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Design of a Plastic Waste Shredder Machine for the Processing of Inorganic Waste at TPS3R in Kudus Regency

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ABSTRACT

In 2022, Kudus Regency produced 4,300.52 tons of inorganic waste, primarily plastic. A plastic waste shredder machine was designed to address this issue at Integrated Waste Processing Sites (TPS3R). This research aims to reduce the volume of plastic waste sent to landfills and increase the economic value of recycled materials, ultimately enhancing waste management efficiency in Kudus Regency. This study employed an Ergonomic Anthropometry method to create a user-friendly design based on the physical characteristics of workers. The machine was tested at TPS3R Rendeng and successfully shredded plastic waste into small pieces, facilitating the recycling process. The machine, with a shredding capacity of 35-40 kg per hour and a maximum shred size of 15 mm, was developed using ergonomic anthropometric data from TPS3R workers. The design features a frame height of 106 cm, a width of 78 cm, and a length of 170 cm to ensure optimal usability. Additionally, this plastic shredder contributes to more efficient waste management in the Kudus Regency by reducing the load on landfills and supporting more sustainable recycling efforts.

1. Introduction

As time progresses, the issue of plastic waste has become a frequent topic of discussion in society, particularly regarding its environmental impact. In developing countries like Indonesia, the amount of waste generated is extremely high, corresponding to a large population, but its management is still suboptimal. In Indonesia, plastic waste is generally only buried in landfills (TPA), including in Kudus Regency.

Plastic waste is an inorganic material that has various benefits but can also cause significant negative impacts if not managed properly. Plastic waste buried in the ground is very difficult for microorganisms to decompose, leading to a gradual reduction in both organic and inorganic mineral content in the soil. This complicates the ability of soil fauna, such as worms and other microorganisms, to find food and shelter [1]. One solution to this problem is recycling. Recycling is a process that transforms waste into new products, reduces waste, decreases the use of new raw materials, and mitigates pollution. Before plastic can be turned into useful new forms, it needs to be shredded into pellets to facilitate further processing [2]. The results of this recycling can be reused to produce plastic-based products [3]. This transformation process is carried out through the shredding of plastic waste.

In Kudus Regency, before waste is transported to the landfill (TPA), it is managed at Integrated Waste Processing Sites (TPS3R) to reduce the residue sent to the TPA. Currently, Kudus Regency has four large-scale TPS3R managed by the Housing, Settlements, and Environmental Service of Kudus Regency. According to Permen PU No. 03 of 2013 on the Organization of Waste Management Facilities, TPS3R is a location for activities such as collection, sorting, reuse, recycling, processing, and final waste treatment.

The main concept of waste management at the 3R Waste Management Site (TPS3R) is to reduce the quantity and/or improve the characteristics of waste that will be further processed at the Final

Processing Site (TPA). The general method of waste management involves collecting and transporting waste residues from the 3R Waste Management Site (TPS3R) to the Final Processing Site (TPA) or directly from the location to the TPA [4]. TPS3R is expected to help meet the increasingly limited land needs for waste disposal sites in urban areas. Therefore, the role and function of TPS3R are very important in achieving better waste management [5]. According to data from Busadipah (Waste Management Paid with Waste) from the Kudus PKPLH Office, the inorganic waste produced by the Kudus Regency reached 4,300.52 tons in 2022. Therefore, waste processing or reduction efforts at the TPS3R stage are necessary to minimize the residues sent to the TPA.

The lack of tools or technology for waste management has resulted in waste processing needing to be optimized. Advances in science and technology in the modern era have led to the creation of more efficient machines [6]. The implementation of waste reduction, especially plastic waste, at TPS3R currently requires waste processing technology, such as shredding machines. Shredding machines are designed to break down both organic and inorganic waste into smaller pieces for further processing [7]. Therefore, the presence of shredding machines, particularly for plastic waste, is crucial to support waste processing at TPS3R.

