People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

Ecole Nationale Polytechnique

المدرسة الوطنية المتعددة التقنيات
Ecole Nationale Polytechnique

Metallurgy Department

End-of-Studies Project Report

for the attainment of the State Engineer's diploma in

Material engineering

(PET) Bottle Recycling for 3D Printing Filament: Producer Machine Development and Material Characteristics

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Presented by : **OUCHENE Mohamed Errachid**

Under the supervision of : **Pr. LARIBI Merzak**

Presented and publicly supported on (23/06/2024)

Composition of the Jury:

President	DAIMELLAH Abderrahmane	Assistant Master	ENP
Examiner	KASSER Abdelmadjid	Senior Lecturer Class A	ENP
Examiner	BELOUADAH Zoheir	Senior Lecturer Class A	ENP

ENP 2024

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Ecole Nationale Polytechnique

Département de Métallurgie

Rapport de Projet de Fin d'Études

pour l'obtention du diplôme d'Ingénieur d'État en

Génie des Matériaux

Recyclage de bouteilles en PET pour filament d'impression 3D : Développement de la machine de production et caractéristiques des matériaux

---

Présenté par: **OUCHENE Mohamed Errachid**

Sous la supervision de: **Prof. LARIBI Merzak**

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Examinateur	BELOUADAH Zoheir	Maître de conférences de classe A	ENP

ENP 2024

ملخص :

هذا المشروع يستكشف استخدام تدوير زجاجات PET في صنع خيوط الطباعة ثلاثية الأبعاد بطريقة مبتكرة للتصدي للمخاوف المتزايدة بشأن البيئة والاقتصاد. من خلال تحويل هذه النفايات البلاستيكية إلى موارد قيمة، يهدف المشروع إلى خفض البصمة الكربونية لإنتاج الخيوط بالإضافة إلى تقديم بديل اقتصادي على سوق الطباعة ثلاثية الأبعاد المتنامي. يركز المشروع على تصميم جهاز فعال لإعادة تدوير زجاجات PET والتحليلات الدقيقة لخصائص الخيوط المنتجة، بما في ذلك مقارنتها بالخيوط PLA و ABS المتوفرة تجاريًا. الهدف الرئيسي من المشروع هو تصميم وتنفيذ الجهاز واختباره، بالإضافة إلى إنتاج الخيط بجودة عالية للاستخدام في التطبيقات الصناعية والإبداعية.

الكلمات المفتاحية :تدوير PET , خيوط الطباعة ثلاثية الأبعاد, تصميم و اختبار الجهاز , خصائص الخيوط المنتجة, مقارنة بين الخيوط PET و PLA و ABS

En résumé

Ce projet explore l'utilisation innovante du recyclage des bouteilles PET pour fabriquer des fils d'impression 3D afin de répondre aux préoccupations croissantes concernant l'environnement et l'économie. En transformant ces déchets plastiques en ressources précieuses, le projet vise à réduire l'empreinte carbone de la production de fils tout en offrant une alternative économique sur le marché de l'impression 3D en expansion. Le projet se concentre sur la conception d'un dispositif de recyclage efficace des bouteilles PET et sur une analyse approfondie des propriétés des fils produits, y compris leur comparaison avec les fils PLA et ABS disponibles commercialement. L'objectif principal du projet est de concevoir, de réaliser et de tester le dispositif, tout en produisant des fils de haute qualité adaptés aux applications industrielles et créatives.

Mots-clés : recyclage PET, fils d'impression 3D, conception et test du dispositif, propriétés des fils produits, comparaison entre fils PET, PLA et ABS

Abstract :

This project explores the innovative use of recycling PET bottles to produce 3D printing filaments as a solution to growing concerns about the environment and the economy. By converting these plastic wastes into valuable resources, the project aims to reduce the carbon footprint of filament production while providing an economical alternative in the expanding 3D printing market. The project focuses on designing an efficient PET bottle recycling device and conducting detailed analyses of the properties of the produced filaments, including their comparison with commercially available PLA and ABS filaments. The primary goal of the project is to design, implement, and test the device, while producing high-quality filaments suitable for industrial and creative applications.

Keywords: PET recycling, 3D printing filaments, device design and testing, properties of produced filaments, comparison between PET, PLA, and ABS filaments

Dedication :

At the culmination of my journey as a materials engineering graduate, I extend my deepest gratitude and dedication.

