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Development of Plastic Shredder Technology to Support Plastic Waste Reduction

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Abstract

The plastic waste problem in Indonesia has reached a severe level. Data from the National Waste Management Information System shows that Indonesia produces around 17 million tons of plastic waste yearly. However, only approximately 66.47% of this plastic waste undergoes recycling, with the remainder ending up in landfills or polluting the sea. This condition places Indonesia in second place in the world after China in terms of the amount of plastic waste produced, making it a country with a plastic waste emergency. This article discusses the development of plastic recycling machine technology as a solution to overcome the plastic waste problem in Indonesia. With a production of around 17 million tons of plastic waste per year, Indonesia faces significant challenges in plastic waste management. Low efficiency often constrains the effectiveness of plastic recycling as a solution. Therefore, this study aims to design and improve the efficiency of a plastic shredder machine. This machine uses specially designed rotating blade technology to produce high-precision plastic flakes. Additionally, we have updated the transmission system to reduce vibration and implemented other innovations to enhance the machine's capacity to shred various types of plastic. We expect this machine to decrease greenhouse gas emissions from the recycling process and lower operational costs. This study shows that the developed plastic shredder machine can work effectively and efficiently, meeting the research objectives of producing plastic flakes quickly. Thus, we expect this machine to significantly reduce plastic waste in Indonesia and support environmental conservation efforts.

Keywords: *Plastic Shredder Technology, Plastic Waste Management, Environmental Innovation, Development, Machine.*

1. Introduction

The plastic waste problem in Indonesia has reached a severe level, creating an urgent environmental challenge. Based on data from the National Waste Management Information System, Indonesia produces around 17 million tons of plastic waste yearly. This figure shows significant growth and reflects the high consumption pattern of plastic-based products. Regrettably, only approximately 66.47% of this plastic waste undergoes recycling. The rest, which reaches around 5.7 million tons, ends up in landfills or pollutes the sea, which can have long-term impacts on marine ecosystems and human health. This condition places Indonesia in second place in the world after China in terms of the amount of plastic waste produced, making it a country with a plastic waste emergency. Plastic bags, bottles, and food packaging, often single-use items, make up most of this plastic waste. This crisis damages the environment and contributes to public health problems, such as increased risk of diseases due to pollution. In recent years, attention to plastic waste management has increased, but the challenge of changing consumer behavior and developing adequate recycling infrastructure is still huge. Various parties, including the government, the community, and the private sector, must take more comprehensive and integrated steps to address this issue. We must consistently implement policies that support the reduction of single-use plastics, educational programs on waste management, and innovations in recycling technology. In addition, collaboration between various stakeholders will be crucial in creating sustainable solutions. With coordinated efforts and higher public awareness, Indonesia can reduce the impact of plastic waste and contribute to a cleaner and healthier environment.

