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Optimization of a Low-Cost Shredder for Handling of PCB Wastes in a Community Scale

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Abstract: Waste banks are well-known community-initiated activities in Indonesia for collecting inorganic waste in neighbourhood areas, in an aim to reduce the volume of waste which goes to the landfill. The collected waste is then sold to industries which resell or reprocess the waste. It has been understood that the sustainability of waste banks depends a lot on the selling price of the waste. Especially for plastic waste, a shredded plastic waste could increase the selling price by almost two times. In this research, design and development of a low-cost shredder for plastic waste is carried out. The shredder with a capacity of +/-30 kg h^{-1} is installed and operated to aid a neighbourhood-level waste bank in Depok. The main shredding component consists of three rotating blades and two fixed blades. With the aid of a screen, the shredder is expected to shred plastic wastes to small pieces of 15 mm in dimension. A 6.5 hp gasoline engine with a transmission pulley are used as the power source. After the development, the performance is evaluated.

INTRODUCTION

Plastics nowadays have become commonly-used materials in every aspects of human being. Consequently, the concern over the plastic waste generated has also been arising steadily over the years. The waste originated from plastics have been reported to cause extensive pollution and environmental damages to rivers, oceans, etc.[1, 2]. As one manifestation of the concept of waste hierarchy, the campaign of reduce, reuse and recycle (3Rs) has been widely promoted, especially to the community from as early as 1970s. The 3Rs is expected to bring communal effort to reduce the amount of waste from its source.

Especially in Indonesia, the spirit of 3Rs had contributed to the rise of the "waste banks"[3]. Waste banks are well-known community-initiated activities in Indonesia for collecting inorganic waste in neighbourhood areas in an aim to reduce the volume of waste, especially plastic wastes which goes to the landfill. Depok, West Java is known as one of the pioneers of waste banks in Indonesia[4, 5]. As per 2017, according to the data from the municipal government there are more than 500 of waste banks in Depok, spread across the region[6].

The collected waste is then sold to industries which resell or reprocess the waste. In industry, the plastic waste such as a PET bottle is shredded and processed further into a form of plastic pellet. It has been understood that the sustainability of waste banks depends a lot on the selling price of the waste. Especially for plastic waste, a shredded plastic waste could increase the selling price by almost two times. Therefore, a plastic waste shredding machine[7] is an important equipment that could help boost the competitiveness of waste banks. However, the commercial machine is often too costly for a community-level waste bank unit. Many researchers had attempted to design and develop small-scale shredding machines which are deemed suitable for the context of developing countries such as in Haiti[8], Nigeria[9] and Indonesia.

In this research, design and development of a low-cost shredder for plastic waste for implementation in Indonesian waste bank is carried out.

MATERIALS AND METHODS

Design of components: The proposed low-cost shredder for plastic waste is aimed for a small-scale waste banks or other collectors. The targeted waste is of soft plastic categories such as PET, PP and PS. The machine is forecast to be able to shred with a capacity of 30 kg h^{-1}. Furthermore, the machine is designed to utilize locally-sourced materials, so that, the user will not be burdened much by the cost of maintenance. This consideration also contributes to cut down the production cost. Some specific design considerations are laid out as follows:

- Consist of two fixed knives and three rotary knives
- Have an adjustable knive gap
- Powered with Gasoline Engine and pulley-belt transmission system
- Have a changeable screen size for different plastic sizes
- Have a wheel caster for transport flexibility

Design of knives fixture: The knives are chosen to be manufactured using the material of SKD-11. SKD-11 is a high-quality metal often used for shredding machines. Its dimension is adjusted according to the dimension of available raw products in the market to ensure the production cost is kept at a low cost. However, some modifications are also made to make sure the targeted capacity of the machine is obtained. This material is also chosen due to its excellent hardness. The characteristic will allow user to sharpen the knives at an infrequent interval when in operation. Furthermore, the knives fixture is made from S45C material which is also used for the making of the shaft. The dimension of the knives and its fixture is designed such that the cutting principle of a scissor can be mimicked as close as possible. An additional feature considered is the ease to adjust the gap between the fixed knives and rotary knives. Figure 1 shows the designed fixed and rotary knives with their fixtures.

Design of main body: The main body of the shredder is made from the material SS400. The shape and the dimension are designed to conform to the shape the knives by also considering the principles of mechanical design and strength. The shaft is made of the material S45C with a diameter of 50 mm and a length of 580 mm, followed by a pillow block bearing type UCP-210 as the shaft holder. The shaft is coupled to a 6.5 hp gasoline engine and a belt-pulley transmission system. The main body including the knives and the fixture is shown in Fig. 2a.

Design of support structure: The support structure is made from the U-channel steel 50 because the dimension is suitable for placing the fixed knives. Aside from dimension, it also has an excellent strength which is deemed appropriate for the machine. The whole design is shown in Fig. 2b. Included in the design is the pulley and gasoline engine. Though not included in the design, wheel casters with a size of 6 inch are to be added for easy mobility of the machine.

Design calculations: Given below are design calculations required for several parts of the plastic waste shredding machine.

