waste.

Table 2. Variable design

Variable Design	Variation		
	Level 1	Level 2	Level 3
Plastic shape	Cup 0,22l	Bottles 0,65l	Cap Bottles 19l
Plastic weight (Kg)	1	2	3

Table 3. Orthogonal Array defence of Time

Variable Design	Weight (Kg)	Time Results		
		Time 1 (minute)	Time 2 (minute)	Time 3 (minute)
Cup 0,22l	1	6,15	6,15	6,15
	2	11,4	11,4	11,4
	3	18,52	18,52	18,52
Bottle 0,65l	1	7,54	7,54	7,54
	2	15,43	15,43	15,43
	3	22,39	22,39	22,39
Cap bottles 19l	1	3,17	3,17	3,17
	2	6,32	6,32	6,32
	3	9,42	9,42	9,42

The results of data processing<sup>32</sup> using the Taguchi method are shown in Table 3. In Table 3 it can be seen that the data processing results with 3 kg capacity of plastic waste is 18.5 minutes for Plastic Cup 0,22 l waste weighting 3 kg, 22.39 minutes for Plastic Bottle 0,65l waste and 9.42 minutes for Cap Bottles 19 l waste. From these results, the average value (mean) from Design of Experiment (DOE) with design variables is obtained as shown in Table 3. Plastic Cap Bottles 19 l waste is a shape of plastic with the most influential factor on the speed of cutting time so that it can produce with a plastic shredder machine capacity with chopped up to 20 Kg/hour (see Figure 7). From this result, shows that if the variation of plastic was<sup>29</sup> mass is increasing so more cutting time required, as shown in<sup>33</sup> Figure 8. Where Figure 8 shows the results of the Signal to Noise ratio in small is better, namely the smaller the signal noise ratio value then the better of the factor is obtained such as shown in the result of the shape of the plastic Cap Bottles 19 l and the smaller the mass tested then the faster the test time.

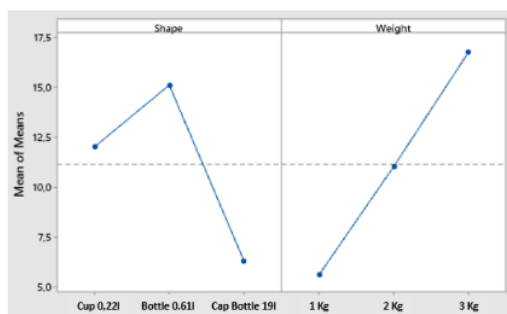


Figure 7. Effect Shape and Weight of Plastic Waste

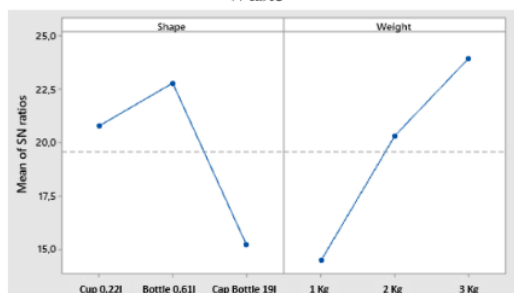


Figure 8. Signal Noise Ratio for Shape and Weight of Plastic Waste

#### 4. CONCLUSIONS

From the research that has been done, it can be concluded that the maximum capacity of the plastic shredder machine is 20 Kg/hour with shape of plastic Cap Bottles 19 l waste test. In testing the capacity of the plastic shredder machine with shape of Plastic Cup 0,22 l waste, the capacity is 10 Kg/hour or 167 g/minute. For shape of Plastic Bottle 0,65 l waste with a capacity of 8 Kg/hour or 133 g/minute and shape of Cap Bottles 19 l waste obtained a capacity of 20 Kg/hour or 333 g/minute. The voltage and power in the plastic shredder machine test for Plastic Cup 0,22 l waste obtained an electric voltage value of 238.9 Volts and 585.96 Watts of power with a shaft rotation of 25.1 rpm, cutting force 54 N and torque of 3.36 Nm. The cutting rotation speed is 0.0337 m/s and cutting speed is 2.025 m/min. For Plastic Bottle 0,65 l waste, the electric voltage value is 238.86 Volt and power is 595.9 Watt with a shaft rotation of 24.8 rpm, cutting force 119.23 N and torque 7.75 Nm. The cutting rotation speed is 0.0328 m/s and the cutting speed is 1.97 m/min. For the Cap Bottles 19l

waste counting, the electric voltage value is 231.5 Volt, and the power is 555.4 Watt with a shaft rotation of 24.96 rpm, cutting force 25.92 N and torque 1.68 Nm. The cutting speed is 0.0331 m/s and the cutting speed is 1.986 m/min.

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