The accumulation of plastic waste in the ocean significantly threatens the marine ecosystem, endangering marine biota and damaging the beauty of the environment. Research by Andrady reveals that dumping plastic into the sea pollutes the water and creates "dead zones" where marine organisms cannot survive [1]. When marine animals, such as fish and birds, mistake plastic waste for food, they can experience severe digestive problems or even death. In addition, plastic that breaks down into microparticles can enter the food chain, potentially impacting the health of humans who consume contaminated fish. Undecomposed plastics will remain in the environment for years, causing long-term impacts on human and animal health. Organisms can absorb hazardous chemicals from microplastics and accumulate them in their bodies. This risks marine life and humans, who depend on seafood for food. Continuous exposure to these toxic substances can cause various health problems, including hormonal disorders and an increased risk of chronic diseases [2]. In addition, plastic pollution also impacts the fisheries sector, which is the primary source of livelihood for many people in Indonesia. Marine pollution can reduce fish catches and the quality of fishery products, which can threaten food security and the economy of coastal communities. The decline in the quality of seafood due to plastic pollution makes consumers hesitate to buy these products, thereby reducing the income of fishermen [3]. Therefore, handling the problem of plastic waste in the sea is not only an environmental issue but also a social and economic situation that requires serious attention from all parties. Plastic recycling is an effective solution to reduce the negative impacts of plastic waste, but this process still faces various obstacles and often does not run optimally. The main challenges in plastic recycling include the lack of adequate facilities, low public awareness, and an unequivocally integrated management system [4]. The lack of infrastructure to support the process leads to the discarding and non-recycling of much plastic waste, causing it to continue accumulating in the environment. One of the critical stages in plastic recycling is shredding or breaking down plastic into small pieces. This process is essential because efficient shredding can improve the quality of recycling results and reduce operational costs. Wibowo et al. conducted research that demonstrates the ability of the right shredding technology to produce uniform flake sizes, thereby simplifying subsequent processes like washing and melting [5]. In addition, Rahmawati et al. found that an optimal shredding method can reduce the energy required during the process, making recycling more economical and environmentally friendly [6]. Plastic shredding has the potential to enhance recycling effectiveness, but proper execution of the entire plastic waste management chain, from collection to processing, is crucial. We can optimize the plastic recycling sector in Indonesia by improving the shredding process and minimizing material losses. This will contribute to reducing the volume of plastic waste polluting the environment and increasing the economic value of the recycled materials produced, benefiting the local economy and overall environmental health.

To address the challenges of the plastic recycling process, this study aims to develop a more efficient plastic shredding machine technology. A well-designed plastic shredding machine not only increases the productivity of the recycling process but can also contribute to reducing greenhouse gas emissions. Syahza and Suarman conducted research that shows an efficient shredding machine can minimize energy use and reduce the carbon footprint associated with plastic processing [7]. Thus, innovations in shredding machine technology can potentially create more environmentally friendly solutions in plastic waste management. The goal of this research, "Development of Plastic Shredding Machine Technology to Support Plastic Waste Reduction in the Environment," is to enhance and boost the effectiveness of current plastic shredding machines. Purwaningrum emphasizes the importance of evaluating the design and performance of existing shredding machines to identify potential areas for improvement [8]. This research will comprehensively analyze various parameters, including the size and type of plastic to shred, the speed of shredding, and the power consumption. Thus, we expect the development of this technology to yield a more effective and efficient shredding machine that can handle various types of plastic and enhance the quality of the produced plastic flakes. With an approach focused on technological innovation, this research will improve the efficiency of plastic shredding machines and contribute to national efforts to reduce the problem of plastic waste. We anticipate enhanced efficiency in the shredding process to expedite the recycling process, boost the economic worth of recycled materials, and foster public awareness about the significance of sustainable plastic waste management. We hope developing more sophisticated technology will significantly impact the environment and economy, promoting a cleaner and healthier future.

The plastic shredder machine incorporates several innovative aspects designed to enhance the efficiency and effectiveness of the shredding process. First, the specially designed rotary knife technology can cut the plastic into small pieces with high precision. This innovation increases shredding efficiency and produces more uniform pieces, which is essential for the quality of recycled results [5]. With sharp knives designed for various types of plastic, the shredding process becomes faster and more effective, reducing the time needed to process raw materials. Second, the updated transmission system functions to minimize vibration and ensure efficient power transfer from the motor to the shredder knife. This is important because it reduces energy loss during the process and increases the stability of machine operation [6]. Third, the improved belt and clutch technology addresses the issue of frequently loose belts, enhancing machine durability and minimizing damage risk. With these improvements, the shredder machine can operate more reliably and consistently, increasing productivity. Innovation in blade design is also an essential aspect of the development of this machine, increasing the machine's ability to shred various types of plastic [9]. In addition, applying sensor technology and automatic control to monitor machine operational parameters will allow for better supervision and rapid response to changing conditions. Emission reduction technology is also integrated to minimize the environmental impact of the shredding process [8]. Finally, using materials resistant to wear and corrosion will increase the machine's service life and reduce long-term maintenance costs [5]. These innovations are expected to create a more efficient, environmentally friendly, and economical plastic shredding machine, supporting efforts to reduce plastic waste in the environment.