The design of work tools is closely related to ergonomic principles. If these rules are ignored during the design process, the tools will not be ergonomic and may have negative consequences for the users. Ergonomics is the science, art, and application of technology aimed at balancing or aligning all facilities used for activities and rest with human physical and mental limitations [8]. On the other hand, anthropometry is a science focused on determining human physical characteristics. Humans vary in weight, shape, and size (such as height and width) [9]. This research is conducted so that TPS3R Kudus can obtain the design of a plastic waste shredding machine that is suitable for the size of the operators, easy to use, flexible, and can be further developed in the future. This is because, generally, machines sold in the market are less suitable in size, not flexible, and challenging to develop as they require permission from the manufacturer or would need significant design modifications. The objective of the object is to obtain relevant data for the design process of the plastic shredding machine to conduct ergonomic anthropometric measurements of the staff at TPS3R in Kudus. This study aims to design an ergonomic plastic shredding machine to reduce plastic waste at TPS3R in Kudus.

2. Methods

The research methodology serves as a guide for conducting a study, designed to ensure that the research process runs smoothly and as planned, as seen in Figure 1. In this study, the method used is Ergonomic Anthropometry. Anthropometry is a crucial tool in product development and redesign, as it considers variations in body size among populations, genders, and ethnic groups. Adjusting product designs based on these factors can challenge system or tool designers [10].

After obtaining the ergonomic anthropometric data, the next step is to design a plastic waste shredder. Product design involves several stages in creating a product, including determining the model, size, and colour to meet consumer needs [11]. This process consists of several steps: identifying needs, designing product concepts, product design, and document preparation [12]. Before proceeding with the design, it is important to develop a concept that will yield various options aligned with the objectives. Designers can choose the best alternatives after evaluating and analyzing each option [13]. To ensure that the research runs smoothly and aligns with the objectives, a research flow needs to be established, which will be explained next.

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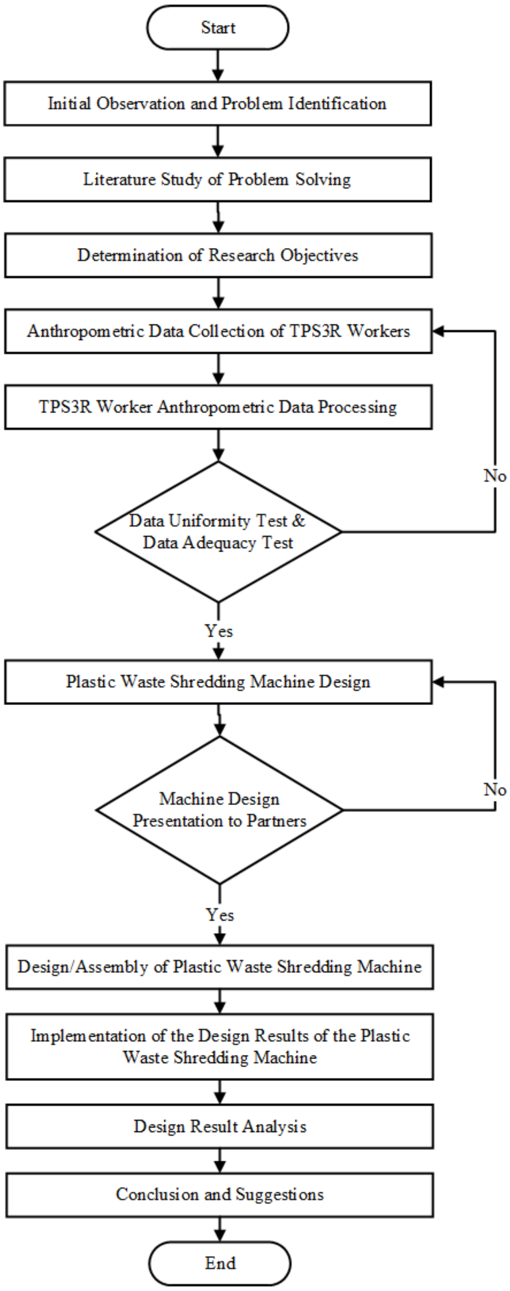

Figure 1. Flowchart of Research

3. Results and Discussions

3.1. Ergonomic Anthropometry Data Measurement

Anthropometry is a crucial tool in the process of product development and redesign, taking into account differences in body sizes across various populations, genders, and ethnic groups. Adapting product designs to these factors can be challenging for system or tool designers [10]. The anthropometric dimension reference used in this research is based on the sources listed in the bibliography used during the study. The anthropometric dimensions are closely related to the position of the operators using the plastic shredding machine. The following in Table 1 are the results of the ergonomic anthropometric measurements obtained from the study.

