SHREDDER FOR PLASTIC WASTE RECYCLING PROCESS

BRATU Marian[1], MANTA Nicoleta-Lăcrămioara[1], TECUCEANU Roxana-Alexandra[1], ALUPEI-COJOCARIU Ovidiu-Dorin[2]
[1]Faculty of Industrial Engineering and Robotics, Manufacturing Engineering Department, Year of study: I Master, e-mail: tecuceanuroxanaalexandra@gmail.com
[2] Faculty of Industrial Engineering and Robotics, Manufacturing Engineering Department, University POLITEHNICA of Bucharest

ABSTRACT: The idea of the current presentation is part of the project 'Precious Plastic', of the department of Manufacturing Engineering Department. The idea to implement this project was inspired by the youth community of Precious plastic, which has spread around the world, with an experience in the market of over 7 years, outlined by many good results over time. The project is also supported by the company 'Technobit Automatizări'. After a thorough analysis, it becomes clear how necessary it is that we increase the amount of recycled plastic, so we decided to study mechanical recycling. Specifically, we chose to design as well then build a shredder for plastic waste. Although there are similar devices on the market, it has a number of unique features, such as a larger number of radially arranged blades, power and level interruption sensors, safety and start/stop buttons, and safety caps.

KEYWORDS: plastic, waste, recycling, shredder

1. Introduction

Recycling represents an operation where the waste is introduced into a technological process in order to be reused, to reduce the processing of new raw materials. The benefits of recycling are many: reducing the number of landfills, reducing greenhouse gas emissions, pollutants released into water and air, reducing energy costs and conserving the Earth's natural resources [1-4].

Globally, there is a unique system for identifying plastics, through the ‘Code of Identification of Resins or Plastics of the Plastic Company and Industries, representing the group of polymers which the material belongs, the meanings being shown in Table 1 [5, 6-9].

Table 1. Classification of materials according to the plastic identification code

Symbol	Name	Use	Characteristics
1 PETE	Polyethylene terephthalate	 bottles, jars, food containers, foils.	- the most common packaging; - very easy to recycle; - cheap, transparent, durable, resistant to heat and chemicals
2 HDPE	High density polyethylene	 cosmetic containers, cleaning products, bags.	- opaque, durable and strong, easy to produce and process, safe (low risk of entering the packaged product); - they are easily recycled if they are thoroughly cleaned beforehand, otherwise not.
3 PVC	Polyvinyl chloride	 in construction, in the textile industry, in the medical field, for cleaning products, motor oil bottles, detergent bottles.	- durable and resistant to chemicals and under pressure from external factors; - not suitable for home use (toxic and carcinogenic); - difficult to recycle; - one of the most dangerous types of plastics for health and the environment.

Symbol	Name	Use	Characteristics
4 LDPE	Low density polyethylene	 bags for frozen food, garbage bags, food foil.	- safe for health; - durable and resistant to high temperatures; - rarely used due to high price; - rarely accepted for recycling.
5 PP	Polypropylene	 in the textile industry, for straw, hangers.	- safe for health; - durable and resistant to high temperatures; - it is used for containers in which hot liquids are stored.
6 PS	Polystyrene	 in construction, for the packaging of certain foodstuffs, electronic or household appliances	- it must be used carefully and in small quantities, especially at high temperatures, because it releases styrene; - widely used, but very difficult to recycle.
7 OTHER	Other plastics	 various plastics: polycarbonate, nylon, ABS, acrylic, PLA	- polycarbonate (technical equipment, electronics, appliances, lenses, armored windows, containers, such as bottles) considered toxic, releases bisphenol

The recycling process can be of several types, detailed below, each including three basic steps. The first step is the collection, then the residue goes through any of these procedures and is transformed into a raw material, and in the final stage, it is transformed into a finished product. [5,9-15].

