JURNAL IPTEK
MEDIA KOMUNIKASI TEKNOLOGI
homepage URL : ejurnal.itats.ac.id/index.php/iptek

Manufacturing and Testing of Plastic Waste Recycling Machines Using a Screw Barrel System with Shredding and Extrusion Mechanisms.

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ARTICLE INFORMATION

Journal of Science and Technology – Volume 28 Number 2, December 2024

Page:
137 – 152
Date of issue :
December 31, 2024

DOI:
10.31284/j.iptek.2024.v28i2.6704

ABSTRACT

Recycling machines with shredder and screw barrel systems have an important role in overcoming the problem of plastic waste and have a positive impact on the environment and industry. The purpose of using this machine is to reduce environmental pollution due to plastic waste that is difficult to decompose. The research method used in this study starts from literature studies, design and calculations, the tool manufacturing process ends with tool testing. The engineering drawing design is done with shapr3D software. This system produces solid flakes on PET plastic with a standard power of 110V, the operation functions well at room temperature, independently of other processes. This extruder is powered by a 220 V AC gearbox motor dynamo, 25 watts with high torque which is equipped with a controller box, the speed used on this extruder ranges from 45 rpm - 55 rpm, depending on the temperature increase of the heating element. Larger flakes / shreds are around 5 mm, most of the flakes are quite small and can be processed by the extruder. This system is capable of producing solid flakes on PET plastic with a standard power of 110V, this operation functions well at room temperature and independently of other processes. The results were obtained from 4 random trials without any planning at all.

Keywords: *Recycling; Plastik Waste; Screw Barrel; Shredder; Extrusion.*

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ABSTRACT

Mesin daur ulang dengan sistem pencacah dan *screw barrel* memiliki peran penting dalam menanggulangi permasalahan limbah plastik dan membawa dampak positif terhadap lingkungan dan industri. Tujuan penggunaan mesin ini dapat mengurangi pencemaran lingkungan akibat limbah plastik yang sulit terurai. Metode penelitian yang digunakan pada penelitian ini dimulai dari studi literatur, perancangan dan perhitungan, proses pembuatan alat diakhiri dengan pengujian alat. Desain gambar teknik dilakukan dengan software shapr3D. Sistem ini menghasilkan serpihan padat pada plastik PET dengan daya standar 110V, operasi berfungsi dengan baik pada suhu ruangan, secara independen dari proses lainnya. Ekstruder ini ditenagai oleh Dinamo motor gearbox AC 220 V, 25 watt dengan torsi besar yang sudah dilengkapi dengan box controllernya, Kecepatan yang dipakai pada ektruder ini berkisar 45 rpm – 55 rpm, tergantung suhu kenaikan dari elemen pemanas. Serpihan/cacahan yang lebih besar sekitar 5 mm, sebagian besar serpihan cukup kecil dan dapat diproses oleh ekstruder. Sistem ini mampu menghasilkan serpihan padat pada plastik PET dengan daya standar 110V, operasi ini berfungsi dengan baik pada suhu ruangan dan secara independen dari proses lainnya. Hasil yang didapatkan dengan 4 kali percobaan secara random tanpa ada perencanaan sama sekali.

Keywords: *Daur Ulang; Limbah Plastik; Screw Barrel; Pencacah; Ekstrusi.*

PUBLISHER

LPPM- Adhi Tama Institute of Technology Surabaya
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INTRODUCTION

Plastic waste is one of the main causes of environmental pollution. Plastic that does not decompose quickly can persist in the environment for hundreds of years. Plastic waste that is not managed properly can pollute water sources, soil, and air, threatening the sustainability of ecosystems and human health. Indonesia as the second largest producer of plastic waste faces serious problems in processing plastic waste. The lack of an effective system for processing and recycling plastic waste makes this problem worse. Many efforts have been made to overcome this problem. One solution is to recycle plastic waste [1]

The negative impact of plastic itself is difficult to decompose naturally so that it pollutes the environment. To overcome the problem of plastic waste pollution, we can contribute in several ways, one of which is by recycling. Recycling can reduce the amount of plastic waste that is thrown away, and can also be a business opportunity. Almost all types of plastic can be recycled [2].In the current scenario, recycling/recovery/management of plastic solid waste (PSW) is a matter of concern. Industries are increasingly interested in plastic manufacturing, so many commodities are manufactured with plastic. Plastic has become an essential part of our lifestyle, and global plastic production has increased rapidly over the last 50 years [3], traditional plastic is very strong and does not easily decompose in the environment, the fact is that plastic will never decompose and will remain in nature for several years [3]

Although plastic recycling practices have been in place, there are still limitations in the ability to recycle all types of plastic. Many plastic wastes are difficult to recycle or require complex and expensive recycling processes. Therefore, more efficient handling of plastic waste is needed. Sorong City in Southwest Papua is very vulnerable to flooding problems when rainfall intensity is high, on March 8, 2024 the flood recurred [4] In addition to the lack of urban planning with infiltration areas, another factor is unmanaged waste due to lack of good management. The results of the survey and direct measurements in the field show that the composition of Sorong City waste is dominated by organic materials (51.37%) and plastic (17.12%) with densities of 286.0242 kg / m3 and 123.9438 kg / m3 respectively. The total density of Sorong City waste reaches 556.7937 kg / m3 [5] Processing in the manufacture of recycling machines (shredder and extrusion into one machine) and the testing stage (producing one product from plastic waste). This selection is based on research that has been conducted by [6], [7], [8], [9], [10], [11], [12], [13], [14].