Table 1. Anthropometric Dimensions Used and Measurement Result Data

No	Measurement	Anthropometric Dimensions	N (Person)	Total (cm)	Average (cm)	Information
1	Standing Elbow Height	TSB	35	3670	104.86	Determining the height of the machine frame
2	Hand Reach	JT	35	2716	77.60	Determining the width of the machine
3	Hand Stretch	RT	35	5917	169.06	Determining the length of the machine
4	Standing Shoulder Height	TBB	35	4699	134.26	Determines the overall height of the machine

3.2. Percentiles of Anthropometric Data Used and Reasons for Selection

In the analysis of the required body size data, the percentile results and the reasons for selecting the dimensions and percentiles used are explained in Table 2. Percentiles represent a certain percentage of a group with dimensions higher, equal to, or lower than the given value. This approach allows for the development of tools that are adaptable and flexible. Percentile values obtained from various anthropometric measurements are commonly applied in ergonomic design. Calculating percentiles is a relatively simple statistical process [14]. The 95th percentile indicates that 95% or less of the sampled population is represented [15]. The 5th percentile shows that 5% of the sampled population falls at or below that value.

Table 2. Selection of Percentiles and Reasons for Choosing Them

No	Anthropometric Data	Percentile 5	50	95	Reasons to Use Percentiles
1	TSB (Standing Elbow Height)	100	106	109	Using the 50th percentile because the average data is 104.86 and so that the height of the machine frame can match the elbow height of the TPS3R worker when standing.
2	JT (Hand Reach)	75	78	80	Using the 50th percentile because the average data is 77.60 and so that the width of the machine can be in accordance with the reach of the TPS3R worker's hands.
3	RT (Hand Stretch)	162.1	170	175	Using the 50th percentile because the average data is 169.06 and so that the length of the machine can match the length of the TPS3R worker's arm span.
4	TBB (Standing Shoulder Height)	128	135	141.3	Using the 50th percentile because the average data is 134.26 and so that the overall height of the machine can match the shoulder height of the TPS3R worker when standing.

In this selection of percentiles, the overall chosen percentile is the 50th percentile. The reason for this selection is that the average value obtained is close to the calculated 50th percentile value. The dimensions applied in the design are made to ensure that the machine can be used by all workers at the TPS3R in Kudus Regency. Additionally, the design must also be compatible with the body sizes of the workers and reflect the majority size of the TPS3R worker population in Kudus Regency.

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3.3. Anthropometric Data Sufficiency Test

The data sufficiency test aims to assess whether the collected data is adequate or not. This process is conducted for each dimension used in the design of the plastic shredding machine. According to [10], the levels of accuracy and confidence are as follows in Table 3.

a. Level of Trust : K:95% =2
b. Degree of Accuracy : S:10%

$$N' = \left[\frac{k/_{s}\sqrt{N\sum X^2 - (\sum X)^2}}{\sum X}\right]^2 \quad (1)$$

Table 3. Results of the Data Sufficiency Test

No	Anthropometric Data	X bar ($\bar{X}$) (cm)	Standard Deviation (cm)	N (Person)	N'	Data Sufficiency Test Results
1	TSB (Standing Elbow Height)	104.86	2.85	35	1.15	Sufficient Data
2	JT (Hand Reach)	77.60	1.80	35	0.84	Sufficient Data
3	RT (Hand Stretch)	169.06	4.28	35	0.91	Sufficient Data
4	TBB (Standing Shoulder Height)	134.26	4.05	35	1.42	Sufficient Data

Based on the analysis of the anthropometric data adequacy test, it was found that all anthropometric data used consisted of 35 samples, and all were classified as adequate after testing. This is because the determination of data adequacy is assessed based on the values of N and N'. If N' < N, then the data is considered adequate and can be used in the research. Therefore, the anthropometric data is ready for use and does not require further data collection.

3.4. Anthropometric Data Uniformity Test

The uniformity testing of data is conducted using control charts, which are suitable tools for analyzing the uniformity of observational data [16]. The purpose of this uniformity test is to determine whether the obtained data shows uniformity or not. The uniformity of the data is determined based on whether the data values fall within the upper control limit (UCL) and the lower control limit (LCL).

