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Design and Manufacturing of The Prototype System for Recycling Waste Generated in 3 Dimensional Production to Filaments by Fused Deposition Modeling Method

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Abstract

Nowadays, three-dimensional (3D) printers have come to an important place in many sectors with the development of technology. 3D Printers that provide layered manufacturing have different raw materials requirements to be able to work the substance called filament is one of the raw materials of 3D printers. The most preferred raw material for a 3D printer is filament compared to other raw materials. The layered manufacturing device may take wrong printing or undesired printing for any reason. It is important to be able to recycle the product resulting from these printings. The aim of this work is to make the filament re-usable for layered manufacturing. The importance of this study is to create the desired diameter filament and make it usable in the industrial field. With a structure consisting of crushers, extrusion, water and air cooling units, pulling, rotary, wrapper and automatic control units, a system including mechanical, electronic and software processes was designed. With this designed system, an average of 1.75 mm diameter filament to be used in 3D printers was successfully obtained in the wrapper unit and filaments of desired dimensions were obtained within the scope of the study.

Keywords: Filament, waste recycling, layered manufacturing, 3D printer, prototype

1. Introduction

Fused Deposition Modeling technique (FDM) is one of the solid-based rapid prototyping systems. In this system, there are all forms in solid state. The solid state in the system can be in the form of filaments, rolls, sheets and granules [1]. The use of some filaments is more preferred in 3D printers. Polylactic acid (PLA) is a lactic acid-based polymer composed of renewable resources that have a greater impact area than petroleum-based plastics [2]. Acrylonitrile butadiene-styrene (ABS) material is one of the polymers used in rapid prototyping technology, which is widely preferred in FDM that was developed by Stratasys Inc. [3-4]. The gain in pre-selection of ABS and PLA filaments emerged after exchanging ideas with 3D printer suppliers [5]. In the FDM printer, the feedstock containing filament is contained in the wrapper and connected to the extrusion nozzle. The nozzle has a heater block that melts a thermoplastic polymer. The parameters to be arranged in the printer [1]software are flow and temperature. These parameters should be arranged according to the desired printing [6].

Studies on the temperature range of ABS and PLA filaments to be heated and determining the filling parameters to be arranged during the re-printing of the filament successfully obtained within the scope of this study play an important role in terms of prediction. The inferences for the determination and use of ABS and PLA filaments in the prototype designed and manufactured waste recycling system within the scope of the study were determined by researching academic sources [7-14]. Some of the information during the printing of the filaments manufactured as a result of the study were obtained by analyzing the article [15]. Waste materials

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generated during 3D printing such as filament ends, scraps and backers importance to the environmental side of FDM.

Generating recycled filaments to actualize waste management is very important for sustainability [16]. Commercial printing filaments are generally polymers such as PLA or ABS while composites are used to create objects by way of conductive, dielectric, and magnetic materials. 3D prints that are printed using plastics are advantageous [17]. These advantages are especially precious for research apparatus and specialist equipment where new designs need to be tested in biomedical applications such as 3D printed aortic valves [18]. Many companies around the world develop and improve their extruders with variations during printing. The decreasing in the cost of both material extrusion printers and plastic extruders was the starting point for recycling polymer waste and parts such as scrap support. In addition, significant economic profits are provided with the filament produced from polymer pellets. The concept of recycling enriched by layered manufacturing has increased its interest from 2008 to the present and has become a reason for the preference for many countries. Typically, non-recyclable polymers such as ABS and PLA were also obtainable in a recyclable format [19]. 3D printers, which play an active role in layered manufacturing technology, cause damage due to go for prints waste caused by the inability to present the desired product to the user and the drying of the filament on the printer (i.e. the raw material of the printer), which has not been properly protected. As a result of the damage, the idea of recycling the filament has emerged and this has been the main problem of this study. In the literature studies, a commercial PLA filament has an average tensile strength of 60 MPa; it is expected that the tensile strength of any piece to be produced in the same cross-sections from the pure PLA filament is also close to that value [20]. In literature has many different studies of PLA. For example, this study investigated the effects of FDM (Fused Deposition Modeling) process parameters on mechanical properties (tensile strength, elongation, and impact strength) of 3D (three dimensional) printed PA12 (Polyamide12) samples using Taguchi method. In the experimental design (L8), four different layer thickness (0.1, 0.15, 0.2, 0.25 mm), extruder temperature (250 and 260°C), filling structure (Rectilinear and Full Honeycomb), and occupancy rate (25 and 50%) were determined [21]. The aim of our study is to recycle the wrong prints created by 3D printers during printing, the unused parts of the support pieces in the main print, as well as the waste filament that was not completed due to any defect. Subsequently, it is melted at desired temperatures (PLA: 200 °C, ABS: 225 °C) after passing through the crusher unit and cooled by cooling units at the end of the extrusion unit. After adjusting the tension of the line with the pulling and rotary units, it is made ready for the 3D printer by virtue of the wrapper unit.

