Design of a Plastic Shredding Machine to Obtain Small Plastic Waste

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***Abstract*—One of the biggest environmental problems in the world is the excess of plastic waste. Although it is true, around the world there are companies that are responsible for recycling plastic waste, since 42% of plastics that are generated worldwide have a single utility. In Peru, the culture of recycling is not promoted, each year approximately each person uses 30 kilos of plastic and that only in Metropolitan Lima and Callao 46% of plastic waste is generated nationwide. In view of this problem, this article will design a plastic shredding machine to obtain small plastic waste to help people to be dedicated to the recycling industry in an automated way, it would also generate jobs since it requires a staff in charge of the machine and it will also be extremely useful to reduce plastic pollution in the environment, which due to COVID-19 is increasing. Through the design of the plastic waste shredding machine, the plastic will be selected by color and type of plastic composition, whether it is Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE), Polychloride vinyl (PVC) or Others (Plastic Mix), then it will go through the shredding process to become small plastic waste, which could be turned into filament for 3D printer.**

Keywords*—Automation; pollution; filaments; recycling; plastic waste

I. Introduction

One million plastic bottles are bought every minute and 500 billion bags are used per year. Eight million tons end up in the oceans every year, threatening marine life [1]. The great problem of plastic is inherent to its usefulness: most of the products made of this material have a very short useful life and are usually easily disposed of [2], for this reason there are many companies that are in charge of recycling plastic to give them different applications. 42% of the plastic used in the world is destined to the packaging of food and manufactured products. In other words, single-use plastics that barely spend a few minutes in the hands of consumers [3]. If no action is taken, by 2050 there will be about 12 billion tons of plastic waste distributed in landfills and the ocean [4].

Plastic in Peru represents 10% of all the waste generated in the country, since 2015 we have had a huge growth in plastic [5]. On average in Peru, approximately 30 kilos of plastic are used per year per citizen [6]. Each year, there are about 3 billion plastic bags, almost 6 thousand bags per minute. In Metropolitan Lima and Callao, 886 tons of plastic waste are generated per day, representing 46% at the national level [6] due to the fact that the population in Peru grows towards the cities, 75% live in urban areas, and this means more garbage production [7], causing, in recent years, several districts such as Comas and San Martín de Porres were declared in sanitary emergency because their garbage collection systems collapsed [8]. According to the ex-Minister of the Environment Muñoz Fabiola, she indicated that in other countries there are no sanitary landfills and that absolutely everything is valued [9].

The quarantine generated by COVID-19 in the world presented positive effects at the environmental level: improvements in water and air quality and less pollution of the ozone layer [10]. The sanitary measures that are now being faced by the COVID-19 causes the index of plastic material to increase the figure spontaneously. The plastics that stand out the most for their use are gloves, masks, alcohol gel containers and plastic bags; There are also the Polyethylene due to the increase in delivery. There are no exact figures, but organizations estimate that household waste grew by 30% to 40% [11].

In Peru, a biodegradable plastic is one that degrades to carbon dioxide (CO_2), methane (CH_4), water and biomass by the action of microorganisms, contains a minimum of 50% volatile solids, has limited concentrations of dangerous chemicals and its degradation is carried out in a reasonable time: 90% degradation in 6 months in the presence of oxygen (O_2) and 2 months in the absence of O_2 [6]. These are the measures that are being taken in Peru to reduce plastic pollution, but even so the culture of recycling is not a common measure that the Peruvian citizen has in mind, it is that only 3% of Peruvians recycle the garbage they generated daily [12].

The objective of the research work is to design a plastic Plastic Shredding Machine to obtain small plastic waste, in such a way that it allows people dedicated to the recycling industry to obtain waste in an automated way and will also be very useful to reduce plastic pollution in the environment. For the development of the design, SolidWorks software was used for the mechanical part that makes up the Shredder machine and an Arduino UNO programmable board that will allow the machine to work in an automated way.

In section II, the methodology will indicate the mechanical, electronic and design of the Plastic Shredding Machine. In Section III, the mathematical calculations, the formulas that were considered for the design of the Plastic Shredding Machine will be placed. In Section IV, the results that are generated according to the tests carried out on the design of the Shredder will be presented. In Section V the discussion will be presented, where the importance of this work with respect to other works carried out will be indicated. Finally, in Section VI, the conclusion and recommendation of the design of the Plastic Shredding Machine will be presented.

