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3D Printing Filament Manufactured by PET Material Recycling Part B: Designing and Prototyping a Device for 3D Printing Filament Extrusion from PET Recycled Material

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Abstract
The paper is the second one of a series of papers regarding a simple method of PET plastic recycling that is desired to be implemented locally at an institution, meaning at Transilvania University of Brasov, the Faculty of Technological Engineering and Industrial Management. This paper presents a simple extrusion device for PET filament manufacturing, as low volume production for internal uses within the faculty. A brief study was made in order to find several constructive structures as a starting phase for the device design. The design stage started with a simplified 2D concept based on which the final 3D model of the filament extruder assembly was performed. The design stage generates the assembly components and their shapes and dimensions. The prototyping started with component manufacturing using cutting processes and also additive manufacturing. The final assembly was partially completed using those manufactured components and using standard parts for montage. The result is one of the simplest and cheapest to implement device in terms of attempts to manufacture PET recycled filament.

Keywords
plastics recycling, PET filament, filament extrusion, extrusion device

1. Introduction

Recently, increased attention has been paid worldwide for environment protection. One of the most environment polluting sources is the plastics industry. Taking into account the circular industry sustainability, for this purpose, in the field of plastics materials, attempts are being made to recycle it as much as possible. In a previous study, a brief review was presented regarding the most used methods of recycling plastics, and which are the most recycled plastics, but also the applications for which these recycled materials can be used.

In the last years, several research groups have turned their attention to recycling one of the most common plastic materials, the polyethylene terephthalate (PET) plastic wastes, to be converted as raw material for a rapid prototyping and additive manufacturing technology that is very widespread. This row material is the filament for 3D printers that are widely used by both young people and adults, within institutions or companies producing goods or for individual uses.

A recent study [1] analysed the possibilities and the potential of reusing various recycled plastics as raw materials for additive manufacturing or 3D printing technologies. The research concludes with several challenges that need to be solved or improved in order to achieve a maximum sustainability potential for such technologies. A first challenge is to attempt to stabilize or to decrease the variability of the mechanical properties for the recycled materials so that they do not affect the printing quality or mechanical performance of 3D printed products. Another major challenge is also to make an effort in order to obtain similar mechanical properties of the recycled materials as those of the original material.

The research group also states that the processing of such materials requires printing equipment with improved performances specific to recycled materials. Furthermore, in order to solve these challenges, it is considered necessary to develop standardized protocols for recycling different types of plastic polymers or for processing natural wastes that provide consistent and homogeneous properties for these materials. This also involves the implementation of quality control protocols that reduce the variability of the properties of the materials obtained [1].

Another research [2] in this domain concludes that the most used recycled plastics for 3D printing are polylactic acid (PLA - which is also one of the most used 3D printing materials in a virgin status), polyethylene terephthalate (PET), the acrylonitrile butadiene styrene (ABS), the polycarbonate (PC), polypropylene (PP), but also more elastic materials such as thermoplastic polyurethane (TPU), thermoplastic elastomer (TPE). In the case of recycled PET material. The study states based on previous research by another group of authors that before a comparison of mechanical tests between a natural PET material and a recycled one, an increase was found both for the shear strength and for the tensile strength for the recycled PET and respectively a decrease in the hardness properties of the compared samples [2, 3].

Following a comparison of load test applied to some 3D specimens printed of PLA and bottle recycled PET, it was found that the recycled PET material supports a higher maximum load before deformation than the PLA specimen. For this research, the tested specimens were created from recycled materials in a study conducted at a Honduras University, as is desired also the implementation of the current study presented in this series of papers. The collection of raw materials consisting of PET bottles was conducted on-site, within the faculty, by promoting recycling among students, professors, support personnel and administrative staff of the faculty [4].

It can be concluded that recycled PET material can be successfully used in additive manufacturing technologies as filament for 3D printers [5, 6] or as filament for 3D melting pen (3D printer pen) [7] or even as direct printing of the row material for the lesser-known shear screw printers (extruders) [8]. Obtaining these filaments is done by extrusion through commercial extruders [3, 5, 7] or by DIY (Do It Yourself) extruders [1, 9] that are designed especially for filament manufacture from recycled materials.

This paper presents a simple solution that can be used in order to convert recycled PET into filament for 3D printers that involves designing and prototyping a extrusion device for this purpose. It is considered to be a simple and cheap solution that can be implemented on any level, on-site, within any institution, as is the case with this study. It is intended to be implemented at the Transilvania University of Brasov, Faculty of Technological Engineering and Industrial Management.

