DIPLOMA THESIS

Rihem Jebali

2024

Hungarian University of Agriculture and Life Sciences

Szent István Campus

Stipendium Hungaricum

Mechanical Engineering Master's training education

Design of a Filament Extrusion System for a Sustainable and Cost-Effective FDM- 3D Printing

Insider consultant: **Dr. László Zsidai**

University professor

Insider consultant's Institute/department: **Institue of Technology / Mechanical Engineering department**

Created by: **Rihem Jebali**

Gödöllő, Hungary

2024

TECHNICAL INSTITUTE

MECHANICAL ENGINEERING MASTER

Technical development specialisation

DIPLOMA THESIS

worksheet

Rihem Jebali (B45K1F)

for

Title of the diploma thesis: Design of a Filament Extrusion System for a Sustainable and Cost-Effective FDM- 3D Printing

Given laboratory process ....

Task reference:

A brief (3-4 lines), in an informative way, of the initial data, the professional task and/or problem to be solved and the tasks to be performed.

- Design of a Filament Extrusion System
- Calculations for the system dimensioning
- Cost calculation of the system

Contributing department: Mechanical Engineering

Outsider consultant:

Insider consultant: *Dr. Zsidai* László university professor , MATE, Technical Institute

Deadline of thesis submission: 2024 year 04 month 29 day

Date: Gödöllő, 2023 year 11 month 15 day

	I approve	**Received**
(head of deparment)	(specialist coordinator)	(student)

Table of contents

Chapter 1 : Introduction

Additive manufacturing has been widespread since the last decade. This 3D printing process consists of creating three-dimensional objects by building them up layer by layer. It has completely changed how we create, test, and manufacture a variety of goods, from basic domestic items to complex industrial parts.

From a digital model of the object, typically using computer-aided design (CAD) software, to a 3D printed part, the printer follows the instructions in the digital file to create the object layer by layer, using a variety of materials such as plastic, metal, ceramic, or even biological materials.

In additive manufacturing, a variety of technologies and methods are employed, such as fused deposition modeling (FDM), one of the most common technologies. It uses plastic filaments as the primary raw material which will be our focus in this work.

My thesis work goals are mainly :

- Focus on the extrusion process of filaments used in FDM (Fused Deposition Modeling)

which is one of the commonly used technologies in additive manufacturing.

- Choose the adequate polymer to carry out our work
- Follow step by step the the extrusion process and main parameters to make the continuous filament.
- Study and design of an extruder machine and the winding system for 3D printing filaments using SolidWorks software.
- Calculate the approximative cost of the system
- Prepare an operating manual for users.

To carry out this work, we started with a literature review where we provided a general overview of manufacturing by melting and its different types. Among these, extrusion and 3D printing.

Then, in a second chapter, we specifically discussed the extruder characteristics while conducting analytical and numerical studies to calculate not only the dimensions of the mechanism but also the rotation speeds and motor selection. Additionally, a study for filament winding was carried out.

In a third chapter, we used SolidWorks to design the machine and we presented the CAD model of various components then we made a small table for cost calculations and steps to well operate the machine.

Finally, this work was concluded with a general conclusion.

Chapter 2 : Litterature Review

2.1. Additive manufacturing

2.1.1.History

Several researchers used additive manufacturing techniques to exhibit working prototypes in the late 1970s and early 1980s. In 1981, Hideo Kodama of the Nagoya Municipal Industrial Research Institute received a patent for a method that would later be called stereolithography. It involved the layer-by-layer curing of photopolymer materials using UV lasers (*Gibson et al., 2014*).

In 1986, Chuck Hull established 3D Systems and introduced the first stereolithography machine for sale (SLA). While employed by Stratasys in 1989, Scott Crump created the first fused deposition modeling (FDM) 3D printer (*Jones et al., 2011*). Since then, advances in additive manufacturing (AM) technologies have accelerated, opening up new applications in industries like consumer items, automotive, aerospace, and medicine (*Wohlers Associates, 2014*). These days, additive manufacturing includes a broad spectrum of techniques that are still upending established manufacturing paradigms.

After the appearance of 3D printing methods in the late 1990s and its quick developemenet, in the early 2000s, 3D printing technologies were first widely investigated in a variety of industries, including the aerospace and medical sectors.

We will present the summarized timeline of 3D printing, along with the development of polymer materials, in the **Figure 1** below made by (*Park et al., 2022*). The development of feedstock materials, especially polymers, is indispensable in the invention of 3D printing. Most polymers, including polyamides (PA), polylactic acid (PLA), and epoxy, were synthesized and developed during the 1920s and 1940s. (*Feldman, 2008*)

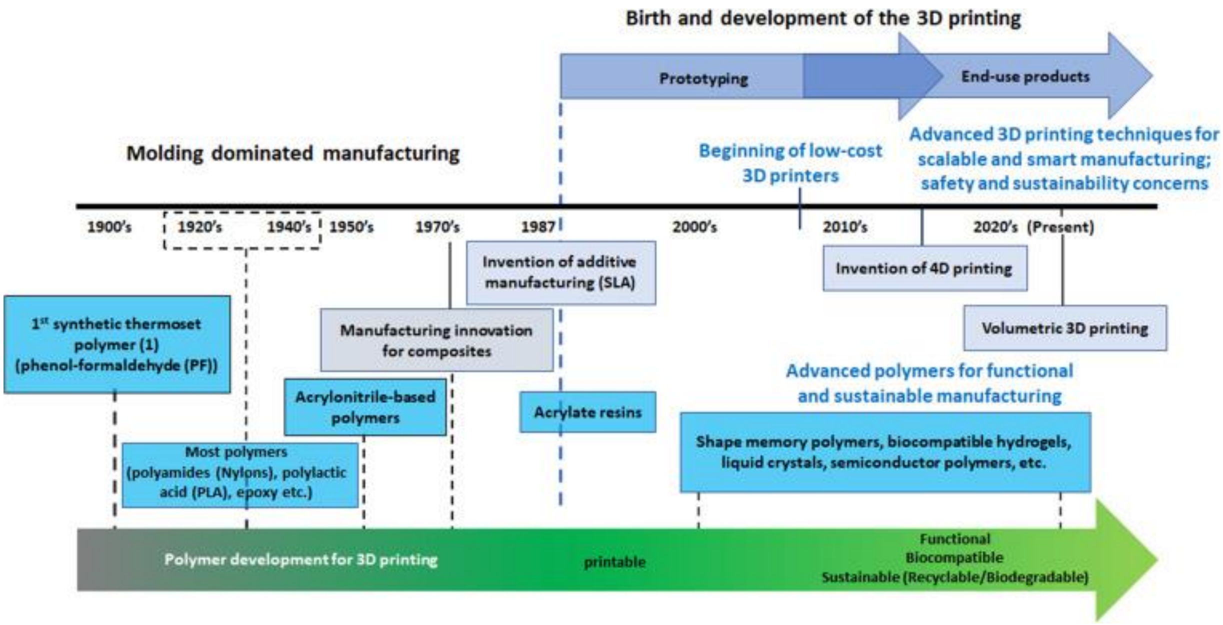


Figure 1: History of 3D Printing and polymer development for 3D printing

Source: (Park et al., 2022)

2.1.2.Definition

Parts that are made using additive manufacturing technologies and are created through consecutive cross-sectional layers are made as follows, a three-dimensional solid model is first designed or scanned as a digital CAD file, which is then sliced into hundreds of layers (depending on the resolution) using slicing software. To produce a printed part, each layer is formed by selective deposition of material (and/or energy to fuse the raw material) (*Chen, Y., Zhou, C., & Lao, J. 2011*)

2.1.3.The fundamentals of additive manufacturing

AM entails a series of steps that lead from a virtual CAD definition to a physical resultant component. And it can be used in many forms and to a varying degree of different products. (*Wong, K., & Hernandez, A. 2012*). Smaller, simpler products may only use AM for visualization templates, while bigger, more advanced products with more engineering material use AM at several levels and iterations during the production process.

The conversion of a part from a CAD model to a real-life part though additive manufacturing is a very simple concept, it is achieved through the deposition of a part's cross section layer by layer shown in **Figure 2** and the final parts surface quality and its accuracy to the CAD model is directly influenced by the deposited layer height.

That is where the term additive manufacturing comes from due to the addition of material be it polymer or metal or ceramic .Every additive manufacturing technology relies on this layer-based manufacturing approach but how to achieve it is where the difference comes from.

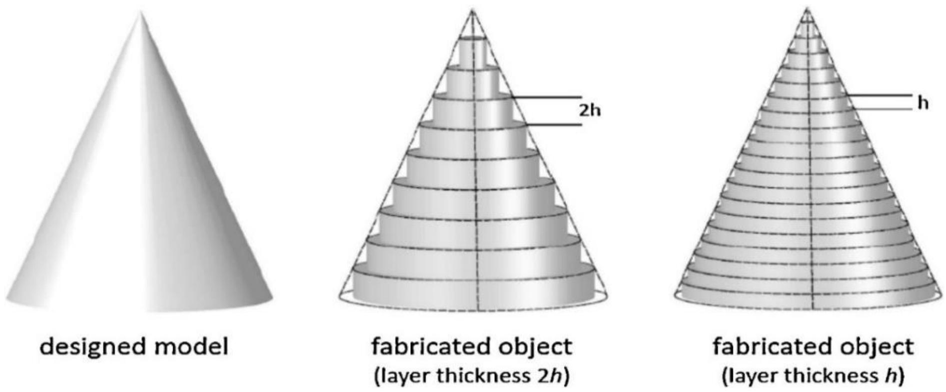


Figure 2: Slicing an object with different layer heights

Source: (Quan, Zhenzhen, et al,2015)

2.1.4.Advantages of Additive Manufacturing

One of the key aspects of additive manufacturing is its luctravity and versatility in the parts that it produce. This advantage for low-volume and complex parts is due to lower costs compared to conventional methods. Traditional techniques like injection molding, CNC machining and die casting require expensive tooling like molds, jigs and fixtures that drive up costs for low production runs. (*Bandyopadhyay & Bose, 2019 p.10*). Each part must also be cut or formed individually, taking machine time. By contrast, additive technologies fabricate parts directly layer-by-layer without tooling, resulting in much lower marginal costs per part. For low volumes or high product mixes, additive manufacturing dramatically lowers costs. (**Figure 3**)

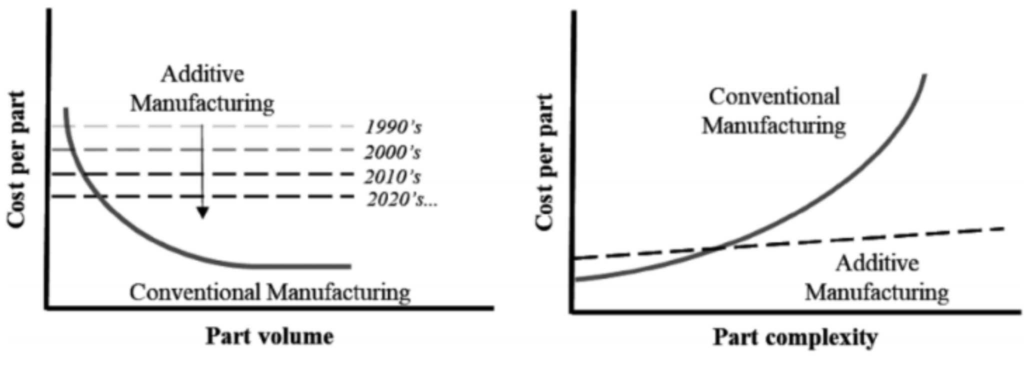


Figure 3: Comparison of conventional manufacturing and AM

Source: (Bandyopadhyay & Bose, 2019)

2.1.5.Application Areas of AM

Additive manufacturing is nowadays used in different area. It is growing in many fields such as medical, engineering, education, design and manufacturing of prototype before starting the full production (*Javaid et al., 2015; Lipton, 2017*). Not to mention that this new trend had also invaded the agriculture are because it offers excellent physical model-making capabilities for agricultural machinery and is projected to encourage innovation in this field. (*Javaid, Mohd & Haleem, Abid. 2019*).

The design of agricultural equipment meets the unique demand of the special consumer, i.e., customised products are manufactured by the AM technology. On the fabrication principle, various AM technologies are introduced in the agricultural field and adapted to meet the demand of agricultural equipment design and materials processing. (*Javaid, Mohd & Haleem, Abid. 2019*).

2.2. Printable Polymers

Different types of 3D printers use different materials (such as polymer, ceramic, metal, and composites). For example, one commonly used 3D printer, fused filament fabrication, uses polymers and polymer-based composites with the addition of different types of fillers, including metal and ceramic nanoparticles. Among various materials, a polymer is one of the most widely used feedstocks in almost all types of 3D printing methods except for directed-energy deposition. Depending on the printing methods and applications, different types of polymers, including thermoplastics and photopolymers, can be tailored to fit the manufacturing process. (*Park et al., 2022*)

As materials for FDM, the standard and engineering levels of thermoplastic such as polylactic acid (PLA), polycarbonate (PC), polyethylene terephthalate (PET), nylon (PA), and acrylonitrile-butadiene-styrene (ABS) have been widely used. As the hot end develops the capability to create high temperature, the advanced plastic such as polyether-ether-ketone (PEEK) and polyetherimide (PEI) are becoming printable. Due to the wide selection of feedstocks, it is important to know material properties (physical and mechanical properties) and printability when choosing the right polymer for the finished product. (*Park and Fu, 2021*)

2.2.1. ABS

ABS (acrylonitrile-butadiene-styrene) is a common thermoplastic which is amorphous in nature and having high impact resistance, heat resistance and toughness, low thermal conductivity (*Kumar and Singh, 2020*)

This thermoplastic material is considered as a useful engineering plastic in subtractive and additive manufacturing processes. In the past two decades, ABS and its composites have been explored for numerous research areas like welding, molding, 3D printing, etc. (*Kumar, Singh and Ahuja, 2022*)

2.2.2. PLA

PLA is the most widely researched and promising biopolymer that is capable of substituting conventional petroleum-based polymers due to its renewability, recyclability, biodegradability and compostability. In addition, PLA has an excellent manufacturing ability as it is suitable to be processed with various methods.

Lactic acid as the raw material is produced by fermentation of glucose or sucrose and is refined to a high purity. Applications of PLA have been developed as food packaging material, textiles, and recently also as engineering plastics. (*Hagen, 2012*)

Injection moulding, film extrusion, blow moulding, thermoforming, fibre spinning and film-forming are among the PLA manufacturing processes (*Abral, 2021*).

PLA is a very useful material to be used as a replacement for petroleum-based polymers because of its good mechanical properties and good processability. PLA, however, is a hydrophobic polymer and has poor toughness, slow degradation rate, less reactive side chain groups, and low thermal stability (*Deshmukh et al., 2017*)

2.2.3. PET-G

PETG, also called PET-G, is a thermoplastic polyester that is notably durable, formable, and resistant to chemicals during manufacture. Polyethylene terephthalate, or PETG for short, is a modified version of PET in which specific chemical properties are provided by the molecular incorporation of glycol. The monomers of PET and PETG modified with glycol are the identical, but PETG performs better at high temperatures and has greater strength and durability as well as greater impact resistance. (*Durgashyam et al., 2019)*

Table 1: Main properties of PLA, ABS and PET-G. Source: (*Lipot, n.d.)*

Materials	Extrusion Temperature	Print bed Temperature	Mechanical Properties	
			Hardness Rockwell	Tensile Strength
PLA	180 °C - 220 °C	Not heated bed required	104 - 118	30 MPa - 50 MPA
ABS	220 °C – 300 °C	90 °C - 110 °C	68	22 MPa - 74 MPA
PET	220 °C – 250 °C	50 °C – 80 °C	104 - 121	50 MPA

2.3. 3D printing technologies

According to the American Society for Testing and Materials (ASTM F2792-12a) there are over 50 different AM technologies, which are classified into the following seven types illustrated in the **Figure 4**: binder jetting, material jetting, material extrusion, vat photopolymerization, powder bed fusion, energy deposition and sheet lamination. (*Zhakeyev et al., 2017*)

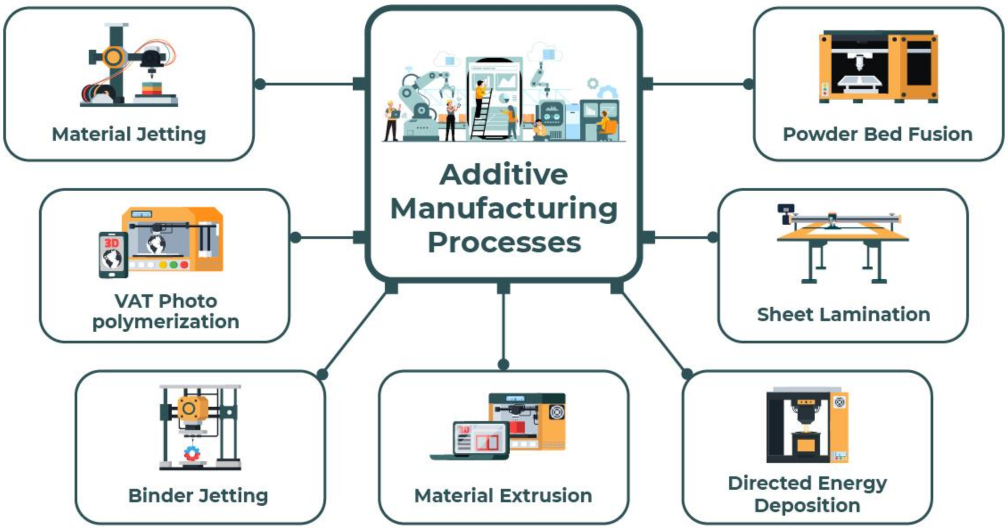


Figure 4: Additive Manufacturing processes

Source: (Kambale, 2021)

Based on the physical condition of the raw material that was utilized and processed to create the product, AM may be further categorized. This classification covers operations that are based on solids, liquids, and powders shown in **Figure 5**. It is also categorized according to the method of processing the base material, such as heat, laser beams, UV rays, etc. (*Alghamdi et al., 2021*)

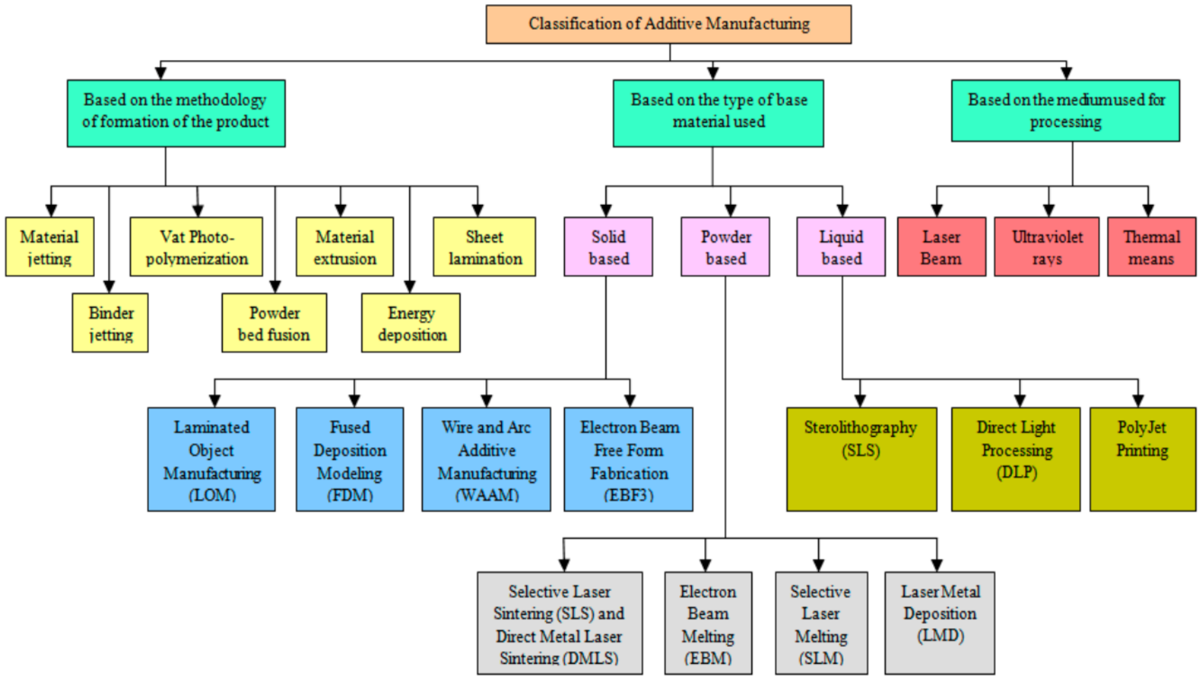


Figure 5: Classification of additive manufacturing processes

Source: (Alghamdi et al., 2021)

Connecting to the classification of additive manufacturing discussed in the previous **Figure 5** we will discuss some of the main 3D printing technologies used for printing polymer.