II. Related Works

Plastic waste shredding machines are of great importance as mentioned below in some studies. For example: In [13], the authors identified that when shredding disposable plastic, the small pieces can be used to make new plastic products, that is why they proposed the development of a plastic waste shredding machine, likewise, the shredding machine was designed with a traditional method of use scissors to cut materials in a small way and from the scraping used by rabbits when digging, some of the blades have sharp curved edges to attract the plastic towards the teeth of the cutting blades. The performance of the machine is 27.3 kg/h and the efficiency is 53% for all types of plastic and 95% for the type of polyvinyl chloride plastic, concluding that the machine could be very useful in a situation in which considerable plastics have to be crushed and also efficient in the crushing of large sizes.

In [14], the author identifies that the PUCP (Pontificia Universidad Católica del Perú) works with 3D printing technology in various areas of the University and that printed material is increasing since it cannot be discarded because they are highly polluting, that is why they proposed the design of a recycling machine oriented to the production of ABS plastic filaments for 3D printing in the PUCP, thus using an Arduino UNO programmable board to control the DC motors, a servo motor and a touch screen, it also uses the Autodesk Inventor 2017 software to design the mechanical part of the system. The result was that the designed system has the capacity to produce at least 0.5kg of ABS per hour, concluding that, by having an interchangeable nozzle extrusion system, a system is obtained capable of manufacturing not only filaments of 1.75, 2.85 and 3.00 mm in diameter as it was determined in the beginning, but also other variants that are in this range of values.

Finally, in [15], the authors identified that most of the PET bottles produced are not recycled, on the contrary, new bottles are produced every time, thus increasing waste, which is why they proposed to carry out the design and construction of a plastic Shredder for the recycling and management of plastic waste, generated in the area of the Petroleum Training Institute, Effurun, Nigeria, thus using a crushing chamber made of a rigid and thick 0.610mm steel plate, also a 0.22mm steel hopper where plastic waste accumulates while shredding is carried out with a base of the shredder casing that has a wire mesh used to regulate the type and size of the shredded plastic waste. Obtaining as a result 98.44% of crushing efficiency, with a crushing rate of 0.575kg/s, concluding that the crushed plastic waste has a size that ranges between 10mm and 20mm and the results obtained reveal that the performance of the machine it is satisfactory.

III. Methodology

A. Mechanical Part

Since the shredding machine will be in constant friction from the cuts of the plastic material, it must be made of a durable material. For this, suitable materials were chosen for the mechanical assembly of the Shredder.

- Aluminum
- Stainless steel
- Close type pulley
- Bearings

Aluminum will be used for the case of the Plastic Shredding Machine, which is also a lightweight and durable material. The blades of the plastic waste shredding machine will be made of stainless steel to maintain the durability of the friction when making the cuts, the shaft that will hold the blades will also be made of stainless steel, which will be supported by rolling bearings for mobility shredding machine.

B. Electronic Part

The electronic part is composed of a DC motor, which will be an important factor through of its force it will allow to crush the plastic waste that is placed in the machine, for this, the power of the motor must be considered. For this project, the DC motor that we will be using has GGM geared motors of the helical coaxial type in DC with powers from 120W M6 with 3.0 N.m (30kg.cm).

It will also have an Arduino UNO board to work together with a driver module and be able to control the DC motor, in such a way that the shredder has an automatic function.

C. Design

To arrive at the result of the design that will be presented in the article, a preliminary study was made which consists of the durability of the product, its efficiency, and its sustainability over time. Mention will be made of the design of the different parts that make up the crushing machine.

The most important evaluation criteria for the "Crushing and Classification" module were selected in the conceptual phase, which were:

- Ease of manufacture
- Ease of assembly and disassembly
- Reliability
- Ease of maintenance
- Low noise and vibration level
- Inexpensive and affordable spare parts
- Recirculation of material
- Under weight
- Little wear on the cutting elements

1) Metal sieve or sieve in the shape of a half moon: The classification of the material already crushed has the appropriate size. To fulfill this function, a metal sieve or a crescent-shaped sieve is used as shown in Fig. 1. Since, thanks to its geometric shape, it does not allow the accumulation or waste of plastic material at any point. Likewise, thanks to its reduced distance to the cutting elements, it allows the recirculation of material not conforming to the appropriate size to reintegrate it in the crushing process.

2) *Storage module*: The most important evaluation criteria for the "Storage" module, as shown in Fig. 2, were selected in the conceptual phase, which are:

- High storage capacity
- Under weight
- Ease of Manufacturing
- Ease of downloading material
- Ease of Installation
- Safety for the operator

3) *Shredding module*: This module allows the size reduction process to be carried out through the cutting elements, which reduce the plastic material that enters the feed hopper to the appropriate size.

