

Design of 3D filament extruder for Fused Deposition Modeling (FDM) additive manufacturing

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Abstract:

Filament extruder produces plastic filaments with specified diameter by using corresponding dies. Input materials (thermoplastics) are used in the form of granules and pellets and waste plastic materials can be used. Rod heaters are used to melt the input materials and Screw is used to feed the input raw materials longitudinally along the barrel. Screw is consisted of three zones namely feed, melt, and transition zone. Input raw material is melted by using rod heater. Two temperature zone with six rod heaters are used to acquire maximum efficiency. Analog temperature controller is used to control the temperature of the two heaters zone. This article describes a filament extruder, which is a plastic extruder capable of making commercial quality 3D printing filament. Specifically, this paper describes the design, fabrication and operation of a filament extruder. A 2.5 mm die was used to extrude the filament at the diameter of 1.75mm. Diameter of the filament can be further reduced by using DC-motor to draw the filament coming out of the die. Production can be further increased by increasing the barrel diameter above 45mm and screw diameter above 16 mm. Mechanical and thermal properties were improved by adding different fillers to the input raw material

Keywords:

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1. Introduction

Rapid prototyping is a manufacturing technique produce components in 3D using computer aided design (CAD). This technique is usually done using 3D printing technology. FDM is one of the techniques used for 3D printing (**Lipson H. and Kurman M. 2010**). It works on the principle of additive manufacturing. Additive manufacturing is the process used for making 3D product by added many layers from materials (**Noorani ,R. 2017**). This type of 3D printing uses plastic filaments to produce a part. Generally plastic filaments used in FDM are acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), poly carbonate (PC), poly amide (PA), polystyrene (PS etc. Available filament for 3D printing high cost and the plastic filaments used aren't manufactured and it is mostly imported (**Hausman. K and Horne, R. 2014**). In order to reduce the manufacturing cost and plastic filament's cost, this extruder machine is developed. Extruder produces plastic filament at the diameter of our required size 1.75 mm (**Jean le Bouthillier, 2016**) (. The main theme of our

project is to produce the extruder machine at low cost. We can use the recyclable plastics in this process and can use this extruder as eco-friendly (**S. Zhong et al, 2018, M. Kreiger et al ,2013**). Strength of the extruded plastics can be increased by adding the fillers while reinforcing the input raw materials. Additionally, the possibility of using extruder to modifications materials 3D printing for improvement in order to suit various applications and study the impact of these amendments at the level of scientific research (**Lafleur,P. and Vergnes, 2014**).

1.1. Research problems:

- High cost of 3D printing filament
- All FDM 3D printing materials in Egypt are imported

1.2. Research Objectives and Importance:

- Development of new filament extruder design
- Conducting modifications to FDM 3D printing materials to improve their properties

