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The Design of a Plastic Shredder Machine with The Crusher Cutting Knife Model for Environmentally Sustainable

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ABSTRACT

Indonesia produced about 31.2 million metric tons of garbage in 2021. Roughly 87.1% of the total waste is comprised-evaluated of plastic waste. Plastic waste takes a very long time to break down in the environment. It took decades for trash made of plastic to decompose. Disorganized waste management at the landfill is a significant source of plastics-related problems. In order to reuse plastic garbage, it must be crushed up first before the recycling process. The primary objective of the design process for the crushing plastic machine used to shred plastic waste was to maximize productivity. The design of the machine that crushes plastic waste was created and prepared with the help of computer-aided design (CAD) and computer-aided manufacturing (CAM) software. One thousand and zero millimeters in length, three hundred and twenty millimeters in width, and twelve hundred and sixty millimeters in height describe this machine for chopping up plastic trash. In terms of crushing time and capacity, variations in the rotational speed of 1000, 1100, and 1200 blades in revolution per minute were optimal. The optimal crushing time for 2 kg-HDPE plastic waste was 37 seconds at 1200 revolutions per minute, followed by 1100 revolutions per minute; 2 kg-HDPE plastic waste was crushed and evaluated. HDPE plastic wastes have typically crushed faster in less time than PET plastic wastes. It has been evaluated and validated for any setting variation operation involving the crushing speed. Three kilograms of HDPE plastic waste yielded an optimum crushing capacity of 194.4 kg/hour at 1200 revolutions per minute. Next, at 1200 revolutions per minute, 2 kg-HDPE plastic waste is crushed. HDPE plastic wastes are typically more effective to crush than PET plastic wastes, regardless of the crushing speed setting variation operations. As a result of this study, plastic waste is being put to better use, helping to cut down on overall plastic use in the plastic waste management

Keywords: *Crushing Plastic machine, HDPE plastic waste, PET plastic waste, Plastic consumption*

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1. INTRODUCTION

Waste management has always been an issue of growing concern in global megacities. Waste management in Indonesia presents challenges, one of which relates to environmental concerns. Plastic waste poses a significant threat to the environment because, in addition to increasing quantity, plastic bags are non-biodegradable and a xenobiotic pollutant. The environment causes the accumulation of pollutant compounds in nature) [1]. Open burning of plastic waste can cause cancer-causing air pollution and a severe skin disease called chloracne. [2]. Plastic trash can get into waterways, irrigation systems, rivers, beaches, lakes, and the ground itself. Researchers have found that certain amounts of plastic trash can cause sediment to build up in waterways and cause them to flood. The National Waste Management Information System - Sistem Informasi Pengelolaan Sampah Nasional (SIPSN) reported 31.4 million tons of waste in 2021. This was about 3.1% less than the 32.3 million tons reported in 2020.

According to the 2021 SIPSN data, the province of Central Java made the most significant contribution to the national waste stockpile, with 5.61 million tons, followed by the provinces of West Java and East Java, with 5.10 million tons and 4.0 million tons, respectively. Semarang district contributes roughly 8 % of the total annual waste produced in the Province of Central Java. The Semarang district produces the most waste, approximately 43074.9 tons, followed by the district of Brebes, which produces 35886.5 tons. Brebes contributed approximately 6% of the total waste generated in the province of Central Java in 2021 [3]. Data on annual waste generation in Central Java province is presented in **Figure 1**.

Figure 1. Distribution of organic and inorganic waste in Central Java province in 2021

Plastic waste will represent around 17.9% of all landfill waste in 2021, making it the second-largest type of waste after organic waste, which totals 31.14 million tons. This equates to approximately 5.62 million tons. This total plastic waste accounts for approximately 78.1% of the nation's plastic demand in 2021, or about 7.2 tons per year [4]. Reusing plastic will contribute to the conservation of the natural environment in a positive way. Plastic waste is an extremely difficult type of waste to decompose in the soil; the decomposition process can take decades. If improperly managed, the improper disposal of plastic in landfills (Tempat Pembuangan Akhir- TPA) will cause problems. This necessitates the processing of plastic waste, which can begin with a waste inventory in order to facilitate recycling. Processing plastic waste is necessary because it makes recycling possible. Figure 2 shows the distribution of national waste types during the 2021 period.