1. Mechanical recycling: is the most widely used method globally and involves the mechanical transformation of residues into new materials, without changing their chemical structures, allowing the polymers to be reused several times. [5,10-11,16];
2. Chemical recycling: it is the most complex method, being in an incipient, which requires technological development, and is represented by the modification of the chemical structures of the materials, being a process that involves high costs and high consumption of energy and resources [5,9-11,13];
3. Energy recovery: consists in the transformation of waste into fuel used for the generation of thermal / electrical energy, being a process that requires little space, but high investments and risks [10,11,16];
4. Biological recycling: applied to biodegradable plastics, microorganisms producing stabilized organic residues, depending on the treatment, aerobic (carbon dioxide, water) and anaerobic (methane) [16].

2. State of the art

Global, plastic production has grown exponentially in just a few decades, from 1,5 million tons in 1950 to 368 million tons in 2019. In the first half of 2020, plastic production dropped sharply, caused by Covid-19, and recovered in the second half of the year. With this return, plastic waste also reappeared [17].

Figure 1 and Figure 2 show the global and European development of plastics production. The figures in the illustrations do not include the production of recycled plastic.

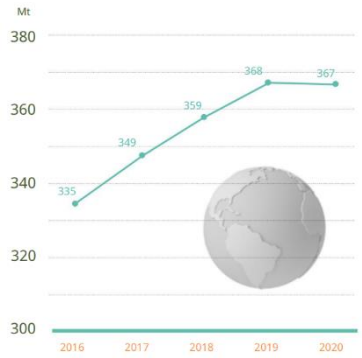


Fig. 1. World plastics production [18]

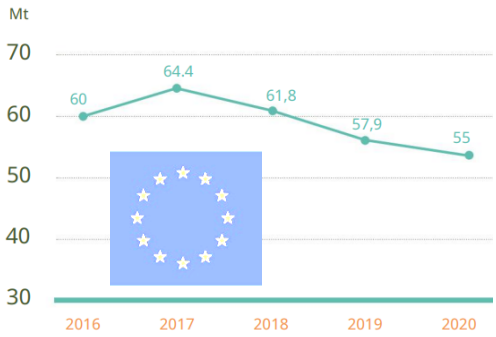


Fig. 2. European plastics production [18]

Table 2 shows the percentage distribution of global plastics production.

Table 2: Distribution of global plastics production [18]

China	NAFTA	Thew rest of the Asia	Europe	Middle East, Africa	Latin America	Japan	CIS
32%	19%	17%	15%	7%	4%	3%	3%

Organic waste, such as food waste, is biodegraded, decomposed or composted shortly after disposal. Plastic products, on the other hand, do not decompose, do not biodegrade and do not compost. These three processes depend heavily on the ability of microscopic organisms to consume and decompose organic waste. Most plastic products are made from synthetic chemical components, such as PET, which cannot be utilized by biodegradable organisms. As such, plastics cannot be easily degraded [19].

In Europe, the most common method of plastic waste disposal is energy recovery, followed by recycling. Landfilling is at 25%.

Half of the plastics collected for recycling are exported for treatment to countries outside the European Union. The main reasons for export are lack of technology, capacity or financial resources for waste treatment locally.

Fig. 3. Time required for decomposition [20]

Due to the low recycling rate of plastics in the European Union, there are enormous losses for both the environment and the economy. Approximately 95% of the value of the plastic packaging material is lost after the short cycle of first use.