2.3.1. Stereolithography (SLA)

To start with the technologies, stereolithography (SLA) is among various potential technologies for 3D printing that is widely used and recognized as the first 3D printing process and the oldest to be commercialised, yet it delivers complex geometries and smooth-surfaced objects owing to its high printing resolution. In 1984, Charles Hull invented and patented the first 3D printing technology using SLA, which belongs to vat photopolymerization. (*Lakkala et al., 2023*). It's the method by which liquid plastic is turned into solid objects using a specially made 3D printing machine known as a stereolithograph apparatus (SLA) as illustrated in **Figure 6**:

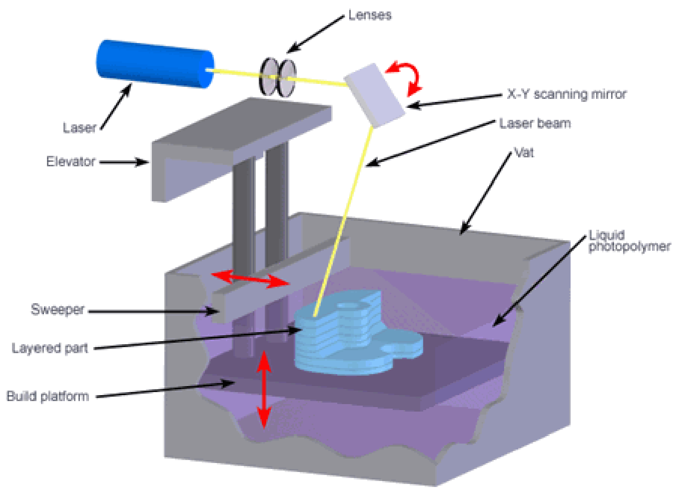


Figure 6: Stereolithography technology

Source: (Bhattacharjee et al., 2016)

We may conclude that stereolithography is an excellent method to create prototypes since it can quickly and affordably build products that are highly precise and durable. AM machines may generate objects with unusual shapes that would be difficult to create using traditional prototyping methods.

2.3.2. Polyjet

This resin 3D printing technology jets layers of liquid photopolymers onto a build tray. The PolyJet printing process is essentially an inkjet technology that is used to create 3D parts. An inkjet head consisting of the photo-resin moves along X and Y axes and deposits the photo-resin according to the CAD. This technique as shown in **Figure 7** utilizes photopolymer materials that rapidly cure when exposed to UV light lamp until the part is completed. (*Alghamdi et al., 2021*)

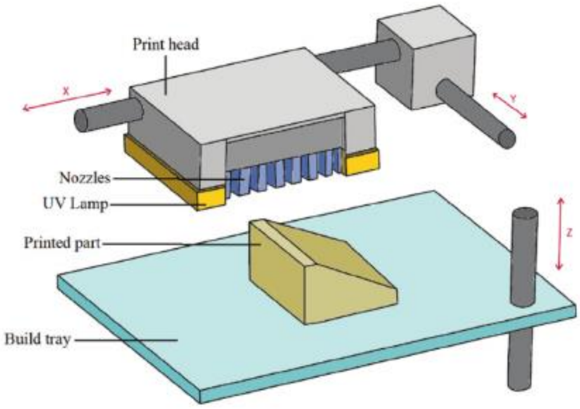


Figure 7: PolyJet 3D printing process

Source: (Pandey, Nayak and Taufik, 2022)

2.3.3. Selective Laser Sintering SLS

Selective laser sintering (SLS) represented in **Figure 8** is a very popular AM technique that consists of sintering thin layers of powdered materials spread over the platform of a printing bed using a laser as power source. (*Farahani et al., 2018*). It is an industrial 3DP technology that uses a powder bed to build up the 3D object, similarly to PB. However, instead of using a spray solution, SLS uses a laser to bind the powder particles together. During the printing process, the laser is directed to draw a specific pattern onto the surface of the powder bed. Once the first layer is completed, a roller distributes a new layer of powder on top of the previous one. The object is built layer-by-layer, which is then recovered from underneath the powder bed. (*Fina et al., 2017*)

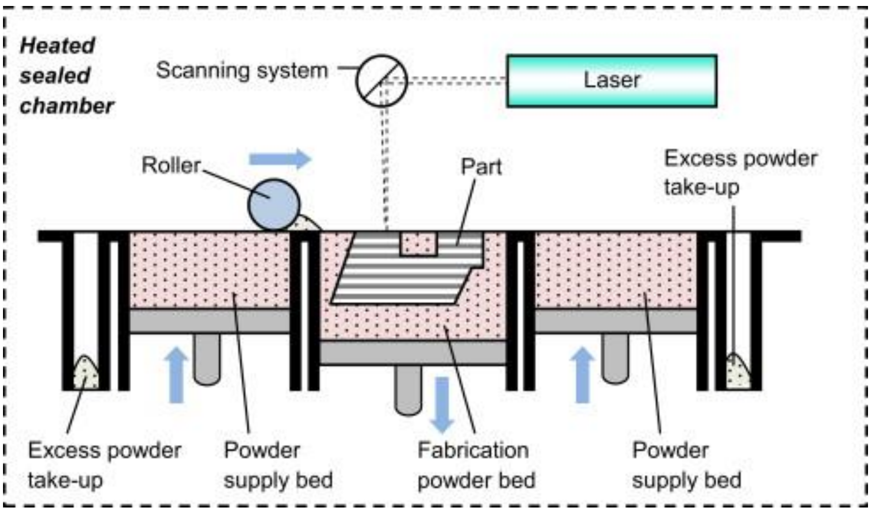


Figure 8: SLS process

Source: (Leong, Liu and Chua, 2014)

2.3.4. Fused deposition modeling or FDM

Among the various 3DP techniques, fused deposition modeling (FDM) is one of the most commonly utilized low-cost processes due to its simplicity and availability of machines at affordable prices, which employs the hot-melt and adhesive properties of thermoplastic materials. (*Zhang, Fan and Liu, 2020*)

Fused deposition modelling (FDM), commonly known as fused filament fabrication (FFF), is a widespread additive manufacturing (AM) technology belonging to the family of "material extrusion" (ME) methods. (*Sola and Trinchi, 2023*).

The process is based on the extrusion of heated feedstock plastic filaments. This thermoplastic filament feedstock, such as acrylonitrile butadiene styrene (ABS) or polylactic acid (PLA), is fed through a heated nozzle tip. The nozzle deposits thin layers of molten plastic onto a build platform layer by layer directly from a digital model, building up parts in an additive fashion. Specifically, FDM prints by heating and precisely extruding thermoplastic filament through the movable nozzle. As the nozzle moves in both horizontal and vertical directions according to the 3D model data, it builds the part by depositing the tiny beads of hot plastic one layer at a time to create the three-dimensional object as shown in the figure. (*Masood, 2014*). We can see the details in **Figure 9** below:

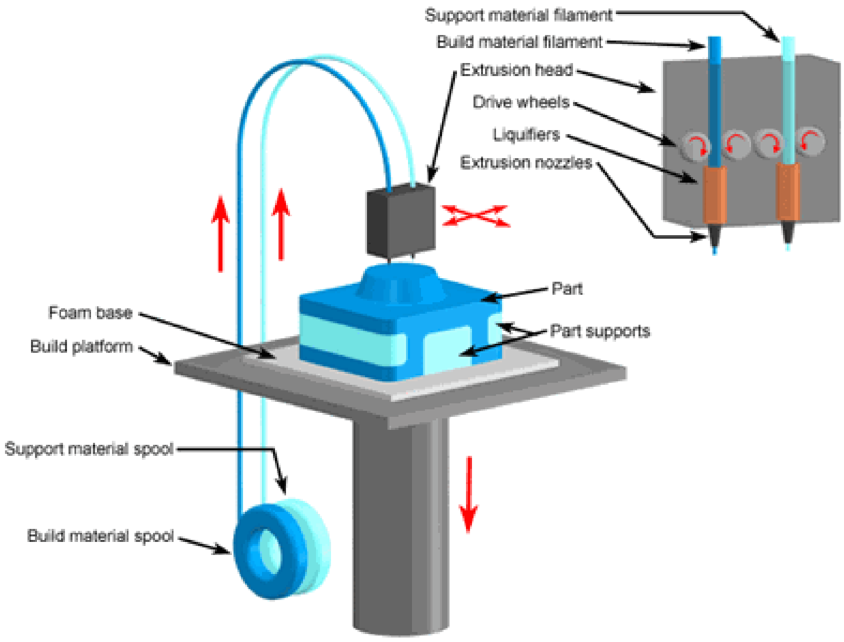


Figure 9: Fused Deposition Modeling (FDM)

Source: (Bhattacharjee et al., 2016)

Due to the simplicity, reliability, and affordability of the FDM process, it has been widely adopted by different industries, academia, and consumers for the fabrication of both prototypes and functional components using both commodity and engineering plastics. (*Dutta, 2022*)

Filament needs to be dry before printing to prevent issues. Moisture can cause bubbles and defects in the print.

In our study, this method is the most relevant for us, since for this method we use the polymer raw material in filament format.

2.3.4.1. FDM Types

While focusing on the FDM we can find different types of this technology as well. We can cite:

- **Cartesian FDM 3D printers:** The most common and reliable type, using X, Y, and Z

coordinates (Cartesian coordinate system) to move the print head or bed. Good for print quality and flexible filaments. (**Figure 10**)

Because most 3D printers on the market today use this kind of design, controlling a linear Cartesian system like this is both mechanically and softwarely straightforward. Plotters, CNC milling machines, and 2D printers are just a few of the devices that have long utilized the cartesian coordinate systems.

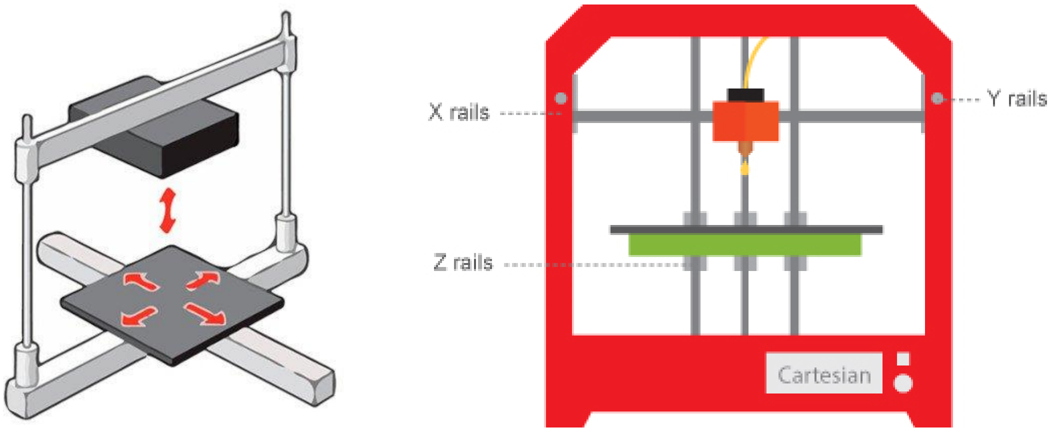


Figure 10: Cartesian type of FDM
Source: (Spadaro, 2014)

- **Delta 3D printers:** A faster and taller type, using a circular print bed and a triangular print head that can move in any direction. Good for speed and large parts. (**Figure 11)**

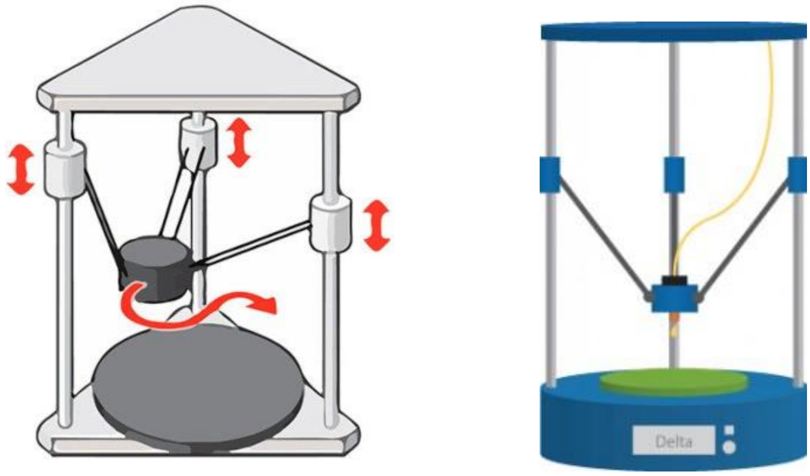


Figure 11: Delta type of FDM

Source: (Spadaro, 2014)

- **Core XY 3D printers:** A much faster version of standard Cartesian builds employing

an innovative **belt-driven design** using belts and pulleys with the two X and Y motors working together to control the printer head allowing them to print far more quickly and precisely than standard FDM printers. (**Figure 12**)

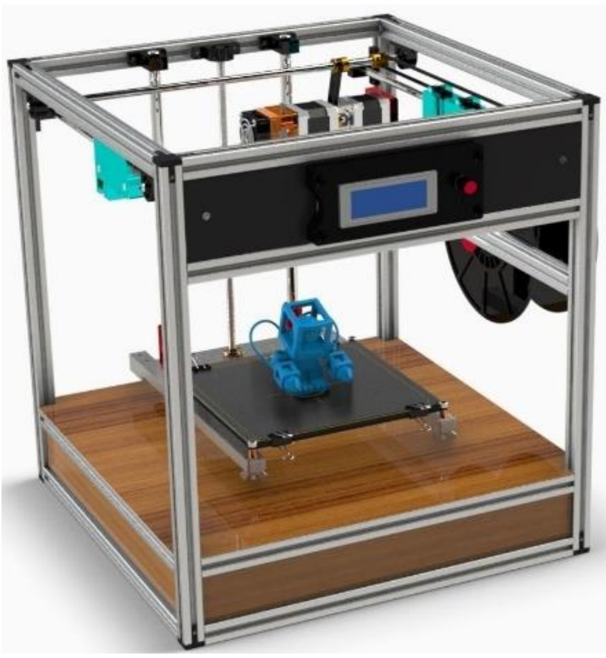


Figure 12: Core XY type of FDM

Source: (PRINTER 3D CORE XY | 3D Model, n.d.)

➢ **Polar 3D printers:** A more efficient and compact type, a polar coordinate system, where the print head moves in a radial and angular direction, rather than the linear motion used in Cartesian systems. It is good for saving space and energy. (**Figure 13**)

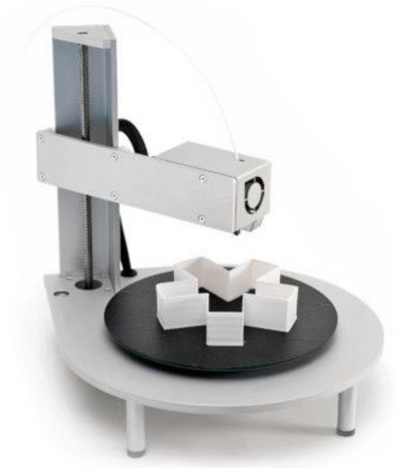


Figure 13: Polar 3D printer

Source: (The 6 Main Types of FDM 3D Printer Explained - 3DSourced, 2024)

➢ **Scara 3D printers**: Use a robotic arm that can print in any direction and location. Most applications are in the 3D printing of houses and other industrial projects. This is because for printing huge structures, like houses, you need to be able to move the house 3D printer to the location. **(Figure 14)**

Figure 14: SCARA 3D printer

Source: (3DSourced, 2024)

2.4. Main polymers manufacturing technologies

More than any other material, plastics offer a wide choice of processing techniques. Initial products [complete formulations (also called polymeric materials), compounds] come in granulate, powder, pellet, paste or liquid form, paste or liquid. Hygroscopic materials (PA, ABS, PBT, PMMA, etc.) undergo pre-drying before processing to avoid moisture-related defects on plastic parts. Plastic or viscous states are necessary to implement polymer shaping techniques. Plastics processors produce finished objects for end-users, using equipment and materials supplied by polymer producers or compounders. (**Table 2)**

Table 2: Main polymers manufacturing technologies

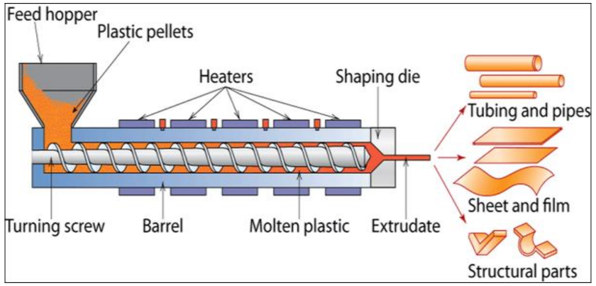
<table>
<tr><th>Process</th><th>Description</th><th>Figure</th><th>Products</th><th>Polymers used</th></tr>
<tr><td>Extrusion</td><td>In the extrusion process the material is forced through a die of required dimension and cross section to produce long continuous filaments or other similar products. It is widely used in various industries and one of the most efficient ways to produce products that are made of thermoplastic input materials. It is also used in producing components that are made of metal. (Christiyan, 2016)</td><td>

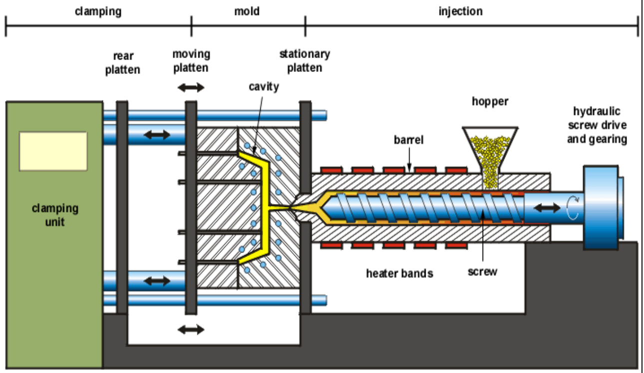
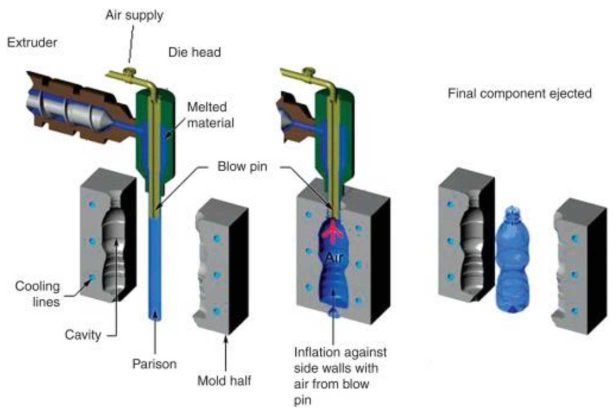
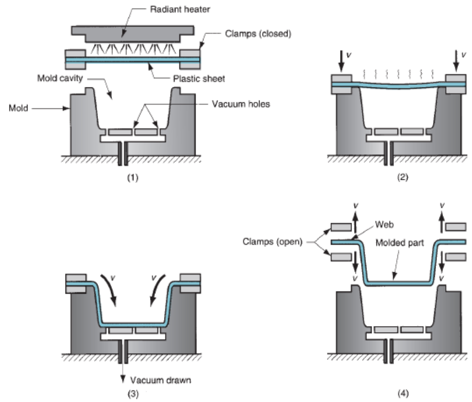
Figure 15: Extrusion process
Source: (Rapiddirect, 2022)</td><td>
</td><td>Polyethylene (PE)
Polypropylene (PP)
Polyvinyl chloride (PVC)
Polyethylene terephthalate (PET)
Polystyrene (PS)
(ABS)
Polycarbonate (PC)
Polymethyl methacrylate (PMMA)</td></tr>
<tr><td>Injection Molding</td><td>Injection molding is a technique to produce thermoplastics. Plastic injection presses are used to make most thermoplastic parts. During the process the plastic is softened, then injected into a mold and allowed to cool. This process is used to make items in big or extremely large manufacturing runs. In addition to other metals and alloys with comparatively low melting points, such as brass, zinc alloys (Zamak), and aluminum alloys, it primarily concerns polymers and elastomers (rubbers). (Banerjee, Ashis. 2006).</td><td>

Figure 16: Injection molding process
(Banerjee, Ashis. 2006).</td><td>

</td><td>Polypropylene (PP)
Polyvinyl chloride (PVC)
Polyethylene terephthalate (PET)
Polystyrene (PS)
(ABS)
Polycarbonate (PC)
Polybutylene terephthalate (PBT)
Polyamide (PA)</td></tr>
</table>

Extrusion Blow Molding	Hollow thermoplastic items, especially bottles and containers, are made using this technology. The process includes putting a parison—a thin-walled, extrusion-formed tube—between two sides of a larger-diameter mold, then pushing the parison out against the mold with a burst of air to expand it. The thin-walled section takes on the external shape of the inside of the mold. By correcting variations in the parison thickness along its length, the finished part's wall thickness can be roughly controlled. (*Poli, 2001*)	 Figure 17: Extrusion Blow Molding Source: (Cherrington and Goodship, 2016)		Polyethylene Terephthalate (PET) High Density Polyethylene (HDPE) Polyvinyl Chloride (PVC) Low Density Polyethylene (LDPE) Polypropylene (PP) Polyethylene Naphthalate (PEN) Polycarbonate (PC)
Thermoforming	A plastic sheet is the starting point for the manufacturing process known as thermoforming. After being extruded, the polymer sheet is subjected to a particular temperature range, which makes it malleable and moldable. Vacuum forming is one type of thermoforming in which a heated sheet is put over a mold and drawn onto the mold's surface under vacuum pressure to create the desired shape.(*Throne, 2011*)	 Figure 18: Thermoforming Source: (EngineeringClicks, 2019)	 	Polyethylene Terephthalate (PET) Polystyrene (PS) High Impact Polystyrene (HIPS) Polyvinyl Chloride (PVC) Acrylic (PMMA) Polycarbonate (PC) High Density Polyethylene (HDPE) Polypropylene (PP)

2.5. Filaments Makers

2.5.1. Definition

To get in deep in the process of FDM, and after talking about the suitable polymers, we need to talk about other important factor in the process which is the filament.