about the design and manufacture of machines but the manufacture, design of how the machine works is not complete, some references only one system such as melting or shredding and the production results of plastic waste materials in the form of filaments etc. The increasing trend of plastic use in various applications encourages more solutions for the reuse of plastic waste. The recycling machines that exist today, which are operational, are expensive and only operate for large-scale industries. In addition, the shredding and extrusion machines work separately but in this study the shredding and extrusion machines are integrated to perform tasks or two functions. This research is still related to further research from [15] and [16].

METHOD

Time and Place of Research

The implementation of the manufacture of this plastic recycling machine took place at the Jalan Kenanga Workshop, Sorong Regency for the design and planning of the tool, the Mechanical and Welding Workshop for the fabrication and assembly stages of the tool and testing the tool. The manufacturing time of this recycling machine was during the months of work starting from May to December 2024.

Tools and Materials used

a. Collection of Tools and Materials Stage

This procurement was carried out by purchasing tools and materials that had been planned from the start.

Table 1. Collection of Tools and materials for each machine mechanism model

Model Mechanism	Tool	Material
Shredder	1 Set Electric drill	Wood (Body Support)
	1 Set Grinder	Bolts and Nuts (Machine Support Body)
	1 Set Electric Welding	1 set machine body refiner (Sandpaper, black and gray spray paint)
	Hammer	Shark brand drive motor (Gasoline Fuel)
	1 Set of measuring tools (Iron ruler, marking pencil, vernier caliper, lighter, steel knife cutter)	1 set of shredder components (15 Pieces of shredder blades, AS Iron, Iron Plate
	1 set cutting machine saw (wood)	1 Set of motor drive (Gearbox, Belt, Pulley)
Extrusion/Melting	Manual screwdriver	Dynamo drive motor
		Set of motor (Gearbox, Belt, Pulley)
		1 Set of extrusion (Hopper funnel, steel threaded rod (*Screw*), steel tube (*Barrel*), 4 pcs of heating elements, nipple nozzle)
		Bolts and Nuts (extrusion machine stand)

b. Work Stages

The work stages in the recycling machine to achieve the expected results and become the goal of this design consist of several stages, namely:
1) Literature study stage

Previous research and projects, relevant information is taken to design and produce a plastic recycling machine that is suitable for automatic plastic waste recycling machines, where the mechanism used for the system is a shredder and extrusion of plastic waste using a hopper model.

2) Concept Formulation and Refinement

The formulation and design concept that has been carried out in previous research, then all the literature concepts taken are combined, then conclusions are drawn for the machine design using two mechanisms with machine performance testing in the form of product results between one of which is a biopore cover, magnetank or paving block.

3) Design Analysis and Engineering Drawings

The analysis used is the analysis of the framework and software for design using the Shapr3D application. The design used is a conceptual design of different alternative mechanisms, detailed component design. Selection of materials/components that are easily obtained and economical and selection of the best mechanism. The concept and selection of plastic recycling machine components consist of a shredder/crushing system, and an extrusion system, where both are combined into one

machine. The selection of the three systems is considered based on maintenance, availability, cost, weight, efficiency and so on.
The following is the overall design from various angles (Top View, right-left side, Rear View).