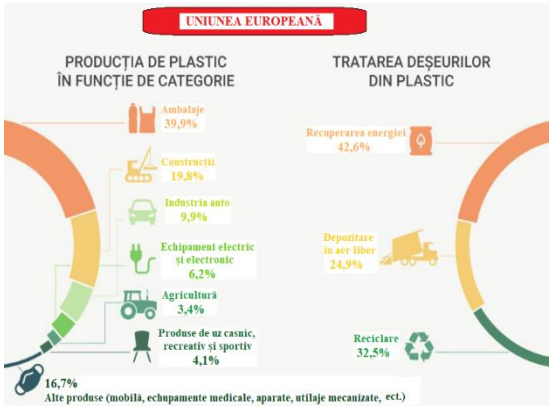


Fig. 4. Production and treatment of waste

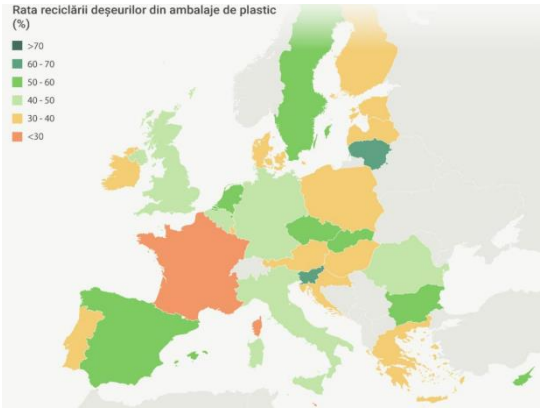


Fig. 5. Waste recycling rate [17].

The researchers found that, the manufacture and combustion of plastics released more than 850 million metric tons of greenhouse gasses into the atmosphere worldwide in 2019. By 2050, those emissions could reach 2.8 billion tons. Some of these emissions can be avoided through better recycling [17]. Considering this, recycling plays an extremely important role in conserving the planet's natural resources, reducing existing waste and contributing to greater energy efficiency. About 500,000 people work in more than 6,000 companies involved in the recycling industry, generating $ 24 billion annually in this segment. The European Union holds about 50% of the global recycling and waste management industry.

While in the Nordic countries, waste is an alternative source for electricity or heat generation, with 50% of the waste being recycled, and the rest up to 99% recovered for energy, in Romania, waste management is another important problem we face.

The practices of improper waste management inherited from the past, which are still applied in Romania today, have resulted in a large number of landfills being ignored and significant produced, being inadequately stored [21].

According to the data provided by AFM, in 2021 the total quantity of plastic introduced on the national market (i.e. including imports) was 45,744,693 tons. Of this amount, 4,935,007 tons were recovered by methods other than recycling.

There are companies that produce plastic "scales" that they export to other countries, and this quantity appears "in methods other than recycling", because it is not a final product recycled for Romania. At the same time, AFM reports 202,619 tons of recycled plastic. Of this amount, PET accounts for only 85,667 tons, considering that the total amount of PET that enters the national market is 144,324 tons. Romania has not used PET in any way other than recycling. From 2015 to 2020, AFM accounts for "0" in this section. Experts say that it requires the heaviest recycling method.

Moreover, if Romania could convert waste into energy, it would have to use the combustion method. This method involves, on the one hand, a profit and, on the other hand, an environmental protection fund that our state does not currently provide. The municipalities, which are not able to manage such a large-scale project, are very controversial.

By 2025, Romania must archive a recycling rate of 55%of all waste, a goal that is difficult for our state to achieve [22].

Table 3 compares some data on plastic production and recycling.

Table 3: Data on plastic production and recycling [17,18, 22 - 24]

The year 2020	Plastic production [t]	Plastic recycling [t]	Plastic recycling [%]
Worldwide	367.000.000	183.500.000	50
European level	55.000.000	19.030.000	34,6
Romania	5.000.000	550.000	11

3. Design and simulation of shredder recycling components

The design and simulation of the chopping plastic equipment, included in the recycling process was done in the Autodesk Inventor Professional design software. The next step was to make the manufacturing drawings, subassembly and assembly, for the components of the machine. A cost analysis was performed to see the final production cost, depending on the classification of the machine parts (purchased from suppliers; manufactured and also those present parts in the stock of the cooperating enterprise – Technobit Automatizări) and we got a total cost of 1500 euros. As future directions, we aim the sustainability of the project, the reduction of costs, an easy maintenance and amortization as soon as possible, generating economic benefits.