The following is the formula for calculating UCL and LCL in data uniformity testing.

$$\text{LCL} = \bar{x} + k\sigma \quad (2)$$

$$\text{UCL} = \bar{x} - k\sigma \quad (3)$$

Information:
$\bar{x}$ = The average value of the data used
K = Level of confidence (The value of K used is 2)
σ = Standard deviation of the data used

Table 4. Results of the Data Uniformity Test

No	Anthropometric Data	N (Person)	UCL (cm)	LCL (cm)	Average (cm)	Data Uniformity Test Results
1	TSB (Standing Elbow Height)	35	110.33	99.39	104.86	Uniform Data
2	JT (Hand Reach)	35	81.20	74	77.60	Uniform Data
3	RT (Hand Stretch)	35	177.25	160.87	169.06	Uniform Data
4	TBB (Standing Shoulder Height)	35	142.36	126.15	134.26	Uniform Data

The analysis of the anthropometric data uniformity test in Table 4 revealed that all the anthropometric data used consisted of 35 samples, and all were classified as uniform after testing. This is because all the data had average values that did not exceed the upper control limit (UCL) and the lower control limit (LCL). Therefore, the anthropometric data is ready for use and does not require additional data collection or adjustments.

3.5. 2D Design of a Plastic Waste Shredding Machine

A 2D drawing is an initial illustration of a product design that includes length, width, and height dimensions. The sketching process is crucial as it depicts the form and dimensions of the design in detail and presents views from various angles, as shown in Figure 2. This helps minimize the likelihood of errors or failures in the product manufacturing process. Therefore, a 2D sketch is an essential step in product development, serving as the foundation for creating a 3D model of the product or its components. Below is the 2D drawing of the plastic waste shredding machine.

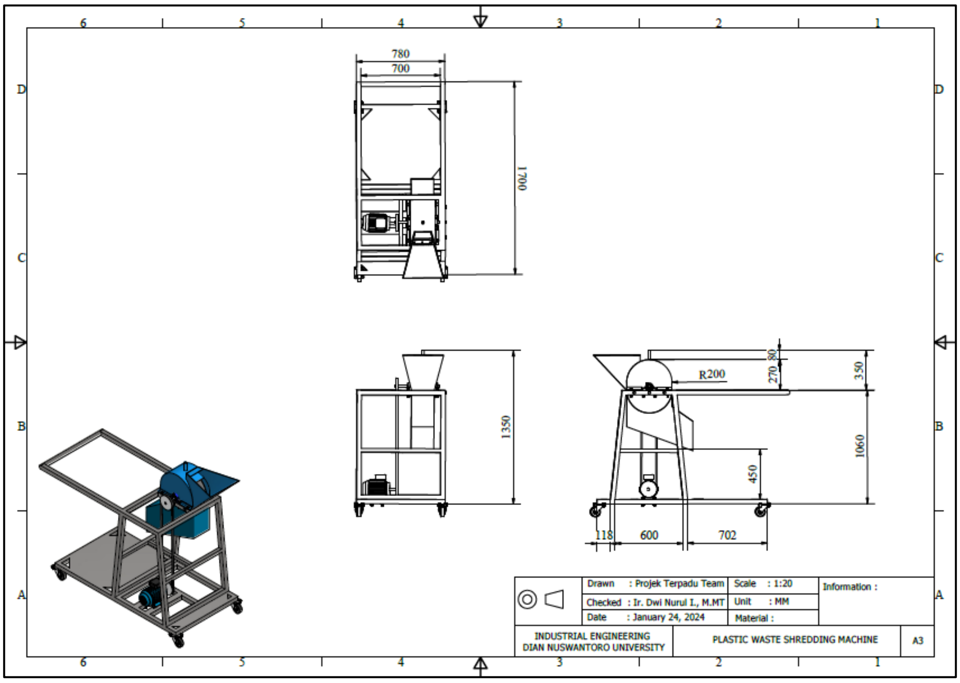

Figure 2. 2D Design of a Plastic Waste Shredding Machine

3.6. 3D Design of a Plastic Waste Shredding Machine

A 3D drawing is a visual representation of a product design that displays dimensions, giving it a volumetric appearance similar to real-world objects. One advantage of 3D modelling in product development is that the design can be viewed from various angles and rotated 360 degrees. This allows for thoroughly evaluating product details, production cost estimates, and the overall design concept. This 3D design was created using Autodesk Inventor software. Figure 3 shows the 3D image of the plastic waste shredding machine.