2. Experimental

2.1. Extruder Design

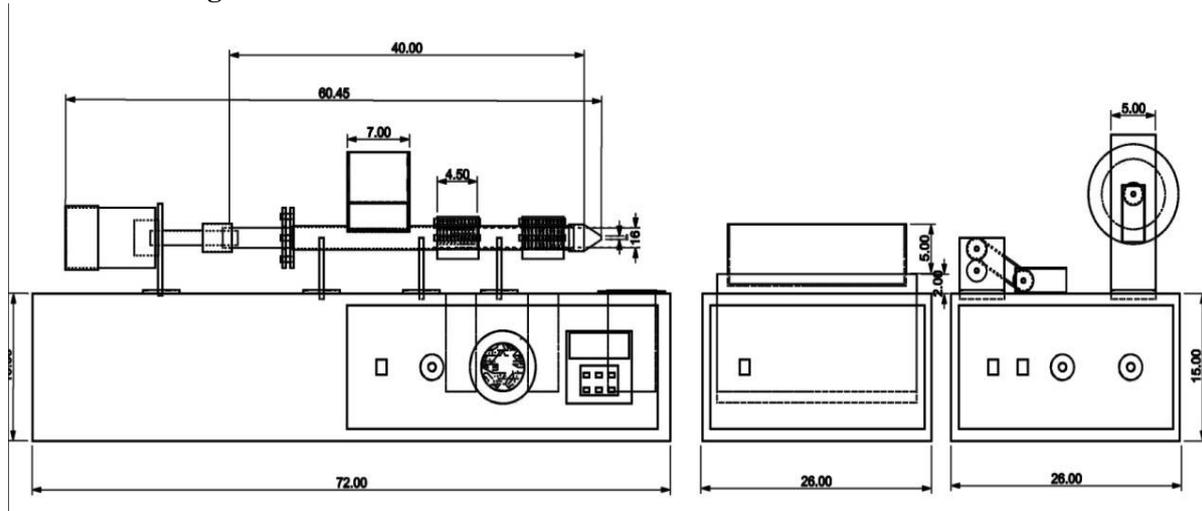


Figure 1: Horizontal extruder design for 3d printing filament

2.2. Materials and methods

- High-density polyethylene (HDPE) Exxon Mobil, supplied by El Sherif For Plastic MFR 0.4 g/10 min. (190 °C/2.16kg).

2.3. Extruder manufacture

- The extruder was manufactured using many components which available in Egypt shown in Table 1.

Table 1: Extruder components

1	Rod heater
2	Auger (screw)
3	Chamber (barrel)
4	Motor
5	Hopper
6	Nozzle (Die)

2.3.1 Auger (Screw)

The screw which is shown in the Figure 2 is fitted inside the chamber. It is driven by AC motor. The screw is divided into three zones as illustrated in Figure 3: the feed zone, the

compression zone, and the metering zone. The feed zone delivers plastic pellets from hopper into the barrel to begin the longitudinal movement of the plastic by using rotation movement; the screw threads move the plastic down the barrel within the chamber. Heaters help the plastic to develop a contact to increase its friction against the chamber wall. In addition, without friction the plastic could not be transfer forward and would merely rotate inside the screw. In the compression zone, the root diameter of the screw increases while the height of the flight decreases. The plastic granules are liquefied here because of compression, shearing and heating produced in the barrel. Next the melted plastic moves through the metering zone. In this zone the screw diameter remains constant and the melted plastic which is under high pressure is pumped into the extruder die (Lafleur. P and Vergnes B., 2014) (Subramanian. MN, 2011).

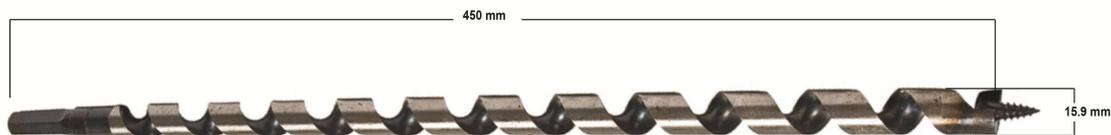


Figure 2: Extruder screw

The screw diameter which we use is 16 mm and for the relation between the length and the diameter we choose, 28/1. The reasons to take these measures and not any others are based basically on the fact that the screw has to be the smallest size possible without increasing very much the price. So, we consider 16 mm to be the

smallest diameter with reasonable price and with precise usefulness. In addition, we choose 28/1 for the relation L/D because we consider 450 mm the maximum length keeping a light screw in terms of weight, considering that if the relation L/D is bigger, the price will be lower.