Transmission system: The transmission system utilized in this machine is pulley and belt. For the calculation, the equation used is:

$$\frac{N_2}{N_1} = \frac{d_1}{d_2} \quad (1)$$

Where:

N_1 and N_2 = The rotational speed of pulley at the gasoline engine and the shredder, respectively

d_1 and d_2 = The diameter of pulley at the gasoline engine and the shredder, respectively

If the effective rotational speed of the gasoline engine, N_1 is rated at 2500 rpm with d_1 = 3 inch and d_2 = 8 inch, hence, the rotational speed of the pulley at the shredder, N_2, can be calculated as follows. The obtained value of 937.5 rpm is a no-load rotational speed of the pulley at the shredder:

$$N_2 = \frac{d_1 N_1}{d_2} = 937.5 \text{ rmp} \quad (2)$$

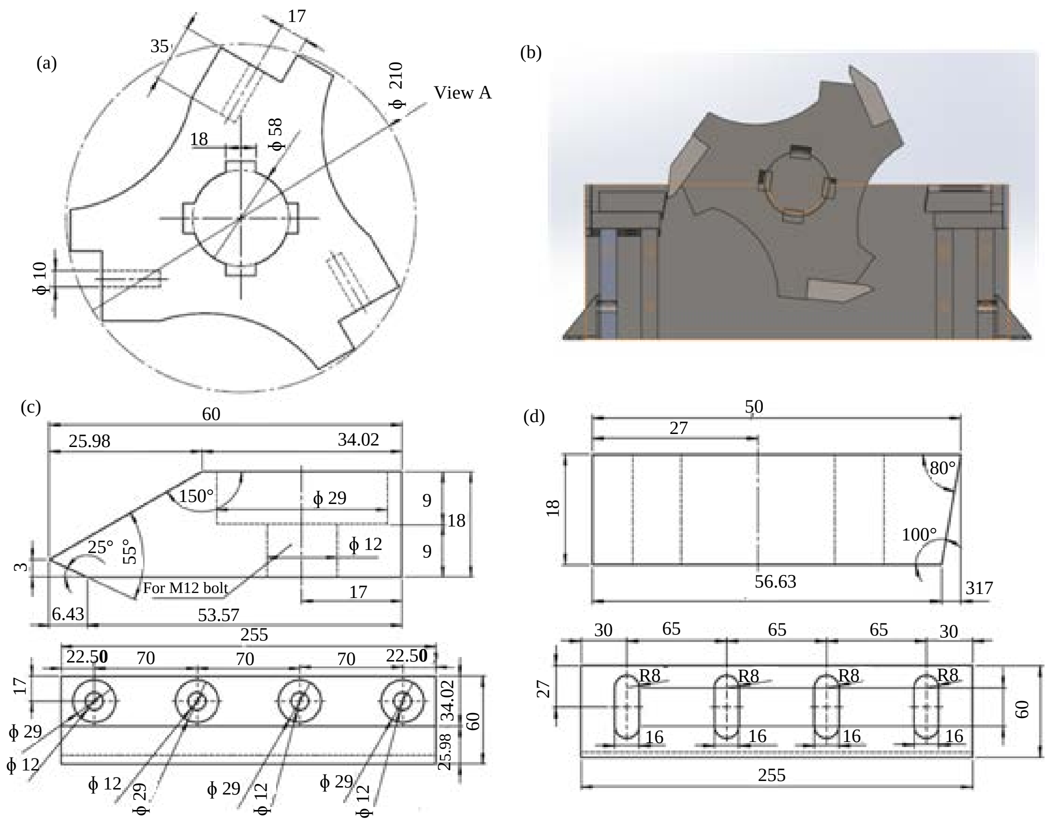

Fig. 1(a-d): (a) Drawing of the rotary knives fixture, (b) CAD image of the rotary knives fixture, (c) Drawing of the rotary knife and (d) Drawing of the fixed knife