This research is expected to provide an effective solution for the community in dealing with the problem of plastic waste that ends up in landfills or pollutes the environment. With the development of more efficient plastic shredding machine technology, the recycling process can be carried out more optimally so that more plastic waste can be processed and reused. This is very important considering that Indonesia is facing severe challenges related to the accumulation of plastic waste, which is detrimental to the environment and impacts public health and the local economy. In addition, this study aims to contribute to environmental conservation efforts and plastic pollution reduction in Indonesia. This study supports the government's and related institutions' initiatives to create a cleaner and healthier environment by reducing unmanaged plastic waste. The Ministry of Environment and Forestry stated that efforts to reduce plastic pollution must be integrated, involving various stakeholders, including the community, industry, and government. Therefore, the results of this study are expected to be part of a broader solution to overcome the problem of plastic waste in the country [9][10]. With a technology-based and innovation-based approach, this study provides direct benefits in plastic waste management and increases public awareness of the importance of recycling and reducing plastic waste. Through education and active community participation in recycling programs, it is hoped that there will be positive behavioral changes, thereby creating an environmentally friendly culture. Thus, this study

does not only focus on technical aspects but also on social aspects, which are very important in achieving the goal of sustainable environmental conservation.

2. Research Method

2.1. Stages of Making a Plastic Shredding Machine

The stages of making a plastic shredder machine begin with formulating the problem, which is the first step in determining the core of the research. At this stage, researchers scrutinize the problem's background to comprehend the issues that need resolution and the research goals. With a clear understanding of the problem, researchers can set the proper focus and make the research process more focused. Ensuring a solid foundation for each subsequent step in machine development is crucial. The next step after formulating the problem is to set specific research objectives and establish clear boundaries. Setting these objectives aims to keep the focus of the research from deviating from the main topic and to ensure that all relevant aspects are considered. Additionally, creating an activity schedule is crucial for optimizing research time. By adhering to a regular schedule, researchers can reduce the likelihood of delays and guarantee that every phase of the research proceeds as per the prearranged plan [11].

The next stage is data collection through literature studies and research. During this stage, researchers gather information on the research topic from various sources, including scientific journals, articles, and books. Comprehensive data collection is essential to understand the context and support the development of the plastic shredder machine. Following data collection, the researcher develops an initial design concept that provides an overview of the mechanism and design of the intended machine. This concept becomes the basis for the next stage in machine development. Following the initial design concept, the researcher gathers data and references to select alternatives. During this process, the researcher compares various references and assigns values based on a predetermined list of demands to assess the other options. The list of demands includes technical needs, functionality, and user preferences. If the researcher finds no alternatives that meet the criteria, they must consider changing the design concept. If the researcher finds a suitable alternative, they will proceed to the original design stage, which will serve as the research objective. The final stages in making a plastic shredder machine include making working drawings, ordering materials, making components, and testing machine performance. Experts in their fields must validate the working drawings, and after being accepted, materials for making the machine are ordered according to the design specifications. We carry out the manufacturing and fabrication processes to produce machine components and assemble them using the approved working drawings. We then test the designed machine to evaluate its performance. If the machine successfully meets the research objectives, we can carry out finishing processes like painting and consider the research complete. If the research objectives remain unfulfilled, we conduct additional analysis to pinpoint and rectify any existing issues. Therefore, we design each of the above stages to ensure a systematic and practical plastic shredding machine manufacturing process, paying particular attention to technical details and the final product quality [12].