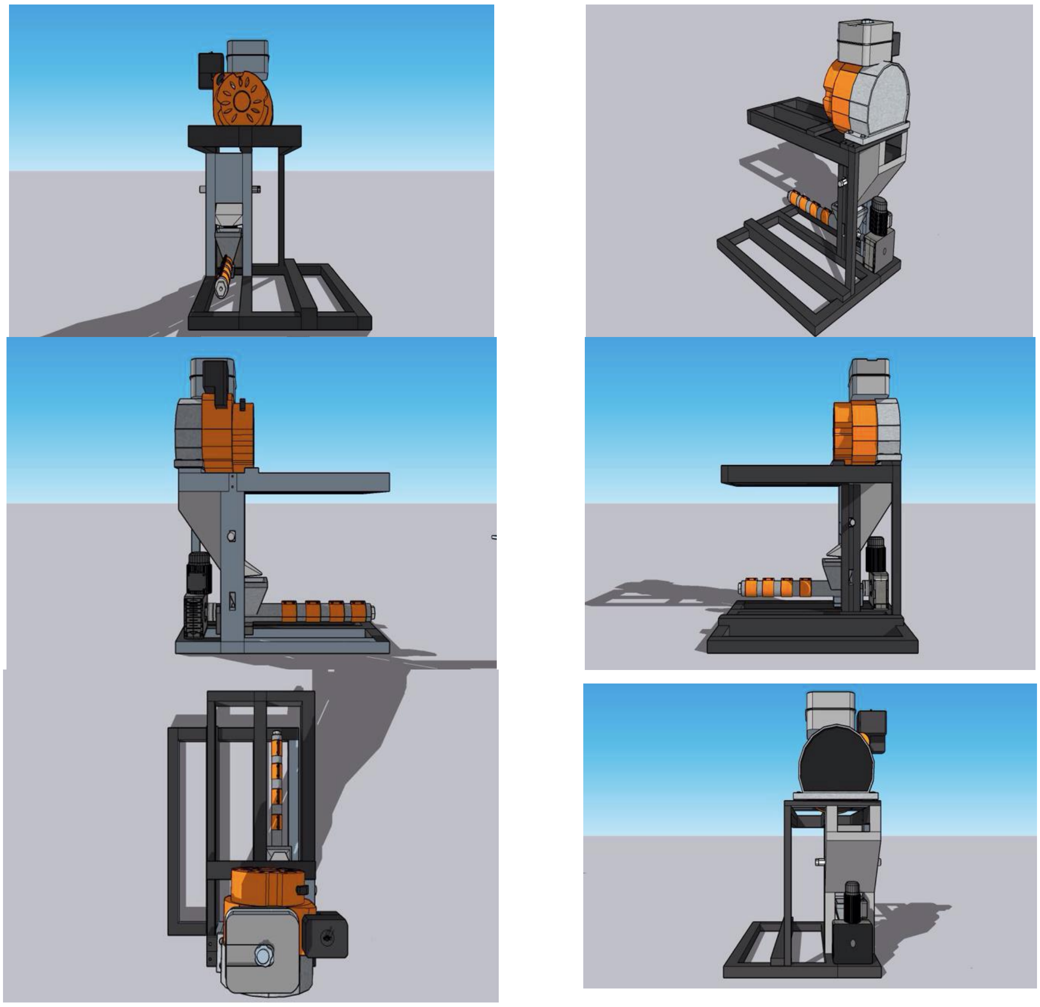


Figure 1. Design of Plastic Recycling Machine for Shredding (top part) and Extrusion (bottom part)

4) Collection of Materials and Design of Recycling Machine

The types of plastic waste that are recycled are all types of plastic waste without exception and plastic waste that is ″thrown away″. What is meant is plastic waste that can no longer be accepted by the waste bank. The cost of purchasing material components for the tool is budgeted from each team with careful calculations to obtain effective production costs.

5) Preliminary Test and Functional Test

A preliminary test is carried out to test the feasibility and initial performance of a newly made or modified recycling machine. At this stage, the machine is run under real operational conditions, but on a smaller and limited scale, for example in a laboratory or in a limited production environment. During the preliminary test, monitoring of machine performance, process efficiency, reliability, and the ability to produce recycled products with the desired quality is carried out. The results of the preliminary test can be used to make further adjustments, improvements, or optimizations to the machine design or configuration before entering the desired production stage. The functional test is carried out after the machine has gone through the preliminary test stage and has undergone the necessary adjustments or improvements. The results of the functional test will be the basis for evaluating whether the machine is ready for use in commercial production or whether it still requires additional adjustments or improvements.

6) Overall Machine Performance Testing and Discussion

Overall machine performance testing is seen from the test results, aiming to evaluate how well the machine can process raw materials into the desired recycled products. During performance testing, several parameters that are usually evaluated include production speed, product consistency, and efficiency of raw material use. Product results also include an evaluation of machine reliability over a long period of time, including the ability to maintain consistent performance and minimize downtime. After testing is complete, the product results will be discussed and evaluated.

7) Conclusion

After the data has been analyzed and compared with the established criteria, the next step is to evaluate the strengths and weaknesses of the machine. The results of the machine performance test are then compared with the criteria or the following planning flow diagram can be seen in Figure 2:

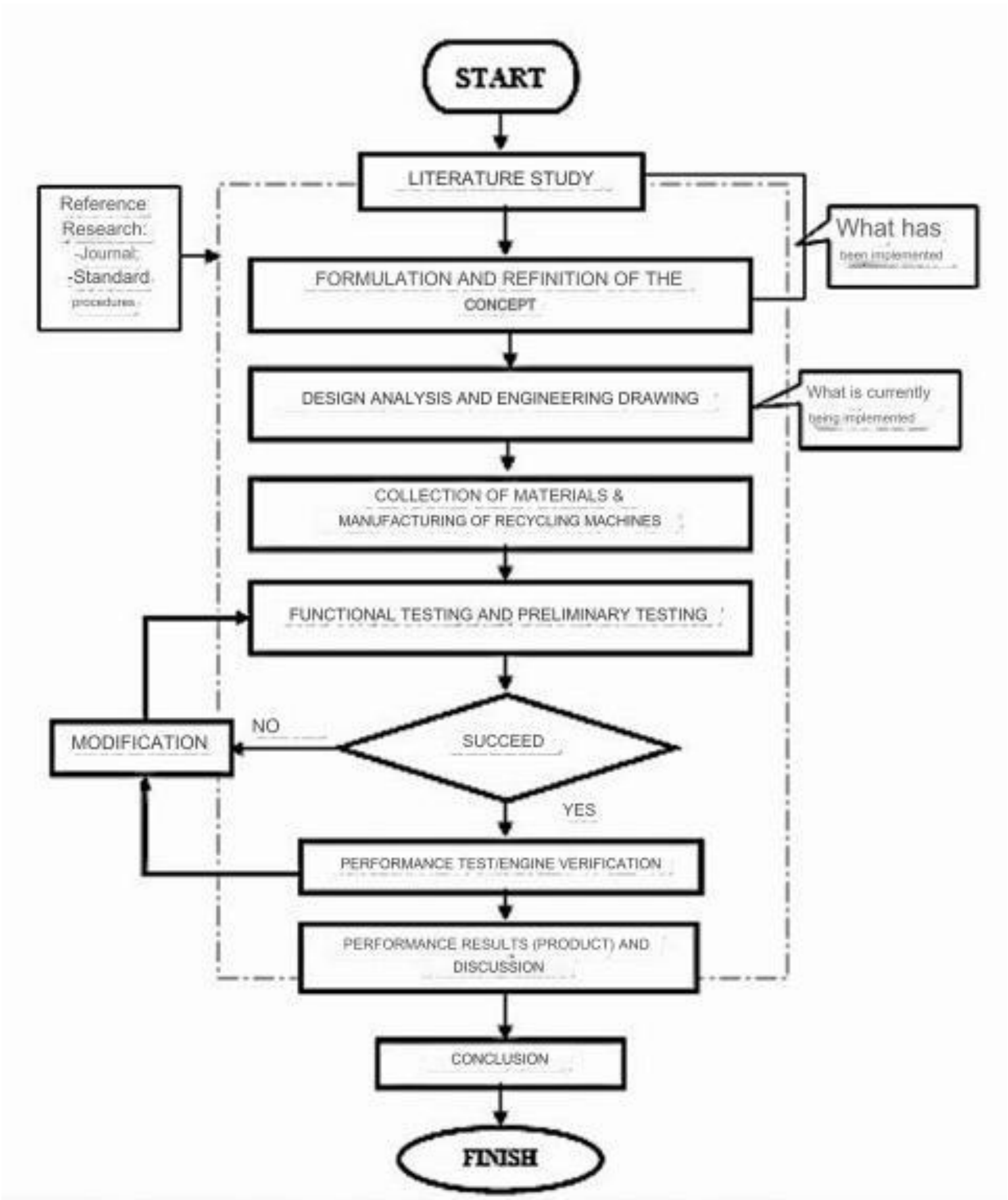


Figure 2. Planning Flowchart

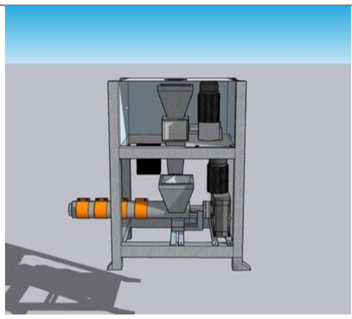
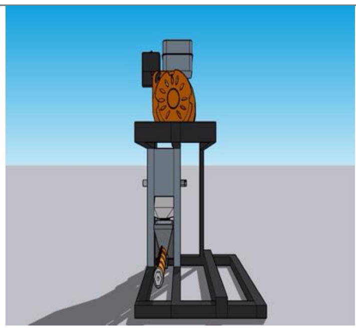
DESIGN PROCESS AND RESULTS

Design Analysis and Engineering Drawings of Machine Design

Determination of Recycling Machine Design

At this stage, the first thing to do is to compare existing designs with the available budget. In general, injection machines are grouped into two, namely horizontal and vertical injection machines based on the location of the machine unit and the direction of plastic fluid injection. There are 2 designs that have been carried out which are still in a series of designs that combine two different functions, namely shredders and extrusions using a screw-barrel system. Both of these designs include several aspects that need to be considered In achieving an optimal design, several considerations are needed in both of these designs.

Table 1. First Design and Second Design of Machine with several considerations

Machine Type	Drive power/Fuel	Advantages	Machine Design Drawing
Type one (Vertical-chopper); Horizontal-Extrusion)	Dynamo/electric motor	- High Efficiency Environmentally Friendly - Low maintinance - Quiet Operation	
Type Two (Vertical-chopper); (Horizontal-Extrusion)	1 Dynamo-electric motor & 1 gasoline motor	- Longer range in terms of fuel - Fast refueling - Low initial cost - Can be designed to rotate using electrical or gasoline	

Due to the current conditions, which are not capable of large electric power volts, the second design type is chosen with several considerations that can change with the situation and conditions.

Equipment and Material Collection Stage

This procurement is carried out by collecting equipment and materials that have been planned in advance.

Table 2. Tools and materials needed

Model Mechanism	Tool	Material
Shredder	1 Set Electric drill	Wood (Body Support)
	1 Set Grinder	Bolts and Nuts (Machine Support Body)
	1 Set Electric Welding	1 set machine body refiner (Sandpaper, black and gray spray paint)

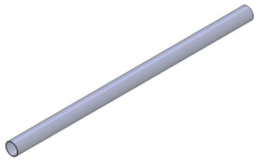
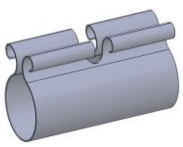
	Hammer	Shark brand drive motor (Gasoline Fuel)
	1 Set of measuring tools (Iron ruler, marking pencil, vernier caliper, lighter, steel knife cutter)	1 set of shredder components (15 Pieces of shredder blades, AS Iron, Iron Plate
	1 set cutting machine saw (wood)	1 Set of motor drive (Gearbox, Belt, Pulley)
Extrusion/Melting	Manual screwdriver	Dynamo drive motor
		Set of motor (Gearbox, Belt, Pulley)
		1 Set of extrusion (Hopper funnel, steel threaded rod (*Screw*), steel tube (*Barrel*), 4 pcs of heating elements, nipple nozzle)
		Bolts and Nuts (extrusion machine stand)