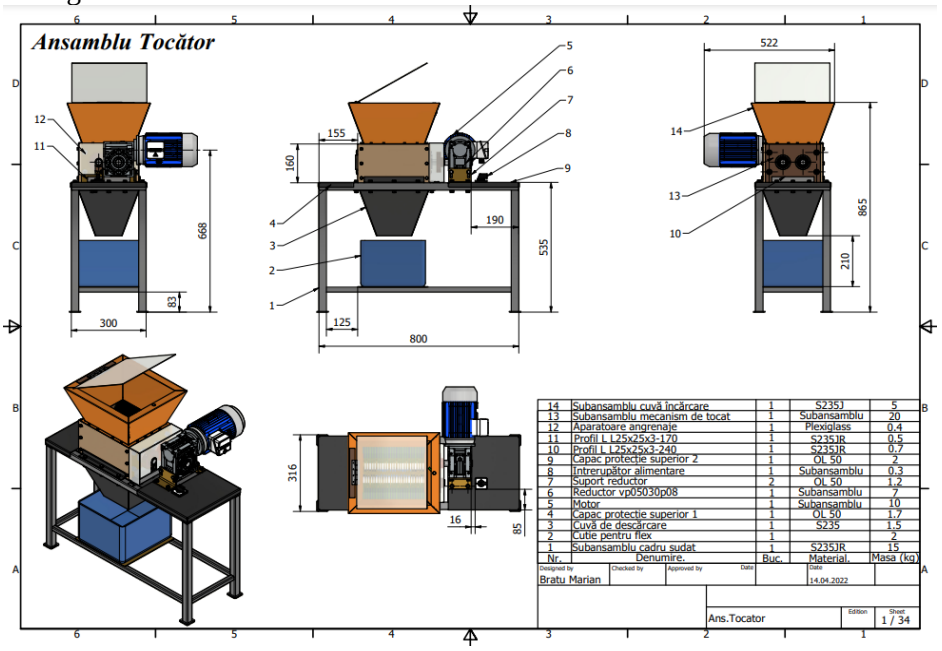


Fig. 6. Assembly drawing components

The shredder can grind any type of recyclable plastic and shape that fits with the intake size of machine. Depending on the chosen engine power and blade configuration, the machine can accept materials with different thicknesses, avoiding equipment jams. The resulting plastic can be used in three different machines: extruder machine, injection molding machine and sheet press. So we defined three different sizes of shredded plastic compatible with each machine. To obtain the plastic flakes a sieve can be installed under the machine in order to shred again thus generating smaller flakes dimensions.

Table 4. Types of flex dimensions

Name	Big	Medium	Small
Visual aspect of the flex [25]			
Flex size [mm]	0-30	0-10	0-7
Works with:	Sheet press	Sheet press Injection molding machine	Sheet press (Figure 14, position 4) Injection molding machine (Figure 14, position 5) Extrusion machine (Figure 14, position 6)

There are distinctive elements that represent competitive advantages over competing products:

- Mounting the blades radially on 12-sided milled shafts, to provide continuous, simultaneous movement through the repositioning frequency, streamlining the time the waste is trapped between the blades;
- Limiting sensor with lever for disconnecting electricity, the safety of the user, positioned on the loading tray of the shredder. When the upper safety cover is lifted, the sensor will stop the operation of the equipment;

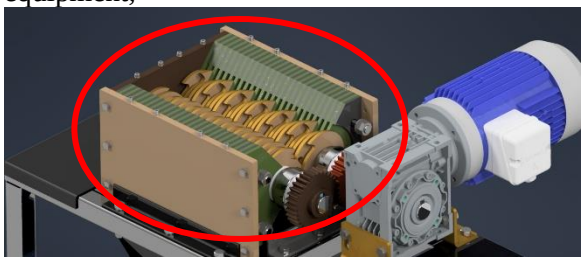


Fig. 7. Blade arrangement

Fig. 8. Electricity disconnection sensor

- Ultrasonic level sensor, to know the flex level from the box.
- Gearing safety cover, implemented for user protection. It prevents injuries in the gears, but also premature gear wear;