I express my heartfelt thanks to Allah for granting me the strength to successfully complete this adventurous journey. This thesis is a personal milestone, a testament to my growth and perseverance.

I dedicate this achievement first and foremost to myself, recognizing the dedication and effort invested in reaching this point. To my beloved mother and father, your boundless love and unwavering encouragement have served as the pillars of my success. Your support has been indispensable, and without you, navigating the challenges of graduate studies would have been an insurmountable task. I extend my profound love and appreciation for everything you have done for me.

This work is also dedicated to my siblings, who have been unwavering pillars of support. To my brothers and sisters, your continuous encouragement and understanding throughout this demanding process have been invaluable. Your presence has made every challenge more manageable and every achievement more meaningful.

A special appreciation is reserved for my brother, whose contributions to this project have been invaluable. His insights and assistance have significantly enriched the quality of this work, and I am grateful for his collaboration.

ACKNOWLEDGEMENTS

I extend my gratitude to Allah for providing me with strength and encouragement, especially during the challenging moments throughout the completion of this thesis.

First and foremost, I express my sincere appreciation to my supervisor, Dr. LARIBI Merzak, for his patience and continuous supervision, guidance, advice, and support that played a pivotal role in the successful completion of this thesis.

I would also like to acknowledge my friend SNOUSY Ilyas, whose professional camera work significantly enhanced the presentation of this project. Additionally, I extend my thanks to my brother's friend ZAHAR Ali for his supervision in the electronics and automation domain, and to BOURASS Yousef for assisting me with my mechanical tests. And also thanks to my friend KHLIFA Menad Dhaiaeddine for his help.

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INTRODUCTION

Introduction

The advent of 3D printing technology has ushered in a new era of manufacturing, offering unprecedented flexibility and customization. However, the environmental toll of traditional filament production, often reliant on non-renewable resources, raises concerns about sustainability. In response to this challenge, an innovative approach emerges — the recycling of PET bottles into 3D printing filament. This endeavor not only addresses the urgent need for eco-friendly practices but also brings forth a myriad of advantages. At the forefront of this initiative is the environmental impact. PET (polyethylene terephthalate) bottles, ubiquitous in our daily lives, contribute significantly to plastic waste. By repurposing these bottles into 3D printing filament, we mitigate the environmental burden associated with their disposal. This approach aligns with the principles of a circular economy, reducing the demand for new raw materials and minimizing the carbon footprint of filament production. Beyond its ecological merits, recycling PET bottles into filament offers a financially viable alternative. The ubiquity of PET bottles as waste material provides an abundant and low-cost resource for filament production. This not only contributes to cost reduction but also positions recycled filament as an economically sustainable choice in the burgeoning 3D printing market. As we embark on this journey to transform waste into a valuable resource, this project focuses on designing and building a device for recycling PET bottles and obtaining 3D printing filament from them. These efforts aim to gain a deep understanding of the mechanical and technical processes involved in this context. The following stages have been considered in designing the device: design and guidance, directing the device towards maximizing the utilization of PET bottles as a source for filament; components and materials, selecting and explaining the components used in the recycling device; and construction process, providing a detailed explanation of the step-by-step process of building the device. In addition to this, the focus will be on examining and analyzing the properties of the material produced by this device: recycling process, explaining the process of converting PET bottles into raw materials for 3D printing; tests and material description, detailing the tests used to describe the recycled filaments and analyzing the physical and mechanical properties of the produced filaments; and comparison with PLA and ABS filament, providing a detailed comparison between the properties of the recycled filaments and commercially available PLA and ABS filaments, highlighting the advantages and disadvantages of each filament type. Through this project, we aim to achieve an efficient device for recycling PET bottles and obtaining high-quality 3D printing filaments.

CHAPTER I

BIBLIOGRAPHIC RESEARCH

I.1. Introduction

In the realm of modern manufacturing and prototyping, 3D printing stands as a revolutionary technology that has transformed the way we bring ideas into reality. Unlike traditional manufacturing methods, 3D printing, also known as additive manufacturing, builds objects layer by layer from digital models. This process allows for the creation of intricate and complex structures with remarkable precision. [1]

I.1.1. What is Additive Manufacturing?

Additive manufacturing is a new process that allows the production of volumetric parts (objects). The process is carried out layer by layer based on a model generated from a CAD software such as "Rhino 3D." Initially intended for prototyping and modeling, additive manufacturing processes are currently meeting demands for functional parts made of metal or composite materials with a metal or polymer matrix. However, the range of materials offered remains limited and is primarily used in the automotive, aerospace, and medical industries.