2. Extruder Design

2.1. Proposed extruder concept

The extruder design process started with a first simplified concept of the device structure. Thus, a study of the constructive solutions was performed, identified in similar products from the literature, which involved the study of both commercial and in-house extruder designs [1, 5, 9]. Based on this study, first decisions were made regarding the main components of the excluder. Those components were implemented within a simplified concept presented in Figure 1. Was considered efficient for the prototyping stage, which was also developed within the faculty, to use as few as possible components and in the same time, as simple as possible, in order that can be manufactured in-house using the faculty facilities or, for small components to be purchased at minimal costs.

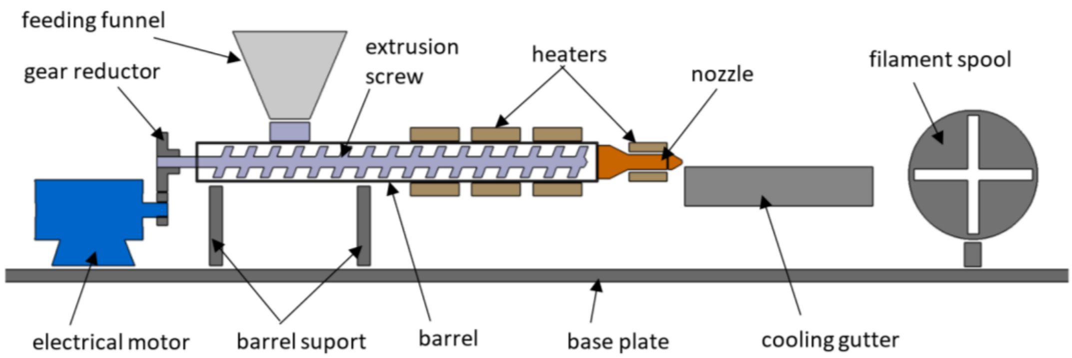

Fig. 1. Extruder simplified concept

Based on the simplified concept presented in Figure 1, a decision was made upon the minimum of components that should compose the structure of the extruder. Therefore, the design phase continues by designing a more detailed 3D model with well-established dimensions and shapes of the components.

2.2. Extruder 3D modelling

The design stage was performed using Catia V5 CAD software, resulting the extruder 3D assemble presented in Figure 2. The 3D design allows to establish dimensions, shapes and components that will compose the extruder assembly that will be prototyped. Step by step through 3D modelling, each component of the device was designed. Some of them will be manufactured as unique parts using the manufacturing facilities within the faculty, and the smaller parts such as the assembly parts, the motor, the bearings, the redactor, the pulleys or the timing belt will be purchased as standard components.

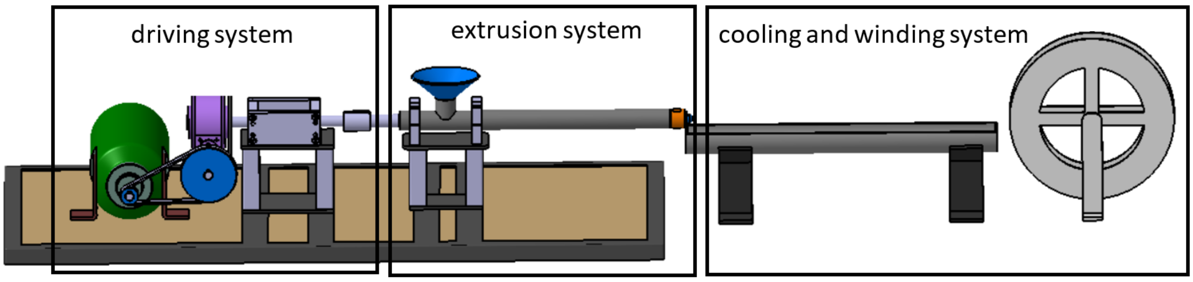

Fig. 2. Extruder assembly (virtual model)

As can be seen from Figure 2, the designed extruder assembly is composed of three subassemblies or systems that works together for the main purpose of processing recycled plastic in order to obtain filament for 3D printers. These subassemblies are further presented. Figure 3 present a detailed view of the extruder driving system and the main components that are parts of this subassembly.