Off-center blades provide the optimal solution to "push" parts into the cutting chamber in the same way that they allow for return. This configuration allows for even distribution of cutting force and simple scissor cutting for greater energy savings, as well as quiet operation and high cutting performance. The geometry of the cutter blades as shown in Fig. 3, allows them to be changed without the need for adjustments, in addition to reducing downtime due to blade change problems.

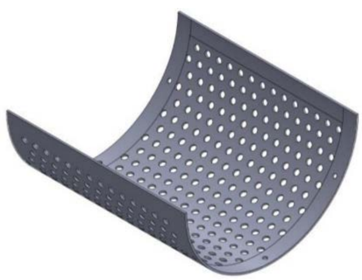

Fig. 1. Half-Moon-Shaped Sieve for the “Crushing and Classification” Module”.

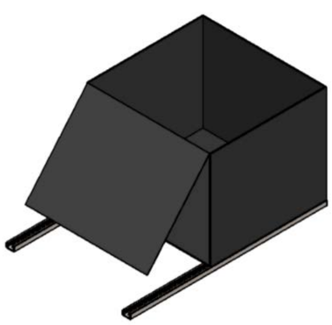

Fig. 2. Storage Module.

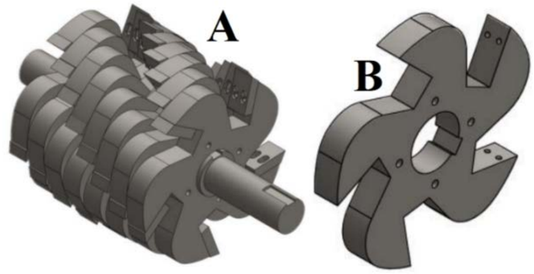

Fig. 3. A) Staggered Blade Design B) Blade Design.

4) *Crushing shaft design:* In this section, the construction of the crushed sleeper is carried out, which is subjected to bending and torsion loads created by the power transmission of the pulley, the cutting forces, and the weight of the elements it contains, as shown in Fig. 4.

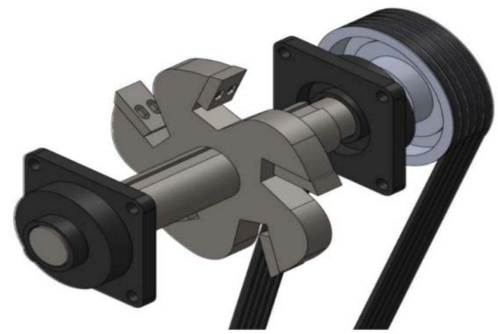

Fig. 4. Isometric View of the Crushing Shaft.

The mechanical part is an important factor, because the machine will be in constant friction that is why durable materials should be considered as mentioned above, which together with the electronic part manage to crush the plastic in such a way that the machine is efficient and not present complications in its operation.

IV. Mathematical Calculations

A. *Mathematical Calculations*

To start the calculation and selection of the different components of the crusher, it is necessary to know the resistance to cutting of the plastics most used in industries. Table I shows the tensile strength values of different materials. It is also necessary to know the resistance to shear of the selected materials, which through of a mathematical formula is the values as shown in Table II.

TABLE I. Tensile Strength Values

Material	**kg/cm^2**
Polyethylene (PE)	110 – 375
Polypropylene (PP)	500
Polystyrene (PS)	350 – 600
PVC	350 - 630

TABLE II. CUT RESISTANCE

Material	**kg/cm²**
Polyethylene (PE)	88 – 330
Polypropylene (PP)	400
Polystyrene (PS)	280 – 480
PVC	280 - 504

With the values already exposed, the resistance to shear cutting will be calculated, through of the following formula [16]:

$$\tau = \frac{4}{5} \times \sigma\ (kg/cm^2) \tag{1}$$

Where:

τ = Resistance to shear cutting (kg/cm²).

σ = Tensile strength (kg/cm²).

In Table III, the values of charpy impact resistance and melting temperature are shown.

TABLE III. IMPACT RESISTANCE AND MELTING TEMPERATURE

Material	Charpy impact resistance (kg/cm²)	Melting temperature (°C)
PET	3.6	170 – 270
PVC	15	80
PP	4 – 20	160 – 270
PS	3 – 12	105 – 270
PE	18	70 – 120

As mentioned above, polypropylene was chosen, which has higher impact resistance than other thermoplastic polymers. To calculate the force required to generate the failure of the polypropylene, the work required to perform the failure of the material must first be calculated, which is calculated using Equation 2 [16].

$$\partial w = \partial W^{el} + G_c \times l \times \partial a \tag{2}$$

Where:

∂W= Work required to break the material (Joule).