Chopper Mechanism Model

- ✓ Making Frame (using wood): (Wood Cutting), Cut the wood according to the planned design. (drilling), the wood joints are connected using nuts and bolts to make it stronger, to make it easier to install bolts and nuts use a drill.
- ✓ Making Chopper Knife and Shaft: cut hard steel to make dynamic and static knives, install the chopper knife item and ring (as a distance for the chopper knife) on the hexagon AS/shaft/chopper knife shaft, filter plate. The items that have been installed are covered with a plate using welding, the side of the chopper machine body is also covered with a bearing plate, then locked with bolts and bearings, after that, finally the parts that need to be locked are welded so that they are strong and do not shift.
- ✓ Installing the motor and transmission system: at this stage, previously checked the power scale, how much power is used. The motor installed uses the shark gasoline engine SE 168X 6.5HP 1 unit, installed on the upper body of the shredder machine stand. (gasoline-fueled driving motor), install the belt and pulley to transfer power from the motor to the shredder knife shaft/axle.
- ✓ Testing and adjustment: Run the machine to ensure all components are working properly. Adjust the knife, motor and transmission system if necessary.
- ✓ Initial testing was carried out by trying several shredding experiments with the newest and oldest bottle waste (waste that was thrown away/not accepted by the waste bank) as samples.

Extrusion Mechanism Model (Melting)
Before assembling the extruder machine body, here are the important items that are part of the plastic extruder/melter machine:

Table 3. Important Components of the Extruder Machine

No.	Component	Processing
		Extruder Body Component/Injection
1	Pipa Ekstrusi (Barrel) 	- Measure and cut 52 cm stainless steel pipe according to the specified dimensions. Then make a hole for the hopper seat in the position according to the design. - Adjust the 2-dimensional Steel Axle using an iron lathe to achieve the specified shape and size, the axle that has been turned through the milling process as an entry point for plastic according to the specified dimensions. - The steel plate that has been cut, as a place for the hopper seat, is perforated for installing bolts and nuts, joined together with the barrel axle using welding.
2	Screw 	- Cut the iron with a size of 60 cm, make a basic screw design according to the design using a lathe by making threads with high precision.
3	Hopper	- Measure and cut the plate according to the specified size requirements, make a trapezoid shape of 4 pieces. - Shape the plate according to your needs and connect the bending results with welding. - Combine all the parts that have been made using welding. - After that, this component will be assembled with the hopper using bolts and nuts.
4	Nipple Nozzel 	- The basic shape of the nozzle is made of steel with a lathe, - Make a hole with a diameter of 1 mm with a drill to ensure optimal flow of melted plastic material.
5	Barrel Heating Plate 	- The shape of the finished plate - Install the heating element, installed by soldering it to the plate. - The cable connected to the heating plate to the barrel is connected to the panel box/control box to monitor the temperature in real time.
		Extruder Machine Drive Components

6	Engine Drive Motor  	- Drives the engine - There are 2 types of drive motors: electric power (dynamo) and manual power (gasoline) - The drive motor is a device that converts energy (usually electricity or fuel) into mechanical energy to drive a machine or tool. This motor is used in various applications, from vehicles to industrial and household equipment.
7	Gearbox 	- Functions as a vehicle and engine transmission system, - Distributes power, changes gear ratio, regulates speed, increases torque, controls direction of motion.
8	Panel Box/Control Box 	- Functions as a control center and power distribution as well as operational control of the extruder machine. - The panel box contains 2 PID controller units (Proportional-Integral Derivative) which have important functions, namely controlling the process, system stability, fast response, reducing errors, temperature control, - 2 dimmer units, dimmer functions to regulate motor speed, - 1 switch unit and 1 connection cable unit.

Component Assembly Stage

At this stage, the previously made shredder machine sub-components and the extruder machine sub-components that have been made become a complete machine. This activity includes:

Shredder Unit Assembly

This machine consists of several supporting component units (drive motor, belt and pulley) with the main component being the shredder box component (14 2-sided knife units, 13 ring units, 2 bearing plate units, 2 sets of side plates, 1 filter plate unit, 1 hexagon axle unit (Hexagon 28 mm, axle diameter 25 mm), 2 bearing units).

Extruder Unit Assembly

This machine consists of several supporting component units (drive motor, gearbox and panel box/control box) with the main components (Barrel, screw, Hopper, nozzle, and barrel heater plate). This stage also involves electronic assembly on the control box including the connection between the PID controller, switch and power cable.

Assembly of the Machine Stand Body

At this stage, the shredder and extruder machines are made into one unit in the machine stand frame. According to the second design, the shredder machine is at the top while the extruder/injection machine is at the bottom. At the installation stage, the first machine on the prepared stand, make sure the machine is installed securely and there are no loose parts. Previously, the machine stand frame body has been painted or coated to protect the body from termites.