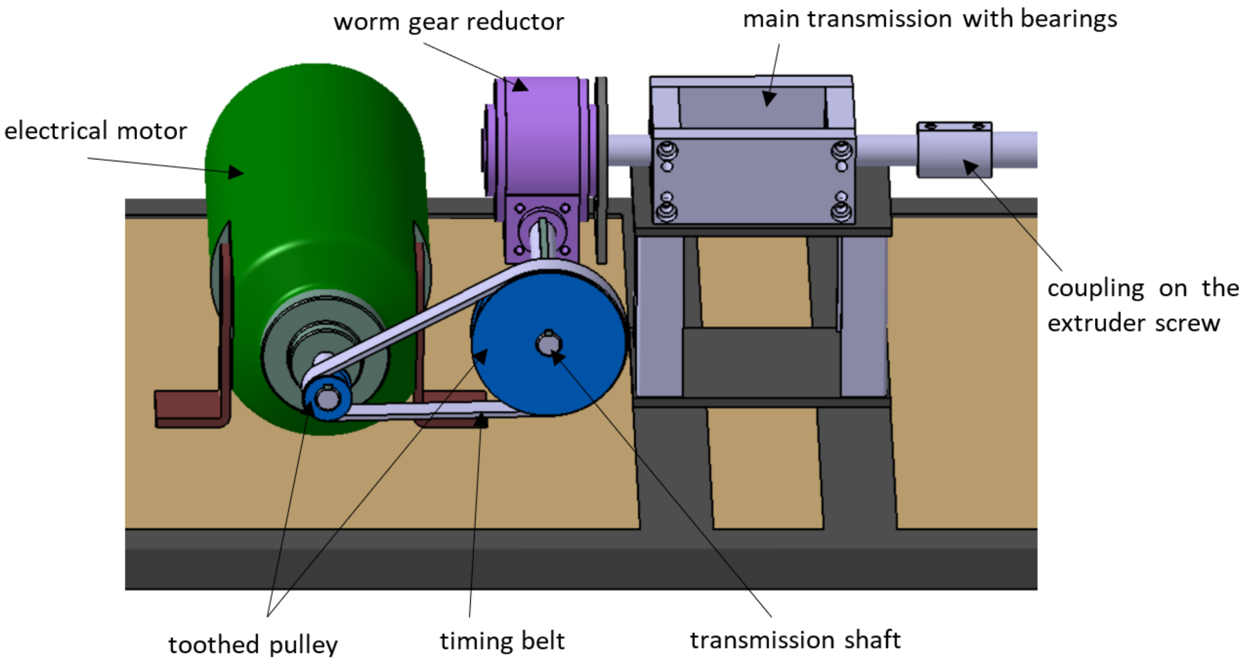

Fig. 3. Detailed view for the extruder driving system (virtual model)

The main role of the driving system is to transmit the circular motion to the worm screw. This rotation is necessary to ensure the transport and mixing of the recycled plastic material. The spindle speed should be a smaller one (smaller than 80-100 rpm [6], preferably even much smaller than that) and is provided by an electric motor and is further reduced by means of two reduction mechanisms. One reduction mechanism uses pulley and toothed belts. The small pulley has 12 teeth and the bigger pulley has 60 teeth, which means a reduction ratio i = 5. The other reduction mechanism is in fact a purchased worm reducer which has the reduction ratio i = 40. Together, both reduction mechanism has a reduction ratio i = 200. The final decision regarding what type of speed reduction mechanisms will be implemented will be made after the purchase of the electric motor and depending on its specifications. If the electric motor will have variable speed up to a minimum value of 200…300 rpm, then only the speed reduction mechanism with pulley and toothed belt will be kept, being much cheaper to be implemented, and the worm reducer will be excluded because is more expensive to purchase. After reducing the spindle speed, it transmitted to the extruder worm screw via the main transmission box and a mechanical coupling. The main transmission box consists of a main axle, an aluminium box which is also the housing of two radial-axial bearings, and a lifting support made of metal profiles.

The filament manufacturing is accomplished by the extrusion system of the device and is in detail presented in Figure 4.