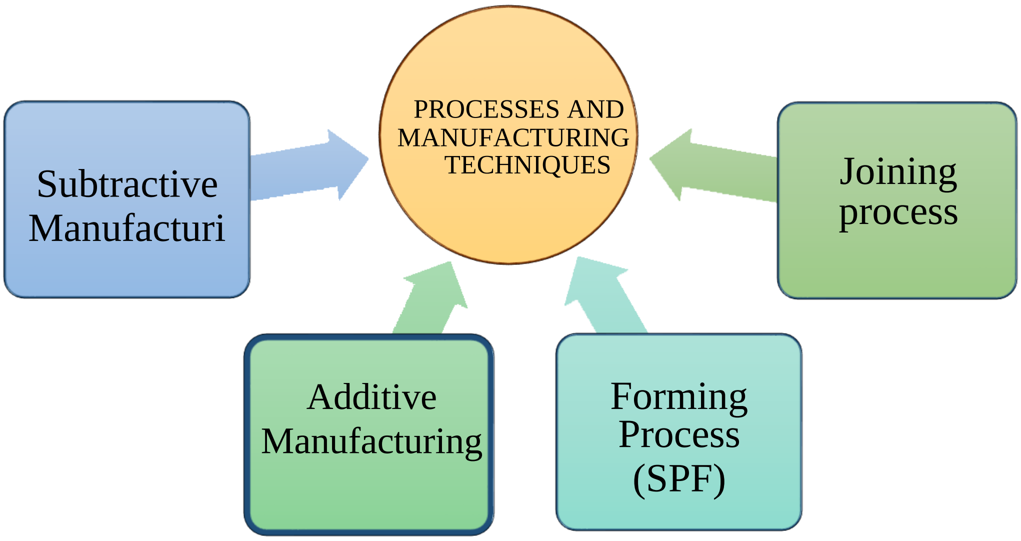


Figure 1 :Scheme Processes and manufacturing techniques [2].

Some of the most used additive manufacturing technologies that best suits to the educational area will be described in the following point of this guide. These technologies are: Fused Deposition Modeling (FDM), Stereolithographic (SLA) and Selective Laser Sintering (SLS).

Figure 2: 3D printers type

I.1.2 How does 3D printing work?

It all starts with making or obtaining a virtual design of the object you want to create. This virtual design can be made in a CAD (Computer Aided Design) file using a 3D modeling program (for the creation of a totally new object) or with the use of a 3D scanner (to copy an existing object). A 3D scanner makes a 3D digital copy of an object. There are also lots of online file repositories where you can download existing 3D files that will help get you started.

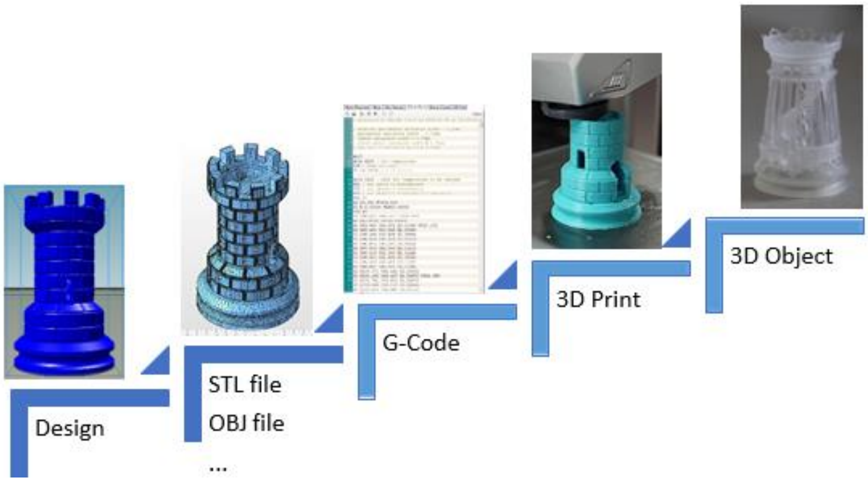
The 3D printing process turns an object into many, tiny little slices, then builds it from the bottom up, slice by slice. The layers then build up to form a solid object. [3]

The full process is explained in the point 3 of this guide.