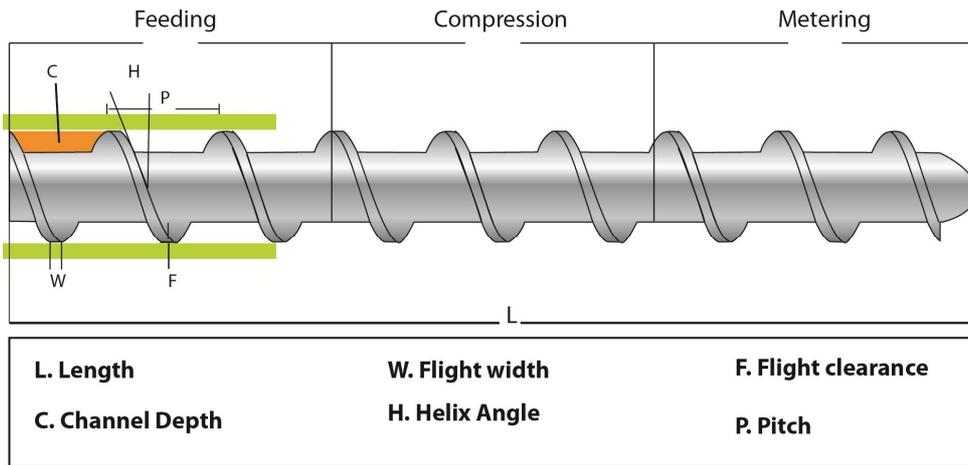


Figure 3: Screw Geometry details

Therefore, defined the first parameters of our screw $D = 16$ and $L = 450$. Also, they have been taken into account other options of diameters and length. (Encyclopaedia of engineering, 2015).

2.3.2. Chamber

The chamber provides the housing for the screw. The plastic shreds are fed into the chamber through the screw. The melting and mixing of the

plastic occur within the chamber before filament is extruded through the nozzle. Since the chamber experiences high temperatures during the extrusion process, the following parameters were used in order to choose the material. The 3D-model is designed in Rhino; it is shown in the **Figure 4**.

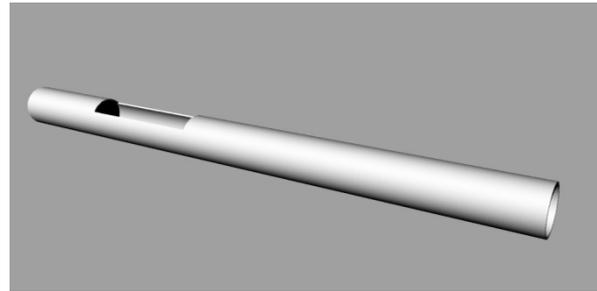
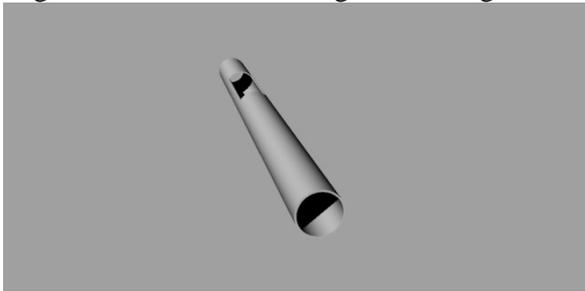


Figure 4: CAD model of Chamber

The material chosen for the cylinder is steel F-174, also must be able to handle with high temperatures and be hard enough to resist degradation due to the friction generated between the inner face of the cylinder and the plastic flow. The cylinder is the part in charge of keeping the material inside while going throughout the screw. For this reason, its inner diameter is the sum of the screw diameter and the clearance calculated above, to a total of 16.1 mm.

2.4.3. Hopper

Hopper is made up of steel sheet metal. There are no specifications for hopper design. Its size varies depending on the application or quantity of production. So, the hopper design is just to fulfill the requirement of this project. It is designed as gravity fed hopper is shown **Figure 5**. Also, is wedge type and the flow of solid in the hopper is mass flow. It is cut and manufactured from 3mm metal sheet with dimensions 150mm x 150mm.

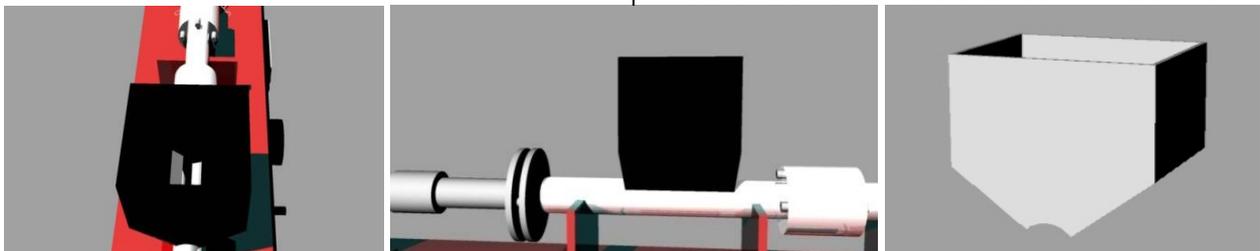


Figure 5: CAD model of Hopper

2.3.4. Motor

The motor for the system is a 35 RPM motor. it is controlled by a PWM (Pulse Width Modulation) speed controller which, controller is wired in series with the power source from 24 V supply and the motor. Also, was the simplest control system.