The plastic material that 3D printers utilize as feedstock is called filament. The extruder head of the 3D printer feeds the thin plastic thread into the machine. To create the three-dimensional item, it melts when heated and is deposited layer by layer (McCarthy and Brabazon, 2021).

Each filament material has different properties that make it suitable for various applications.

The diameter is usually 1.75 mm, though some industrial printers use 2.85 mm filament, but we should always remember that we need consistent diameter for proper feeding through the printer.

Filament spools come in a variety of diameters and typically weigh one kilogram. To prevent any tangles during printing, the filament must be twisted carefully and tightly onto the spool. The type of filament material used determines the attributes of the printed product, including strength, flexibility, and heat resistance. Different materials have unique properties that affect print parameters and output quality. Furthermore, the use of pigments makes it possible to create personalized or colorful prints without sacrificing the intrinsic qualities of the filament (*G, 2024*).

2.5.2. Different Filament makers

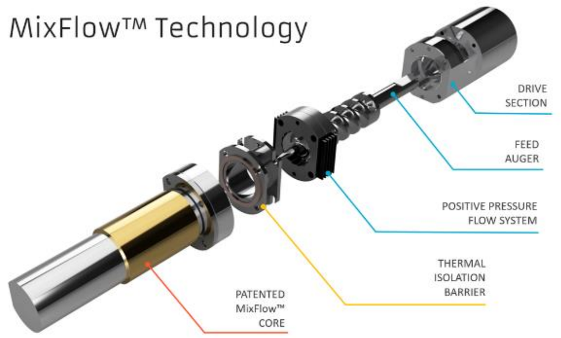
Some of the major filament extruder machines commonly available in the market that we can mention :

- **ProtoCycler V3**

The ProtoCycler V3 which characteristics are shown in **Table 3** is a desktop filament extruder that allows users to recycle and reprocess 3D printer filament waste. It works by using a motorized feeding mechanism to pull filament scraps or failed prints into a heated extruder barrel. This barrel reaches temperatures up to 300°C to melt the filament, which is then extruded through a 0.4mm nozzle by a driven gear system. The newly extruded filament strand can be collected on a take-up spindle. Controlled via an onboard interface, the ProtoCycler V3 can efficiently remake filaments from recycled materials, reducing 3D printing waste and giving makers a way to further utilize their filament scraps. (*ReDeTec [online]*)

Table 3: Characteristics of ProtoCycler V3 Filament Extruder Source: (ReDeTec [online])

Extrusion rate	Filament	Extrudable Plastics	Physical Characteristics	Price
Over 0.5kg of filament per hour	**Filament Sizes:** 1.75mm and 2.85mm	PLA, ABS, PETG, HIPS, Nylon 12, and more	Weight: 10kg and dimensions of 38.1cm x35.56cm x 22.86cm	**1.520.900 Ft**



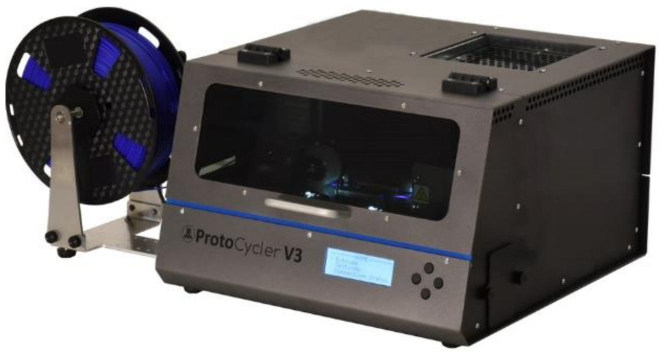


Figure 19: ProtoCycler V3Source: (ReDeTec [online])

- **Filabot EX2 Filament Extruder**

The Filabot EX2 is a popular desktop filament extruder ideal for hobbyists and small businesses. It utilizes a single screw feeding system to take recycled plastic scrap materials like bottles and containers, then melts and extrudes them into 1.75mm plastic filament. The EX2 features an easy-to-use control panel with options to adjust temperature, speed and filament diameter. It can reach melting temperatures up to 250°C to process a variety of plastic types including PLA, ABS, HIPS and more. With a large hopper that can hold up to 5 pounds of material, the EX2 has a high material throughput. It also includes a filament spooler and automatic trimming to produce professional quality spools of custom filament. The Filabot EX2 provides an affordable and accessible way to make personalized filaments without needing large volumes.**(Table 4)**

Table 4: Characteristics of Filabot EX2 Filament Extruder (Anon., n.d – Filabot EX2.)

Extrusion rate	Filament	Extrudable Plastics	Physical Characteristics	Price
Over 0.91kg of filament per hour	**Filament Sizes:** 1.75mm and 2.85mm	ABS, ABS Flame Retardant, 4043D PLA, 3D850 PLA, 3D870 PLA, PC, HIPS, PETG, and WAX. Lower Melt Flow Polymer	Weight: 12.7kg and dimensions of 45.75cm x17.78cm x 22.86cm	**1.251.500 Ft**

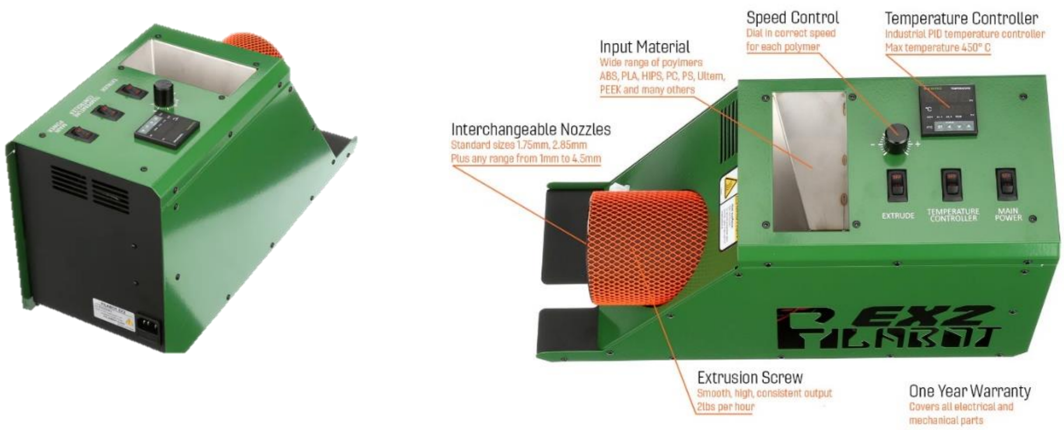


Figure 20: Filabot EX2 Filament Extruder (Anon., n.d – Filabot EX2)

➢ Wellzoon desktop filament extruder B

It is a portable and easy operated device that converts plastic waste into filament for 3D printing. Its easy-to-use features include adjustable extrusion speed and accurate temperature control for reliable filament quality. It can handle a variety of plastic kinds while operating at a maximum temperature of 300°C. It uses only 120W of power and may run on a 220V or 110V power supply. With a 400ml hopper capacity, it works well for modest recycling operations. **(Table 5)**

Table 5: Characteristics of Wellzoon desktop filament extruder B

Extrusion rate	Filament	Extrudable Plastics	Physical Characteristics	Price
25.4 cm~66.04cm / min	1.75mm and 3.00mm(2 nozzles)	PLA ,ABS, PVA and wood-plastic etc.	50.8x14x25.4 (No holder)	**354,394 Ft**

Figure 21: Wellzoon desktop filament extruder B

- **3devo Composer 450 filament maker**

The 3devo Composer 450 is an industrial-grade filament production system well-suited for businesses with higher volume needs. It uses a twin-screw extruder that can process materials much faster than a single screw design. The two counter-rotating screws can efficiently mix and melt scrap plastic feedstock into uniform filament. The Composer 450 is temperature controlled up to 300°C and allows for production of a wide variety of thermoplastics including PLA, ABS, Nylon, and TPU. (**Table 6**) It produces strong and consistent 1.75mm filament at speeds up to 6.5 kg per hour. The industrial PC touch interface provides full control and monitoring. Additional features include automatic bobbin winding, magnetic filter for clean output, and easy access for tool-less material changes. For manufacturers that require high throughput, precision, and uptime, the 3devo Composer 450 provides commercial grade filament making in a package taking up less space than traditional extruders.

Table 6: Characteristics of 3devo Composer 450. Source: 3devo online website

Extrusion rate	Filament	Extrudable Plastics	Physical Characteristics	Price
25.4 cm~66.04cm / min	1.75mm and 3.00mm(2 nozzles)	PLA, ABS, PA12, PEEK, PC and PS	50.8x14x25.4 (No holder)	**354,394 Ft**

Figure 22: 3devo Composer 450. Source: 3devo online website

➢ 3d filament maker desktop printing consumables extruder

It is a small extruder with a desktop convenient design as shown in **Figure 23**. There no much information about the system but this is another design with very affordable price of 126,399 Ft.

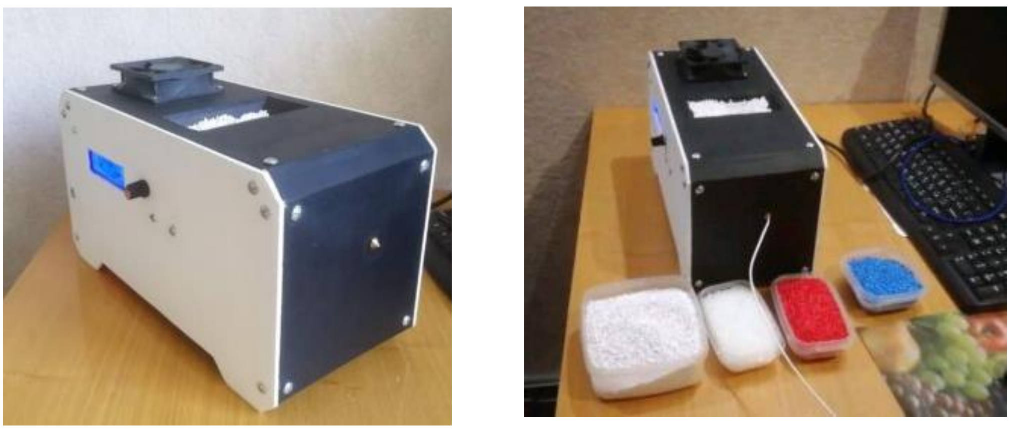


Figure 23: Desktop filament machine. Source: (Anon., n.d. 3d Filament Maker Desktop Pinting Consumables Extruder 1.75mm 3mm. eBay)

➢ **DESKTOP SJ35 3D PRINTER FILAMENT EXTRUDER MACHINE AND FILAMENT PRODUCTION LINE**

This filament extruder is a simple and practical device for producing 3D printing filament from plastic. This machine rapidly converts plastic trash into useable filament thanks to its user-friendly design. With a maximum temperature of 300°C, it can be used with a variety of plastic kinds. The machine uses only 120W of power when operating and requires a 220V or 110V power supply. With a 400ml hopper capacity, it is perfect for small-scale filament manufacturing endeavors. For your 3D printing requirements, the Desktop Sj35 delivers simplicity and dependability, whether you're recycling unwanted prints or experimenting with bespoke filament blends. (**Table 7**)

Table 7: Desktop Sj35 3d Printer Filament Extruder Machine

Extrusion rate	Filament	Extrudable Plastics	Physical Characteristics	Price
Around 0.9kg/hour	2,5 mm	PE, PP, PVC, ABS, ABS/PP, PE/PP	145kg, 160X50X80cm	**1299400 Ft**

Figure 24: Desktop Sj35 3d Printer Filament Extruder Machine and Filament Production Line

2.6. Comparison of machines

As we delve in the design of the filament extrusion system, it is crucial to compare the available machines studied earlier in this chapter.

The compiled **Table 7** presents the evaluation of various specifications such as the price, variety of printable polymers and design specifications.

Through this analysis, I aim to identify the most suitable filament extruder that aligns with my specific project needs and design objectives.

Table 8: Comparaison of different filament extruder machine in the machine

	Usability	**Variety of Printable polymers**	**Extrusion rate**	**Price**
ProtoCycler V3	★★☆☆☆	★★★☆☆	★★★★☆	★☆☆☆☆
Filabot EX2	★★★★★	★★★★★	★★★★☆	★★★★★
Wellzoon	★★★★☆	★★★★☆	★★★☆☆	★★★★★
3devo	★★★☆☆	★★★☆☆	★★★☆☆	★★★☆☆
3d filament maker desktop printing	★☆☆☆☆	★★☆☆☆	★★★☆☆	★★★★★
Sj35 3d Printer	★★★☆☆	★★★☆☆	★★★☆☆	★☆☆☆☆

According to this table, we will choose the usability of Filabot or Wellzoon for our system where we can fit all components in small box to make it easily portable. They also have a wide range of printable polymers comprising PLA and ABS and the price shouldn't be expensive for a small machine.

2.7. Research Methodology

This study was the result of research that included a review of the literature on filament extrusion, polymer manufacturing technologies, fused deposition modeling, and additive manufacturing. Additionally, data from the websites of other filament extruder manufacturers has been utilised. Additionally, journal articles and book parts pertaining to the current topic have been obtained through the usage of research databases such as Google Scholar, Research Gate, and Science Direct.

- With the help of literature, we learn about previous researches, models and designs which is related to our projects.
- The designs have been made using Solidworks in order to initiate and prepare our project.
- The dimensions are finalized according to our requirements (a small desktop machine).
- Materials are selected according to some factors like weight, ease to manufacture, minimum price etc.
- The report has been prepared.

2.8. Critical Review

In this literature review we provided a comprehensive exploration of additive manufacturing (AM) and its application in 3D printing, focusing on polymer materials and filament extrusion technologies. We dove into the world of 3D printing and how it created objects from polymers and plastic filament. We started with a brief history of additive manufacturing (AM) to understand how it worked and why it was revolutionizing product design and manufacturing.

The chapter begins with a historical overview of additive manufacturing (AM), an overview of its fundamental concepts, and a summary of the advantages it offers over conventional production techniques. According to its definition, additive manufacturing (AM) is a revolutionary process that builds products layer by layer while providing faster prototyping, less material waste, and more design freedom.

Next, we looked at some common 3D printing techniques like Stereolithography (SLA), PolyJet, Selective Laser Sintering (SLS), and Fused Deposition Modeling (FDM). Each had its own unique process and suitable materials. Understanding the strengths and weaknesses of each type helped determine the best application.

We also briefly covered traditional polymer fabrication to provide context for how AM fit within broader materials production and then a significant focus was on FDM printing and filaments we focused on FDM technology for our project.

Filament choice hugely impacted print quality and applications. We examined common filament polymers options like PLA, ABS, and flexible materials to help producer pick the right material.
Finally, we compared several popular desktop filament extruders found in the market. Understanding their key features and performance capabilities allowed us to have an idea on how to design our filament extruder suited for the application and material needs.

By wrapping together these topics on AM, polymer 3D printing technologies, filaments, and extruders, this chapter laid the foundation for deeper dives later in the thesis.

Chapter 3 : Methods and Materials

3.1. Introduction

One method for transforming plastic materials that enables the production of various items is the extrusion process. The latter include the plastic filaments that are well-known and utilized in 3D printing. This is all accomplished by use of a machine known as an extruder, the study and design of which we shall cover in this chapter. We will begin with its design and work our way down to its functioning, doing some calculations to correctly choose the right components for the system like screw characteristics, required speed, and the best motor choice for the job. With the necessary computations, we complete the filament winding system design.

3.2. Design of the system

The system to be studied makes it possible to extrude the plastic material then produce spools of filaments for 3D printing.

3.2.1. Orientation of the system

We started the first design idea with vertical configuration of the filament extruderas shown in **Figure 25**.

The filament extruder's vertical orientation design may be able to achieve higher volumetric output and faster extrusion rates, which would boost productivity.

Some of the disadvantages we can list is the back pressure issue. The gravitational force pressing on the polymer melt column in a vertical extruder can result in a significant amount of internal back pressure. Also, it makes the melting polymer less affected by gravity, resulting in a non-uniform filament. Because of its own weight, the material is likely to distort as it flows downward. Because the extruder motor may find it difficult to handle the additional pressure, maintaining a constant filament diameter and volumetric flow rate may be difficult as a result of this increased pressure.

In vertical designs with increasing infill densities, careful management of the extrusion temperature, screw speed, and other parameters becomes more important to regulate the pressure.

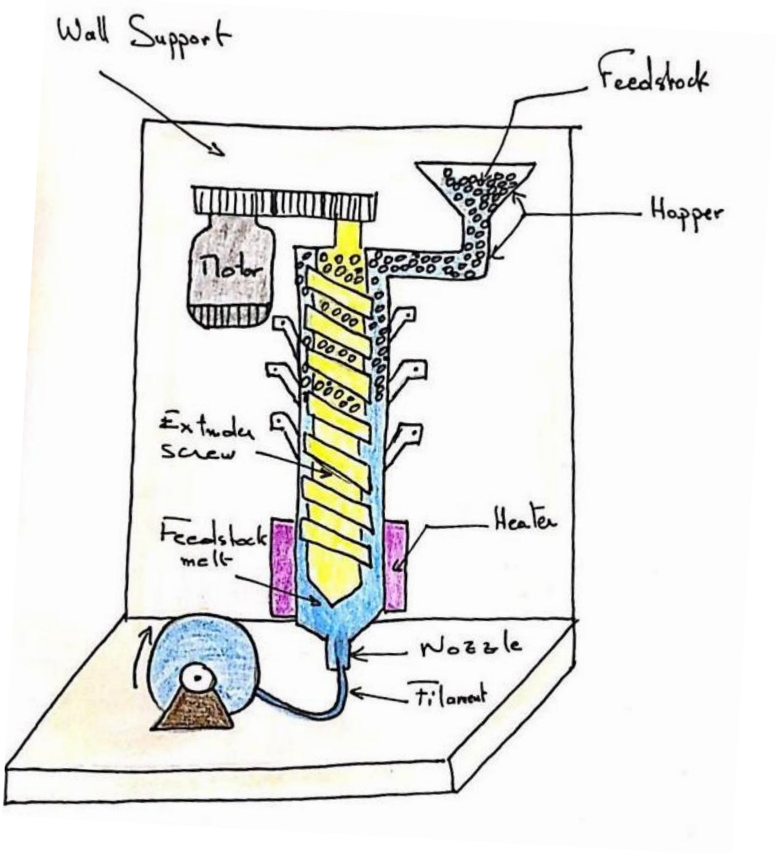


Figure 25: Vertical orientation of the extruder.

On the other hand, we found that horizontal configuration (**Figure 26**) is a better option for us due to its simpler, more basic mechanical design compared to the vertical configuration, it can make it easier and potentially more affordable to produce, assemble, and maintain.

In addition, heat stratification and convection currents are less significant with a horizontal extruder, making it easier to maintain constant thermal control throughout the polymer melt. The entire reliability and stability of the extrusion process can be increased by improved heat control. Additionally, the horizontal arrangement makes it easier to reach the die and feed hopper, two crucial extruder components, which simplifies repair and maintenance tasks.

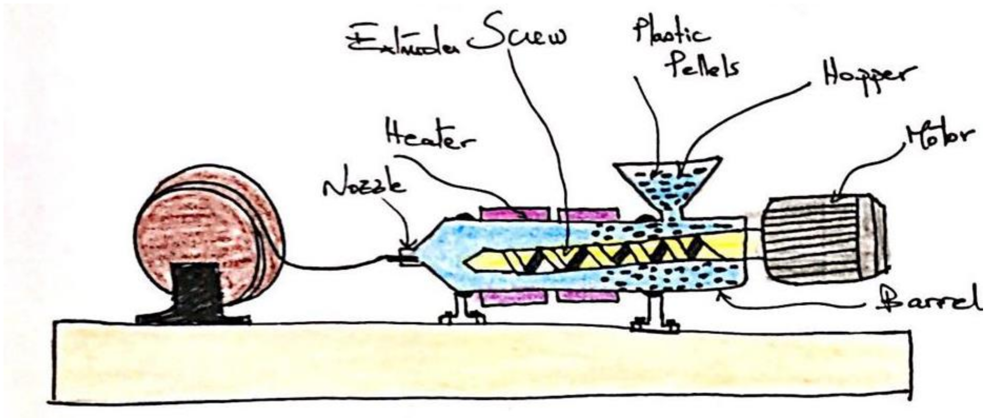


Figure 26: Vertical orientation of the extruder.

3.2.2. Choice of filament material

There are several filaments used in 3D printing, and among the most widely used thermoplastics, there are 2 dominant consumables: PLA and ABS, polymers that become soft and malleable when heated and return to a solid state when cooled. For our study, we chose PLA "Polylactic acid" as it is biodegradable, and more environmentally friendly compared to ABS, PLA also typically requires lower printing temperatures and exhibits less warping, which simplifies the printing process and makes it more suitable for beginners. Furthermore, PLA tends to produce more vibrant colors and can be easier to post-process, allowing for smoother finishing touches on printed objects. Since, the PLA characteristics are not very common, we will use ABS proprieties to help us in the dimensioning of the system.