2.2. Draft Demands List

The list of demands for designing a plastic shredder machine begins with the importance of simplicity and efficiency. We must make the machine's construction uncomplicated, meet the user's needs, and avoid excessive space use. Additionally, we must consider aesthetic aspects to enhance the machine's visual appeal. During manufacturing, the design should simplify the shape to ensure efficient and quick production. The selection of materials is also crucial; the production facility's equipment must quickly obtain and process the materials. The focus shifts to the availability of tools and the machine's ease of operation. The tools needed for assembly must be available at the production facility, and the assembly process must not require special tools. Speed and smoothness in this process are essential to ensuring efficient time and effort [12].

Furthermore, the design of the machine should prioritize ease of use, eliminating the need for special certification from the operator. Various groups can operate the machine without experiencing fatigue, provided it functions quickly and doesn't require high power requirements. The last but equally important aspect is the safety and maintenance of the machine. We must design the machine with operator safety in mind and equip it with adequate protection features to prevent accidents. We must also conduct the assembly process safely to avoid potential safety issues. Moreover, the design of the machine should facilitate easy maintenance, allowing for easy access to replace necessary components. Maintenance should be simple and not require complicated procedures, with low cost and time, so operations remain efficient and well maintained [13].

2.3. Division of Functions of Plastic Bottle Shredding Machine Components

The division of component functions in a plastic bottle shredding machine is crucial to support its overall performance. First, the machine frame functions as the main supporting structure, providing the stability and strength needed to withstand the overall load of the machine. A sturdy frame will ensure that all machine components can function properly without the risk of damage. Furthermore, the machine cover protects the shredded results from spreading during the process, maintaining the cleanliness of the work area and ensuring operational safety. The most crucial component in the shredding process is the shredder blade. When plastic bottles pass through the hopper, this blade cuts them into small pieces [13].

Additionally, the shaft serves as a holder for the blade and transmits the rotation from the connected Pulley. This shaft allows power transfer from the motor to the cutting component, thus ensuring efficient shredding. Conversely, the bucket serves as a container for the shredded results, gathering and removing the processed fragments. The shredder machine's primary power source is the drive motor, which provides mechanical energy to drive the entire system. This motor is crucial for the operation of the machine, ensuring that all components function optimally. The transmission facilitates the motor function by transferring rotation from the motor to the reducer, thereby ensuring efficient distribution of the generated power. The reducer changes the motor output rotation to a slower speed, allowing the shredding process to occur correctly. The connection between the reducer and the shaft is the clutch, which ensures smooth rotation transfer and reduces the possibility of interference in the mechanism. Finally, the gears connect the various shafts, transmitting rotation from one shaft to another. Thus, all these components collaborate to maintain the cutting mechanism's harmonious and efficient operation, thereby ensuring the smooth operation of the plastic bottle shredding process [14].

2.4. Product Manufacturing Method

Creating a plastic bottle shredder machine involves several crucial steps, each employing specific methods and techniques for each principal component. First, we make the machine frame by marking the cutting area on the material for use. After marking, we use a cutting grinding technique to produce pieces that match the required size [15]. Next, we connect the frame components through the SMAW (Shielded Metal Arc Welding) method, ensuring the strength and stability of the structure. This process ends with drilling holes to facilitate the installation of other components. Next, manufacturing the input hopper begins with markings on the plate to determine the exact cutting area. Depending on the thickness of the plate, either a cutting, shearing technique, or a hand grinding machine performs the cutting. After the plate is cut, the formation is carried out according to the design using the sheet metal method. The next step in this process involves drilling holes for installation, culminating in welding the input hopper's parts together. The manufacturing process for the output hopper is similar to that of the input hopper, with the same steps starting with marking, cutting, forming, drilling, and welding. Moving on to manufacturing the motor mounting plate, the process begins with marking the plate, which is then cut using a bending process to form the plate to the required size. Next, the process involves drilling holes to mount motor components and creating slot grooves using the quickie technique [16]. We then connect the motor mounting plate to the machine frame via SMAW welding. Likewise, the reducer mounting plate follows the same steps: marking on the plate, cutting, drilling holes, making slot grooves, and finally welding to the machine frame. Finally, the manufacture of the Pulley begins with cutting the material to the required size. After that, we turn the material using a lathe to achieve the desired shape and size. The pulley manufacturing process ends with finishing to ensure the pulley surface is smooth and ready for use. Each stage must ensure that all plastic bottle shredder machine components function optimally and efficiently.