It is a variable speed control system with the RPM is selected by varying the duty cycle the speed of the screw show be around 22 RPM so that the material mixing, and melting will be proper.

2.3.5. Nozzle

The material most commonly used for die is brass



because it has to withstand high temperatures. Likewise, is a good conductor of heat, quality that is needed to heat fast and uniform the nozzle as the printing material needs to be printed around 200°C. Brass is one of the materials with best characteristics and therefore why we are choosing it for the nozzle. It is also one of the most important elements of extruder, as it defines the

final shape of the plastic (Giles. HF et al 2013). Otherwise, its characteristics were going to remark its hardness and the fact that it perfectly keeps its conditions for a long period of time. Also, it doesn't get affected by the external conditions. Its characteristics make it one of the best materials in the market but with a lower price. The die that is used is M12 Brass plug with 2.5mm hole.

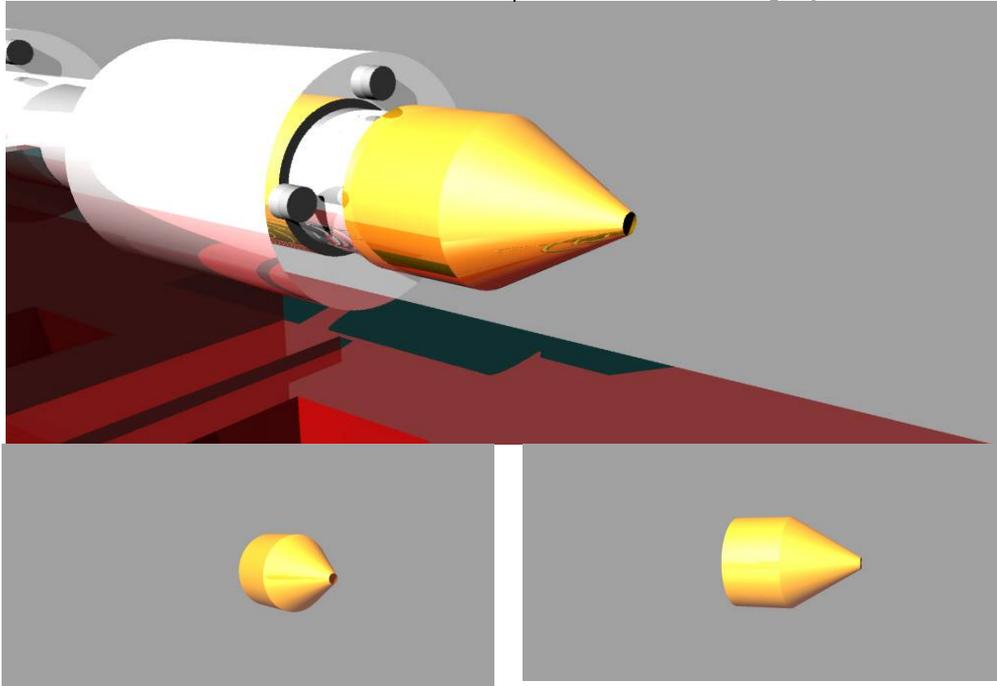


Figure 6 : CAD model of brass nozzle

2.3.6. Heater system design

Heaters were located along the barrel, with thermocouples in each zone to control the heaters and barrel temperature. The heaters cover as much barrel surface area as practical, minimizing hot

and cold spots along the barrel length. In an individual extruder temperature zone, there may be one, two, or three heater bands with one thermocouple controlling them.