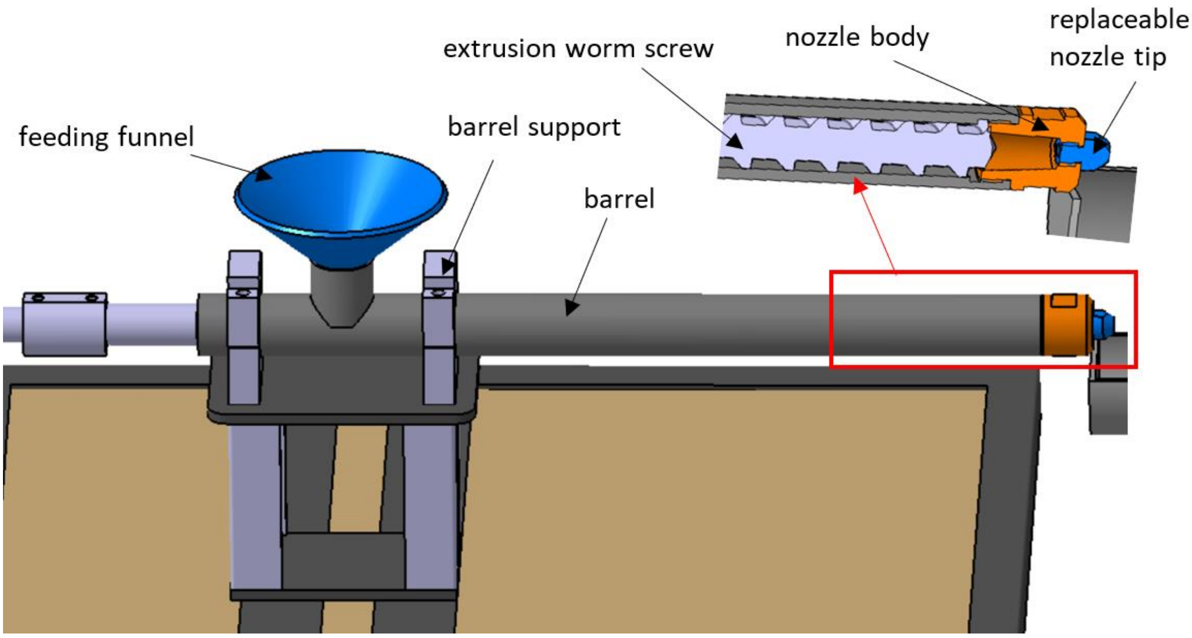

Fig. 4. Detailed view for the extrusion system (virtual model)

The transformation of shredded PET plastic flakes into filament starts by feeding the shredded plastic flakes into the extruder via a feed funnel. From where, the flakes arrive inside of the barrel and are transported to the end of the cylinder by the work screw. The warm screw ensures both the transport and the contact between the flakes and the inner wall of the barrel. The barrel is heated up to 280 ºC [8] electric heaters that are not drawn in Figure 4. The heaters ensure the flakes melting together with the worm screw that ensures the flakes mixing. The melted material is further collected into the nozzle body. This melted material is further pushed outward by the continuous rotation of the worm screw, through a small hole manufactured in the centre of the nozzle tip. This tip is replaceable for an easier change between tips with different hole diameters, in order to allow manufacturing, the most used filaments worldwide, those with 1.75 mm or 2.85 mm diameter.

The last extruder system is the cooling and winding system for the obtained filament (Figure 5). When the filament is extruded by the hot nozzle, it cannot maintain its shape and diameter because it is still hot and deformable, therefore it must be cooled. For the proposed extruder presented in this work, the cooling system is the simplest possible and consists of using a gutter filled with water into which the filament will fall after extrusion and will cooled while maintaining the extruded shape and dimensions. The gutter is positioned immediately below the extrusion nozzle using two support legs. In order for storage, packaging or direct reuse of the filament on the 3D printer, the cooled filament is wound on a roll similar or identical to the one used for 3D printer supply. This roll can be used directly on the 3D printer similar with that one purchased from the market.

In the figures above which present the filament extruder, the assembly elements such as screws, nuts and bolts are not represented. These will be chosen according to punctual needs in the prototyping stage, following the parts manufacturing that require it and are not standard components.

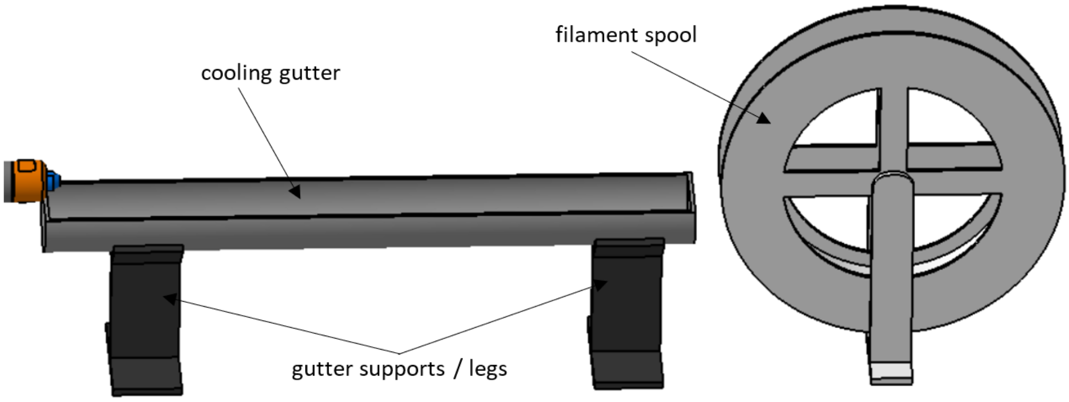

Fig. 5. Detailed view for the cooling and winding system (virtual model)