2. Material and Methods
2.1 Crusher Unit

Firstly, the filaments to be recycled were specified within the scope of this study. The filaments specified by using the crusher unit consisting of 2 stages were made to suitable sizes for the extruder entrance. A double-stage and screen crusher design was commenced. In the current layout, the blade thickness is 5 mm in the rough breaking (1st Stage). section. The blade thickness is 3 mm in the fine breaking (2nd Stage) section. Each stage is driven by a separate DC gearmotor.

Table 1. Materials Used in Crusher Unit

Quantity	Product name	Description
2	Gear	M1.5 | DP= 42 | DE=45 | Z=28 | d=30 | D=12
2	Gear	M1 | DP= 22 | DE=24 | Z=22 | d=18 | D=8
2	Coupler	8x8 Aluminum Shaft Coupling
2	Motor	12v 15 Rpm L Dc Gearmotor
10	Bearing	16x8x5 radial bearing
4	Square shaft	8x8mm 215mm Square shaft
4	Sigma Profile	20x20 266mm Sigma profile
2	Sigma Profile	20x20 300mm Sigma profile
1	Sigma Profile	20x20 280mm Sigma profile
4	Sigma Profile	20x20 148mm Sigma profile
2	Sigma Profile	20x20 190mm Sigma profile
2	Sigma Profile	20x20 104mm Sigma profile
2	Shaft	5x148mm Shaft
2	Motor Driver	Dc Motor Driver
200	Bolt	YSB M5x10
100	Bolt	YSB M5x15
200	Nut	M5/20 Sigma Profile knurled channel nut
150	Corner joint	20x20 Sigma Profile Corner Joint
1	Laser Cut	Laser cutting for crusher

Roller bearings are used to provide movement at each stage and gears with a 1: 1 ratio to transfer the movement. The materials used in the crusher unit are shown in Table 1.

The crusher unit is shown in Figure 1.

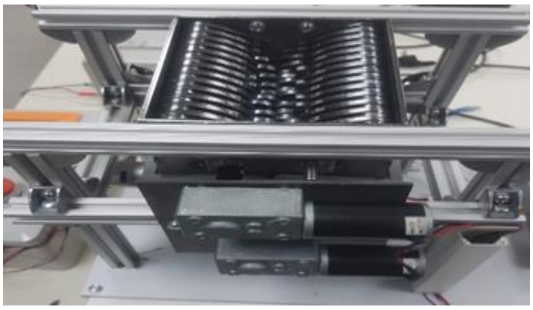

Figure 1. Crusher Unit

2.2. Extrusion Unit

The extrusion unit is essentially designed as 7 pieces. These are reducer motor, input feed silo, extrusion shaft, extrusion shaft sleeve, nozzle, heater cartridge and thermocouple. Extrusion shaft and sleeve on the system are determined according to ABS plastic material. The number of spirals on the extrusion shaft, the distance between the spirals and the helix angle are determined according to the type of material to be melted. Subsequently, the power of the heater cartridges was determined and a sleeve design proper for the shaft was made [22].

As a result of the tests and evaluations made, it was seen that ABS plastic was melted in the desired properties. The choice of dc gearmotor was determined after calculating the power required for pushing the molten, semi-melted and solid plastic. The entire extrusion unit is shown in Figure 2.

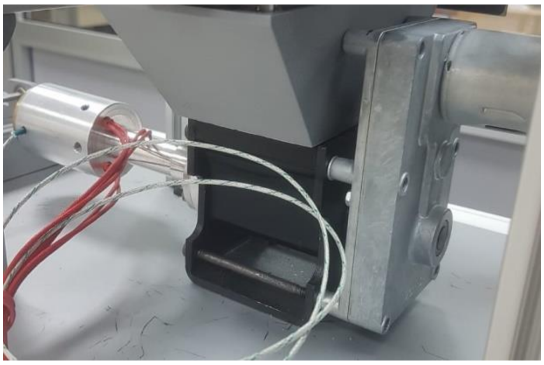

Figure 2. Extrusion Unit

2.3. Cooler Units

The cooling section on the system consists of two parts. These are water-cooling unit and air-cooling unit.

2.3.1. Water-Cooling Unit

In the water-cooling unit, the hot filament coming out of the extrusion unit is passed directly through the water and cooled. The water in the overflow chamber and the water in the main chamber were circulated with the help of the water pump on the unit. The water was ventilated and the heat on it was removed. The water-cooling unit is shown in Figure 3.