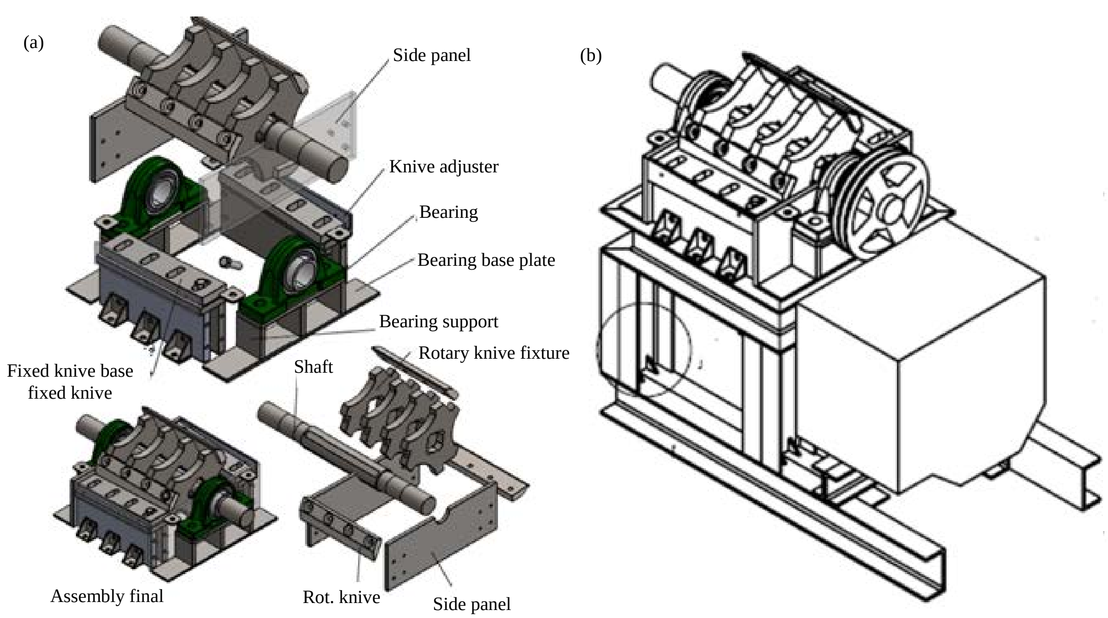

Fig. 2(a, b): (a) Design of the main body and (b) Design of the machine as a whole

Shaft design: The shaft in a shredder machine is the part that transmits the power from the gasoline engine to the cutting process using the knives. The whole transmission results in a torque which can be calculated using Eq. 3:

$$\tau = Fr \quad (3)$$

Where:
- τ = The torque exerted by the shaft
- F = The required force
- r = The distance between the knife to the center of the shaft

Combining with the equation of angular velocity and the Newton second law of motion, we can then rearrange Eq. 3 into Eq. 4 below:

$$F = \frac{2\pi m N_1 r}{60t} \quad (4)$$

Where:
- m = Mass of the shaft
- N_1 = The rotational speed of the gasoline engine

From Eq. 4, it can be inferred that in 1 second, the required force, F is:

$$F = \frac{2\pi m N_1 r}{60} \quad (5)$$

Substituting Eq. 5 into Eq. 3, we can then calculate the required torque to be:

$$\tau = \frac{2\pi m N_1 r^2}{60} = 30.68 \text{ Nm} \quad (6)$$

Finally, the required power can be calculated:

$$P = \tau\omega = 3.02 \text{ kW} = 4.04 \text{ hp} \quad (7)$$

With 4.04 hp of required power, we had chosen a 6.5 hp gasoline engine as the power source.

RESULTS AND DISCUSSION

Developed machine: The developed machine is shown in Fig. 3, showing the hopper Fig. 3a. Another side view is depicted in Fig. 3b in which the main components, i.e. the gasoline engine connected to the rotating shaft via a pulley are shown. Additionally, Fig. 3c shows the close-up view of the fixed and rotary knives with a screen at the bottom.

Preliminary performance evaluation: Preliminary performance evaluation was carried out. The machine was

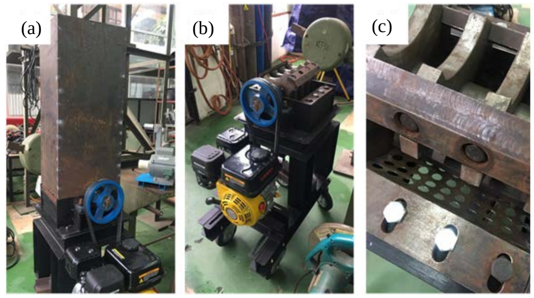

Fig. 3(a-c): (a) Developed hopper installed on top of the machine, (b) The gasoline engine, connected to the shaft via. a pulley and (c) The fixed and rotary knives with a screen at the bottom

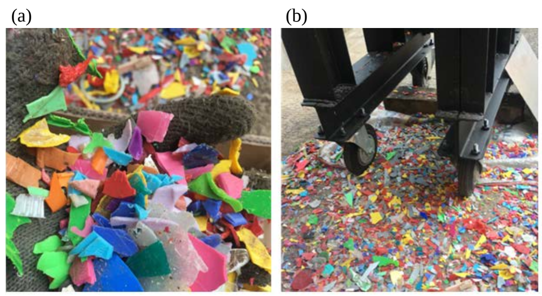

Fig. 4: Images of the resulting plastic flakes

run by the gasoline engine and it has been observed to run well in a stabile condition. Though the machine has a design which allows for an adjustment of the knives gap, in this evaluation, a fixed gap was used. Recorded rotational speed was around 660-670 rpm. Plastic wastes of PP were inserted through the hopper and the machine was able to shred them accordingly. The sizes of the resulting plastic flakes varied in dimension with an average length of 2-5 cm as shown in Fig. 4.

CONCLUSION

The design and development of a low-cost shredder for plastic waste has been carried out. The machine has also been evaluated and had shown a good preliminary result.

RECOMMENDATION

In the near future, further performance evaluations are to be carried out including the impact of different types of plastic waste materials and different angles and gaps between the fixed and the rotary knives.

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