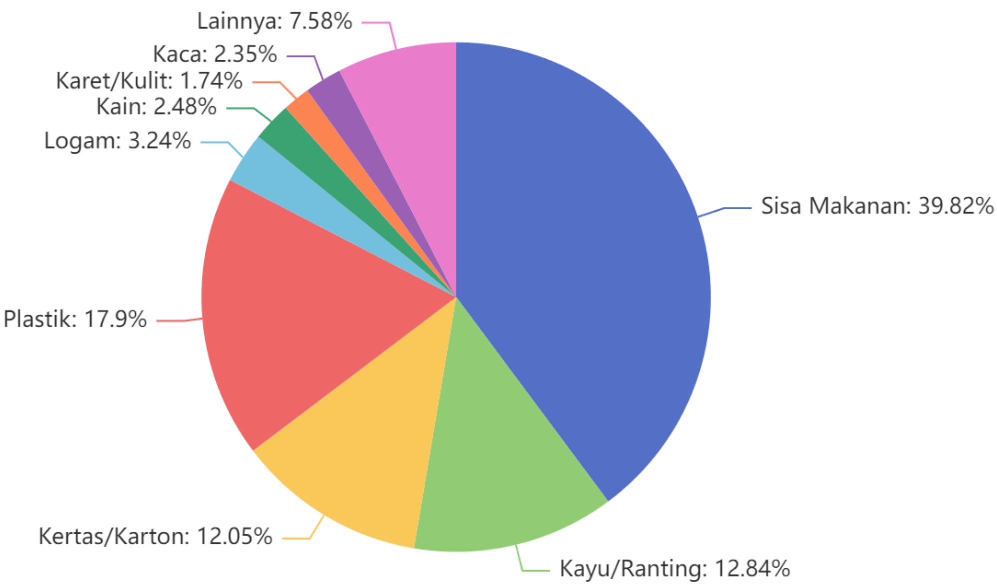

Figure 2. Types of organic and inorganic national waste in Indonesia in 2021

Previously, numerous studies on plastic choppers have been conducted. Wang [5], conducted research on perfectly elastic plastic ring counters with two-point loading. The focus of the study is the large deformation of a thin, perfectly elastic ring compressed by two opposing point loads. Elliptic integrals can be used to express solutions to nonlinear governing equations. In general, the load increases monotonically with deflection as the shape of the ring continuously transforms from circular to biconcave. Okusanya [6], also conducted follow-up research by investigating the design and development of more efficient plastic waste crushers. The waste plastic crusher consists of four major components: the feeding unit, the crushing unit, the power unit, and the machine frame. The flatware is made from 6 mm-thick sheets of mild steel [7]. The crushing chamber consists of a shaft measuring 539 millimeters in length and 40 millimeters in diameter. Attached to the shaft is a cutter that creates a spiral blade. This cutter has a 12-millimeter-long, 270-74 mild steel blade with a flat edge. This blade is welded to a 270-millimeter-diameter cylindrical drum. 53 millimeters is the circumference of the spiral blade when measured from the center of the shaft. The space between the adjustable stationary blade and the spiral blade is 3 millimeters wide.

Mataram et al. [8] studied the distribution of rectangular leaves and star blades on plastic crusher machines by employing the finite element analysis technique. When the blade was loaded with 200N, 400N, and 600N, the blade experienced an increase in stress and displacement. The rectangular blade is von Mises spread and has a compressive strength of approximately 3,855 x 103 N/m^2, which is greater than the star blades. Both blade designs contain a small number of concentrated red areas, with a star blade containing 3.66 x 10-6 mm displacement and a rectangle blade containing 3.24 x 10^{-6} mm displacement. The difference in displacements between the two blades is negligible, so they have nearly identical displacements. There is no significant deformation as a result of the minimal movement of both blades. The safety factor of these two blades is 1.5 with a load of 1000 N, which is greater than 1, making them suitable for plastic crushing. [9]. The design of a crusher-type plastic Crushing machine with a capacity of 50 kg per hour was carried out by [10]. Therefore, when designing the crusher type plastic chopper, calculations were made and the components of the enumerator machine, such as the power, blade, shaft, bearing, peg, v-belt transmission, and pulley, were chosen. This plastic counter machine has dimensions of 400 mm by 300 mm by 1100 mm and is simple to use. One fruit shaft and blade cylinder serves as the counter blade holder in the plastic chopper process, which uses a total of six-blades, four dynamic knives and two static knives. One horsepower of an electric motor with a 1400 revolutions per minute motor speed and a 260-revolutions per minute motor are the primary motors in plastic chopper machines.

