Design and Modeling of Shredding Machine for Recycling Plastic Waste

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Abstract—**Coronavirus 2019 (Covid-19) pandemic affects the plastic waste management all over the world. Plastic waste from medical field such as surgical mask and personal protective equipment is massive. Improper management of the plastic waste that comes from the medical field especially from the covid-19 patient may lead to negative impact not only for the human health but also for the environment. There are several strategies to improve the plastic waste management, one of them is to recycle the plastic waste. A plastic shredder is a machine used for cutting plastics into smaller parts called granules or pellets. The focus of this paper is to design a shredding machine used for recycling plastic waste. The outcome of this shredding machine can be used for subsequent plastic processing machine such as extrusion and injection machine. The proposed design is prepared using 3D computer aided design (CAD) software and use several sources on the market to make improvements. This paper covers the design, material used and strength analysis of the machine.**

Keywords—Shredding Machine, Plastic Waste, Recycle, Covid-19 pandemic, Design and modelling

I. INTRODUCTION

The amount of plastic waste produced in the world especially in Indonesia is keep increasing. Indonesia currently produces 6.8 million tons of plastic waste per year and only about 10% of it ending up in recycling centers [1]. The plastic waste impacts multiple environmental and economic issues. Some plastic materials are hard to be degraded in the soil. It can take years to be degraded. Furthermore, some plastic materials are difficult to be dissolved in the water. The un-recycle plastic waste piled up on the landfill and some drive away into the ocean.

Plastic waste management in many countries is highly impacted due to the COVID-19 pandemic [2]. Medical wastes especially from plastic such as mask and personal protective equipment lead to the global waste management crisis. Inappropriate management of plastic waste can affect not only to the human health but also to the environment. In addition, to promote health and hygiene lifestyle and protocol due to Covid-19 pandemic, the use of plastic is estimated to increase by 40% in packaging sector and 17% in other applications [3].

In the case of medical waste, the waste needs to be specially treated such as disinfected before it is returned to the environment. Therefore, in order to prevent contrary effect caused by unwanted part disposal process and to minimize the waste disposed to the environment, the simpler and cost effecting plastic recycling system needs to be developed. Simpler and cost effective plastic recycling system may come as a solution in plastic waste management [4].

One of the machines in the plastic recycling system is shredding machine. A shredding machine is a machine used for cutting plastic waste into smaller parts called granules or pellets. During the shredding process, the plastics waste are fed into the shredder and the blades break down the plastic into smaller pieces. Such outcomes are then stored and can be used for the subsequent plastic forming process such as extrusion machine or injection molding machine or send to industries [5]. The injection molding machine offers many advantages because of the ability to produce complex shapes for mass production, high productivity with minimal losses from scrap, and minimal finishing requirements.

This paper focusses on the development of simple and cost-effective plastic shredding machine for various types of plastics especially medical grade plastics. The basic design is adapted from the reference [6]. In this paper, the basic design is modified, developed and constructed using 3D computer aided design (CAD) based on engineering specifications and specific conditions especially the user in Indonesia. The required items to construct the design will be listed and defined. Finally, strength analysis of the proposed design will be conducted. It is expected that this design can be used for recycling plastic waste especially related with the medical grade plastic waste.

II. Methodology

A. Design Process

The design is developed based on shredding machine available in the market. However, the design is then adjusted to fulfill certain needs and criterions. This design process is important to ensure that the materials from the required components are available and affordable in the market. The development of design is conducted using 3D CAD software.

The design process began with determination of the shredding machine dimensions. The dimensioning process involves measuring the detailed dimensions of each part of the shredding machine and the common space to place this machine. The precise dimensioning that has been determined for the design will then be processed further. The proposed precise dimensions are then projected and implemented by creating the 3D design of the shredding machine using Solidworks and Fusion360 software's.

B. Material Selection

Finding, selecting, and evaluating materials are importance processes. A good product especially engineering product not only needs to have good technical function but also made from compatible material properties. There are various materials possible to be used for shredding machine. Selecting the right material in product design should consider both technical and industrial needs. Selecting lighter materials to substitute the standard materials need to be followed by comparable performance especially the strength [7].

Selecting the suitable materials is important and not an easy job in product design. In terms of the general factor, the component size, the weight, and precision required should be considered in material selection process. Divergent properties and characteristic of the material need to be considered in material selection process. The other factor such as the price and the availability in market also play big role in material selection process.

C. Strength Analysis

Strength analysis plays an important role in product design process [7]. Strength analysis in the development of shredding machine is used to find the minimum safety factor for the specific components. Safety factors is used as risk assessment to express how stringent the design of the product.

In this project, strength analysis is carried out on specific components that are critical for the strength of their design and material selected. The strength analysis was carried out using two methods: by manual calculation and with the help of software.