Some advantages of Additive Manufacturing compared to conventional processes:

- Fewer steps between the CAD model and the production of the part.
- Generally, few human resource requirements due to a high level of automation.
- A large number of geometrical forms can be manufactured, enabling for instance the production of parts which are topologically optimised, with internal channels, etc.
- High-speed manufacturing for small, complex parts.

- Generally, less material wastage.
- Possibility to reconstruct damaged sections of existing objects, depending on the part material



I. 2. Fused Deposition Modeling (FDM)

Process, Materials, Application Areas

Home printers typically work with plastic filament. The technology behind this is often referred to Fused Deposition Modeling (FDM) is a 3D printing technology that works by extruding a thermoplastic polymer through a heated nozzle which gets deposited on a building stage. FDM is also considered to be a form of additive manufacturing, which at the same time is a "process of joining materials to make objects from 3D model data, usually layer upon layer".

Creating a 3D printed object through FDM requires, in the first place, to work on a STL file (stereo lithography file format) which mathematically slices and orients the model for the next building process. Sometimes, the software is capable of generating support structures for the object automatically. In general, the machine requires materials for both the object and the support. [4]

The mere process involves a plastic filament which is fed by a spool to the nozzle where the material is liquefied and "drawn" on the platform. As soon as it touches the build stage, the filament hardens while being gradually deposited, following a certain structure, in order to create the final 3D print. When a layer is drawn, the platform lowers by one layer thickness so that the printer is able to start working on the next layer.

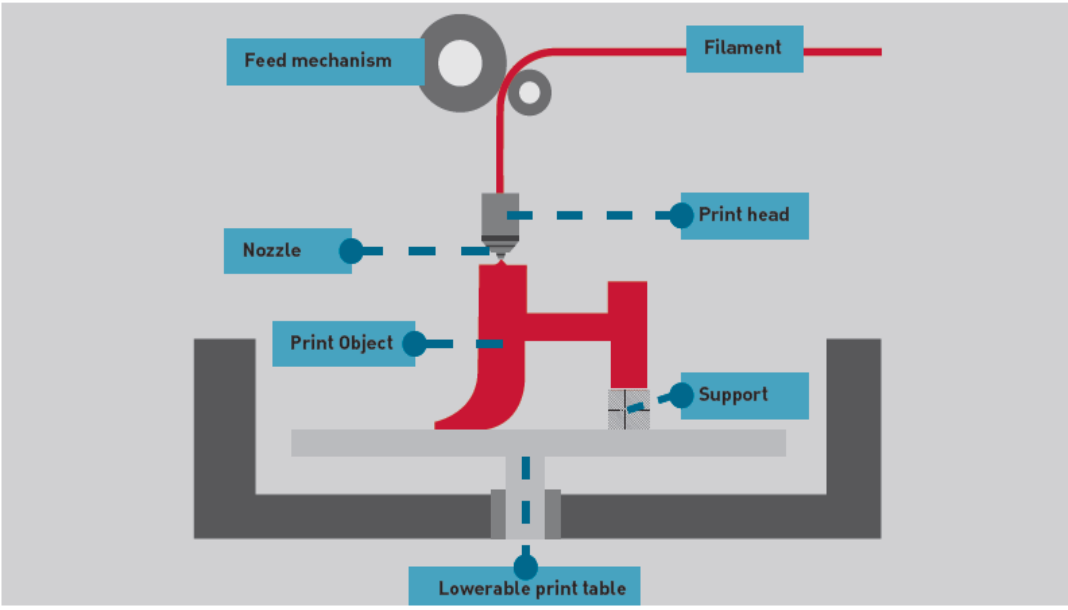


Figure : 4 FDM Scheme

There are many different materials which can be used with FDM. In the first place, they are divided between the industrial and the consumer categories. The most commonly used are ABS (Acrylonitrile Butadiene Styrene), PLA (Polyactic Acid) and Nylon (Polyamide), but other exotic varieties of materials can also be used, like a material blend of plastic and wood or carbon. [5]

Because this technology presents some very good pros, FDM is often used in the area of non- functional prototypes in order to produce concept parts, functional models, prototypes in general, manufacturing tooling and modeling, and end use parts. More specifically, FDM can be used for low-volume production and prototypes aimed at form, fit and function tests.

I.3. 3D Printing materials

I.3.1. Overview

When it comes to 3D printing, materials are often one of the most important choice. Earlier AM technologies were making use of certain materials which proved to be non-resistant enough and were degrading quickly. With time, the knowledge about 3D printing has been extending and has been spreading all over the world. With more people interested and the idea that this technology has the right potential to lead to new innovative ways of manufacturing, further studies and analysis has been conducted and new materials have been created.