Although research has been conducted on plastic chopping machines, plastic crusher machines with a capacity of 21 kg/hour are still rarely used. This study aimed to create a plastic chopping machine and determine its average production capacity by modifying the crusher-type blade with a total of 8 blades, 2 shafts, each of which has 4 blades, 8 mm thick, 80.0 mm wide, and a 30-degree angle. High Density Polyethylene (HDPE) and Polyethylene Terephthalate (PET) plastics are the types of plastics that need to be chopped for validating. This investigation utilizes a 5.5 horsepower engine with a V-belt transmission. The length, width, height, and distance between the axles of a plastic waste chopper are 1000 mm, 320 mm, 1260.0 mm, and 400 mm, respectively. Parallel to and beneath the helicopter is the driving motor. Placing the drive motor parallel and below the chopper reduces vibration, improves construction, and simplifies the overall appearance. V-belts are being utilized. The v-belt transmits large quantities of power at low voltage and operates more quietly and smoothly than gears and v-belt chains. As for the drive used in the plastic waste chopping machine, a 5.5-horsepower gasoline engine (house power) is appropriate due to its simple construction and high power, which is compatible with the steel blades, discs, and bearings. A gasoline engine with a high torque is necessary for optimal performance of the plastic waste chopping blade.

2. RESEARCH METHODOLOGY

2.1. Plastic-waste material

Plastic is a synthetic material made from organic polymers like polyethylene terephthalate (PET), high density polyethylene (HDPE), Polyvinyl chloride (PVC), and low-density polyethylene (LDPE) [11][12]. Oil-based plastics are nonbiodegradable, lightweight, and break resistant [13]. Any property of a large number of synthetic polymers, usually organic, that have a polymeric structure and can be shaped when soft and set. Large molecules formed by joining thousands of monomers. Fine, film, elastomers, and biopolymers are other polymers [14]. High density polyethylene (HDPE) and polyethylene Terephthalate (PET) plastic were used to collect the sample of plastic waste. The characteristic of HDPE such as abrasion resistant, high impact resistance, low coefficient of friction, scratch and marking resistant, chemical resistant, water and moisture resistant [15]. Mechanical and Physical properties of HDPE and PET plastic presented in **Table 1**[16] [17].

Table 1. The mechanical properties of HDPE and PET plastic material

Property	**HDPE** [16]	**PET** [18]
Density (g/cm³)	0.035- 0.96	0.0700 - 1.45
Water Absorption, 24 hrs (%)	<0.01	0.050 - 0.80
Tensile Strength (N/mm²) at 22.2 °C	31.72	55.0 – 60.0
Tensile Strength (N/mm²) at 65.6°C	2.76	22.0 - 95.0
Tensile Modulus (GPa)	1.38	1.57 - 5.20
Tensile Elongation at Break (%)	400	3.5 - 5.83
Flexural Strength at Yield (N/mm²)	10.34	55.3 – 135
Compressive Strength (N/mm²)	31.72	20.0 – 109
Hardness, Shore D	69	71.4 - 87

2.2. *Crushing Force and Torque*

The thickness of the material, the tensile share strength of the material and the shape of the crushing tool all influence the magnitude of the crushing force required to perform a cut on plastics, whether metal or another material. From the factors that influence the magnitude of the crushing force, the following formula can be derived for determining the magnitude of the crushing force when crushing with an inclined blade [6] [19].