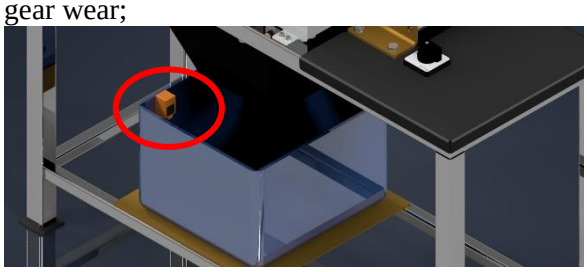


Fig. 9. Level sensor

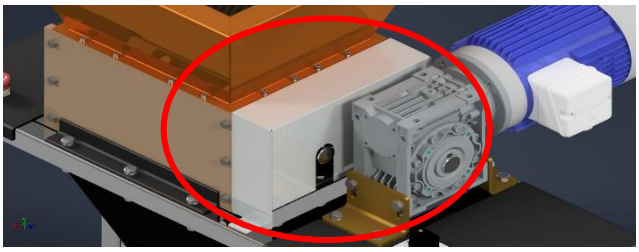


Fig. 10. Gear safety cover

- Security button, with immediate stop function;
- On / off button, which reduces time and energy consumption.

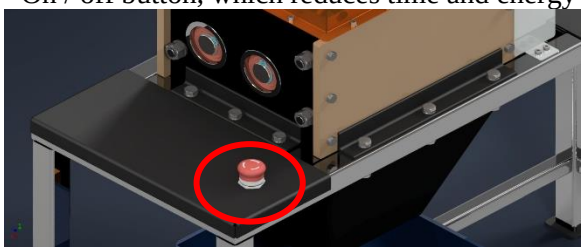


Fig. 11. Security button

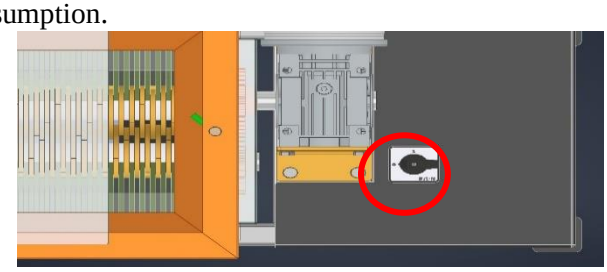


Fig. 12. On / off button

4. Technological flow and the way working of designed equipment.

Description of the technological flow:

1. The first step in recycling is to collect waste. This step is shown in Figure 14, position 1. Subsequently, the plastic waste must be sorted in dedicated containers, differentiated by colors which are shown in Table 1, depending on the classification of the materials from which they were made. The sorting of collected waste can be found in figure 14, position 2. There are two important categories: thermosetting and thermoplastic. Thermosetting materials contain polymers that bind together and creates an irreversible connection, which means they can't be melted, once they have taken a shape, they will be solidified forever, thus eliminating the possibility of recycling. Thermoplastics materials are polymers that become soft when they are heated and hard when are cooled, also this process can be performed several times. 80% of the world's plastics are thermoplastic, which means they can be recycled and turned into new products, which is an advantage. Thermoplastics materials are divided into subsequent subcategories, depending on their structure and properties, classification can be found in table 1 [25].

The different types of plastic should never be mixed, as this will drastically reduce their quality and make the recycling very difficult. When they are melted together, they tend to separate in phases, like oil and water, and settle into layers, resulting structural weakness and inferior products. [25]. Therefore, the first step in the plastic recycling process is to collect it according to the categories mentioned above and sorting according our needs. The next step is to prepare the waste, which consists in cleaning, drying, separating the elements if they are made of different materials (in most cases the label). This step can be done entirely manually or in a combined process, both manually and automated, depending on resources.

2. *Operating steps of the designed machine:* The first machine used in the technological described process is the shredder, which represents the studied product for development in this work paper, found in Figure 13 and Figure 14, heading 3. It starts by connecting the machine to a power source and setting the button to the on position. The material is fed through a loading tank located above the mechanism, which has a sensor attached to turn off the power when the top cover is raised, to eliminate the risk of the user inserting their hand into the area of the blades when they are in operation. The feeding can be done manually or with a conveyor belt. The shredding mechanism consists of a series of blades driven by an electric motor. After the waste is placed in the loading tank and the top lid is brought to the closed position, the shredding process begins. If we want to obtain the smaller flex, a sieve can be installed under the blades. The resulting flex falls into a lower tank or is picked up by a conveyor belt, to be sent to the next machine. In the event of an emergency, press the safety button to switch off the equipment. As a last step, stop the shredder with the stop button.