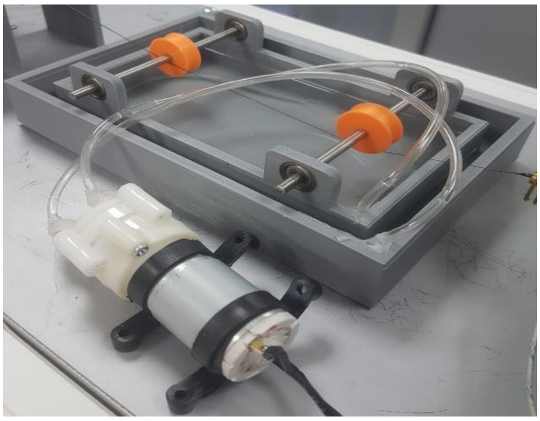

Figure 3. Water-Cooling Unit

2.3.2. Air-Cooling Unit

An air-cooling unit is designed to dry the wet filament coming out of the water-cooling unit and to remove the remaining heat. The air-cooling unit is shown in Figure 4. The materials concerning to the cooling units are given in Table 2.

Table 2. Materials of Refrigerating Units

Material Type	Quantity / Description
Ø5x100mm shaft	2
626zz roller	6
3d printer prints	Refrigeration unit auxiliary materials
Ø5x60mm shaft	1

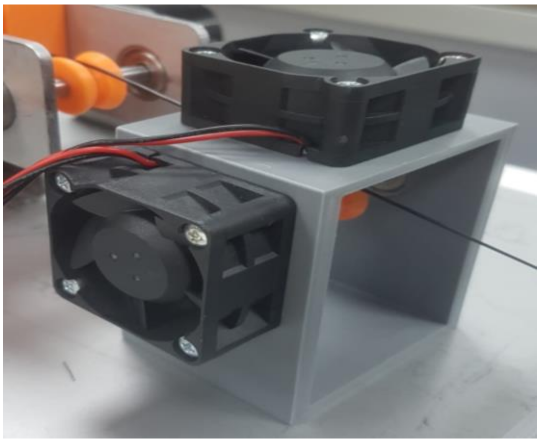

Figure 4. Air Cooling Unit

2.4. Pulling Unit

A suitable diameter of filament is formed by calibrating the speed of the line with the pulling unit. Silicone wheels are used in the unit due to pull the filament more effectively. The suitable torque is provided for the maximum and minimum speeds of the line with the DC gearmotor used on the system. The length of the filament produced on the line is determined with the encoder on the system [23]. The materials used in the pulling unit are given in Table 3.

Table 3. Materials of Pulling Unit

Material Type	Quantity / Description
DC gearmotor	12V-30 revolution per minute
Silicon wheels	51x30mm 2 pieces
6x100 mm shaft	2 pieces
6x60 mm shaft	2 pieces
Tow spring	2 pieces
Encoder	Omron encoder
Sheet metal cutting production	Auxiliary parts
3d printer parts	Pulling unit auxiliary materials
6x8 Coupler	2 pieces
6x6 Coupler	2 pieces
626zz Roller	6 pieces

Pulling unit is as shown in Figure 5.

3. Results and Discussion

The following results are obtained, if the innovative aspects and determinations of the filament recycling system designed and manufactured are analyzed.

- By virtue of the designed filament recycling system, the inert filaments formed in cases such as calibration, power cut, filament depletion, and extruder clogging up have been enabled to produce the desired filaments with contributing to nature.
- Waste support pieces were recycled.
- Recycling of inert filaments was recovered.

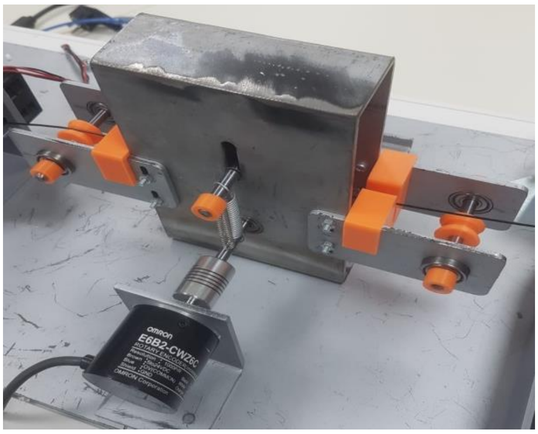

Figure 5. Pulling Unit

2.5. Wrapper Unit

The wrapper unit consists of two parts. These are divided into rotary and pulley winding. It is aimed to reel up the filament properly in the rotary part. For this reason, it operates automatically at a speed that can be arranged linearly on the screen. A conical plug-in system is designed that can be easily demounted and mounted to the wrapper part. However, the pulley can be easily mounted with its full or empty state. With the DC gearmotor in the wrapper part, speed arranged and torque control can be done in empty or loaded state. The image of the wrapper unit is given in Figure 6.