$$F_c = 0.5 \frac{s^2}{\tan\varphi} \tau_b \qquad (1)$$

Where F_c described for the crushing force in Newtons, s is donated for the plastics thickness, $\boldsymbol{\tau_b}$ is donated for tensile share strength of material in N/mm², and $\boldsymbol{\varphi}$ is blade angle in degree (°). The calculation of the crusher blade's torque is performed using equation 2[20][21].

$$T = F_c . r \qquad (2)$$

Where T would be the torque in N-metre and r is the length of the blade crusher in meters. The design of the blade crusher is depicted in **Figure** 3. The blade holder was made from SPHC material of 5 mm of the thickness and the material specification according with [22][23][24]. The blade crusher was made from SKD 11 material in accordance with [25] [26] [27].

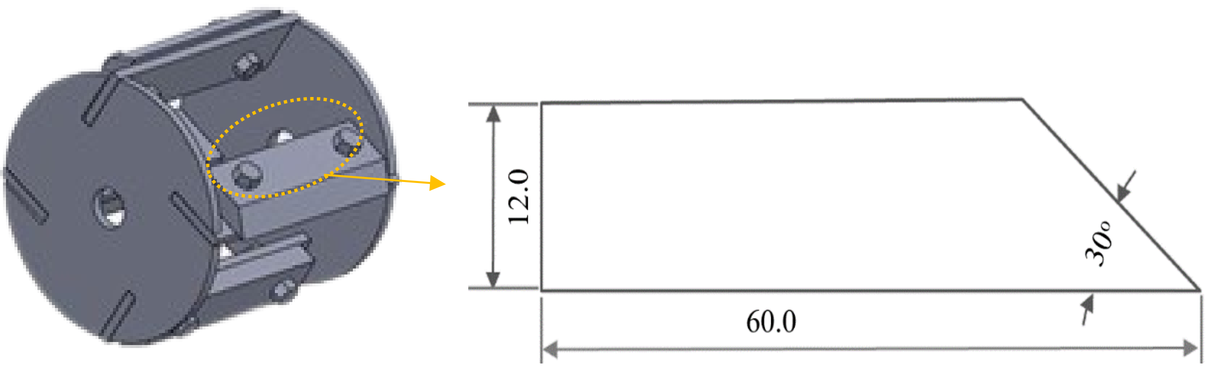

Figure 3. HDPE and PET plastic crusher blade design (all dimensions in mm)

2.3. *Desain Plastic Crusher Machine*

According to the requirements of the plastic shredder, blades and shafts are designed in order to create the crusher machine. The expected capacity of the shredder is 172.26 till 187.92 kg per hour of plastic waste that has been shredded. The construction of the crusher was made to be easily movable after the design had been executed. **Figure 4** depicts the propulsion system for this crusher, which utilizes a gasoline engine.

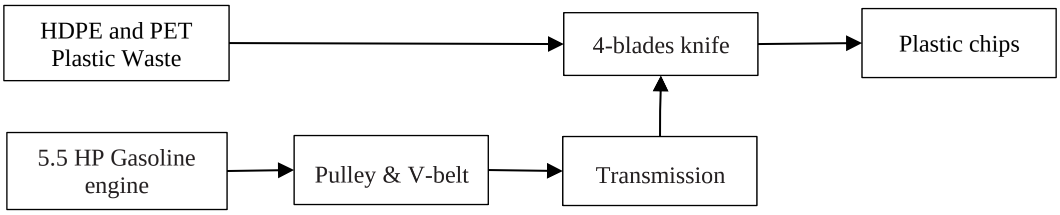

Figure 4. Schematic design of plastic crusher machine

In order to realize the concept of machine construction design, mechanical calculations of the plastic chopping machine's components were required. These components included the chassis, drivetrain, and transmission. The design and construction were carried out using the CAD and CAM software. The length, width, and height of the plastic waste-crusher machine with a crusher-style design are 1040 mm, 320 mm, and 1258.01 mm, respectively. The frame and chassis material of the plastic waste-crusher machine provided with steel S 45C. The mechanical properties and chemical composition consist by previously studied [26] [28]. The engine of the plastic-crushing machine is a Honda GX 160 T2 type. Maximum engine speed is 3600 revolutions per minute, and maximum power output is 5.5 horsepower. Maximum engine torque for the GX 160 T2 is 10.3 N-meter at the operating speed of 2500 revs per minute. **Figure 5** depicts the outcomes of the design process for the construction of the machine.