3. Result And Discussions

We obtained a design concept for optimizing the plastic bottle shredding machine based on assessing alternatives and their combinations. The design concept aims to enhance the machine's efficiency and performance in plastic bottle shredding. Figure 1 illustrates the design concept, showcasing 17 primary components of the machine. Each part in the picture serves a specific function, working together to achieve optimal goals in shredding plastic bottles. You can find information about each part by following the numbers listed in the picture, which clearly explains each component's role and contribution to the overall system. With this integrated design, we expect the plastic bottle shredding machine to operate effectively and meet user needs.

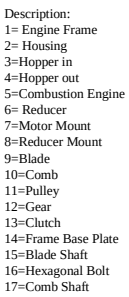

Fig 1. Design Results

3.1. Machine Construction Manufacturing Process

Making the machine frame begins with preparing the materials and tools needed for construction. Typically, we use iron angles due to their strength and stability. After all the tools and materials are available, the first stage marks the angle according to the dimensions in the working drawing. This marking is essential to ensure that each cut will match the planned dimensions. After marking, the next step is to cut the angle using a cutting wheel grinder according to the length specified in the working drawing. Careful cutting ensures precise and clean resulting cuts. After completing all cuts, the next step involves connecting the pieces using the welding process. Following the specified design, this welding process aims to form a sturdy and stable frame. After welding the frame, we must smooth out any sharp parts or untidy welding results to prevent potential injuries. We use a hand-grinding machine with a sharpening cutting blade to carry out this process, ensuring a smooth and safe finish. After all stages are complete, the machine frame will be ready for use by the specified working drawing, providing a robust and reliable structure to support other machine components.

Fig 2. Making the Frame

The hopper manufacturing process begins with preparing the necessary materials and tools. The design guides the formation of a plate into a hopper, which serves as the primary material. The first step is to mark the plate according to the dimensions stated in the working drawing. This marking is essential to ensure that each cut and shape produced is accurate and according to specifications. Once the marking is complete, a hand-grinding machine cuts the plate to the specified size. The plate undergoes bending to shape the desired hopper parts after the cutting process. We will file the sharp edges of the cuts at this stage to prevent any danger during the assembly process. Once we confirm the safety of all corners and edges, we drill rivet holes using a hand drill to secure the hopper parts. Once we drill the rivet holes, we use rivets to fasten the plates. This binding process aims to unite all hopper components into a solid and stable unit. Upon completion of all stages, the resulting hopper will conform to the specified working drawings, be ready for installation in a plastic bottle shredder, and function as intended.

Fig 3. Making Hopper

3.2. Motor Mounting Plate

The component manufacturing process begins with preparing the necessary materials and tools. We use a plate as the primary material, forming it according to the specifications in the working drawing. The first step is to mark the plate according to the size stated in the drawing. Once the marking is complete, a shearing or bending machine cuts the plate to the specified length. This cutting ensures that each part has the correct size before proceeding to the next stage. After cutting, the next step is to drill to make bolt holes. We use a table drill with a diameter corresponding to the required hole size in the workpiece for drilling. This process is essential to ensure the resulting hole is accurate and ready for installation. In addition, the slot groove is made using a Quickie machine according to the length specified in the working drawing. The creation of this slot groove aims to facilitate the process of fastening and installing components into the machine. A hand-grinding machine will remove sharp edges or untidy slot grooves after all these stages. This smoothing process ensures

that all edges and corners of the component are safe to hold and do not pose a danger during the assembly process. Finally, we carry out welding to install the motor mounting plate on the machine frame, ensuring the proper function of this component in the plastic bottle shredding machine system.