3. Depending on the needs, the following equipment will be chosen from the technological flow and implicitly the type and dimensions of the flex that we want to obtained by shredding. The resulted plastic can be transferred to the mentioned machines, in Table 4: sheet press, injection machine and extruder.

The sheet press works by inserting the flex, which it will be pressed between two plates at a high temperature. The result is a rectangular plastic sheets, by the size of the plates. The sheet press can take any type of flakes (small, medium and large), but it is recommended to use the large ones, to reduce the shredding time. The sheet press is shown in Figure 14, heading 4.

The injection machine has a fast and high precision production, but it takes a little more effort at first, to design and build a mold. Medium shredded plastic enters to the loading tank and it is heated and pressed by a long shaft into the mold. Different colored materials can also be introduced into this machine. The injection machine is shown in Figure 14 at position 5.

Extrusion is performed using an extruder and is a continuous process where small plastic flakes enter to the loading tank, where is heated and pressed with a screw through a long shaft, and the result is pieces of plastic, with cylindrical shape. With this machine we can create filament, and the obtained material is wrapped around a reel. We can introduce flex with different colors to get certain shades and patterns. The extruder is shown in Figure 14, position 6.

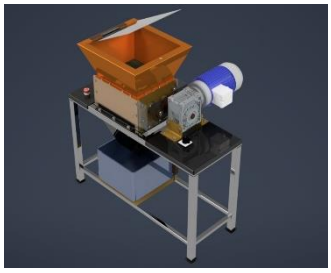
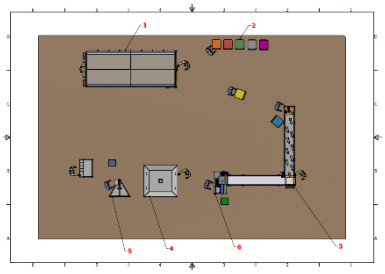


Fig. 13. Shredder assembly



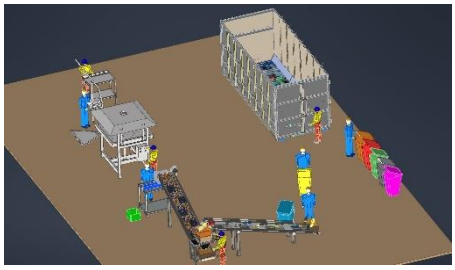


Fig. 14. Technological flow

5. Conclusions

- General

Worldwide, millions of tons of plastic are produced (approximately 359,000,000 t) and the time required for its decomposition varies from a few years (10 years - plastic bag) to several hundred years (600 years of fishing line). The amount of plastic waste recycled varies from country to country. Romania is the penultimate country in the EU in terms of recycling with a percentage of only 11%. The purpose of recycling is to reduce the processing of new raw materials and to reduce environmental pollution. Some of the benefits of recycling are: reducing the amount of landfills, greenhouse gas emissions, pollutants released into water and air, energy costs and conserving the Earth's resources.

- Original contributions in the realization of the plastic shredder

Arranging the blades radially on 12-sided milled shafts to provide continuous, simultaneous movement through the repositioning frequency. This mounting method makes the time in which the waste is trapped between the blades more efficient; Electric safety disconnection sensor for user safety, positioned on the loading tray of the shredder. When the upper protective cover is lifted the sensor will stop the operation of the equipment; Level sensor, with function of determining the degree of filling of the box for the obtained flex; Gear guard cover, implemented for user protection. It prevents damage to the gears, but also premature gear wear; Safety button, with immediate stop function in case of need; On / off button, which reduces time and energy consumption.

- Directions for improving the shredder for the plastic waste recycling process:

Increasing the degree of silence; Reducing production costs by replacing components; Improving the degree of reliability; Easy maintenance.

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7. Abbreviations

The next symbols are used in the current presentation:
ABS = acrylonitrile butadiene styrene;
PLA = polylactic acid;
PET = polyethylene terephthalate;
t = tons (unit of measurement);
mm = millimeters;
AFM = The Environmental Fund Administration;
Mt = million tons;
NAFTA = The North American Free Trade Agreement;
CIS = The Commonwealth of Independent States;
UE = European Union.