III. Result and Discussion

A. Design of the Sheredding machine

The proposed design of shredding machine has overall dimension of $1205 \times 650 \times 1512$ (mm). One of the criteria for the dimension size is the machine height. The height especially the location of the hopper is adjusted according to the average adult height of Indonesia people. The required torque for the motor of the machine is 1100NM-3000NM. The shredding machine has four main components which are the shredder, the frame, the pusher and the hopper. It has built-in storage that can be easily modified by adding the bag. In addition, this design also comes out with sieve to filter different granules and pellet sizes. Hence, it can easily remove and clean. Figure 1 shows the overall design of the shredder machine.
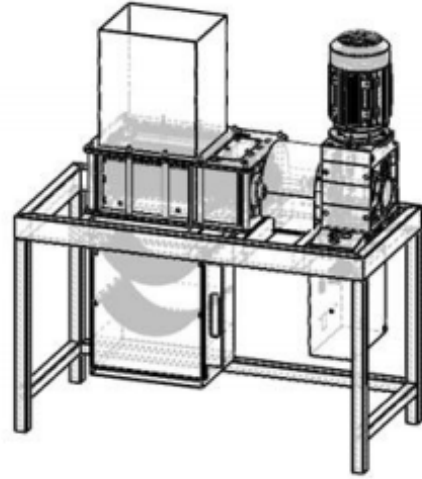

Figure 1. Overall Design

Moreover, the design is lightweight and requires low maintenance. The proposed shredding machine has a greater number of blades than other machines in the market. This implies that it has bigger shredding area and can crush and shred the plastics into smaller pieces.
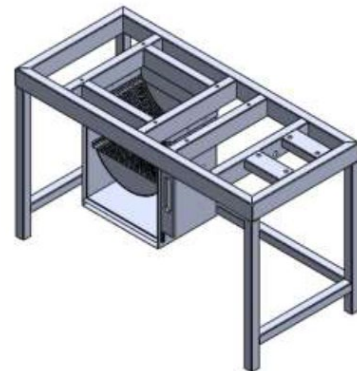

Figure 2. Frame, sieve and collector design

The frame design is shown in Figure 2. The frame is important as the support for the shredder. In addition, the sieve and granules collector are attached on the frame.The pusher is designed to push the plastic into the hopper and passed on to the shredder to destroy the plastic faster and easier due to external force by the operator. The pusher is controlled directly by the user. The force of the pusher comes from the strength of the user. Hence, the pusher design should be comfortable for the user. Figure 3 shows the pusher design.
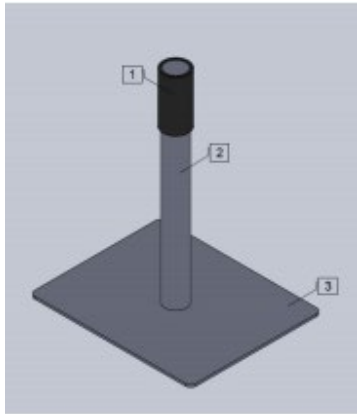
Figure 3. Pusher design

The body of the pusher is directly in contact with the user and the bottom plate is in direct contact with the plastic and push it to the shredder. Its dimensions must also be adjusted to the availability of materials on the market.
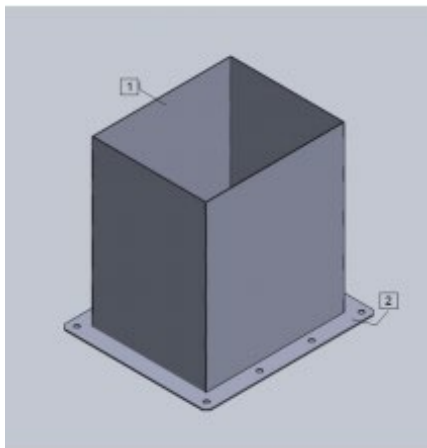

Figure 4. Hopper set

A hopper is a part of the machine that plastic must pass to be fed into a plastic shredder. The design of the hopper is a box to make pusher can get more leverage to enter the hopper until the bottom part. The bottom plate in the hopper is also needed to unite the hopper with the shredder box, by using the shaft and the rod. Figure 4 shows the design for the hopper set. Accessories such as the sieve and granules collector are added into the frame parts. The design of sieve and plastics granules collection is shown in Figure 5.
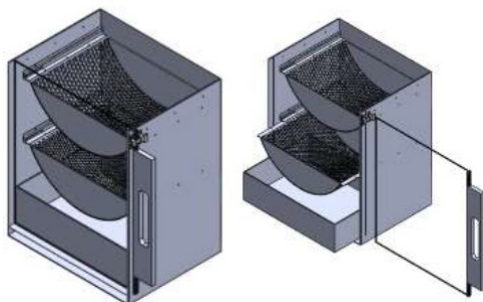

Figure 5. Sieve and collector components

B. Material Selections

There are several materials used for the shredding machine. The materials are choose based on the use of each component in the machine. The material is decide based on several point of view, such as the characteristic, the economical point of view and the availability on market. The material selections are divided into four main components of the machine, which are frame, drawer, pusher and hopper set.

1) Frame

The frame is the essential part of the shredding machine. The frame needs to be strong enough to carried out the shredding machine and the added weight such as the force that user given when using the machine. The selected material for the frame or the table is steel material in the shape of square hollow. Steel is selected because of its characteristics especially the strength, availability in the market and the price.