The transmission system is a system of machine components that serves as a carrier and transferor, connecting and transmitting a motion and load. In addition, the frame houses driving components such as electric motors, reducers, and transmissions [29]. A motor and a reducer comprise the driving component. A reducer controls the motor's rotation, and a sprocket and v-belt connect the drive shaft to the motor. The operating speed of the crusher depend on the operating speed of pully that fixed on the machine as transmissions system. The pully that fixed on the machine has diameter d1 54 mm, whereas the diameter that installed at the crusher machine has diameter d1, 80 mm. The rotating velocity of the blade shaft can be calculated and estimated by equation 3 [30].

$$\frac{n_1}{n_2} = \frac{D_p}{d_p} \quad (3)$$

Where, n_1 and n_2 described for the rotating velocity of the electric motor and blade shaft respectively, D_p and d_p donated for the diameter of the driven and driving pulley, respectively.

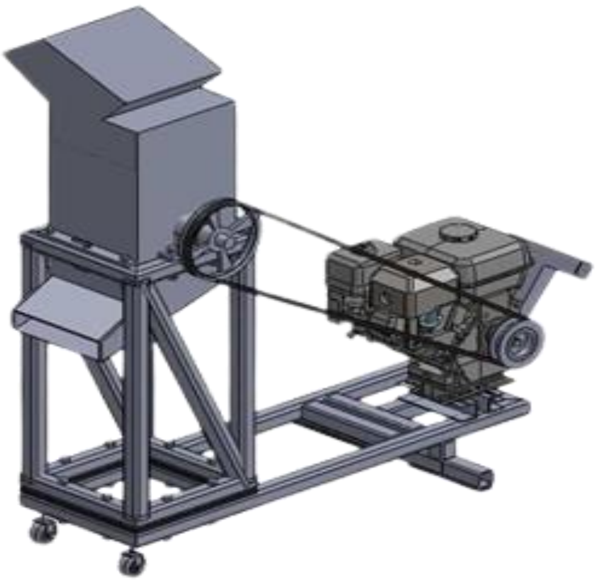

Figure 5. Design a plastic crusher with a capacity of 21 kg per hour.

2.4. Crushing capacity and power

The minimum crushing velocity required to achieve Q (kg/h). Equation 4 in the rotational system for anticipated crushing speed, it is possible to determine how quickly the crushing blade must rotate to achieve the desired crushing speed and the required crushing power of the machine.

$$Q = l.w.s.\rho.n.60.z \quad (4)$$

Where l and w are described for length and wide of the material to be cut in mm, respectively, $\boldsymbol{\rho}$ is donated for density of the plastic in kg/m^3, n is donated for motor rotation speed needed in revolutions per minute, and z is donated for the number of blade crushing. The maximum rotations speed can be identified by equation 5 [30].

$$n = \frac{Q}{l.w.s.\rho.n.60.z} \quad (5)$$

The input parameter's motor rotation speed has been determined and set to 1100 or 1200 revolutions per minute. The minimum power required of the crushed machine can be calculated by equation 5 (in N-metre.s^{-1} or Watt) and equation 7 in horsepower (HP) [31].

$$P_c = \frac{F_c \pi D_c f_k \eta}{6\,.10^4} \quad (6)$$

$$P_c = F_c.\pi.D_c.f_k.\eta.(0.2235)(10^{-7}) \quad (7)$$

Where P_c is donated for minimum power needed for crushing process, D_c is donated for diameter of the crushing blade in mm, f_k is the safety factor and $\boldsymbol{\eta}$ efficiency ratio in %.

3. RESULTS AND DISCUSSIONS

3.1. Design Analysis

In accordance with Table 1, the tensile strength of PET material is greater than that of HDPE material. Therefore, the PET materials of maximum tensile strength is used to calculate the crushing force. This design employs a blade angle of 30 degrees, so the minimum crushing force required for chopping plastic with a thickness of 3.0 mm is 467.65 N. Using equation 2, the torque at the tip of the blade against the base of the crusher blade is calculated to be 28.10 N-meter based on figure 3. The distance between the tip of the crusher blade and the shaft's center of rotation is designed to be 150 millimeters, so that the maximum torque at the tip of the crusher blade is 70.85 Newton-meters.