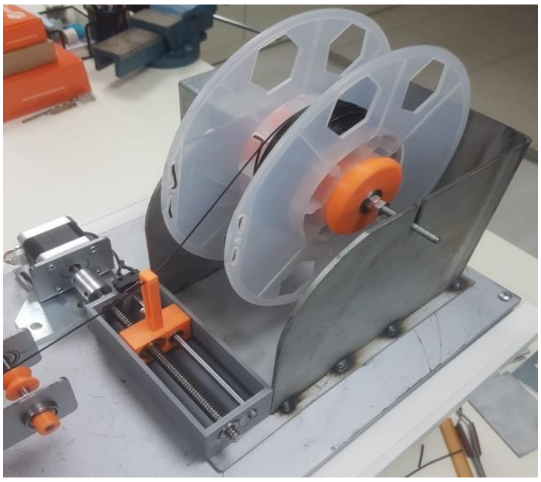

Figure 6. Wrapper Unit

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- With the prospective studies, it is foreseen some materials such as plastic cups, plastic bottles etc. that can be crushed in the crusher unit and recovered.
- It is thought that bronze, fiber, wood, carbon fiber, elastic reinforced fibers can be obtained from waste filaments in consequence of prospective ideas.
- The designed wrapper unit had performed the wrapper synchronously with the other units and there was no speed problem.

During the testing and start-up stage of the filament recycling system, prototype manufacturing and assembly were completed and the production tests of ABS material were carried out between 5-9 revolution per minute and at 200-235 degrees Celsius. A filament with an average diameter of 1.75 mm was obtained that suitable for FDM printers. It gave the best result among the previous studies, with an output of 11.3 Volts from the ABS filament extruder motor at 200 degrees at 5 rpm. As the number of revolutions increases, the tension of the filament at the exit of the extruder increases and the balance between the other units gradually disappears. In order to prevent this, the filament is moved in the right-left direction in the traversing unit, so that it has a diameter of approximately 1.75 mm before it comes to the wrapper unit.

4. Conclusion

Successfully completed filament recycling system, prototype design and manufacturing enabled the desired filament to be obtained on a product basis. Some of the 3D printers using FDM technology require a filament diameter of 1.75 mm. In this study, 1.75 mm filament diameter was realized with 2% tolerance and made suitable for material production. ABS type filament gave more successful results than PLA type filament. Robust, highly resistant and flexible materials can be produced with ABS filament with a melting temperature of 220 degrees. In this way, the filament to be used for the 3D printer can be recycled with high efficiency and an important contribution is made to us and the relevant units economically. In case of urgent raw material need arising from additive production technology, the recycling system will be easily put into use. It has provided great convenience in terms of time for the production process, especially when material supply is needed. The entire filament recycling system is shown in Figure 7.

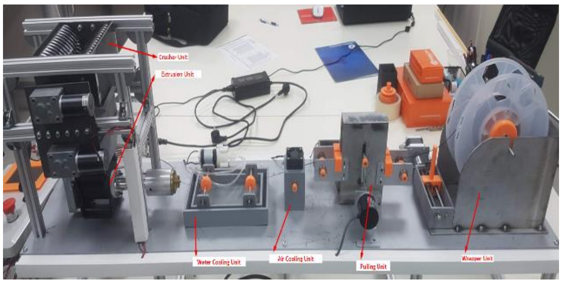

Figure 7. Experimental Setup Equipment.

Crusher unit is first equipment in this study. Its mission is crushing waste filaments and transport to extruder unit. The second equipment is extruder unit that heating the filament until 225 degrees and set the revolution per minute. When the filament is heated it has been ready for cooling. The third one is cooling units that cooling the heated filaments on air and water. Cooling step is necessary for hardness because the filaments must be high steaminess. The fourth one is pulling unit which set the tension on the filaments. This tension is important for system. Because filaments diameter is set by this equipment. The fifth one is wrapper unit which wrap the filaments. Filaments is ready for print on 3D printers in this section.

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Author's Contributions

İlker ERTUNA: Drafted and wrote the manuscript, performed the experiment and result analysis.
Ceren Göde: As the project consultant, supervised the works and helped prepare the manuscript.
Uğur Can TOPÇU: Assisted in analytical analysis on the structure, supervised the experiment's progress, result interpretation and helped in manuscript preparation.
Çağrı YALÇINKAYA: Assisted in analytical analysis on the structure, supervised the experiment's progress, result interpretation and helped in manuscript preparation.
Defne AÇIKGÖZ: Searched the literature and helped in manuscript preparation.
Ezgi CIRIK: Searched the literature and helped in manuscript preparation.

Ethics

There are no ethical issues after the publication of this manuscript.

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