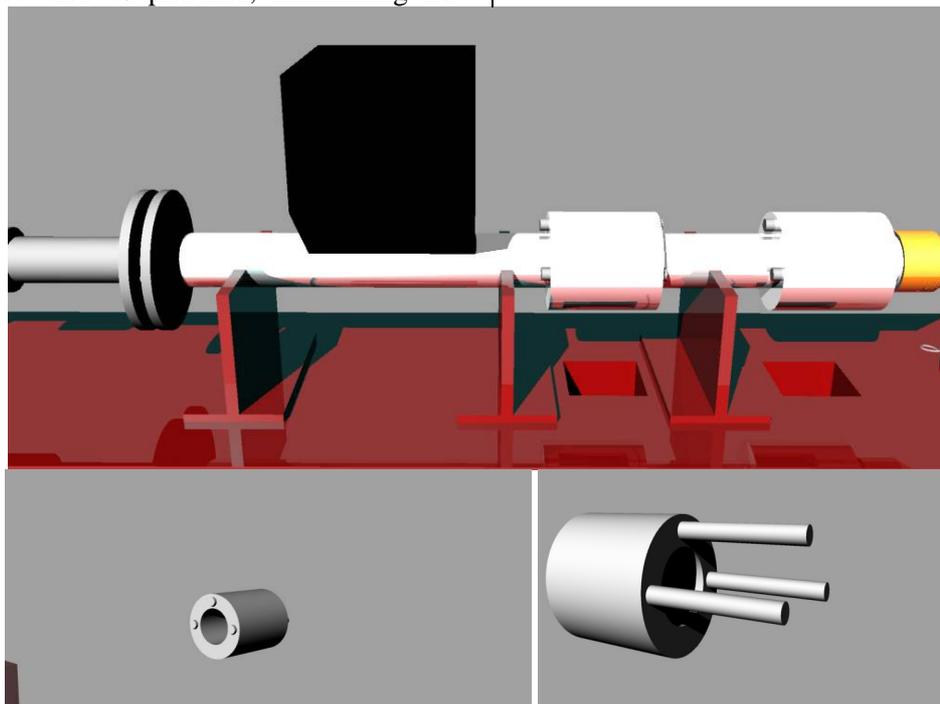


Figure7 : CAD model of heating system

2.3.8. Extruder body design

The external body of the extruder was designed 3d modeling with rhino core 5 software is shown

Figure 8. 3D design was transformed into 2D drawing and cut with laser cut machine. Metal sheets were used in thickness 3mm.