3.2.3. Dimension of the filament

We would like to obtain a PLA filament with diameter D_{fill} = 1,7 mm. This is the universally commercialized filament for 3D printing.

After deciding what material we should use and the diameter of the required filamentm, we will now divide the machine into two sections according to the chronological order of their functions :

3.2.4. The extrusion part

The extrusion sercton consists of passing the melted polymer through the extrusion die. This one gives us the desired shape of the polymer which is the filament.

3.3. System working principle

First, the material is added to the hopper in granular form. The hopper is then fed continuously to the screw feeder (Part I), which simultaneously heats, mixes, pressurizes and dispenses the material, which is then pressed into the extrusion head. The head contains a die which gives the final shape to our filament, and the filament is solidified and cooled by water or air. Finally, we guide our filament to the spool (Part II: winding).

3.3.1. Extrusion section components

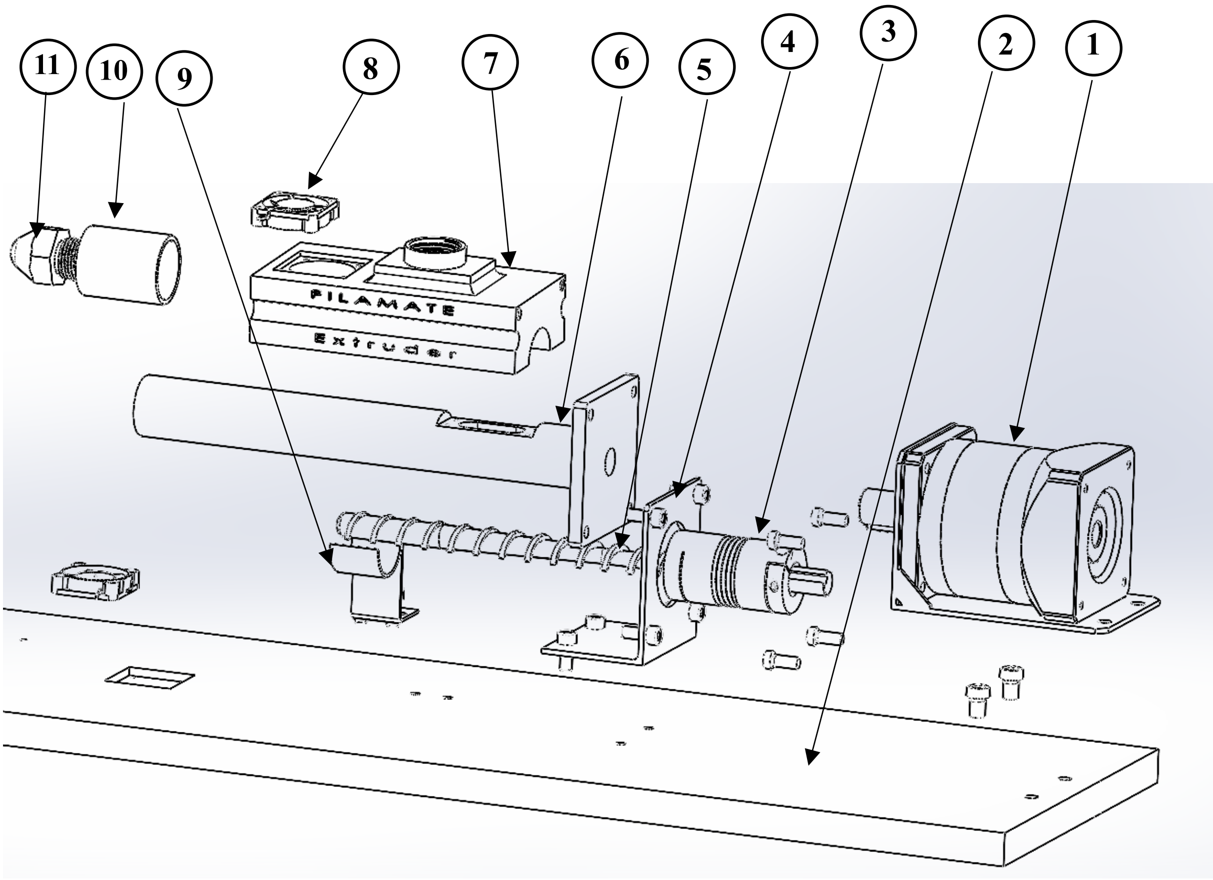


Figure 27: Components of the extrusion section.

Table 9: Extrusion section components

10	01	Nozzle
10	01	Heating Collar
9	01	Barrel support
8	02	Cooling fan
7	01	Hopper
6	01	Barrel
5	01	Extruder screw
4	01	Barrel mounting
3	01	Coupling group
2	01	Base
1	01	Motor and its mount
Number	**Quantity**	**Name**

➢ **Hopper**

It receives the granulated material, which descends by gravity to the screw feeder.

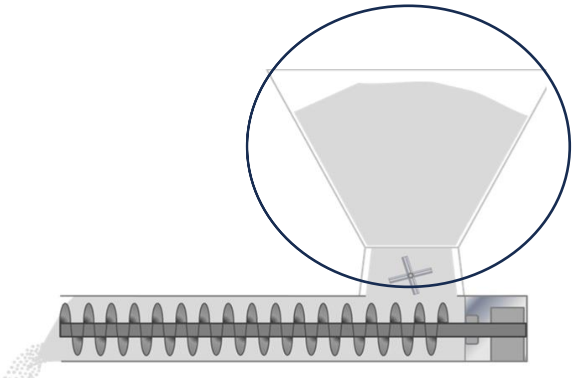


Figure 28: The typical extruder hopper. Source: (Freeman Technology)

For less expenses, we will use a PET bottle as a hopper instead.

➢ **Screw-Barrel group**

The screw-barrel assembly contains a cylinder (barrel), a screw and heating collars.

- **Barrel** : is a cylinder heated by a heating system (heating collars + thermocouples), so it will ensure the balanced temperature needed to melt the plastic, so it represents a path for the material to pass through.
- **Screw** : is a cylinder with a helical groove (sometimes several), which joins it to a threaded rod. It is the most important part of our machine, and rotates in a heated cylinder (barrel) to transport the material from the hopper to the extrusion head.
- **Nozzle**: to provide the final shape we need. It can be a simple design.It will be mounted directly to the barrel.

Figure 29: Barrel-Screw and nozzle group E16SB300- B08S6MJ521

- **Heating collars and thermocouples :** In the screw-barrel assembly, heating collars are

used to heat by conduction and regulate the entire system to the working temperature of the polymer used. They are circular in shape, enabling them to surround the cylindrical barrel. To operate, they are connected directly to the extruder's electrical system. There are a number of different types of heating collars, to suit different power requirements.

3.3.1.1. Geometry of the screw

The geometry of the screw is defined to allow the process to work optimally depending on the polymer used.

- The diameter of the screw body generally increases from the rear to the front of the machine, either over the entire length or only over part of the length.
- In the latter case, which is the most common, three geometric zones can be distinguished:
  - the feeding zone, where the depth of the channel is constant.
  - the compression zone, where the depth of the channel decreases gradually.
  - the pumping zone, where the depth of the channel is again constant, but lower than in the feeding zone. Sometimes in this pumping zone, mixing elements are found.

The figure below shows the essential geometrical elements of the screw-barrel system.

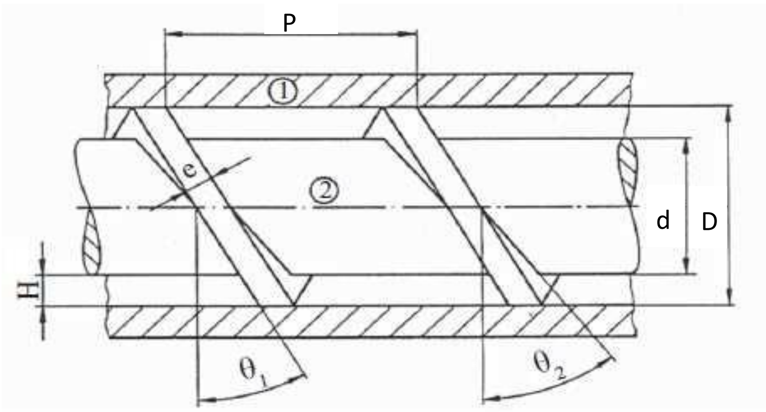


Figure 30: Geometry of the screw

We will use an extruder screw that will be bought online with the following details:

According to the figure we can conclude the main parameters to define the geometry:

- The inner diameter of the sleeve: D = exterior diameter of the screw = D = 16mm
- The diameter of the body, or inner diameter, of the screw: d = 14 mm

- For most extruders screws the pitch of the screw which is the distance from the centre of one thread to the centre of the next thread, is equal to the diameter (*CPE: Lesson 32 Screw Conveyor* [online]), therefore: P = 16 mm
- The thread thickness: e. The first two parameters allow calculating the depth of the channel H: $H = \frac{D-d}{2} = \frac{16-14}{2} = 1\,mm$
- Screw flight e = 3 mm
- Length of the screw = $l = 225$mm
- Number of threads n = $\frac{l}{p} = \frac{225}{16} = 14$
- Compression ratio : 2.5

We have the figure below that represents the main parameters discussed:

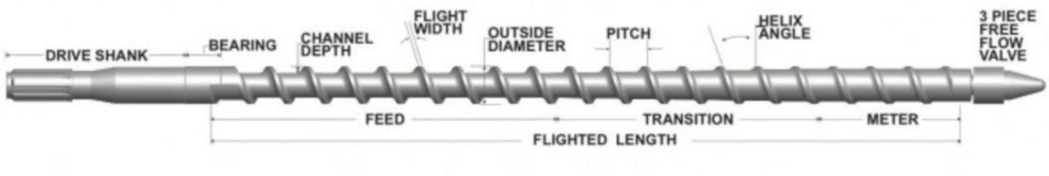


Figure 31: Main parameters of the screw

- **The maximum rotational speed of the screw**

The maximum rotational speed is provided by the screw manufacturer which is 60 rpm.

3.3.3.2. Motor Selection for the Extrusion Part

In order to choose a geared motor for the extrusion part of our machine, we need to go through the following steps:

• Determine the desired flow velocity.

• Determine the optimal volumetric flow rate $Q_{optimal}$.

• Calculate the optimal rotational speed of the screw that ensures this flow rate, $N_{optimal}$

• Calculate the nominal power, P_{N1}.

• Choose the geared motor.

- **Flow velocity**

In filament extrusion, the flow velocity ranges from 0.05 m/s to 0.30 m/s. We will choose an average flow velocity of 0.05 m/s to control it well manually. From the moment the filament exits the die until it reaches the spool.

- **The optimal volumetric flow rate $Q_{optimal}$**

The flow velocity represents the distance traveled by the filament wire per unit of time. Therefore, the flow velocity Vflow = The length volume of filament wire per unit of time. The volumetric flow rate represents the volume of filament wire exiting the die per unit of time, so the optimal volumetric flow rate: $Q_{optimal}$ = Volume of filament wire per unit of time.

For t=1 minute, we have: V flow =0.05(m/s) * 60 (s) = 3m

Thus, for one minute, we have a filament length equal to 3m.

$$\textbf{Volume of the filament} = \mathbf{S \times L} \qquad (2)$$

with :

S: the surface area of the filament

L: length of filament = 3m

For the filament required of 1.7 mm diameter we have

$$\mathbf{S} = \frac{\boldsymbol{\pi . D_{fil}}^2}{\mathbf{4}} \qquad (3)$$

$$S = \frac{\pi.\, 0{,}0017^2}{4} = 0{,}00000227\ m^2$$

Now Volume of the filament =S × L = 0,00000227 × 3 = 0,00000681 m^3

Therefore the optimal flow rate $Q_{\mathbf{optimal}}$ = 0,00000681 m^3/min

- **The required rotation speed of the screw N2**

We have to following formula

$$\mathbf{Q = S \times P \times N2 \times \boldsymbol{\varphi} \times C} \qquad (4)$$

With :

S: the effective section: $S = \pi\ (\frac{D^2 - d^2}{4}) = \pi\ (\frac{0{,}016^2 - 0{,}014^2}{4})$ = 0,00004712 m^2

P: Pitch of the screw

N2: the rotation speed of the screw

φ: filling degree: between 0.15 and 0.45; higher value for materials with high fluidity and low friction coefficient.

C: speed coefficient: between 0.5 and 1.

Note: There is a 2% flow reduction for every 1° of pitch angle. Rule applicable for pitch angles up to θ = 20°. So, for a pitch angle θ = 17°, the flow has a reduction of 2% × 17 = 34%.

$$\boldsymbol{Q_{optimal}} = \mathbf{0{,}66.\,Q} \qquad (5)$$

$$Q = \frac{1}{0{,}66}\, Q_{optimal}$$

$$\mathbf{Q = S \times P \times N2 \times \varphi \times C} = \frac{\mathbf{1}}{\mathbf{0,66}}\, \boldsymbol{Q_{optimal}}$$

$$\text{Thus, } \boldsymbol{N_2} = \frac{\boldsymbol{Q_{optimal}}}{\mathbf{0{,}66 \times S \times P \times \varphi \times C}}$$

For ABS, which has an average friction coefficient, we have chosen: φ = 0.25 and C = 1

$$\text{Then:} \boldsymbol{N_2} = \frac{0{,}00000681}{0{,}66 \times 0{,}00004712 \times 0{,}016 \times 0{,}25 \times 1} = 54{,}74 \text{ rpm}$$

- **Torque of the screw**

We can calculate the torque required in our screw with its relation the shear stress experienced by the material being worked on using the equation below. In our case the material ABS have a shear stress of 45MPA.

$$T = \frac{\tau.\pi \cdot d^3}{16} \qquad (6)$$

$$T = \frac{45.\,10^6.\pi \cdot 0.016^3}{16}$$

$$T = 36{,}19\ Nm$$

- **Power requirement**

After the calculation of the torque which is approximately 40Nm, we can now calculate the nominal power P1 by this equation :

$$P_2 = \frac{N_2 \times T}{9550} \qquad (7)$$

$$P_2 = \frac{54{,}74 \times 36{,}19}{9550}$$

$$\boldsymbol{P_2 = 0,207\ kW}$$

Taking into consideration an efficiency factor **n=0,96 , we can determine P1 .**

$$n = \frac{P_2}{P_1} \qquad (8)$$

$$P_1 = \frac{P_2}{n}$$

$$P_1 = \frac{0,207}{0,96}$$

$$P_1 = 0,215\ kW$$

To calculate the nominal power required, it is necessary to take into consideration the characteristics of the machine to be driven and its motorization. We multiply P_1 by the service factor *Fs*, in the case of the plastic extruder operating for an average of 3 to 10 hours/day. *Fs*=1.25.

- The nominal power, $P_N = P_1 \times Fs$ (10)

Therefore, $P_N = 0.215 \times 1.25 = 0.268$ KW

➢ Choice of the motor

Choosing the best motor for a small desktop filament extruder machine depends on several factors such as the desired extrusion speed, torque requirements, power consumption, and available space. The role of the motor in the extrusion section is to ensure rotation of the screw. AC and DC motors can be used for the job.

We choose the motor in **Figure 32** because it fits to our needs.

Figure 32: Chosen motor EG34-G10. (Source : StepperOnline)

3.3.3.3. Choice of coupling

The role of the coupling unit is to couple the motor to the screw in the following steps:

- The motor rotates at a known speed, then turns the shaft via a keyway between them.
- A screw receiver is installed by clamping with the shaft, so it will rotate at the same speed as the shaft.
- A screw installed by clamping with the screw receiver, so it will rotate at a speed equal to the motor speed.

Permanent couplings are mechanical components designed to permanently join two shafts placed end to end, possibly with alignment defects.

In order to choose the right coupling for our system we need to calculate the torque needed expressed in the following equation:

$$T = 9550 \times \frac{P_{motor}}{N} \qquad (11)$$

$$T = 9550 \times \frac{0{,}75\ kW}{60}$$

$$T = 119.37\ Nm$$

This torque T multiplied by a safety factor S depending on the application and the temperature factor ST (see table page 14) gives the required nominal coupling torque $T_{nominal}$

$$T_{nominal} \geqq S \times S_T \times T \qquad (12)$$

We will choose

S = 1.75 for electric motors

S_T = 1.8 for +80° T

$$T_{nominal} \geqq 1.75 \times 1.8 \times 119.37$$

$$T_{nominal} \geqq 376.03 \text{ N.m}$$

Selection: **Habix® size 38 flexible element 92° Shore D**

$$T_{nominal} = 405 \text{ N.m}$$

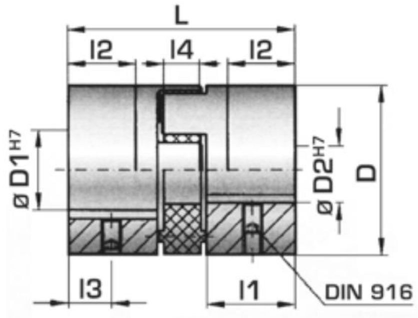


Figure 33: HABIX® – FLEXIBLE COUPLINGS. Source: (optibelt catalog)

3.4. Winding system

The winding part's role is to install the filament around a spool as the filament comes out.

3.4.1. Operating Principle

After extrusion, the filament will be guided to wind onto the spool. First, the filament needs to pass through a filament guide that has a back-and-forth system to ensure the filament's translation along the length of the spool, and then it will be secured onto the spool. As soon as the spool starts to rotate, the filament will rotate and wind around it.

3.4.2. Components of the winding section

- **Motor**

We will use a small motor ZGA37RG DC MOTOR, which provides rotation for the spool. It is inspired from the Fixtruder machine which uses the same type and it fits our need.

- **Support**

The support is designed to secure the installation of the components of the winding section.

- **Spool**

The spool is responsible for winding the filament after extrusion.

- **Spool Placement**

We need to ensure that the filament is solid and cool when it reaches the spool.

3.4.3. Winding system parameters

- **Filament Cooling Time (Solidification)**

In order to calculate the filament cooling time we need to determine the thermal diffusivity first. Thermal diffusivity describes the rate of temperature spread through a material. (Mishra, Militký and Venkataraman, 2019).

It is the thermal conductivity divided by density and specific heat capacity at constant pressure. It measures the ability of a material to conduct thermal energy relative to its ability to store thermal energy. High diffusivity means heat transfers rapidly. (Zhang, 2016)

Thermal diffusivity is calculated as given below :

$$\alpha = \frac{\lambda}{\rho\ .\ C} \quad (13)$$

Where, λ : thermal conductivity

ρ: material density

c: specific heat capacity of the material

For ABS :

λ = 0,17 W/m.K = 0,00000148732 Cal cm^{-1} $°C^{-1}$ s^{-1}

ρ = 1,05 $g.cm^{-3}$

C = 1,8 J/g.K = 0,00157582418 $Cal.g^{-1}.°C^{-1}$

Units : 1 watt = 1/4.1868 $cal.s^{-1}$; 1m=10^2 cm ; 1 Kelvin= 273 Celsius ; 1 joule = 0.239 cal.

Numerical application:

$$\alpha = \frac{0,00000148732}{1,05\ .\ 0,00157582418}$$

$$\boldsymbol{\alpha = 0,0008988916\ cm^2/s.}$$

Solidification Time

$$t = \frac{r^2}{\alpha \cdot 5.784} \times \ln\left(1.599 \times \frac{T_m - T_s}{T_e - T_s}\right) \quad (14)$$

With: T_m: Temperature of the material at the nozzle outlet in °C.

T_e: Solidification temperature of the material.

T_s: Ambient temperature.

r: Radius of the filament in cm.

For an ambient temperature of 23°C :

$$t = \frac{0,085^2}{0,0008988916\ \times 5.784} \times \ln\left(1.599 \times \frac{135 - 23}{80 - 23}\right) = 1,59\ s$$

The filament will solidify in 1,6 seconds.

- **Cooling Time**

We want our filament to reach a temperature of 30°C when it arrives at the spool, so we need to apply Newton's cooling law to determine the time required to reach a temperature of 30°C. Newton's cooling law is:

$$T \geq Ta : T(t) = r.e^{-kt} + Ta \quad (15)$$

k: is a positive constant,

Ta: ambient temperature = 23°C,

T: Temperature in (°C), t: time in (s),

r: is a constant = (T_0-Ta).

- For t = 0s , we have the temperature T_0 = 135°C $\Longrightarrow$ $T(t) = r.e^{-kt} + 23$

with r + 23 = 135 $\Longrightarrow$ **r = 112**

- For t = 2 on a $T = 80°C \Longrightarrow T(t) = r.e^{-k(2)} + 23 = 112.e^{-2k} + 23 = 80$

$\Longrightarrow$ $e^{-2k} = \frac{80-23}{112}$ = 0,5089e

Therefore, $\mathrm{Ln}(e^{-2k}) = \mathrm{Ln}(0,5089)$ $\Longrightarrow$ $k = \ln(1.599 \times \frac{135-23}{80-23})$

From (a) and (b), we can write the Newton cooling law that governs our case:

$$T(t) = 112.e^{-0,3377t} + Ta$$

Pour $T = 30°C \Longrightarrow T(t) = 112.e^{-0,3377t} + 23 = 30$

$\Longrightarrow$ $e^{-0,3377} = \frac{30-23}{112}$ $\Longrightarrow$ $t = \ln\frac{(-2,772)}{-0,3377} = 8,21s$

We will reach the temperature 30°c after 8.21s the filament out of the nozzle.