Component Testing Stage

Functional Test

At this stage, the previously assembled machine is run without load by going through the following flow:

- Turn on the machine, pay attention to the machine's performance path whether it is running optimally, starting from the belt pull on the pulley, the shredder rotation, Reset if there is/needs repair. The same goes for the extruder machine, turn on the machine by pressing power on, check the machine's performance path for any obstacles.

Preliminary Test

At this stage, the machine that is run is tested with a load, through the flow:

- Turn on the machine, insert the material to be chopped into the machine, observe the performance of the machine when chopping the material, including the speed and quality of the chopped results. Simultaneously starting by turning on the extrusion machine by pressing power on, the chopped material automatically enters the hopper of the extruder machine, observe the rotation of the screw carrying the chopped plastic into the barrel through the heating plate.
- Setting the hot temperature, and the speed of the screw rotation if there are obstacles to the material, also observe the melted plastic (filament) that passes through the nipple nozzle. Or with steps like this:

This stage is used to test the program that was created, and take samples of the printed product. Starting from the chopping process to entering the extrusion process. The testing steps that will be carried out are as follows:

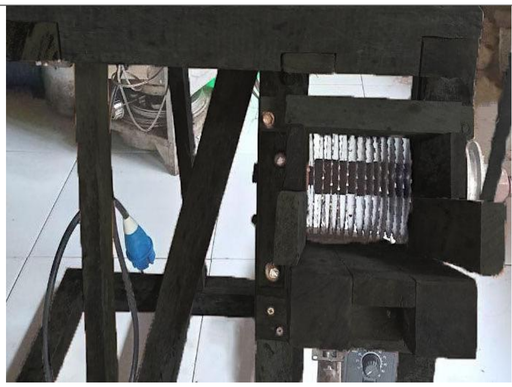
a. Prepare samples of test materials in this case are waste plastic bottles or cups, used bottle caps that have just been used and waste bottles/cups, used bottle caps that have been thrown away (not used by the waste bank).
b. Turning on the shredder
c. Insert the test material into the hopper of the shredder;
d. Turning on the extrusion machine
e. The shredded material automatically enters the hopper of the extrusion machine;
f. Setting the temperature and rotation speed on the control box to obtain the expected product results.
g. Observing, comparing the results of the shredding and extrusion results (filament) with the tested parameter settings and rotation speed.

RESULTS AND DISCUSSION

Tool Design Results Plastic Shredder Unit

From the design results of the shredder unit section, a plastic shredder tool can be produced:


(A)


(B)

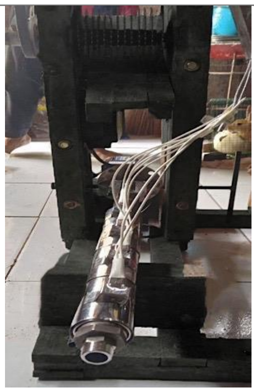

(C)


(D)

Figure 3. (A) Front View of the Shredder; (B) Rear View of the Shredder; (C) Right View of the Shredder; (D) Left View of the Shredder

- Plastic Extruder Unit

From the design results of the extrusion unit section, a plastic extruder can be produced:


(A)


(B)


(C)


(D)

Figure 4. (A) Front View of Extruder; (B) Rear View of Extruder; (C) Left View of Extruder; (D) Right View of Extruder