The motor rotation speed of the input parameter has been determined and set to 1100 or 1200 revolutions per minute. The theoretical crushing capacity could be calculated by using equation 3. The length, width, and thickness of the material to be cut are 10, 10, and 3 millimeters. The material with the highest density is PET, which has a value of 1.45 grams per centimeter. The number of crushing blades was designed with six units. The crushing capacity at 1000, 1100 and 1200 revolutions per minute can be estimated to be 104400, 114840 and 125280 grams per hour, respectively. It is mean the crusher machine of plastic has capacity about 104.4, 114.84 and 125.28 kg per hour for each rotation speed. The transmission was used the v-belt modeling and has an efficiency about 99 % [31][32] and the safety factor has been provided in 1.5. The minimum power required is 1.04 kW at 1100 revolutions per minute and 1.14 kW when the speed increases to 1200 revolutions per minute. The outcomes of 1.40 horsepower and 1.53 horsepower are comparable to one another. Because the design's minimum power requirement is lower than the maximum power output of the Honda gasoline engine provides about 5.5 horsepower. The design can be correctly-implemented because the minimum power requirement is lower than the maximum power output of the Honda gasoline engine. It has been according by fundamental theoretical [33] and previously studied by [6] [13].

3.2. The confirmation analysis

Evaluating the measuring and experiment validation of PET plastic waste with a mass of 2 kg at revolutions per minute 1000, 1100 and 120 yielded a time of 65, 56 and 50 seconds respectively. Those process has been corresponding with crushing capacity of 110.77, 128.57, and 144.0 kg per hour. Evaluating the measuring of HDPE plastic waste with a mass of 3 kg at revolutions per minute 1000, 1100 and 1200 yielded a time of 97, 85 and 78 seconds respectively. Those process has been corresponding with crushing capacity of 111.34, 127.06, and 138.46 kg per hour. Evaluating the measuring and experiment validation of HDPE plastic waste with a mass of 2 kg at revolutions per minute 1000, 1100 and 120 yielded a time of 45, 41 and 37 seconds respectively. Those process has been corresponding with crushing capacity of 160.0, 175.61 and 189.47 kg per hour. Evaluating the measuring of HDPE plastic waste with a mass of 3 kg at revolutions per minute 1000, 1100 and 120 yielded a time of 67, 61 and 55 seconds respectively. Those process has been corresponding with crushing capacity of 161.20, 177.05, and 196.37 kg per hour.

Figure 6 illustrates the difference in crushing speed between PET and HDPE plastics material when operating at different RPMs. According to the data in Figure 6, processing two kilograms of PET plastics takes significantly longer than processing two kilograms of HDPE plastics. The identical phenomenon occurred while producing three kilograms of HDPE and PET plastic material. The mechanical properties of PET material are superior to those of HDPE material, as demonstrated in **Table 1** [16] [18]. Due to the superior mechanical properties of PET material, this is easily comprehended. In the interim, the crushing capacity of HDPE plastic material tends to be greater and more directionally oriented than that of PET plastic material.