∂Wel= Elastic energy change (Joule).

Gc= Energy absorbed per unit area (Joule/m^2).

l = Length of the material cut by the blade (length of the cutting edge) (m).

∂a= Advancement of the fracture during impact (m/s).

Also, Fig. 5 shows how the material will be cut, the so-called scissor cut, which is essentially a shear cut that offers greater energy savings.

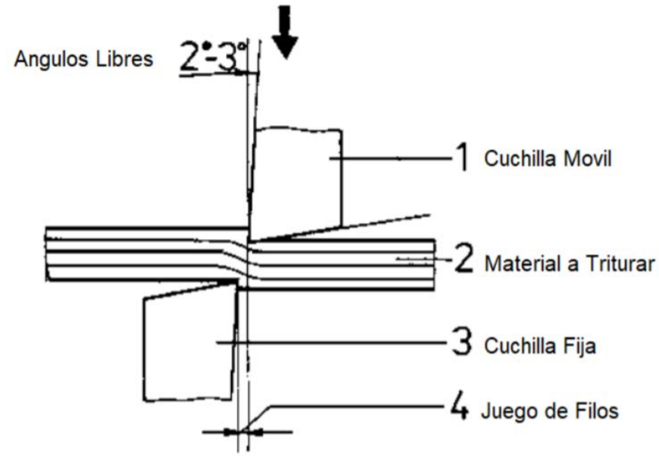

Fig. 5. General Structure of Shear or Scissor-Type Cutting.

Based on Fig. 6, Newton's second law is implemented, which allows us to relate the movement of the body with the forces acting on it through equations 3 and 4, which are written in their tangential and normal components.

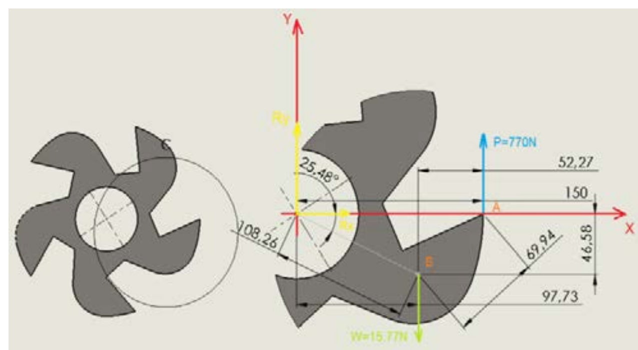

Fig. 6. Center of Mass of the Blade Holder.

$$\sum F_t = m \times a_t \tag{3}$$

$$\sum F_n = m \times a_n \tag{4}$$

Where:

m= Mass of the element (kg).

F= Forces on the element (N).

at= Tangential acceleration (m/s^2).

an= Normal Acceleration (m/s^2).

Tangential acceleration and normal acceleration are defined by equations 5 and 6.

$$a_t = r \times \alpha \tag{5}$$

$$a_n = r \times \omega^2 \tag{6}$$

Where:

r= Radius (m).

α= Angular Acceleration (rad/s^2).

ω= Angular speed (rad/s).

And finally, Equation 7, which refers to the sum of the moments around a point, will be applied to determine the reactions and the angular speed of the body; it should be considered that this is a non-centroid movement, since the axis of rotation does not coincide with the center of mass of the body, for this reason the system of external forces is not reduced to a couple Iα, in the same way we consider that the rotation is constant, therefore the angular speedy (ω) is constant and the angular acceleration (α) is zero.

$$\sum M_0 = I \times \alpha \quad (7)$$

Where:

M0 = Moments of a point (Nm).

I = Moment of inertia (kg x m2)

Through equations 3 and 4 the force summations will be carried out.

V. Results

In the article, a complete study was elaborated on the efficiency of the plastic crushing machine that will have a sustainability in time with the role that it is exercising. With this, the purpose of reducing pollution by plastic waste would be fulfilled, since it would fulfill its main role, which is to obtain small plastic waste. Inside the shredding module, the shaft formed by the blades is placed as shown in Fig. 7. The container where the small parts of the plastic shredded by the blades accumulate is shown in Fig. 8.

The design of the plastic waste shredding machine would have an approximate efficiency of 85%, because it does fulfill the main job that is shredding plastic, but that missing percentage is since the blades are not strong enough for the plastic bottles additionally.