Results of Making Tools

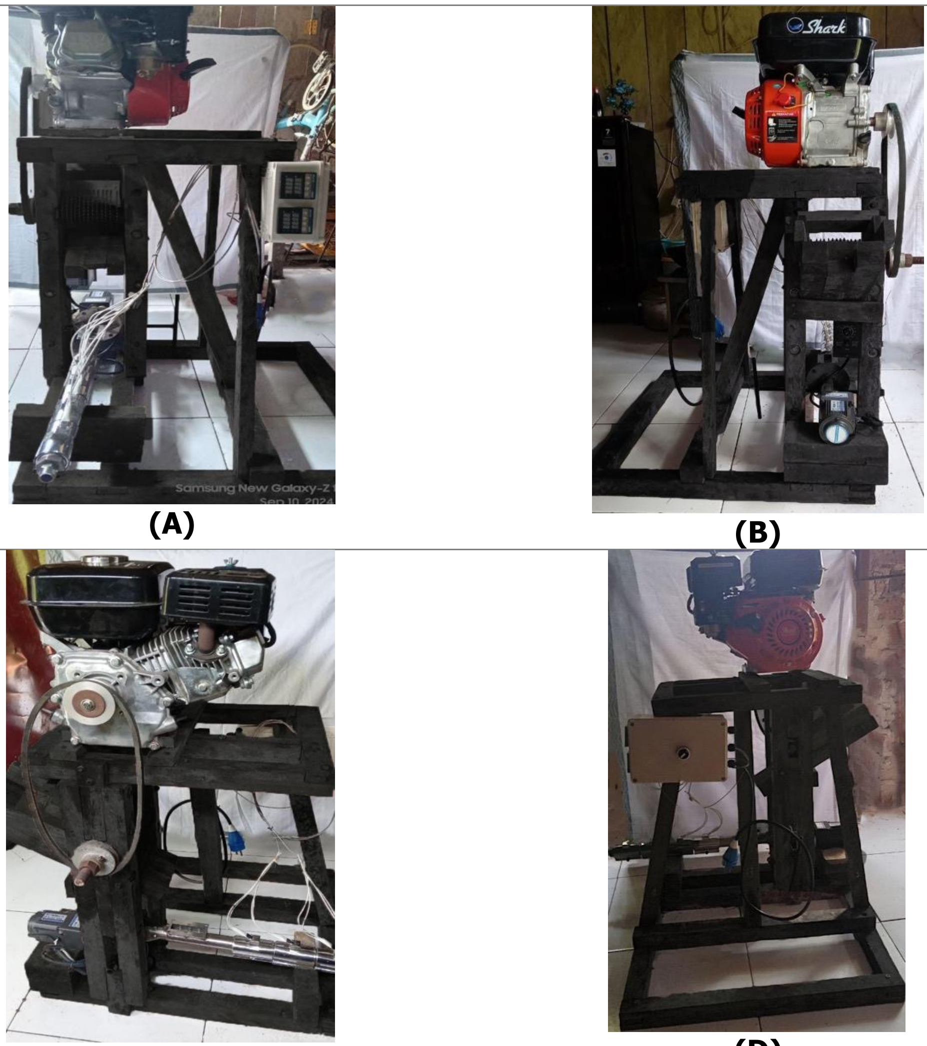


Figure 5. (A) Front View of the Machine; (B) Rear View of the Machine; (C) Left View of the Machine; (D) Right View of the Machine

Measurement and testing of the shredder

Measure important parameters such as the rotation speed of the power used and the time required to shred the material. The material is shredded on the shredder, the flakes are obtained as in Figure 7 below, the flakes are further processed through the shredder, the flakes have an average size of about 3-5 mm. The third Figure 6 shows larger flakes/flakes of about 5 mm, due to the orientation of the flakes entering the shredder, the output prevents the shredder screw from crushing the material quickly, so higher torque is needed to shift the large flakes in the shredder opening. Although the flake size distribution is larger than originally intended, most of the flakes are small enough and can be processed by the extruder. This system is capable of producing solid flakes on PET plastic with standard 110V power, this operation works well at room temperature and independently of other processes. Some aspects of the shredding process have significant room for future improvement. Shredder Waste material Plastic “wasted” after being washed is PET.

Figure 6. Sample of PET type plastic bottle

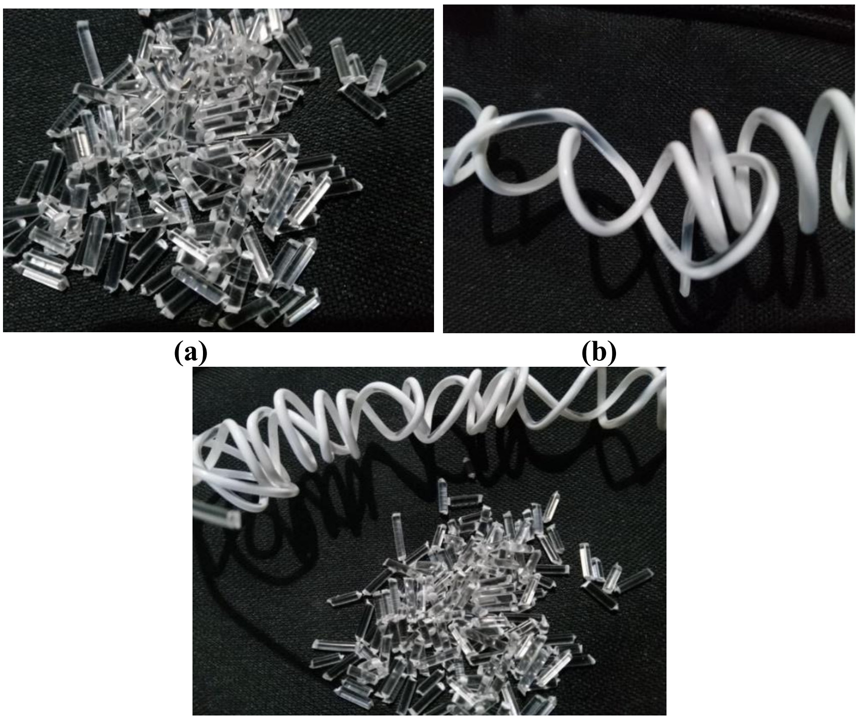
Figure 7. Results of shredding used plastic waste

Measurement and Testing of Extruder Tool

The parameters at the testing site of this extruder system machine such as high humidity areas follow different parameter values for successful extrusion. Humidity does not exceed 45%, thus extrusion above 50% humidity has the potential to follow different parameters. This project was carried out in an open test site with an air temperature of around 20% to 22%°C. Based on these environmental conditions, the optimal extrusion temperature is at 170°C for smooth extrusion, as shown in Figure 7. Along with the optimal temperature is around 15 grams every 4-6 minutes or until the shreds in the extruder hopper run out/empty. With the parameters measured during the extrusion session, the filament diameter is 3 mm according to the nipple nozzle hole. Initially inconsistent with the initial size but left until the filament size remains consistent. In the next experiment, the filament was left on the ground without a receiver/winding, the standard deviation of the diameter changed between a minimum of 3.09 mm and a maximum of 3.5 mm. Showing that winding the filament helps reduce the variation in diameter with the unwinding extruder.