- **Spool placement**

We want the filament to reach the spool with a temperature of at least 30°C. Therefore, it will take a minimum of 8.21 seconds after leaving the die.

With a flow rate V_flow = 0.05 m/s, we will calculate the required distance between the die and the spool.

D = t(s) x Vflow

D = 0,05x 8,21 =0,4105 m

For this, we will choose to place our spool at a distance of 0,5 m from the die. And to ensure filament cooling, we can add fans.

Chapter 4 : 3D Design and discussions

4.1. Introduction

Continuing from the previous chapter, this section aims to introduce the environment of the SolidWorks software and to carry out the design of various elements of the extrusion machine and winding system using this software. The drawings of some parts will be included in the end of this report. Throughout this chapter, we will demonstrate how each component was meticulously crafted and integrated within the overall design framework and the result of our system.

4.2. Design Methodology

All software and geometric modeling methods used in product design, virtual testing with numerical simulation techniques and computers, and tool manufacturing are all referred to as computer-aided design (CAD). CAD uses several software programs, such as Abaqus, SolidWorks, TopSolid, FreeCAD, Solid Edge, Kompas 3D, and more. We designed some components of the machine using SolidWorks software as part of our design and simulation work. Then, we put everything together to create the extruder's final design. SolidWorks gave us the resources and capabilities we needed to realize our idea, from designing individual parts to assembling our machine.

To make it easier we divided our design into three main parts:

Extrusion section: We downloaded the CAD file of the motor we selected in the previous Chapter, and then used SolidWorks to design all the necessary parts of our machine (such as the screw, the nozzle, the sleeves, etc.). Afterward, we assembled them together.

Winding section: We downloaded the file of the motor we chose in Chapter 2, MB 63-40 006, and proceeded to design the parts and assemble them.

Main base: This is the foundation where we will install parts 1 and 2, integrating them into a cohesive unit.

4.3. Design of components

In this section, we will show how the design work is carried out for the main parts of the system.

4.3.1. Extrusion section components

- **Motor**

For the motor we downloaded the CAD file of our chosen motor from Chapter 2 and then we designed all the necessary parts of our machine (screw, nozzle, sleeves, etc.) using SolidWorks, and finally, we assembled them

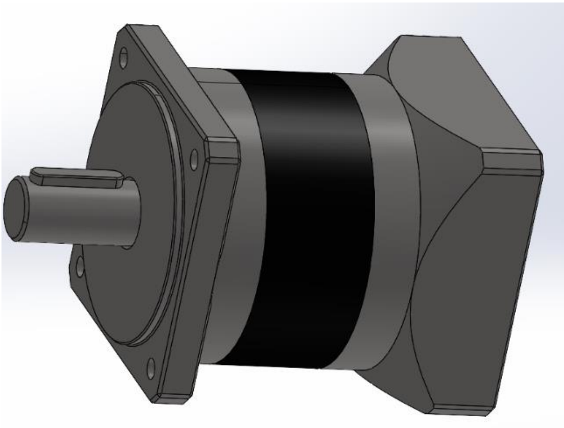


Figure 34: 3D model of the motor PLE34-G10

- **Screw**

The figure below shows the extruder screw that will use in this machine. We should look carefully for the geometry.

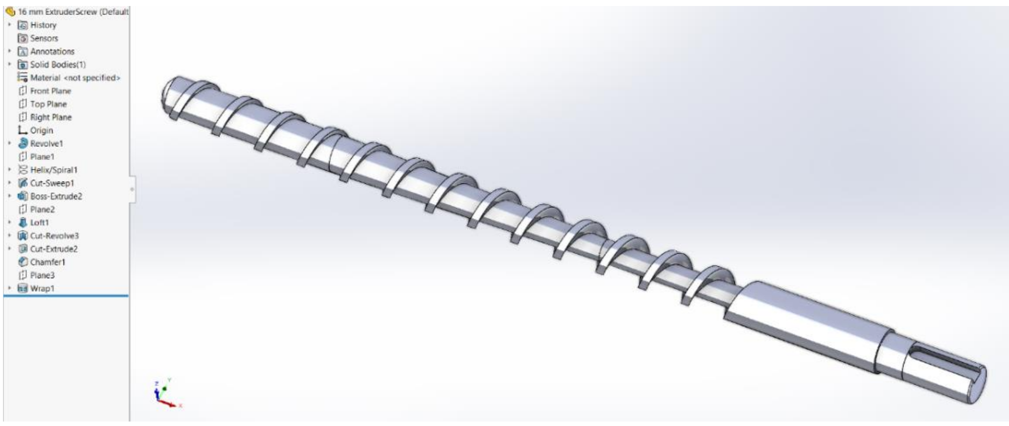


Figure 35: Design of the screw. Source: (Robotdigg Manufacturer)

The diameter difference in each section of an extruder screw is crucial for controlling various aspects of the extrusion process, including material feeding, melting, compression, and homogenization.

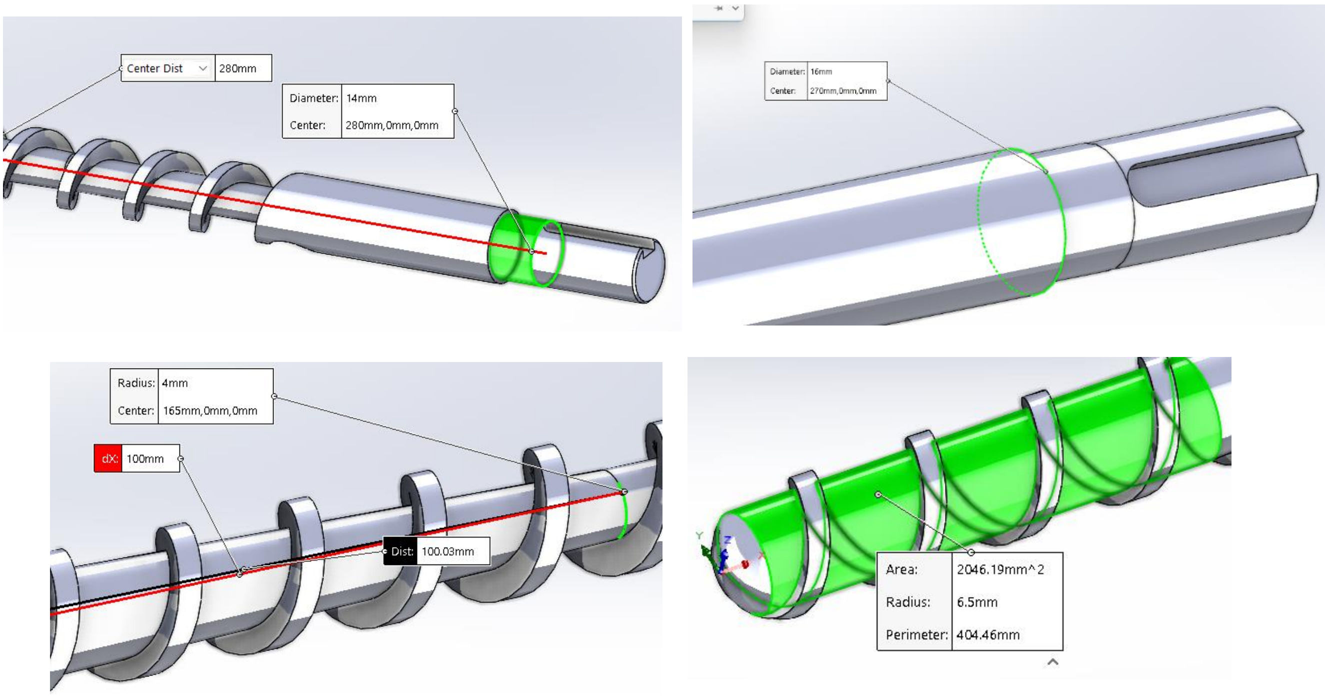


Figure 36: Different sections of the screw. Source: (Robotdigg Manufacturer)

- **Barrel**

We designed the barrel so it can fit for two ways :

There is a thread at 20 mm from the end to fit either directly a nozzle with the dimensions we will discuss, or an extrusion head on wich we can fit a standard nozzle from the market.

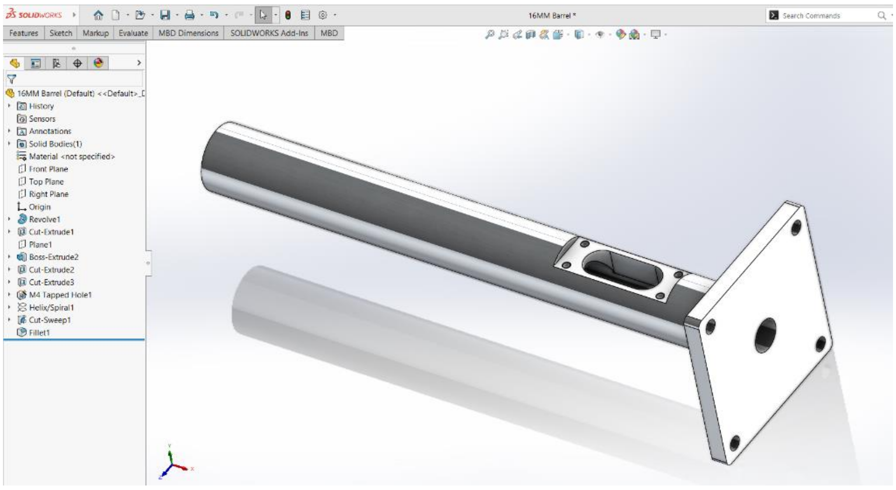


Figure 37: Design of the barrel. Source: (Robotdigg Manufacturer)

- **Nozzle**

The nozzle in the **Figure 38** below is designed by the manufacturer so that it can be mounted directly in the barrel. It is an alternative choice to extrusion head and it lessens the cost and can be removed easily to clean or changed.

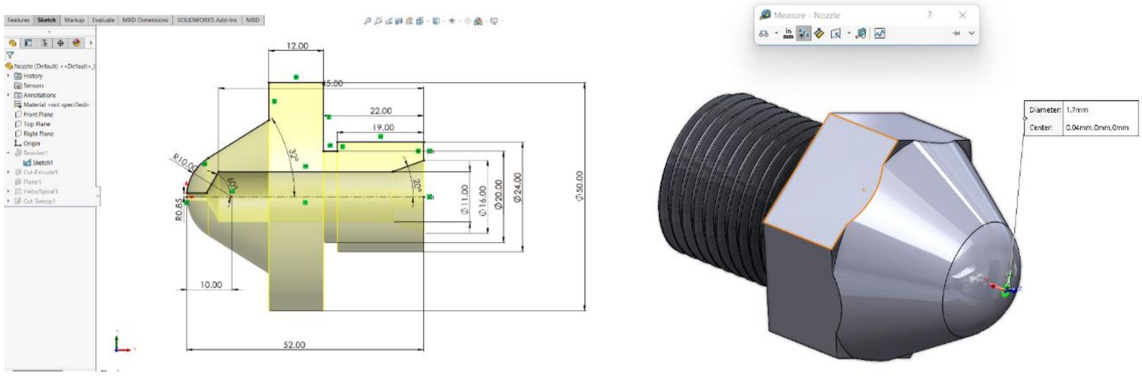


Figure 38: Nozzle. Source: (Robotdigg Manufacturer)

- **Flexible coupling**

We downloded the flexblible coupling CAD directly according to the desired dimensions.

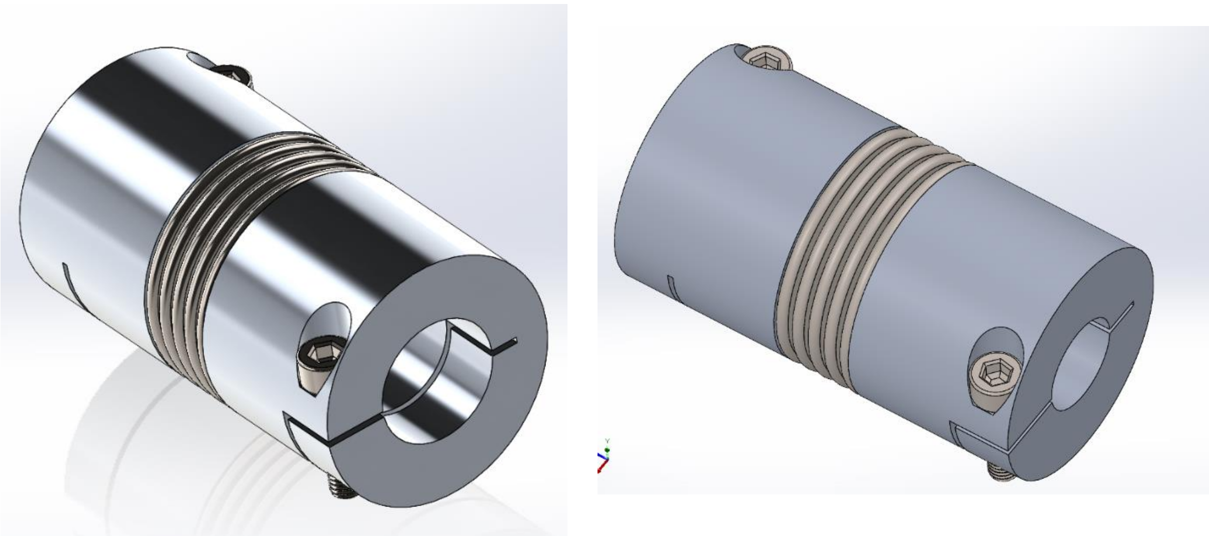


Figure 39: Flexible coupling

- **Hopper**

The hopper in **Figure 40** is a 3D printed ABS part, it has the hole to fit for PET bottle as a feeder, and a cooling fan disposition to equality distribute the cooling in the system. It will mounted to the barrel with screws.

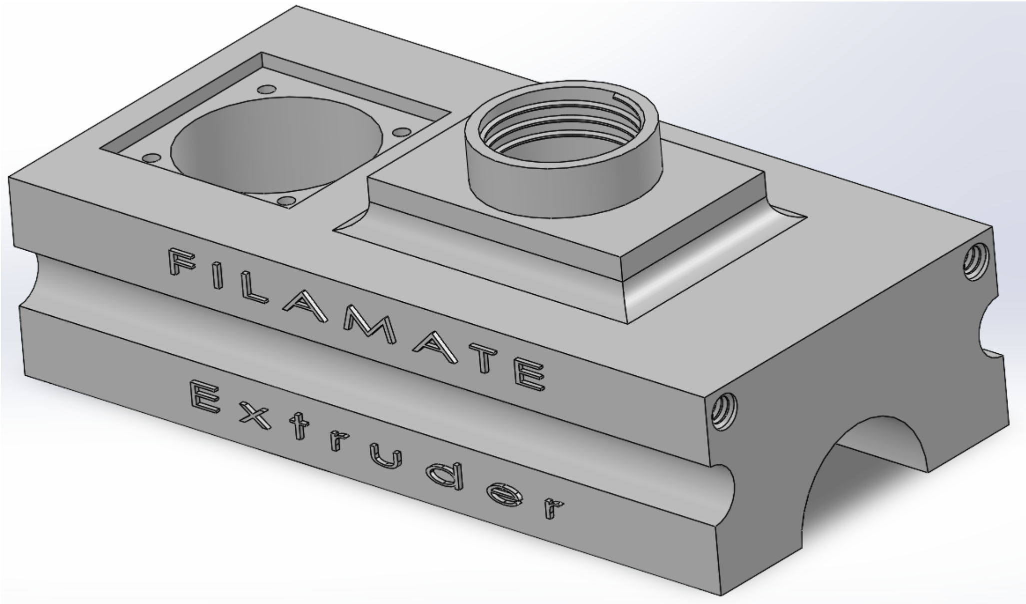


Figure 40: Extruder hopper

- **Heating collars**

We will use 1 small heating collar which will be mount around the barrel.

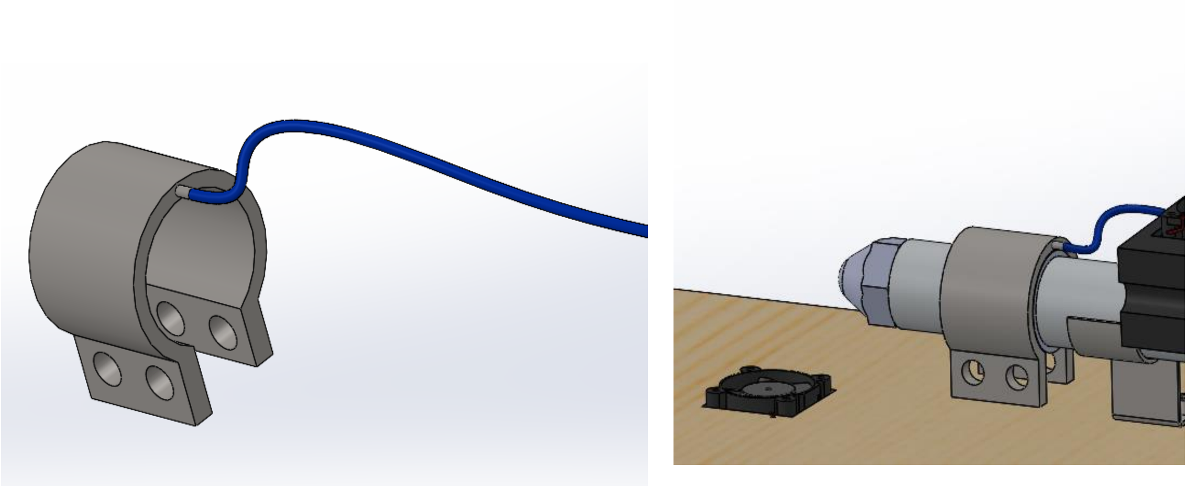


Figure 41: Heating collar

➢ Barrel support

This is a simple sheet metal support for the barrel. Since we have the barrel-screw system in fixed the mounting, the weight is reduced therefore we don’t need much support to carry it.

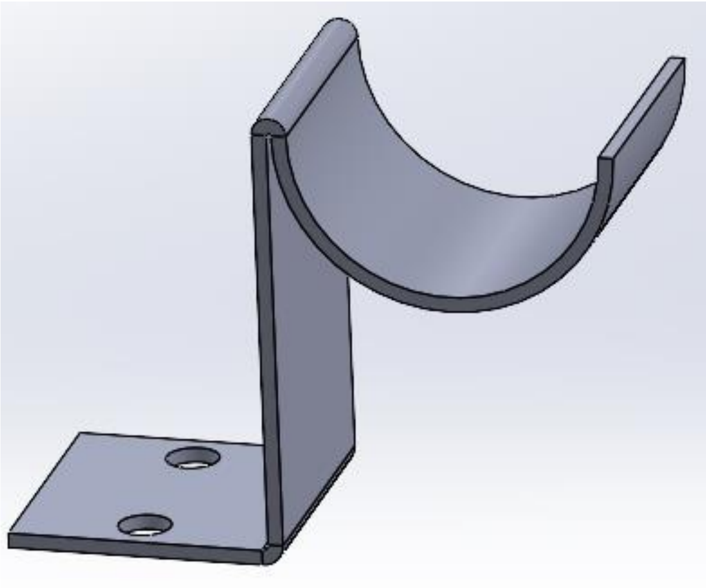


Figure 42: Barrel support

The initial idea was in **Figure 44** below, which is not practical in our case. We may lose time and money in the manufacturing process producing this part if we use traditional technologies (such as machining the lower section and welding the tube).

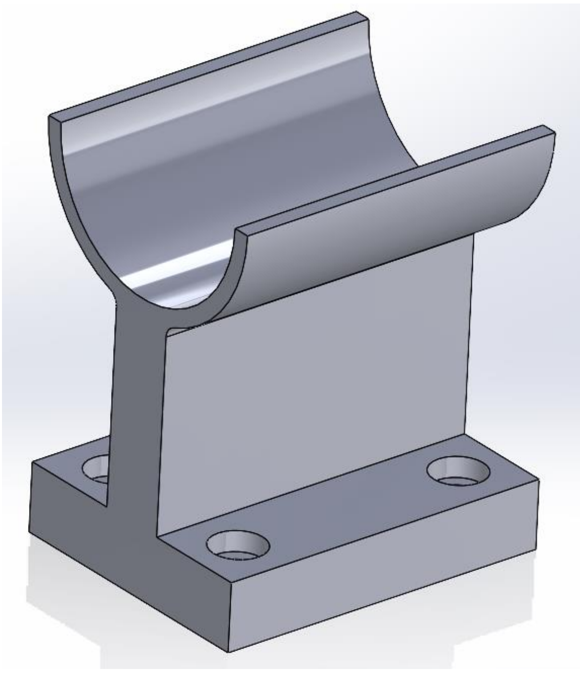


Figure 43: Initial design of barrel support

➢ Cooling fan

The fan is designed according to the common dimensions of fans available in the market.