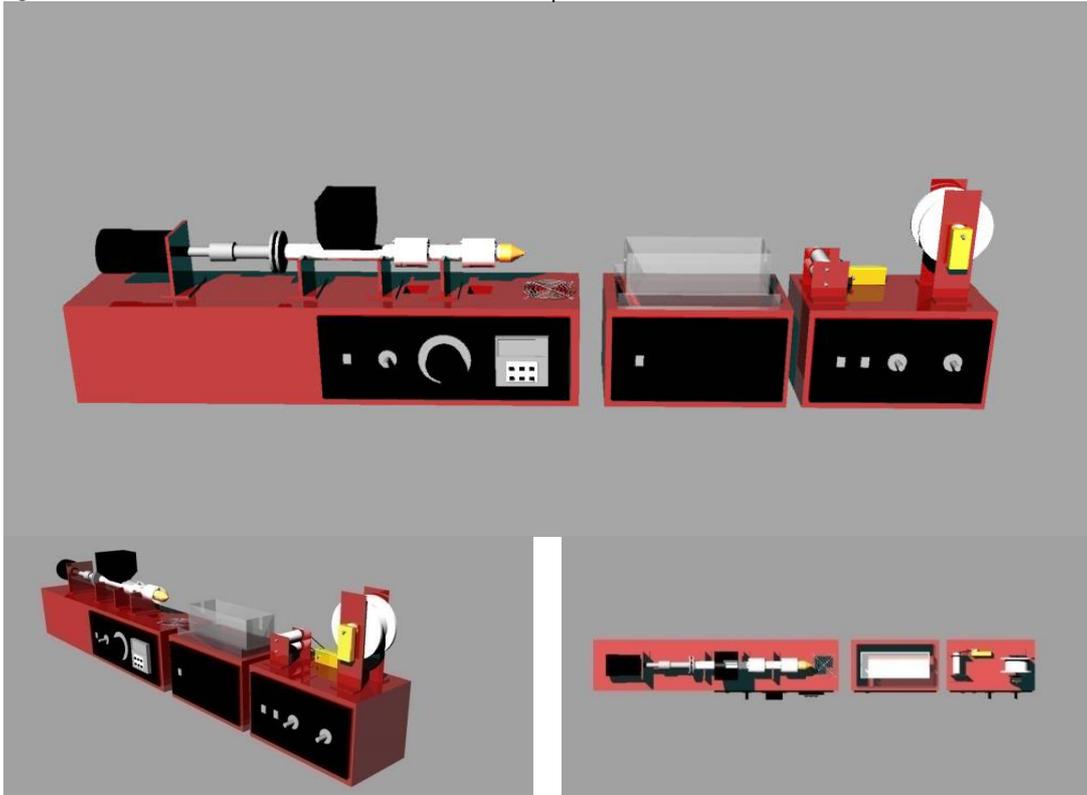


Figure 8 : CAD model of extruder design

3. Result and Discussion

3.1. Extruder Manufacturing

The filament extruder shown in **Figure 9** was tested with various polymers and can handle any thermo polymer up to a maximum temperature of 250°C. It should be noted that the highest temperature achievable is 300 °C, which is the maximum operating temperature. However, 250 °C is the maximum tested to provide a safety factor.

The filament extruder was validated with HDPE. The system can create a full kilogram spool of virgin HDPE in 2 h (± 15 min). The HDPE extrusion rate is 0.5 kg/h after the initial heating of 20 min.

The cost per kilogram of HDPE pellets is 28 L.E. Thus, for the cost of electricity of 1.4 LE per kWh, filament costs can be reduced to 40 L.E /kg or less. It should be noted there is a wide range in the costs of commercial filaments materials.



Figure 9: Filament extruder

3.2. Filament extrusion

The filament was produced using our extruder that as two temperature zones. The first zone function as feed zone heating temperature, the second zone

is the compression zone heating and heats the pumping zone and the die. During the extrusion, several cooling methods were performed to obtain the filament size such as cold-air gun and water-

bath. Where an electric spooling device serves as a puller for the filament during production while the filament was wrapped around a plastic profile tube. HDPE were provided in pellet form. The material granules were fed into the extruder hopper where they were heated to molten state and forced through the die producing filament. Materials were not pre-dried before extrusion process. Water bath



and a pulling unit with a device shown in **Figure 10** and 2.5 mm nozzle die was used to achieve 1.75 mm diameter of the filament by drawing to final diameter. The water-cooling section was a 31 cm length and was positioned at 10 cm from the extruder die. The filament puller was positioned at 75 cm from the extruder die.



Figure 10 : water bath and pulling unit

Several trial tests were run to optimize conditions for the HDPE extrusion process. It was found that HDPE filament was better than satisfactory. HDPE extrusion went without any complications. The HDPE filament surface did not contain foreign particles as shown in **Figure 11**.

The extrusion process parameters for HDPE were selected based on the results of several trial runs. For HDPE extrusion, the water bath temperature was

set to room temperature to have a slow cooling process and to control the diameters of filaments. The cooling water temperature was crucial to the roundness and diameter tolerance of the filament. To cool the extrudate uniformly on all sides; it was positioned at 90° at the water bath dam entrance, which was cleared in **Figure 12**.



Figure 11: Produced filament from HDPE



Figure 12: Filament cooling the water bath

3.3. Filament roundness

The filament die of 2.5 mm was tested with virgin HDPE at the same cooling method. to be optimized. More than four trials were made but the only reasonable data was recorded. The preliminary set data was indicated as the test run in **Table 2**.

During the second production, the extrusion speed was reduced by 25% of the virgin material production (18 RPM) then the filament size got close to the wanted size and cooling method was also changed to water bath.