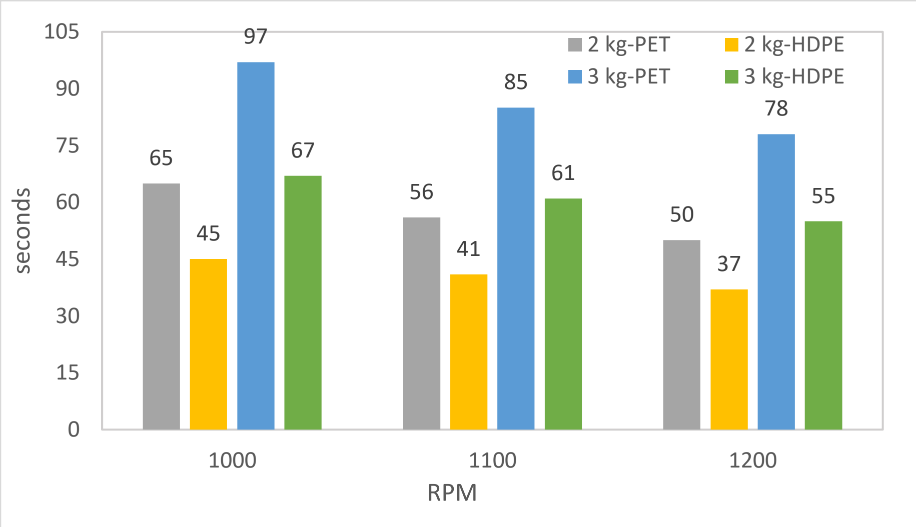

Figure 6. Crushing speed at the different RPM

Figure 7 depicts, in kilograms per hour, the crushing capacity of PET and HDPE plastic material at varying RPMs. According to this result, processing two kilograms of PET plastics takes significantly lower than processing two kilograms of HDPE plastics. The identical phenomenon occurred while producing three kilograms of HDPE and PET plastic material. The mechanical properties of PET material are superior to those of HDPE material, as demonstrated in **Table 1** [12] [13]. Due to the superior mechanical properties of PET material, this is easily comprehended. In the interim, the crushing capacity of HDPE plastic material tends to be greater and more directionally oriented than that of PET plastic material.

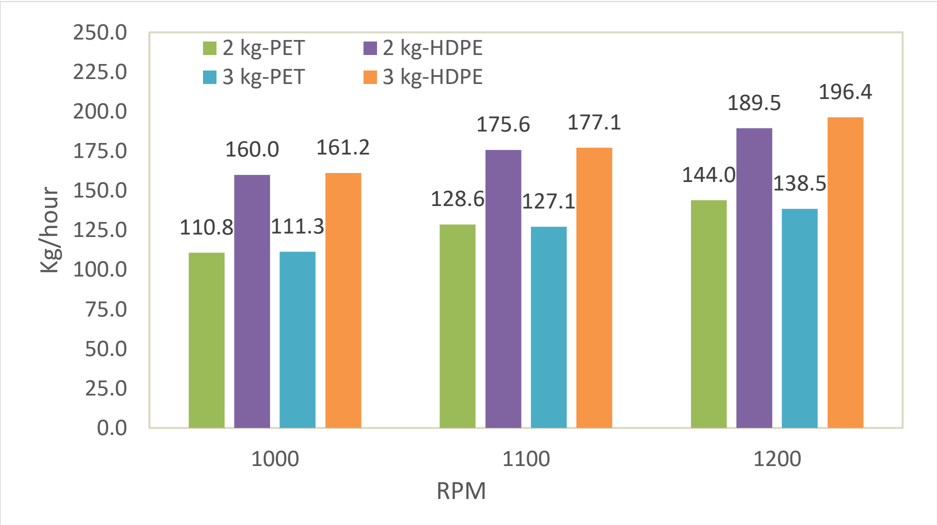

Figure 7. Crushing capacity at different RPM

4. CONCLUSIONS

The crusher-style plastic waste chopper dimensions are 1000.0 mm x 320.0 mm x 1260.0 mm. The SKD 11 with 8.0 mm in the thickness of the blade has been chosen for design of the crushing plastic machine. The design of the crushing machine is powered and supported by 5.5 horsepower. There is has some of conclusion as follow.

a. The crushing time is indirect propositional with the tensile strength of the material. HDPE is faster speed than the PET material because the tensile strength of the HDPE is lower than PET plastic material. The fastest crushing time has been achieved when using the 2 kg-HDPE at the time of 37 second by using crushing speed setting in 1200 rev. per minutes.
b. The crushing capacity is direct proportional with the crushing speed that describe in RPM. The higher RPM will have the higher crushing capacity. The highest crushing capacity has been achieved when using the 3 kg-HDPE at the crushing capacity of 196 kg/hours by using crushing speed setting in 1200 rev. per minutes.

AUTHOR'S DECLARATION

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

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