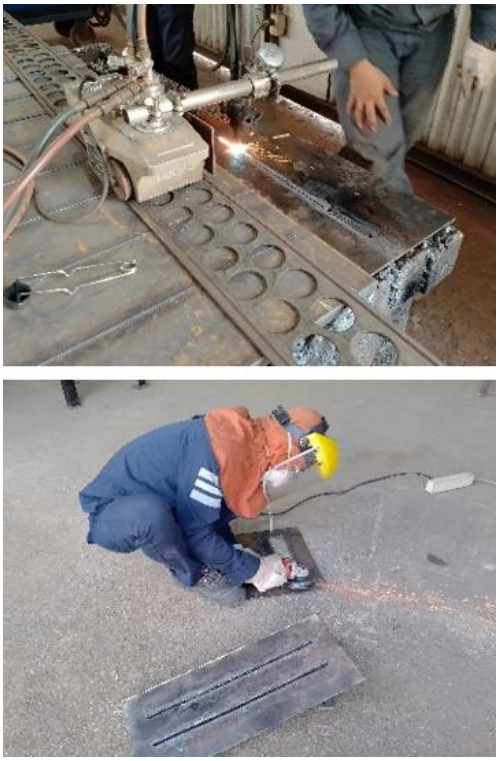

Fig 4. Motor Mounting Plate

3.3. Making Pulley

The pulley manufacturing process begins with preparing the necessary materials and tools. The aluminum round bar was chosen because it is lightweight and durable. The first step is to mark the round bar according to the dimensions in the working drawing. This marking is crucial to guarantee accurate cutting placement. Once the marking is complete, we use a bench saw machine to cut the round bar to the specified length in the working drawing. We carefully conduct this cutting process to ensure the results meet the required specifications. Next, the cut round bar enters the turning stage. At this stage, we use a lathe to shape the Pulley according to the dimensions and shapes specified in the workpiece drawing. This turning aims to achieve the correct dimensions and ensure a smooth pulley surface. Upon completing all stages, we will check the resulting Pulley to confirm that all dimensions align with the specified workpiece drawing. This process is essential to ensure that the Pulley can function adequately in the plastic bottle shredder system, meet the expected quality standards, and be ready for use in machine assembly.

Figure 5. Pulley Manufacturing Process

3.4. Calculation of Material and Machine Element Strength

When designing a plastic bottle shredder machine, it's crucial to calculate the power or torque on the shaft that connects to the cutting edge or blade. The machine's ability to process hard and dense materials like plastic bottles directly depends on torque, one of the critical parameters that affect its cutting performance. In this construction, the cutting axis is connected to the gear using a 1:1 ratio, which means that the torque generated on the blade axis will be the same as the output torque from the reducer. The reducer's output torque of 870,390 Nmm corresponds to the same torque on the blade axis. This demonstrates the optimization of the torque transmission design in the gear system, which ensures the efficient transmission of the motor's power to the cutting edge. The machine operates more stably due to this 1:1 ratio, as the cutting edge directly follows every rotational movement without any reduction or increase in speed that could

potentially interfere with the cutting process. In addition, accurate torque calculations are essential to ensure the safety and reliability of the machine. Knowing the torque that the shaft and cutting edge must withstand, engineers can determine the correct material and dimensions for the shaft and ensure that the other components can work harmoniously in the system. To ensure optimal operation and long service life, engineers must also consider further evaluation and analysis of the material's strength and potential external factors that may affect the machine's performance.