Figure 44: Cooling fan GDT4010S12B

The characteristics of the cooling fan are show in the table below. (Brand : GDSTIME , item number : AM1495 from ampul online)

Table 10: Table of characteristics of cooling fan GDT4010S12B

Product	Specifications	
	Input voltage	12V
	Consumption in motion	<50mA
	Dimensions mm	40 x 40 x 10mm
	Speed	6500 rpm
	Motor Type	DC Brushless
	Power	0,84 W
	Life	35000 hours

- **Fitting together the extrusion components**

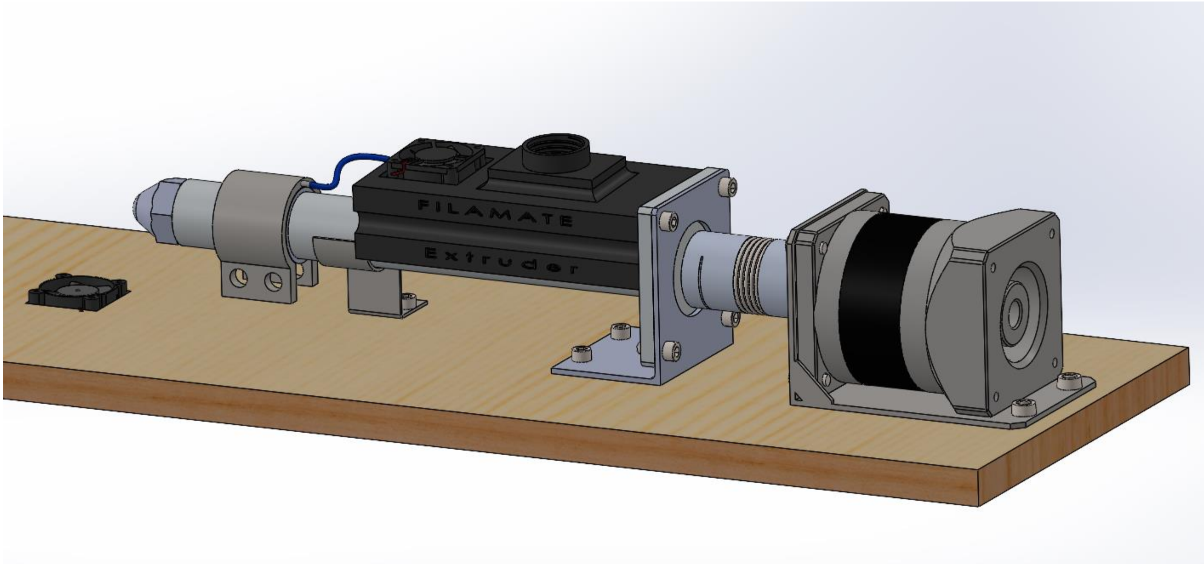


Figure 45: Extrusion section

4.3.2. Winding system

- **Spool**

This is a normal spool with typical diameter of the spools in the market.

We can reduce our expenses by just using the available old spool of purchased filament.

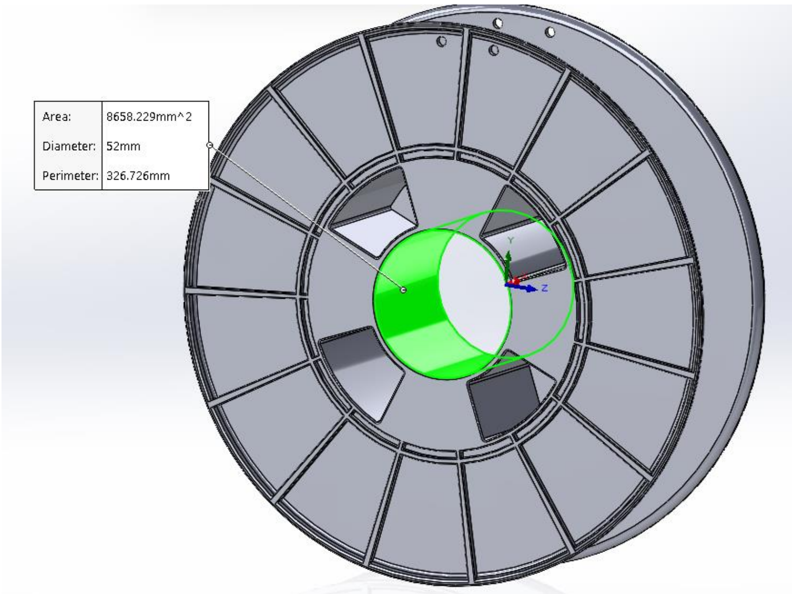


Figure 46: Filament spool

➢ Spool holder

We need two support for both side to help holding the spool. This part can be made by 3D printing as well.

Figure 47: Spool holder

➢ Shaft for spool supoort

This shaft is designed according to the diameter of the spool and the internal bearings diameter that will be mounted.

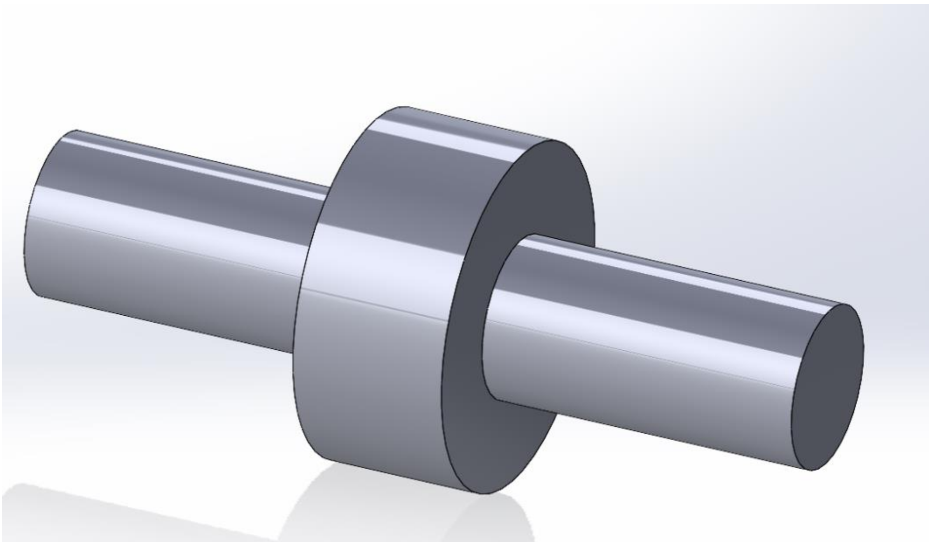


Figure 48: Shaft

➢ Gear system

We will add a gear system in order to transmit the power and rotate the spool.

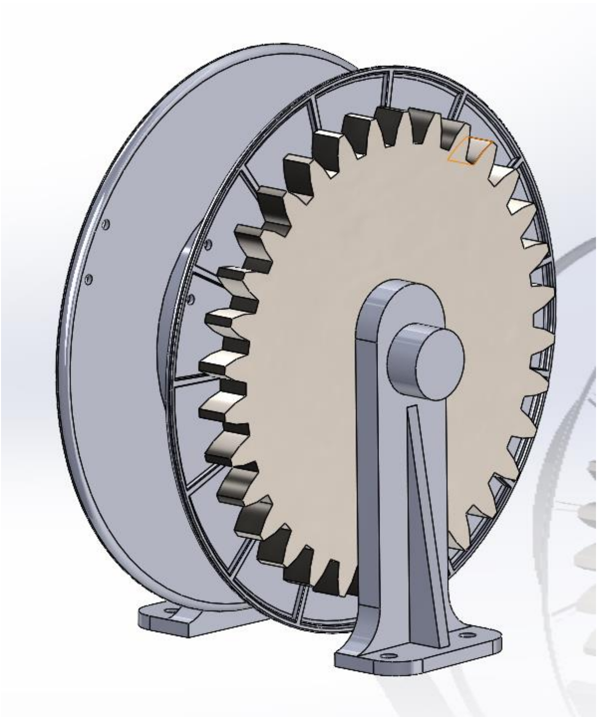


Figure 49: The led gear

➢ Fitting together the winding system components.

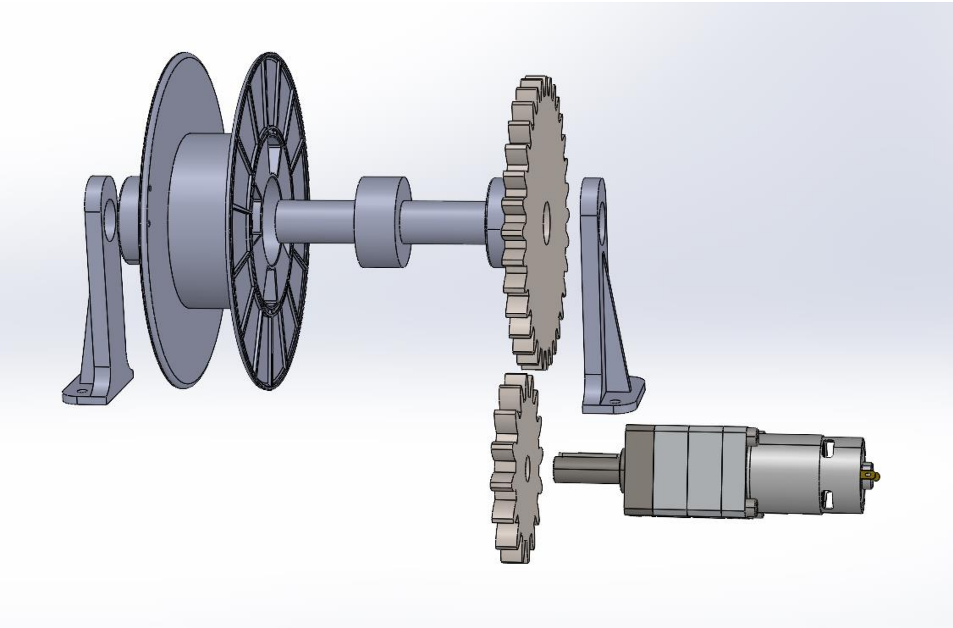


Figure 50: The winding system

4.3.3. Final assembly of the system

In **Figure 55** below is the final assembly of the system which contains all main parts.

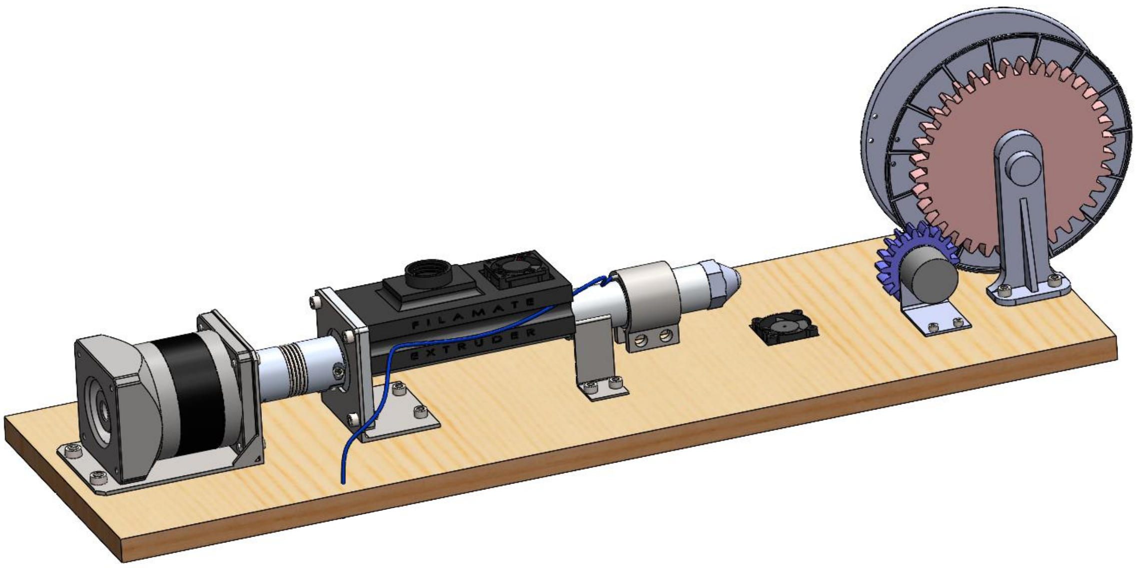


Figure 51: Assembly of extruder system

Cost Calculations

The next stage after finishing the machine design is to decide which parts should be purchased externally and which ones should be produced.

Table 11: Costs of main machine components

Parts	Purchasing Price
Extrusion section Motor	25000 HUF
Winding system motor	5000 HUF
Barrel + Screw + Nozzle	250000 HUF
Flexible coupling	7000 HUF
Thermocouples	2000 HUF
Cooling fan	1000 HUF
Bearings	1500 HUF
Screws	1000 HUF
Total cost	292500 HUF

Table 12: Costs of other parts

Parts	Method
Wood base	MDF base 20000 HUF
Barrel Support	Sheet metal 5000 HUF
Hopper	3D printing 9000 HUF
Spool holder	3D printing 6000HUF
Spool	Using old spool
Gears	3D printing 6000 HUF
Total cost	42000 HUF

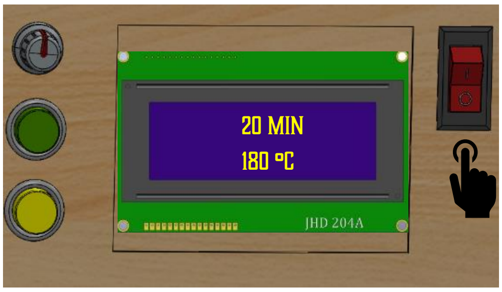
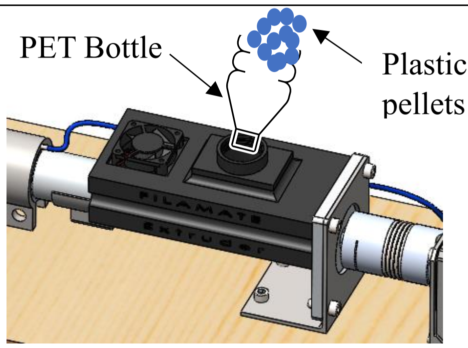
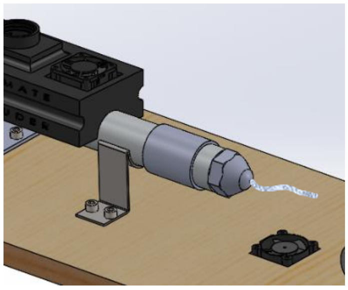
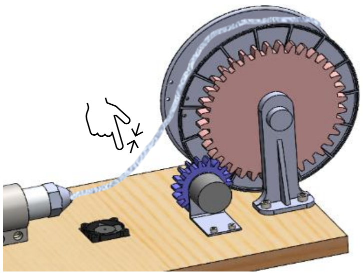
Note : The price of 3D printing is 3000 HUF/hour , in our case we will need around 3 hours

The price

4.3.4. Operating Manual

The table outlines some steps of operating manual for the designed filament extruder system. This simple guide provides a clear and basic instructions for effectively operating the machine. The table covers ,main steps, from the initial setup and material preparation to the final filament winding and quality control. It includes instructions for properly loading the polymer feedstock, configuring the appropriate temperature and speed settings, and monitoring the extrusion process to ensure consistent filament production.

Table 13: Operating manual of FILAMATE Extruder

<table>
<tr><td>STEP 1:
Machine Preparation</td><td>First turn on the machine and set the temperature according to your needs then wait for 20 minutes to allow the machine to reach optimal temperature.</td><td>
</td></tr>
<tr><td>STEP 2:
Loading the material</td><td>Introduce the desired plastic into the machine hopper and start the motor.</td><td>
</td></tr>
<tr><td>STEP 3:
Initial Cleaning</td><td colspan="2">During the first two minutes, the material coming out of the machine is meant to clean out residue from previous sessions.
Once this step is completed, the machine is ready for production.</td></tr>
<tr><td>STEP 4:
Extrusion process</td><td>Start the extrusion process and make sure to have a uniform diameter of the filament</td><td></td></tr>
<tr><td>STEP 5:
Filament Winding</td><td>Manually guide the filament and securely attach it the filament to the spool.</td><td></td></tr>
<tr><td>STEP 6:
Spool loading</td><td colspan="2">Simultaneously start the spool and crank motors wait for it to be fully loaded with filament. Then when you finish production cut the filament and retrieve the final product: the filament spool.</td></tr>
</table>

Conclusion

Through this work, which forms part of our master's degree program, we have gained a better understanding of how to solve a problem or technical issue in the design of a mechanical manufacturing system through its study and conception. In order to produce filaments meant for 3D printing, we carried out a design of a small extruder coupled with a winding system during our work.

We gave a thorough explanation of the extruder and performed an analytical and numerical research to determine the screw parameters, rotational speeds, and motor selections for the extruder and winding system, following the creation of some machine component using SolidWorks software.

As we result, we designed a small design which can be made as DIY. It is manual machine with low power required as the motor maximum power is 300W. Also, the characteristics and parameters of the system can produce different polymers. This system is easy to make with the right choice of material, components, and calculations.

To conclude, extrusion machines can be small desktop devices or huge industrial scale systems used to produce filaments for 3D printing. To guarantee reliable and superior filament manufacturing, these devices are built to accurately regulate the extrusion process's temperature, pressure, and speed. Advanced extrusion machines have the potential to integrate extra functionalities, such quality control systems and inline monitoring, to guarantee that the filament fulfills the required standards for 3D printing purposes.

The significance of the filament extrusion process and the capabilities of extrusion machines will only rise with the ongoing need for additive manufacturing. Consistent high-performance filament manufacturing will be made possible by ongoing advancements in extrusion technology, such as inline monitoring and quality control systems, which will allow for the manufacture of ever-more-complex and useful 3D printed objects.

To sum up, developments in filament extrusion technology are an essential part of the larger additive manufacturing ecosystem that help to sustain the development of 3D printing as a revolutionary manufacturing technique.

Summary

The design and development of an extrusion and winding system for the production of 3D printing filaments was the main goal of this research project. The enormous rise and revolutionary effects of 3D printing and additive manufacturing in the last ten years served as the impetus for this study.

3D printing enables the production of complex, customized parts and products by building them up layer by layer from digital models, utilizing a variety of materials including plastics, metals, ceramics, and even biological materials. One of the most popular 3D printing techniques, fused deposition modeling (FDM), uses plastic filaments as its main raw material.

The research primarily looked at the plastic extrusion technique used to make these filaments, with an emphasis on ABS and PLA materials. To form a continuous filament, the raw plastic material is melted and then forced through a small nozzle or die in the filament extrusion process. Our primary tasks of this study were to use SolidWorks software to develop an extruder system and a winding system for the production of 3D printing filaments. It is a small and simple DIY system with affordable price and can be used for wide range of polymers.

An extensive survey of the literature served as the study's first step, and then analytical and numerical research was done to ascertain the extruder's specifications. The CAD design of the various machine components using SolidWorks came next.