2) Drawer

The main material for the drawer of the plastic shredding machine is made of carbon steel. Carbon steel is selected due to its strength and easy to be manufactured. Moreover, from the economical point of view, the material is also affordable. Hence, the cost of the machine can be lowered. Carbon steel is also selected as main material of the drawer machine because of the board availability in market. Table 1 summarize the component and material for the drawer.

Table 1. Drawer Component and Materials

Components	Material
Outer case	Carbon steel
Mesh	Carbon steel
Sliding door	Acrylic

3) Pusher

The pusher consists of two parts (handle and bottom plate) are made of the same material, namely PVC (Polyvinyl chloride). PVC material is preferred over steel because steel is too heavy to be a pusher, about 5 kilograms. In the ergonomic aspect, it will be very uncomfortable to use.

There are only two manufacturing processes used in this component, drilling and gluing. Drilling is used for perforating the bottom plate according to the cylindrical diameter of the PVC. Then the gluing process is used to join the handle and bottom plate.

4) Hopper set

The hopper consists of two kinds of plate sizes, which are the right-left plate (400x300x1.5 mm) and the front-back plate (400x400x1.5 mm). The hopper set is all made of

carbon steel with different sizes. The bottom plate hopper that joins the hopper and shredder is also made of carbon steel in the sheet form. However, to make holes in the desired shape, a milling process is needed. In addition, a welding process is needed to join the edges from the sized plates and make a complete hopper set. After the whole hopper set has been combined, the last fabrication process that needs to carry out is a coating process. This coating is used to avoid corrosion and rust easily. Paint coating method is used because it is simpler and cheaper.

C. Strength Analysis

The strength analysis is carried out on the specific components of the machine. The components are essential parts when the user operating the machine. The strength analysis is conducted using software with manual calculation check. The software used in this analysis is Fusion360.

1) Frame

Strength analysis is needed on the frame or the table to confirm the proposed design is suitable with the needs. This frame or table is expected to withstand the weight of a reasonably heavy machine; therefore, it is necessary to test its strength. The analysis found that the safety factor from this table is 5.26, and it is sufficient to support the load. This number means that the design is not expected to bend or break in condition that has been setup. Figure 6 and Figure 7 show the result of the strength analysis for the frame.
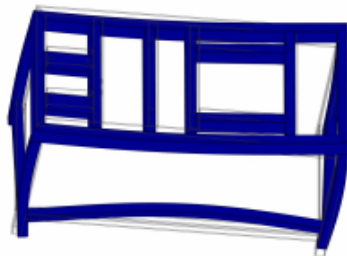

Figure 6. Safety factor analysis result for frame
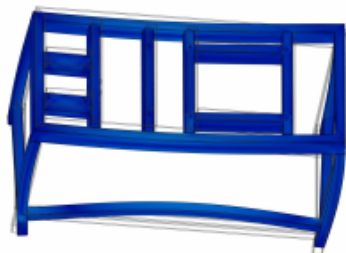

Figure 7. Von mises analysis for the frame

2) Pusher

Strength analysis is required on the pusher specially to confirm the design and the selected material is correct. The goal is to test whether the PVC is strong enough to withstand the thrust given by the operator and the feedback that the plastic gives when it enters the shredder. The analysis found that this pusher's minimum safety factor is around 3.06 and that the load given should not exceed 150 N. Figure 8 shows the result of the strength analysis for the pusher. This result can be accepted because the load given by the user is not exceeding 150 N.

Figure 8. Safety factor result for the pusher

D. Discussion

The proposed shredding machine for plastic waste is also equipped with additional parts such as built-in storage/sorter. The storage can be modified by adding some canvas bag to easily move/wash the plastic shred. The sieves to filter the granules and pellets size can be changed easily. This machine is also more efficient than shredding machine pro available in the market and more suitable for Indonesian user.

The main part contributes to the cost of the machine is the shredder box which depends on the numbers of blades or spacers. While other parts are considered not significant compared to the shredder box. Hence, the proposed shredding machine when combined with injection molding and extrusion machine as a recycling plastic system can be used for educations and small-medium enterprise (SME).

The system can be built for small-scale production to recycle plastic waste material into various plastic products. The cost of the setup is affordable for small to medium scale enterprise (SME) or *UMKM* (*Usaha Mikro Kecil Menengah*) and tertiary institutions for teaching and research purposes. Hopefully, the development of this machine is not only limited for reducing plastic waste but also able to create job opportunities and to generate economic activities for the community.

IV. CONCLUSION

The shredding machine as one of approach to recycle plastic waste has been proposed and developed in this paper. The 3D design has been created using 3D design software following many aspects such as the dimensions, materials and strength.

proposed design and model of the shredding machine as one of approach to recycle the plastic is achieved in this paper.

The design of shredding machine has overall dimension of $1205 \times 650 \times 1512 \ (mm)$. The torque for the motor of machine power is in the range of 1100NM-3000NM. The shredder has three main components which are the machine, the hopper and the pusher. The strength analysis shows that the machine is strong enough to be used.

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