Figure 8. Fine filaments passing through the nozzle

From this experiment, the extrusion parameters in 4 experiments, the initial experiment, ranged from 3 mm, 2.8 mm, 1.35 mm and 0.9 irregularly, in figure 8 are experiments 3 and 4 with consistent sizes ranging from 1.35 mm can be seen in figure 8. To overcome this, the 0.8 mm nipple nozzle was re-drilled into a 1.35 mm hole based on the ratio of the diameter of the extruded filament to the nozzle size.



(a) **(b)**

(c)

Figure 8. (a) filament cut (b) result of intentionally rolled/bent filament
(c) Filament cut and hardened filament roll

Judging from the results in Figure 8, when the hardened filament is bent or rolled intentionally, it is elastic, unless bent strongly it is brittle, this applies to PET plastic samples. This extruder is powered by a 220 V AC, 25 Watt gearbox motor dynamo with high torque. Which is equipped with a controller box, has a maximum speed of 100 rpm. The speed used on this extruder ranges from 45 rpm - 55 rpm, depending on the temperature increase of the heating element.

Evaluation

Evaluate the shreds to ensure they meet the desired specifications. From the results discussed above, the shreds that are further processed through the shredder, the shreds have an average size of about 3-5 mm. The third figure 6 shows larger shreds/shreds of about 5 mm, due to the orientation of the shreds entering the shredder, the output prevents the shredder screw from crushing the material quickly, so higher torque is needed to shift large shredders at the shredder opening. Because the team had problems with some shreds flying out of the gap between the bottom of the knife and the hopper of the micro shredder, it is better to add a fully enclosed shroud above the shredder hopper to reduce the gap. This modification will allow the shredder to fall directly into the hopper of the micro shredder, thereby reducing volume loss due to flying shredders. The distance between the 80/20 frame and the side wall must also be adjusted properly to prevent shredders from moving through the gap. The extruder shaft consisting of the screw and barrel is made of 4.5 cm diameter steel pipe, the body of which is perforated to provide a place for the hopper. The pipe is threaded to a connector for the nozzle on one side and to a bolted flange on the other. The tapered pipe thread between the flange and the pipe allows it to rotate to generate pressure under rotational loads. This arrangement is a cost-effective and quite functional way to extrude plastic, but it can be improved with a little extra time and money. Custom-made similar-sized extruder screws exist and may be less prone to jamming in the extruder. This would require additional resources to test and implement.

CONCLUSION

Based on the research conducted, several conclusions can be drawn as follows: To address the increasingly worrying environmental issues related to plastic sustainability, the team has completed a proof of concept recycling system that demonstrates the feasibility of implementing a small and low-cost solution to recycle PET waste into filaments; The system used includes a shredder and extruder system with 1 machine body, This system is capable of producing solid flakes on PET plastic with standard 110V power, this operation functions well at room temperature and independently of other processes. This extruder is powered by a 220 V AC, 25 Watt gearbox motor dynamo with high torque. Which is equipped with a controller box, has a maximum speed of 100 rpm. The speed used on this extruder ranges from 45 rpm - 55 rpm, depending on the temperature increase of the heating element. Parameters at the testing location of this extruder system machine such as areas with high humidity follow different parameter values for successful extrusion. Humidity does not exceed 45%, thus extrusion above 50% humidity has the potential to follow different parameters. This project was carried out in an open test site with an ambient air temperature of 20% to 22%°C. Based on these environmental conditions the optimal extrusion temperature is at 170°C for smooth extrusion. The results of the flake test that were further processed through the shredder had an average size of around 3-5 mm. Larger flakes/shreds were around 5 mm, most of the flakes were small enough and could be processed by the extruder. This system is capable of producing solid flakes on PET plastic with standard power of 110V, this operation works well at room temperature and independently of other processes. The results obtained with 4 random experiments without any planning at all. initial experiments, ranging from 3 mm, 2.8 mm, 1.35 mm and 0.9 irregular, experiments 3 and 4 with consistent sizes ranging from 1.35 mm. To overcome this, the 0.8 mm nipple nozzle was re-drilled to a 1.35 mm hole based on the ratio of the extruded filament diameter to the nozzle size. The hardened filament is bent or rolled intentionally, it is elastic, unless bent strongly it is brittle, this applies to PET plastic samples. The team has identified several parts of the process in the system that can be further developed to obtain better results and hopes that the results of the project can support further research into improving the sustainability of the technology.

ACKNOWLEDGEMENT

We would like to thank the Ministry of Education, Culture, Research and Technology (Kemendikbudristek) for the research funding support that has been provided. And to the Institute for Research and Community Service (LPPM) of the University of Muhammadiyah Sorong which has accommodated and facilitated the administration of completeness, so that the implementation of this research runs smoothly. This assistance is very meaningful in realizing our research and supporting efforts to improve the sustainability of recycling technology. Hopefully the results of this research can provide a positive contribution to the development of science and technology.

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