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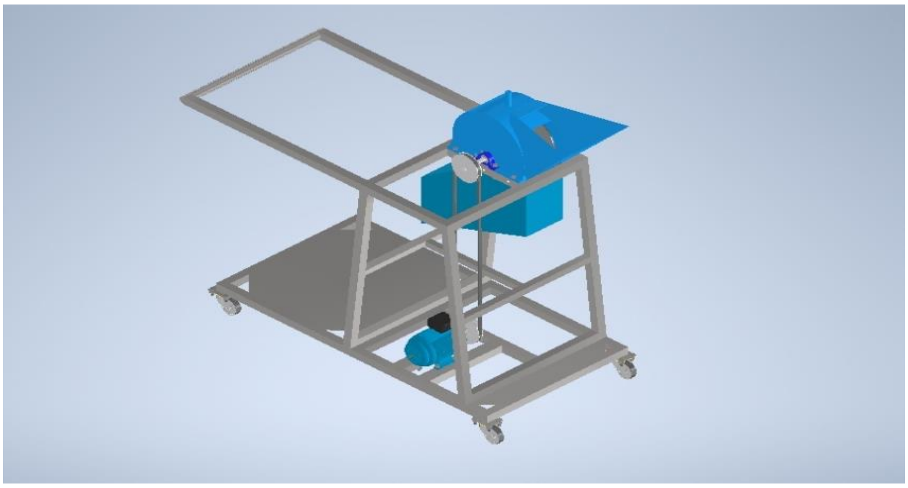

Figure 3. 3D Design of a Plastic Waste Shredding Machine

3.7. Implementation of the Plastic Waste Shredding Machine Design Results

The plastic waste shredding machine is designed using angle iron for the frame, lightweight steel plates for the upper and lower hoppers, steel plates for the shredder blades, and a 2 HP electric motor dynamo as its power source. The design process of the plastic waste shredding machine begins with the construction of the frame, upper hopper, and lower hopper as the main components, followed by the rotor, wheels, electric motor, bearings, and pulleys. During the design process, once the frame is completed, it is first equipped with driving wheels to facilitate the design process and allow the machine to be moved flexibly. Precision during the assembly stage is crucial to ensure all parts fit correctly. This machine is designed for portability, equipped with wheels and a detachable handle, and can shred plastic at 35-40 kg per hour. The trial was conducted on January 15, 2024, at TPS3R Rendeng in Kudus, starting with sorting plastic types, followed by using the machine, resulting in tiny shreds measuring less than 15 mm, as shown in Figure 4. This research aims to enhance the economic value of waste and reduce the burden on the final processing site.

Figure 4. Implementation of the Plastic Waste Shredding Machine Design Results in TPS3R Kudus

4. Conclusion

The plastic waste shredding machine is designed using angle iron for the frame, lightweight steel plates for the hopper, steel plates for the blades, and a 2 HP electric motor dynamo as its power source. The design process begins with the construction of the frame and hopper, followed by the rotor, wheels, motor, bearings, and pulleys. This plastic waste shredding machine is designed to reduce the amount of plastic waste, with dimensions based on the 50th percentile of anthropometric data. The machine's dimensions include a frame height of 106 cm, a width of 78 cm, a length of 170 cm, and an overall height of 135 cm. The shredding capacity trial conducted at TPS3R Rendeng in Kudus resulted in a shredding capacity of 35 to 40 kg per hour with a maximum shred size of 15 mm. Furthermore, this research on the plastic shredding machine supports TPS3R Rendeng in enhancing the economic value of waste and reducing the burden on the final processing site (TPA). Recommendations include increasing the literature on the design of the plastic shredding machine to maximize understanding and streamline the process. Moreover, collaborating with several partners can expand the design scope, making it more effective in reducing plastic waste generation at TPS3R.

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