ANNEXES

ABS Material Datasheet from IEMAI 3D

Physical	Condition	Test Method	Typical Value
Density		ISO 1183/B	1.06 g/cm^3
Apparent Density		ISO 60	0.66 g/cm^3
Melt Volume-Flow Rate (MVR)	220 ℃ / 10.0 kg	ISO 1133	5g / 10 min
Molding Shrinkage-Flow		ISO 294-4	0.42 to 0.72 %

Mechanical	Condition	Test Method	Typical Value
Tensile Modulus	3.20 mm	ISO 527-2	2270MPa
Tensile Stress	Yield, 3.20 mm	ISO 527-2/50	46.0MPa
Tensile Strain	Yield, 3.20 mm	ISO 527-2/50	2.50%
Flexural Modulus	3.20 mm	ISO 178	2350MPa
Flexural Strength	3.20 mm	ISO 178	69.0MPa

Impact	Condition	Test Method	Typical Value
Notched Izod Impact Strength	23 ℃	ISO 180/A	19 kJ/m^2
Charpy Izod Impact Strength	23 ℃	ISO 170 1eA	19 kJ/m^2

Thermal	Condition	Test Method	Typical Value
Heat Deflection Temperature	1.8 MPa, Unannealed	ISO 75-2/A	97 ℃
Vicat Softening Temperature		ISO 306/B50	95 ℃

Elastomers	Condition	Test Method	Typical Value
Fogging		ISO 294-4	97%

Flammability	Condition	Test Method	Typical Value
Burning Rate	2.00 mm	ISO 75-2/A	55 mm/min
Flame Rating		UL 94	
	1.50 mm		HB
	3.00 mm		HB
Carbon Emission		VDA 277	25.0µg/g

Print Recommendation	
Nozzle Temperature	220 -260 ℃
Bed Temperature	90 -110 ℃
Print Speed	30-70 mm/s
Chamber Temperature	50-70 ℃
Cooling Fan	0-50%

PLA Material Datasheet from IEMAI 3D

PHYSICAL PROPERTIES		
Property	Testing Method	Typical Value
Density	ISO1183, GB/T1033	1.17 g/cm^3 at 21 ℃
Melt Index	210℃, 2.16 Kg	7-10g/10min
Light Transmission	N/A	N/A
Flame retardancy	UL94	V2

CHEMICAL RESISTANT DATA	
Effect of weak acids	Not Resistant
Effect of strong acids	Not Resistant
Effect of weak alkalis	Not Resistant
Effect of strong alkalis	Not Resistant
Effect of organic solvent	No data available
Effect of oils and grease	No data available
Effect of Sunlight	No data available

Thermal Properties		
Property	Testing Method	Typical Value
Glass transition	DSC, 10℃/min	61 ℃
Melting temperature	DSC, 10℃/min	150 ℃
Crystallization temperature	DSC, 10℃/min	113.5 ℃
Decomposition temperature	TGA, 20℃/min	N/A
Vicat softening temperature	ISO 306 GB/T 1633	62.9 ℃
Heat deflection temperature	ISO 75 1.8MPa	58.1 ℃
Heat deflection temperature	ISO 75 0.45MPa	59.8 ℃

Mechanical		
Property	Testing Method	Typical Value
Young's modulus (X-Y)	ISO 527, GB/T 1040	2636 ±330 MPa
Young's modulus (Z)		N/A
Tensile strength (X-Y)	ISO 527, GB/T 1040	46.6 ±0.9 MPa
Tensile strength (Z)		43.5 ±3.1 MPa
Elongation at break (X-Y)	ISO 527, GB/T 1040	1.90 ±0.21 %
Elongation at break (Z)		N/A
Bending modulus (X-Y)	ISO 178, GB/T 9341	3283 ±132 MPa
Bending modulus (Z)		N/A
Bending strength (X-Y)	ISO 178, GB/T 9341	85.1 ±2.9 MPa
Bending strength (Z)		N/A
Charpy impact strength (X-Y)	ISO 179, GB/T 9343	2.68 ±0.16 KJ/m^2
Charpy impact strength (Z)		N/A

Print Recommendation	
Printing temperature	190 -220 ℃
Bed temperature	0-50 ℃
Print Speed	30-70 mm/s
Chamber Temperature	0-40 ℃
Cooling fan	0-100%

PETG Material Datasheet from IEMAI 3D

Physical	Condition	Test Method	Typical Value
Density		ASTM D792	1.29 g/cm^3
Bulk Density			0.73 g/cm^3
Intrinsic Viscosity		ISO 1628-5	0.80 dl/g
Water Absorption		ASTM D570	0.12%
Colour	b*	ASTM D6290	≤ 1
	L*	ASTM D6290	≥64

Mechanical	Condition	Test Method	Typical Value
Tensile Modulus		ISO 527-2	3000 MPa
Tensile Yield Stress		ISO 527-2	53 MPa
Elongation at Yield		ISO 527-2	4%
Tensile Strength		ISO 527-2	53 MPa
Elongation at Stress		ISO 527-2	4%
Stress at Break		ISO 527-2	19 MPa
Nominal Elongation at Break		ISO 527-2	31%
Flexural Modulus		ISO 178	2040 MPa
Flexural Stress		ISO 178	171 MPa
Deflection at Flexural Strength		ISO 178	8.6 mm

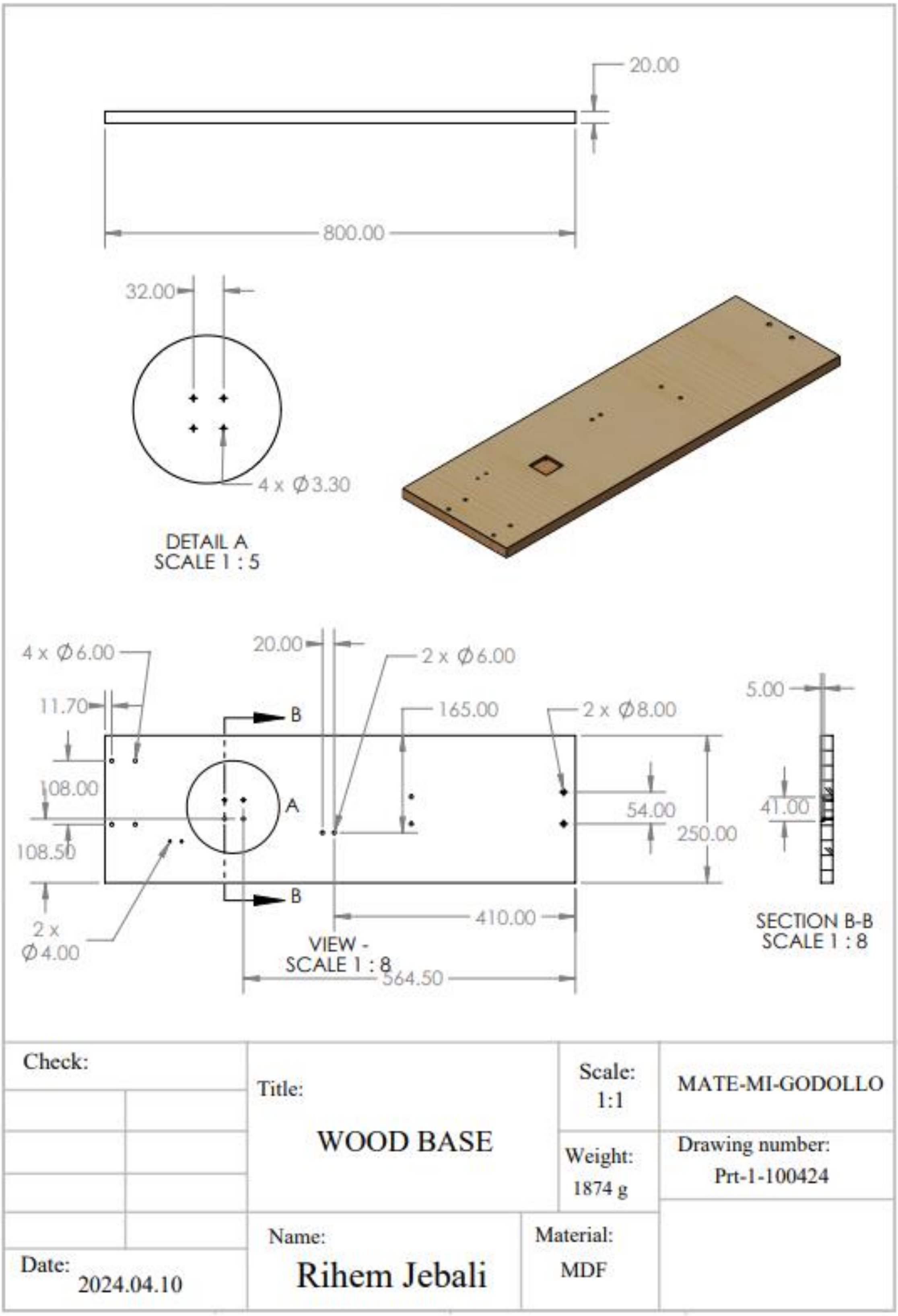
Impact	Condition	Test Method	Typical Value
Notched Izod Impact Strength	23°C, 50 % RH	ISO 180	4.5kJ/m^2
Unnotched Izod Impact Strength	23°C, 50 % RH	ISO 180	No Break

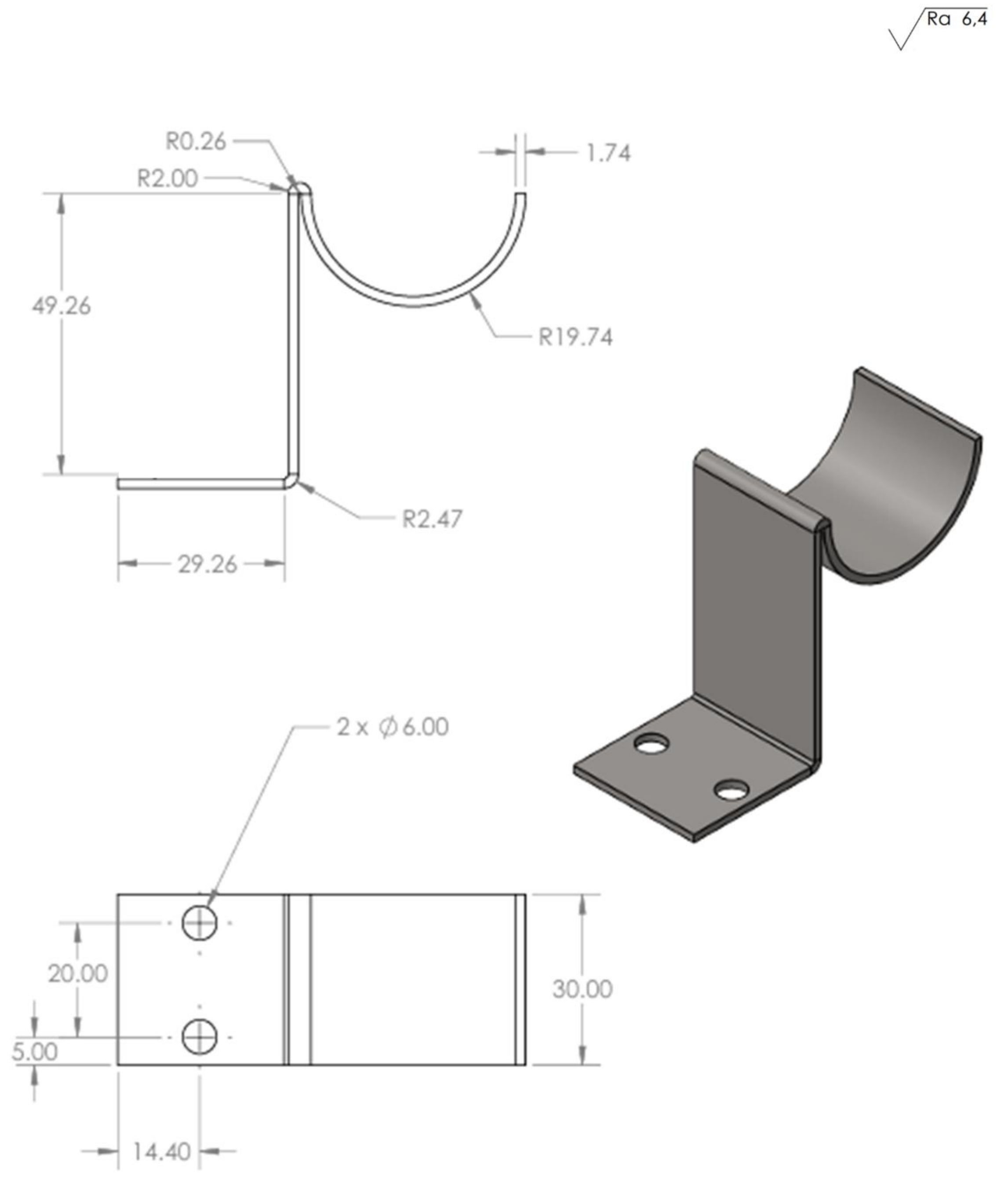
Hardness	Condition	Test Method	Typical Value
Shore Hardness		ASTM D2240	70

Thermal	Condition	Test Method	Typical Value
Heat Deflection Temperature			
	0, 45 MPa	ISO 75-2	68°C
	1.8 MPa	ISO 75-2	62°C
Vicat Softening Temperature		ISO 306	78°C
Glass Transition Temperature		ASTM D3418	80°C

Print Recommendation	
Nozzle Temperature	210 -235 °C
Bed Temperature	50 -80 °C
Print Speed	30-70 mm/s
Chamber Temperature	50-70 °C
Cooling Fan	0-100%

Drawings


20.00
800.00
32.00
4 x Ø3.30
DETAIL A
SCALE 1 : 5
4 x Ø6.00
20.00
2 x Ø6.00
11.70
B
165.00
2 x Ø8.00
5.00
108.00
A
54.00
41.00
250.00
108.50
B
410.00
SECTION B-B
SCALE 1 : 8
2 x
Ø4.00
VIEW -
SCALE 1 : 8
564.50
Check:
Title:
WOOD BASE
Scale:
1:1
MATE-MI-GODOLLO
Weight:
1874 g
Drawing number:
Prt-1-100424
Name:
Rihem Jebali
Material:
MDF
Date:
2024.04.10



Check:

Title:

Barrel Support

Scale:
1:1

MATE-MI-GODOLLO

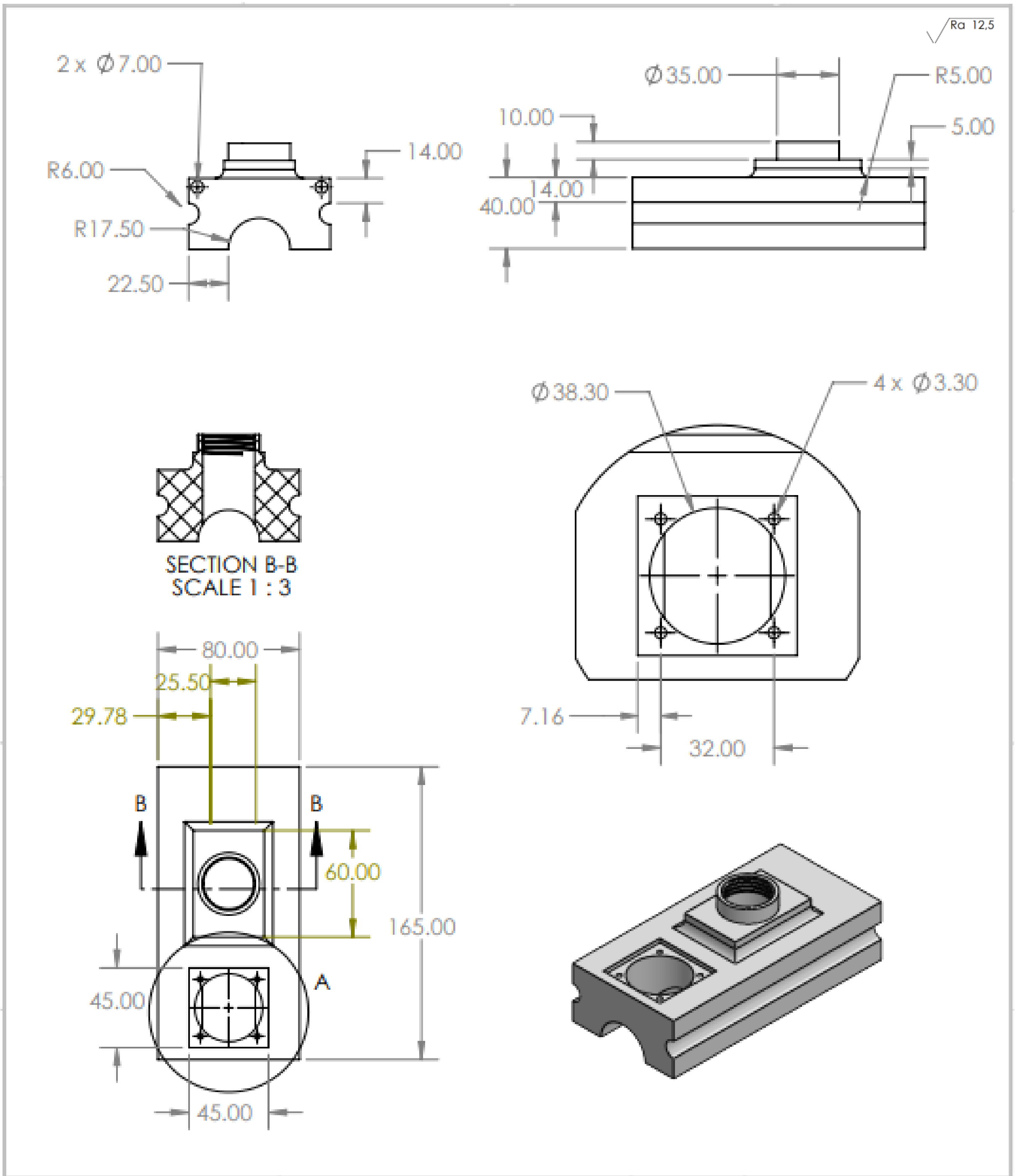
Weight:
60 g

Drawing number:
Prt-2-100424

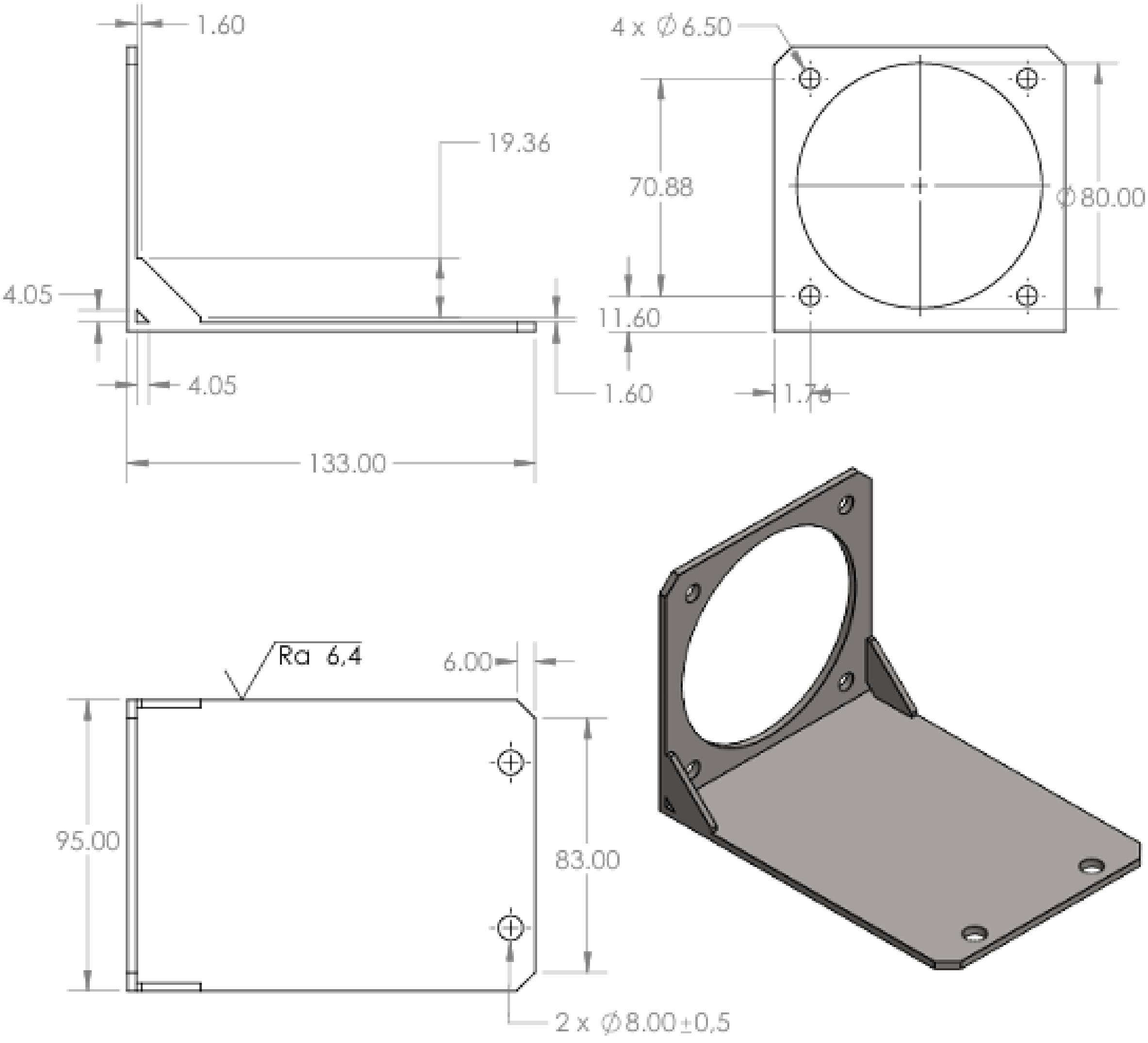
Date:
2024.04.10

Name:
Rihem Jebali

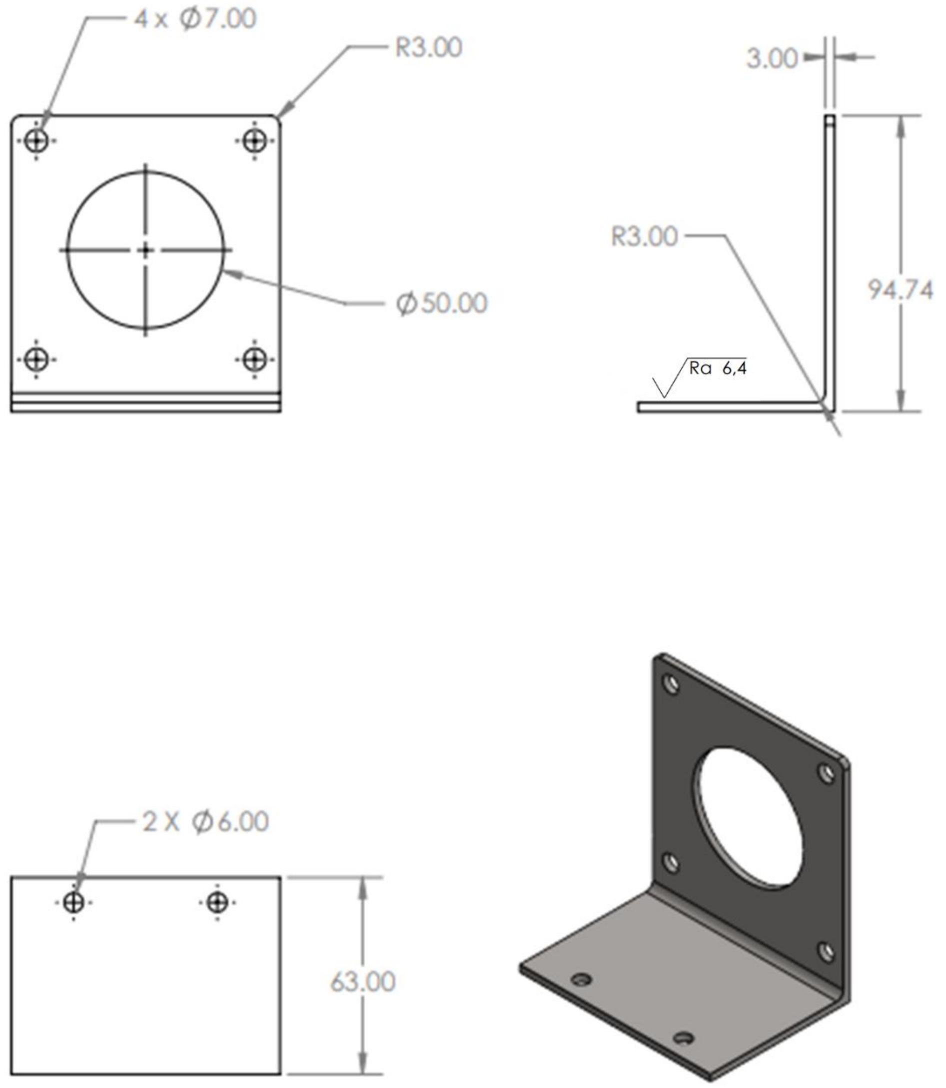
Material:
SS-304



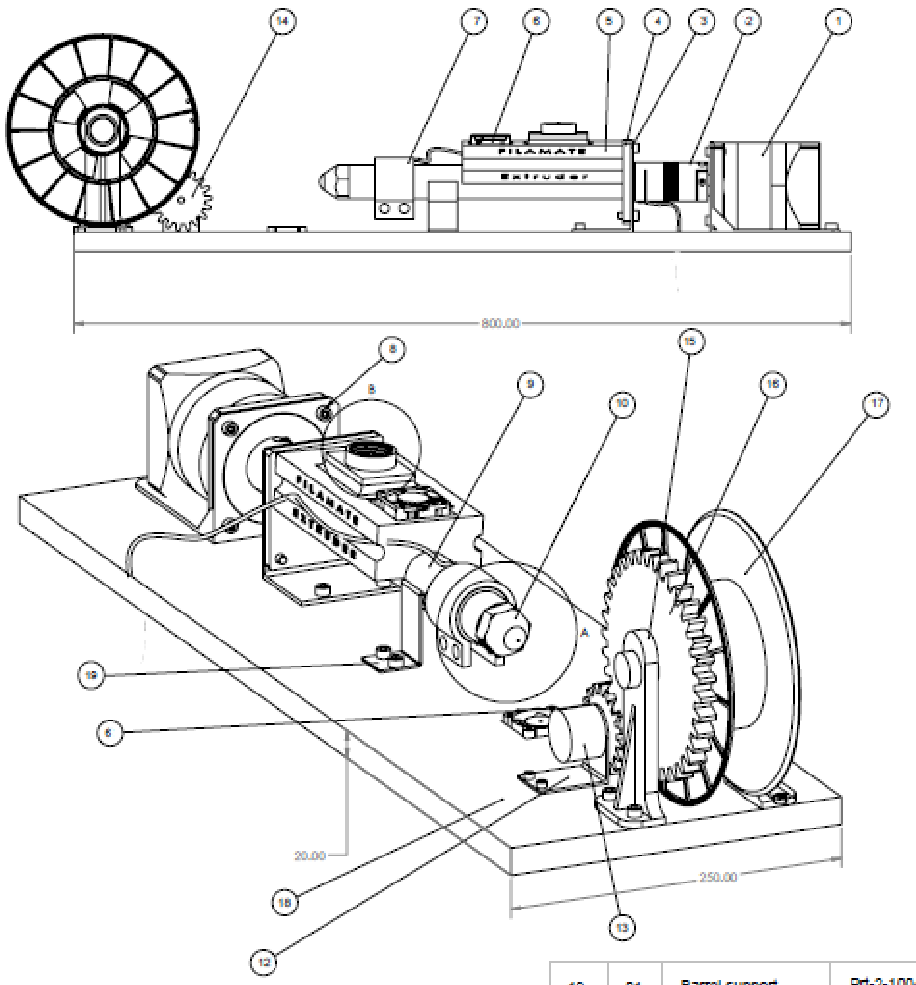
Check:	Title:	Scale: 1:1	MATE-MI-GODOLLO	
	Hopper	Weight: 410 g	Drawing number: Prt-3-100424	
Date: 2024.04.10	Name: Rihem Jebali	Material: ABS		

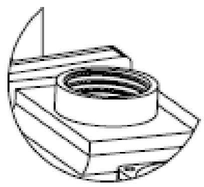


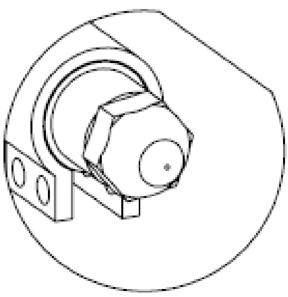
Check:	Title: MOTOR Mounting	Scale: 1:1	MATE-MI-GODOLLO
		Weight: 357 g	Drawing number: Prt-4-100424
Date: 2024.04.10	Name: Rihem Jebali	Material: Cast Alloy Steel	



Check:	Title: Barrel Mounting	Scale: 1:1	MATE-MI-GODOLLO
		Weight: 250 g	Drawing number: Prt-5-100424
Date: 2024.04.10	Name: Rihem Jebali	Material: Cast Alloy steel	







Nb	Qty	Part name	Part number	
19	01	Barrel support	Prt-2-100424	
18	01	Base	Prt-1-100424	
10	01	Nozzle		
8	01	Motor mounting	Prt-4-100424	
7	01	Heating collar		
6	02	Cooling fan		
5	01	Hopper	Prt-3-100424	
4	01	Barrel- Screw system		
3	01	Barrel Mounting	Prt-5-100424	
2	01	Flexible coupling		
1	01	Motor EG34-G10		

Check:	Title: FILAMENT EXTRUDER SYSTEM	Scale: 1:1	MATE - MI - GODOLLO
		Weight: 6 kg	Drawing number: Assm-1-150424
Date: 2024.04.	Name: Rihem Jebali	Material:	

References

LIPOT, L., n.d. *Properties of commonly used polymers* [online]. [online]. Available from: https://www.notesandsketches.co.uk/Polymer_properties.html.

Bandyopadhyay, A., & Bose, S. (2019, October 29). *Additive Manufacturing Second Edition*. p.10

Britannica, T. Editors of Encyclopaedia (2022, June 22). Louis Le Prince. Encyclopedia Britannica. https://www.britannica.com/biography/Louis-Le-Prince

Gibson, I., Rosen, D., & Stucker, B. (2014). Additive manufacturing technologies: 3D printing, rapid prototyping, and direct digital manufacturing. Springer.

Jones, R., Haufe, P., Sells, E., Iravani, P., Olliver, V., Palmer, C., & Bowyer, A. (2011). RepRap – the replicating rapid prototyper. Robotica, 29(1), 177-191.

Wohlers Associates. (2014). Wohlers report 2014: 3D printing and additive manufacturing state of the industry annual worldwide progress report. Wohlers Associates.

Chen, Y., Zhou, C., & Lao, J. (2011). A layerless additive manufacturing process based on CNC accumulation. Rapid Prototyping Journal, 17(3), 218-227. doi: 10.1108/13552541111124806.

Wong, K., & Hernandez, A. (2012). A Review of Additive Manufacturing. ISRN Mechanical Engineering, 2012, 1-10. doi: 10.5402/2012/208760.

BHATTACHARJEE, N., URRIOS, A., KANG, S., and FOLCH, A., 2016. The upcoming 3D-printing revolution in microfluidics. *Lab on a Chip* [online]. 16 (10), pp. 1720–1742. Available from: http://dx.doi.org/10.1039/c6lc00163g.

Quan, Zhenzhen, et al. "Additive Manufacturing of Multi-Directional Preforms for Composites: Opportunities and Challenges." Materials Today, vol. 18, no. 9, Nov. 2015, pp. 503–512, 10.1016/j.mattod.2015.05.001. Accessed 25 May 2021.

MITCHELL, A.D., LAFONT, U., HOŁYŃSKA, M., and SEMPRIMOSCHNIG, C., 2018. Additive manufacturing — A review of 4D printing and future applications. *Additive Manufacturing* [online]. Available from: https://doi.org/10.1016/j.addma.2018.10.038.

Park, S., Shou, W., Makatura, L., Matusik, W., & Fu, K. (2022, January 1). *3D printing of polymer composites: Materials, processes, and applications*. Matter. https://doi.org/10.1016/j.matt.2021.10.018

FELDMAN, D., 2008. Polymer History. *Designed Monomers and Polymers* [online]. 11 (1), pp. 1–15. Available from: http://dx.doi.org/10.1163/156855508x292383.

WOHLERS, T., GORNET, T., MOSTOW, N., CAMPBELL, I., DIEGEL, O., KOWEN, J., HUFF, R., STUCKER, B., FIDAN, I., DOUKAS, A., DRAB, B., DRSTVENŠEK, I., EITSERT, N., ESPALIN, D., FELDHAUSEN, T., GHANY, K.A., GILLETT-CROOKS, M., GUO, D., HELD, A., HARGOVAN, S., HOLMEGAARD, L., JENG, J.-Y., JURRENS, K.K., KEATING, B., KSY, A., KIRCHER, R., DE BEER, D., BRANDT, M., VASCO, J.O.C., KHORASANI, M., OVERY, C., PARK, K., CHEN, S., PEARCE, N., and PEELS, J., 2023. History of Additive Manufacturing. *Social Science Research Network* [online]. Available from: https://doi.org/10.2139/ssrn.4474824.

LAKKALA, P., MUNNANGI, S.R., BANDARI, S., and REPKA, M.A., 2023. Additive manufacturing technologies with emphasis on stereolithography 3D printing in pharmaceutical and medical applications: A review. *International Journal of Pharmaceutics: X* [online]. Available from: https://doi.org/10.1016/j.ijpx.2023.100159.

Anon., n.d. *Rapid Prototyping - Stereolithography (SLA)* [online]. [online]. Available from: https://www.custompartnet.com/wu/stereolithography.

SOLA, A. and TRINCHI, A., 2023. Basic principles of fused deposition modeling. *Elsevier eBooks* [online]. Available from: https://doi.org/10.1016/b978-0-323-98823-0.00001-9.

MASOOD, S.H., 2014. Advances in Fused Deposition Modeling. *Elsevier eBooks* [online]. Available from: https://doi.org/10.1016/b978-0-08-096532-1.01002-5.

PANDEY, P., NAYAK, A., and TAUFIK, M., 2022. Evaluation of mathematical models for surface roughness prediction of PolyJet 3D printed parts. *Advances in Materials and Processing Technologies* [online]. pp. 1–10. Available from: http://dx.doi.org/10.1080/2374068x.2022.2097416.

Anon., n.d. *Fused Deposition Modeling (FDM)* [online]. [online]. Available from: https://www.custompartnet.com/wu/fused-deposition-modeling.

ZHAKEYEV, A., WANG, P., ZHANG, L., SHU, W., WANG, H., and XUAN, J., 2017. Additive Manufacturing: Unlocking the Evolution of Energy Materials. *Advanced Science* [online]. 4 (10). Available from: http://dx.doi.org/10.1002/advs.201700187.

FARAHANI, R.D., THERRIAULT, D., DUBÉ, M., BODKHE, S., and MAHDAVI, M., 2018. 6.13 Additive Manufacturing of Multifunctional Nanocomposites and Composites. *Elsevier eBooks* [online]. Available from: https://doi.org/10.1016/b978-0-12-803581-8.10019-0.

FINA, F., GOYANES, Á., GAISFORD, S., and BASIT, A.W., 2017. Selective laser sintering (SLS) 3D printing of medicines. *International Journal of Pharmaceutics* [online]. Available from: https://doi.org/10.1016/j.ijpharm.2017.06.082.

LEONG, K.F., LIU, D., and CHUA, C.K., 2014. Tissue Engineering Applications of Additive Manufacturing. *Elsevier eBooks* [online]. Available from: https://doi.org/10.1016/b978-0-08-096532-1.01010-4.

PARK, S., SHOU, W., MAKATURA, L., MATUSIK, W., and FU, K., 2022. 3D printing of polymer composites: Materials, processes, and applications. *Matter* [online]. Available from: https://doi.org/10.1016/j.matt.2021.10.018.

KUMAR, R. and SINGH, R., 2020. Application of Nano Porous Materials for Energy Conservation and Storage. *Elsevier eBooks* [online]. Available from: https://doi.org/10.1016/b978-0-12-803581-8.11278-0.

KUMAR, V., SINGH, R., and AHUJA, I.S., 2022. Graphene-reinforced acrylonitrile butadiene styrene composite as smart material for 4D applications. *Elsevier eBooks* [online]. Available from: https://doi.org/10.1016/b978-0-12-823725-0.00004-7.

ABRAL, H., 2021. Polylactic Acid (PLA) Biocomposite: Processing, Additive Manufacturing and Advanced Applications. *www.academia.edu* [online]. Available from: https://www.academia.edu/62451890/Polylactic_Acid_PLA_Biocomposite_Processing_Additive_Manufacturing_and_Advanced_Applications.

VON HAGEN, R., 2016. PLA (Polylactic Acid). *Elsevier eBooks* [online]. Available from: https://doi.org/10.1016/b978-0-12-803581-8.01530-7.

DUTTA, N., 2022. Additive Manufacturing of Polymer Materials: Progress, Promise and Challenges. *rmit* [online]. Available from: https://www.academia.edu/88822154/Additive_Manufacturing_of_Polymer_Materials_Progress_Promise_and_Challenges.

BRANDAU, O., 2012. Material Basics. *Elsevier eBooks* [online]. Available from: https://doi.org/10.1016/b978-1-4377-3527-7.00002-x.

WANG, D., LIU, Q., WANG, Y., LI, M., LIU, K., CHEN, J., and QING, X., 2015. Reinforcement of Polyethylene Terephthalate via Addition of Carbon-Based Materials. *Elsevier eBooks* [online]. Available from: https://doi.org/10.1016/b978-0-323-31306-3.00003-8.

CHRISTIYAN, J., 2016. Fabrication of Basic Screw Extruder to Manufacture 3D Printers' Filament. *msruas* [online]. Available from: https://www.academia.edu/66895900/Fabrication_of_Basic_Screw_Extruder_to_Manufacture_3D_Printers_Filament

CHERRINGTON, R. and GOODSHIP, V., 2016. Introduction to Multifunctionality and Manufacture. *Elsevier eBooks* [online]. Available from: https://doi.org/10.1016/b978-0-323-34061-8.00001-6.

POLI, C., 2001. Polymer Processing. *Design for Manufacturing* [online]. pp. 25–37. Available from: http://dx.doi.org/10.1016/b978-075067341-9.50007-0.

THRONE, J., 2011. Thermoforming. Applied Plastics Engineering Handbook [online]. pp. 333–358. Available from: http://dx.doi.org/10.1016/b978-1-4377-3514-7.10019-4.

EngineeringClicks, 2019. What is Thermoforming and what is it used for? - EngineeringClicks. *EngineeringClicks* [online]. Available from: https://www.engineeringclicks.com/thermoforming/

PARK, S. and FU, K., 2021. Polymer-based filament feedstock for additive manufacturing. *Composites Science and Technology* [online]. Available from: https://doi.org/10.1016/j.compscitech.2021.108876.

HAGEN, R., 2012. Polylactic Acid. *Elsevier eBooks* [online]. Available from: https://doi.org/10.1016/b978-0-444-53349-4.00269-7.

DESHMUKH, K., AHAMED, M.B., DESHMUKH, R.R., PASHA, S.K.K., BHAGAT, P.R., and CHIDAMBARAM, K., 2017. Biopolymer Composites With High Dielectric Performance: Interface Engineering. *Elsevier eBooks* [online]. Available from: https://doi.org/10.1016/b978-0-12-809261-3.00003-6.

KAMBALE, B., 2021. *Which Additive Manufacturing Process Is Right for You?* [online]. [online]. Available from: https://manufacturing.report/articles/which-additive-manufacturing-process-is-right-for-you.

ZHANG, X., FAN, W., and LIU, T., 2020. Fused deposition modeling 3D printing of polyamide-based composites and its applications. *Composites Communications* [online]. Available from: https://doi.org/10.1016/j.coco.2020.100413.

Anon., n.d. EX2 Filament Extruder. *Filabot* [online]. Available from: https://www.filabot.com/products/filabot-original-ex2.

Javaid, Mohd & Haleem, Abid. (2019). Using additive manufacturing applications for design and development of food and agricultural equipments. International Journal of Materials and Product Technology. 58. 225. 10.1504/IJMPT.2019.10018137.

Javaid, M., Kumar, L., Kumar, V. and Haleem, A. (2015) 'Product Design and development using polyjet rapid prototyping technology', International Journal of Control Theory and Informatics, Vol. 5, No. 3, pp.12–19.

Lipton, J.I. (2017) 'Printable food: the technology and its application in human health', Current Opinion in Biotechnology, Vol. 44, pp.198–201.

Rapiddirect, 2022. What Is Plastic Extrusion: A Definitive Process Guide - rapiddirect. *rapiddirect* [online]. Available from: https://www.rapiddirect.com/blog/plastic-extrusion-process/.

Banerjee, Ashis. (2006). Computer Aided Design of Side Actions for Injection Molding of Complex Parts.

MCCARTHY, E. and BRABAZON, D., 2021. Additive Manufacturing for Sustainability of Composite Materials Production. *Encyclopedia of Materials: Composites* [online]. pp. 263–275. Available from: http://dx.doi.org/10.1016/b978-0-12-819724-0.00067-7.

G, D., 2024. Types of Filament for 3D Printing: The Ultimate Guide. *Wevolver* [online]. Available from: https://www.wevolver.com/article/3d-printer-filament-types-functional-filaments.

Anon., n.d. ProtoCycler V3 Filament Maker and Recycler. *ReDeTec* [online]. Available from: https://redetec.com/products/protocycler?variant=39805378658352.

CPE: Lesson 32 Screw Conveyor [online]. [online]. Available from: http://ecoursesonline.iasri.res.in/mod/page/view.php?id=854.

MISHRA, R., MILITKÝ, J., and VENKATARAMAN, M., 2019. Nanoporous materials. *Elsevier eBooks* [online]. Available from: https://www.sciencedirect.com/science/article/abs/pii/B9780081026090000079?via%3Dihub.

ZHANG, Z., 2016. Effect of Temperature on Rock Fracture. *Elsevier eBooks* [online]. Available from: https://www.sciencedirect.com/science/article/abs/pii/B9780128026885000051.

ABS Material Datasheet : https://www.iemai3d.com/wp-content/uploads/2020/12/ABS_TDS.pdf

EG Series Planetary Gearbox Gear Ratio 10:1 Backlash 15arc-min for Nema 34 Stepper Motor - EG34-G10|STEPPERONLINE. *StepperOnline* [online]. Available from: https://www.omc-stepperonline.com/eg-series-planetary-gearbox-gear-ratio-10-1-backlash-15-arc-min-for-nema-34-stepper-motor-eg34-g10.

DURGASHYAM, K., REDDY, M.I., BALAKRISHNA, A., and SATYANARAYANA, K.G., 2019. Experimental investigation on mechanical properties of PETG material processed by fused deposition modeling method. *Materials today: proceedings* [online]. Available from: https://www.sciencedirect.com/science/article/pii/S2214785319314300

List of figures

List of tables

STATEMENT ON CONSULTATION PRACTICES

As a supervisor of **Rihem Jebali** , Neptun Code: **B45K1F**. I here declare that the master's thesis has been reviewed by me, the student was informed about the requirements of literary sources management and its legal and ethical rules.

I recommend the master's thesis to be defended in a final exam.

The document contains state secrets or professional secrets: yes no

Gödöllő, 2024.04.26

Internal supervisor

DECLARATION

on authenticity and public assess of <u>mater's thesis</u>

Student's name: Rihem Jebali

Student's Neptun ID: B45K1F

Title of the document: Design of a Filament Extrusion System for a Sustainable and Cost-Effective FDM- 3D Printing

Year of publication: 2024

Department: Mechanical Engineering

I declare that the submitted master's thesis is my own, original individual creation. Any parts taken from an another author's work are clearly marked, and listed in the table of contents.

If the statements above are not true, I acknowledge that the Final examination board excludes me from participation in the final exam, and I am only allowed to take final exam if I submit another master's thesis.

Viewing and printing my submitted work in a PDF format is permitted. However, the modification of my submitted work shall not be permitted.

I acknowledge that the rules on Intellectual Property Management of Hungarian University of Agriculture and Life Sciences shall apply to my work as an intellectual property.

I acknowledge that the electric version of my work is uploaded to the repository sytem of the Hungarian University of Agriculture and Life Sciences.

Gödöllő, 2024.04.26

Student's signature