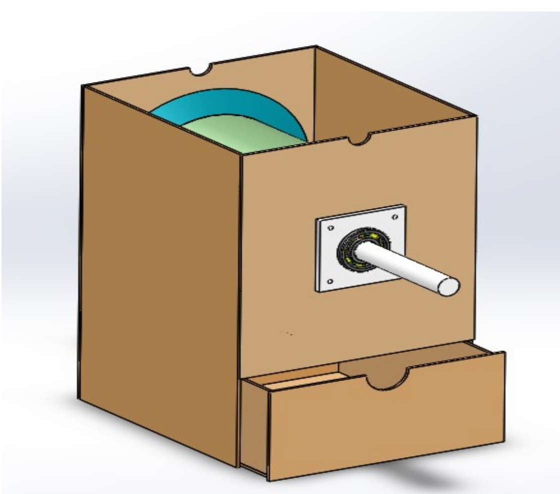

Fig. 7. Shredder Module.

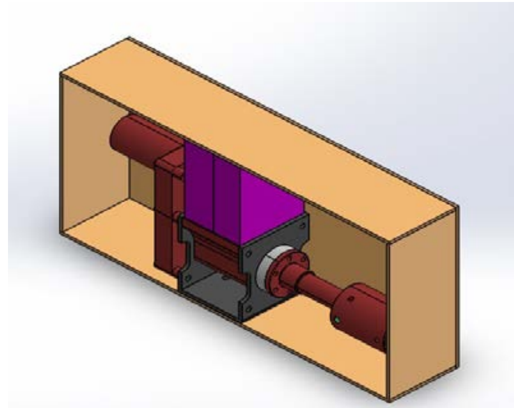

Fig. 8. Storage Module.

In Fig. 9, the implementation of a plastic shedder machine that generates filaments for 3D printers is observed, where the motor will help in the rotation of the blades and thus crush the plastic bottles with the help of an extruder generate filaments that are used a lot in 3D printers. In addition, the power source to feed the system is also identified in the lower part of the motor, so this would be a more complete project.

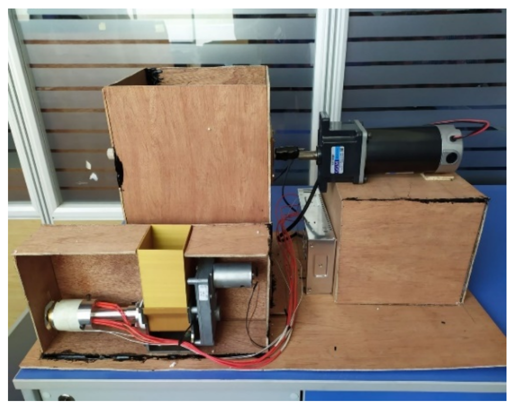

Fig. 9. Plastic Shredding Machine that Generates Filaments for 3D Printers.

VI. Discussion

The articles made about shredding machines share the same purpose, which is to reduce plastic waste that pollutes the environment over the years. The design of a shedding machine does not require a microcontroller as mentioned [13], since to carry out the crushing function only a good mechanical part is needed, that is why it adapts to the work carried out by [15], since the machine when shredding plastic does not require any programming. On the other hand [14], it indicates that it is necessary to use an Arduino UNO since it will give one more function to the shredding machine, therefore, it is necessary to indicate what function it will perform the shredding. Although it is true, each job has a specific efficiency, and they are of great importance for those people who are dedicated to the recycling business. It should be noted that these works serve as a basis for other projects that are intended to be carried out.

VII. Conclusions

It is concluded that the plastic crushing machine works efficiently, this would confirm that the use of this system will help reduce the pollution generated by the plastic, since by crushing the plastic bottles it allows them to be recycled faster than traditional recycling.

It is concluded that the crushing machine has a structure that is not strong enough to push and bring the plastic towards the blades, due to this it has difficulty in crushing some plastic bottles. Although, it is capable of crushing Technopor, it is a more porous and structured alloy of small balls.

It is concluded that the use of metal blades is strong enough to crush plastic bottles, initially plastic blades were considered for the crusher, but they could not crush the plastic bottles.

It is concluded that the use of the Arduino UNO board helps a lot to control the motors that are part of the shredder machine, and its programming is more user-friendly unlike other microcontrollers.

As work in the future, a heating system will be placed as shown in Fig. 9, which will be of great help to obtain filaments for 3D printers that are used by various professionals, for example, in the biomedical field. This would be making the most of the plastic shredded by the machine.

It is recommended to consider that the blades to be incorporated into the structure of the crushing machine can withstand the force generated by the motor when the machine is in operation. It is also necessary that the blades are staggered on their shredding axis as it allows the cutting to be more efficient.

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