Furthermore, the production, the water bath cooling method was observed to be enough for cooling at one-meter distance to the pulling device. This gives the molten plastic an

approximate 70% cooling before been pulled by the pulling device. Then, it finally cooled down after passing through the puller. The top and bottom wheel of the puller was adjusted to ensure the filament formed the required circularity shape that would fit the 3D printer nozzle available in the lab.

The filament size measurement was done with digital caliper at an interval of 2 meters **Figure 13** with a tolerance of +0,02 in order to be as accurate as possible while producing them. The tolerance of +0,02 was allowed according to previous type filament production and the available 3D printer also gives a room of 0,05 tolerance (1,75mm+0,05 tolerance).

Table 2: Filament size with different condition

Test	Extrusion temperatures zone(°C)	Extrusion speed (RPM)	Cooling method	Filament size (mm)
1	180	22	Cold air gun	1.81 mm ±0,02
2	180	22	Water bath	1.68 mm ±0,02
3	180	18	Cold air gun	1.74 mm ±0,02
4	180	18	Water bath	1.65 mm ±0,02



Figure 13 :Digital caliper verification filament from virgin HDPE pellets

3.4. Cost Estimation

The components purchased were at low cost and the quantity of the components purchased is given in the **Table 3**.

Table 3: Extruder components price

	Parts	Quantity	Price
1	Screw	1	250 LE
2	Chamber	1	60 LE
3	Motor	1	450 LE
4	Hopper	1	90 LE
5	Nozzol	1	75 LE
6	Heater	6	300 LE
7	Temperate control	2	450 LE
8	Body	1	350 LE

Conclusion

Extrusion of high-quality filament requires that the temperature and extrusion rate be appropriately set. If the extrusion rate was too high the raw plastic would not fully melt, and small solid pieces would cause roughness and bubbles in the resulting filament. This condition can be avoided by decreasing the motor speed for an appropriate temperature. This allows enough heat to be delivered to the plastic pellets, fully melting them and resulting in a homogeneous and smooth plastic filament. Experimental part showed that the prototype could extrude good quality filament with motor speed 18 (RPM) and the temperature in excess of 200°C, the melting point of the HDPE pellets in use for the experiment. The final diameter of the filament was determined by both the size of the die and the speed at which the hot filament was drawn away from the outlet.

References

- [1] Lipson. H, & Kurman. M (2010), Fabricated: The New World of 3D Printing, John Wiley & Sons, Incorporated, Somerset. Available from: ProQuest Ebook Central.
- [2] Noorani. R (2017), 3D Printing: Technology, Applications, and Selection, CRC Press, Milton. Available from: ProQuest Ebook Central.
- [3] Hausman. KK. & Horne. R (2014), 3D Printing For Dummies, Wiley, Somerset. Avail-able from: ProQuest Ebook Central.
- [4] Jean le Bouthillier(2016), The Importance of High Quality 3D Printer Filament, Boot Industry.
- [5] S. Zhong, J.M. Pearce, (2018) , Tightening the loop on the circular economy: coupled distributed recycling and manufacturing with recyclebot and RepRap 3-D printing, Resour. Conserv. Recycl. 128, 48–58.
- [6] M. Kreiger, G.C. Anzalone, M.L. Mulder, A. Glover, J.M. Pearce, (2013) , Distributed recycling of post-consumer plastic waste in rural areas, MRS Online Proceedings Library Archive 1492 ,91–96.
- [7] Lafleur. P, & Vergnes, B (eds) (2014), Polymer Extrusion, John Wiley & Sons, Incorporated, Somerset. Available from: ProQuest Ebook Central.
- [8] Subramanian. MN (2011), Basics of Troubleshooting in Plastics Processing: An Intro-ductory Practical Guide, Wiley, Hoboken. Available from: ProQuest Ebook Central.
- [9] Encyclopaedia of engineering (2015), Extrusion of Plastics| Extrusion moulding| Ex-trusion Process.
- [10] Giles. HFJ, Wagner. JRJ. & Mount.EM(2013), Extrusion: The Definitive Processing Guide and Handbook, William Andrew, Saint Louis. Available from: ProQuest Ebook Central.