3.5. Designed Products

Figure 6 below illustrates the successfully assembled product design. This image displays the neat and functional installation of all plastic bottle shredder machine components. The meticulous assembly process and the use of suitable materials guarantee this machine's aesthetic appeal and its ability to operate by the established specifications. We designed this machine to meet various plastic bottle processing needs efficiently and effectively. After a series of tests, this machine has proven to function well, producing shredded plastic bottles that meet the expected standards. With optimal operational capabilities, this machine can assist in recycling, which is crucial in reducing plastic waste and protecting the environment. The success of the assembly of this machine is a significant step toward implementing environmentally friendly technological solutions. By utilizing innovative design and proper manufacturing techniques, this machine not only functions mechanically but also has a positive impact on plastic waste management in the community. We expect this machine to find widespread use in the recycling industry and integrate into a broader sustainability initiative.

Fig 6. Designed Product

The plastic bottle shredding machine begins with preparing the necessary tools and materials. Ensure the availability and readiness of all equipment, including the plastic bottles for shredding, at this stage. A thorough inspection of the machine's condition must ensure it has enough fuel to operate. Preparing all the necessary tools and materials ensures a smooth and effective shredding process. After the preparation, the next step is to turn on the machine and set the rotation speed as needed. Depending on the machine type, the operator can start by pulling the lever or using a combustion engine starter. After running the machine, the operator must set its rotation speed using the available controls or levers. To ensure optimal shredding of plastic bottles without compromising the quality of the shredded results, it is crucial to set the rotation speed correctly. Next, plastic bottles are fed through the hopper (input) to initiate shredding. To ensure the machine operates effectively, the operator must correctly feed the bottles, either one by one or several at once. The shredding process will take 1 to 5 minutes, depending on the number and size of bottles fed. The operator must monitor machine performance to ensure that no obstacles or disturbances affect shredding results. After shredding the plastic bottles, the machine's hopper will automatically release the shredded results. The operator needs to prepare a container to accommodate the shredded output. After taking the shredded results, it is essential to check the size to ensure it is as expected. After completing the process, please turn off the machine and clean it to remove any remaining shredded material from the cover area and surrounding areas. This cleaning is essential to keep the machine in excellent condition and ready to use for the following shredding process and to prevent potential fires due to remaining fuel.

Figure 7 below shows the shredded results of plastic material that the shredding machine has processed. The shredded results reflect the efficiency and effectiveness of the machine in processing plastic bottles into small flakes. The shredded flakes are consistent in size, indicating that the machine functions correctly according to the expected specifications. Processing this plastic material is crucial for supporting recycling efforts and managing plastic waste, enabling the reuse of the shredded results in various applications like product creation or material mixing. The success of the shredding process also shows the potential of the machine to increase the efficiency of plastic processing, which can contribute to environmental sustainability. Figure 7's shredding results demonstrate the well-executed design and construction of the shredding machine, resulting in output that meets industry standards. This process not only helps reduce the volume of plastic waste but also provides opportunities to reuse shredded materials, making them more valuable and environmentally friendly.

Fig 7. Plastic Shredding Results

4. Conclusion

This research has successfully developed a more efficient and innovative plastic shredder, marking significant progress in waste management technology. A specially designed rotary knife technology equips the machine for precision cutting, ensuring uniform shredding results that meet recycling needs. In addition, the updated transmission system reduces vibration during operation, thereby increasing user comfort and safety. The results of the performance trials show that the developed shredder can meet the research objectives: to efficiently shred plastic bottles into small pieces quickly. We carried out the design and manufacturing process of the machine systematically and effectively, paying particular attention to technical details and the product's final quality. We carefully planned every step, from material selection to component assembly, to ensure optimal machine operation. This approach focuses on machine performance, durability, and ease of maintenance, which are essential aspects for long-term use. The success of this shredder lies not only in improving the quality of plastic recycling results but also in significantly reducing operational costs. With higher efficiency, users can reduce expenses related to plastic waste management. In addition, this machine also contributes to reducing greenhouse gas emissions, supporting efforts to achieve environmental sustainability targets. We expect this plastic shredder machine to significantly reduce plastic waste in Indonesia and support environmental conservation efforts. We hope this innovation can serve as a model for developing other waste management technologies, bolstering the recycling movement, and fostering positive impacts on the ecosystem and society.

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