3. Extruder Prototyping

The prototyping phase began with the mechanical processing of the components that required this stage. The manufacturing was carried out by cutting processes using the faculty machine-tools and equipment for a considerable number of components including all shafts, the components of the main transmission box, the worm screw, the barrel and his supports, both nozzle body and tips. The manufacturing process used were conventional lathe turning, CNC milling, drilling, taping, water jet cutting, grinding and polishing. All the lifting supports parts were manufactured from simple metal profile by cutting and welding. The feeding funnel were obtained by 3D printing and for cooling gutter, a PVC tube was used. The filament spool is a commercial filament roll on a 3D printed support that will be operated manually for winding the filament.

The components from the driving and the extrusion systems are al mounted upon a base plate because those stays together and does not need disassembly during extruder use. The cooling system it is free from the rest of the components because it is probably to require adjustments by changing the position relative to the extruder for both the cooling gutter and also for the winding roll.

The conventional electric motor was replaced with a part of a mixer used in the construction field which is in fact also an electric motor but with a good-looking design because it has an plastic shell. The advantage of choosing such a mixer as spindle motor is that it comes with a low speed of 300 revolutions per minute. Therefore, it was decided to exclude the worm gear reducer, which is quite expensive, keeping only the spindle speed reduction system using pulley and toothed belts. Another advantage of this mixer is that it is already equipped with a slow spindle start which helps with the progressive rotation when the worm screw starts. Furthermore, the mixer has already implemented a start button, without the need to implement such automation as is required for a conventional electric motor.

Taking into account the above presented aspects, after the prototyping process, according to Figure 6, the result product was obtained. Unfortunately, several components such as the electric heaters and other electric or electronic components are still missing from the prototype.

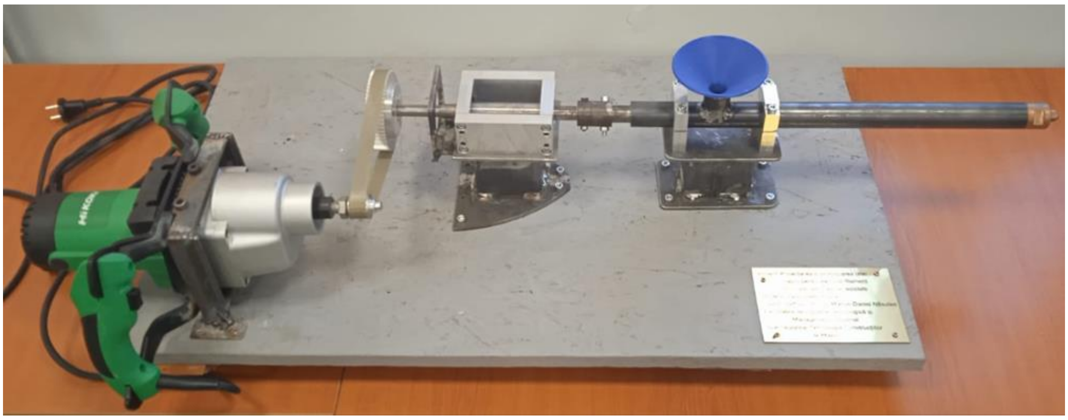

Fig. 6. The first extruder prototype, partially completed

During the prototyping process, a series of components were locally modified in order to simplify aspects such as the manufacturing process or the assembly or simply the constructive solutions in different cases. Therefore, the first extruder prototype slightly differs in comparison with the extruder 3D model presented in the previous chapter.

4. Conclusions

The paper proposes a device for recycled PET filament extrusion in order to be used on commercial 3D printers. The research presents the design stage and the prototyping process of the extruder. A study regarding the extrusion devices identified in the literature. Based on this study, the research starts the design stage with a first concept where the main components are established. Forward, based on that concept, a complete 3D model of a device is created. Further, these designed components were manufactured and assembled, obtaining a partial prototype of the extruder. Considering that the extruder is not completed, future research involves implementing the missing systems as the tube heating systems (band heaters) or the implementation of electronic elements such as temperature sensors together with voltage regulation sources of electrical heaters in order to increase or decrease the heating temperature of the barrel and the nozzle.

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