Today, the 3D printing market offers a variety of choice for what concerns materials. From polymers and metals, to ceramics and composites, many are the materials that have been created, each of them with its own advantage and disadvantages. Some examples are visible on 3d hubs.com, a portal which provides 3D printing services on a global level. [6]:

- **Prototyping Plastic,** suitable for fast and cost-effective prototyping;
- **High Detail Resin,** suitable for intricate designs and sculptures;
- **SLS Nylon,** for functional prototypes and end-use parts;
- **Fiber-Reinforced Nylon,** for engineering strong parts;
- **Rigid Opaque Plastic,** for realistic prototypes with high accuracy;
- **Rubber-Like Plastic,** simulating rubber;
- **Transparent Plastic,** to create see-through parts and prototypes;
- **Simulated ABS**, with high precision and functional molds;
- **Full Color Sandstone,** for photo-realistic models;
- **Industrial Metals,** for prototypes and end-use parts.

The industry's offer is, of course, much wider than what is reported here. For what concerns the demand instead, here the use of a certain material is strongly influenced by not just the type of technology adopted, but also the popularity of 3D printing machines.

According to the global 3D printing report for 2016 which collected information from companies using a variety of 3D printing technologies, the demand for materials in this case shows that metal is leading the competition. Metals are currently being in areas like aerospace and automotive for many reasons. Apart from the high quantity that companies need in this case, 3D printing technology using metals allows to create lightweight components. Weight is, in fact, extremely fundamental for those companies which produce aircraft components, for example. It impacts the quantity of fuel that is used by the aircraft with very important cuts for what concerns the costs of the airlines. [7]

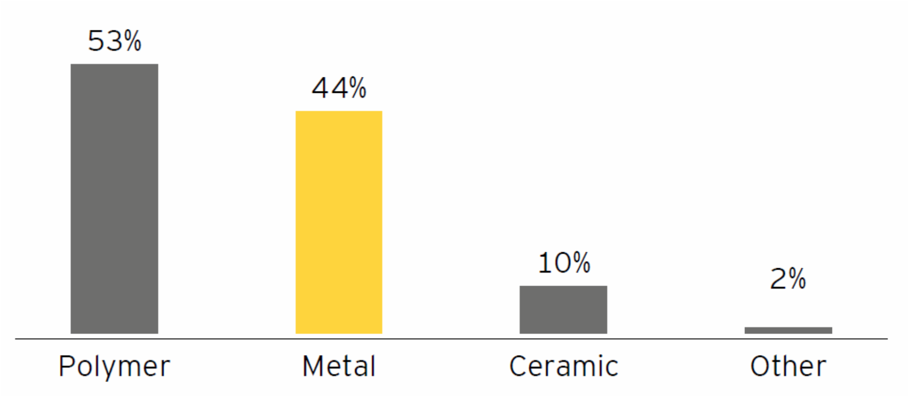


Figure 5:3D printing materials used. [8]

The graph above shows, instead, the percentage demand of 3D printing materials, as of 2016. Here, the leaders are the polymer materials followed shortly after by metals. This is due to the fact that companies have a lot of experience for what concerns the use of both categories, but much less use is registered for ceramics. Here, instead, the use is much lower. Only 10% of the companies make use of it and this is probably due, in the first place, to its durability and flexibility.

Ceramics don´t allow a certain kind of item to be created like plastics or filaments do. Meanwhile, metals allow them make use of materials like titanium, which has a very strong resistance, steel and aluminium. [9]

Today's trends confirm the path that has been undertaken already. As of late 2017, it has been reported that PLA materials are currently at the top of the chart with a 32%

of the total share. It is shortly after followed by ABS filaments, with 14% of the share. Standard Resins are reported to be the third most used material, with an 8% of the share. At the same time, what the trends are showing is that some materials have been used more than before due to the increase of use of a particular machine and therefore of a specific technology. In this case, for example, PA 12 material has been increasing in its use thanks to the new machines for SLS technology that the market offers currently, alongside with HP's Multi Jet Fusion
Technology. [10]

The following are instead some of the indicators regarding the current offer of 3D printing materials, including the amount of bio-based materials used, as well as the colours and the diameters available, alongside with many other characteristics.

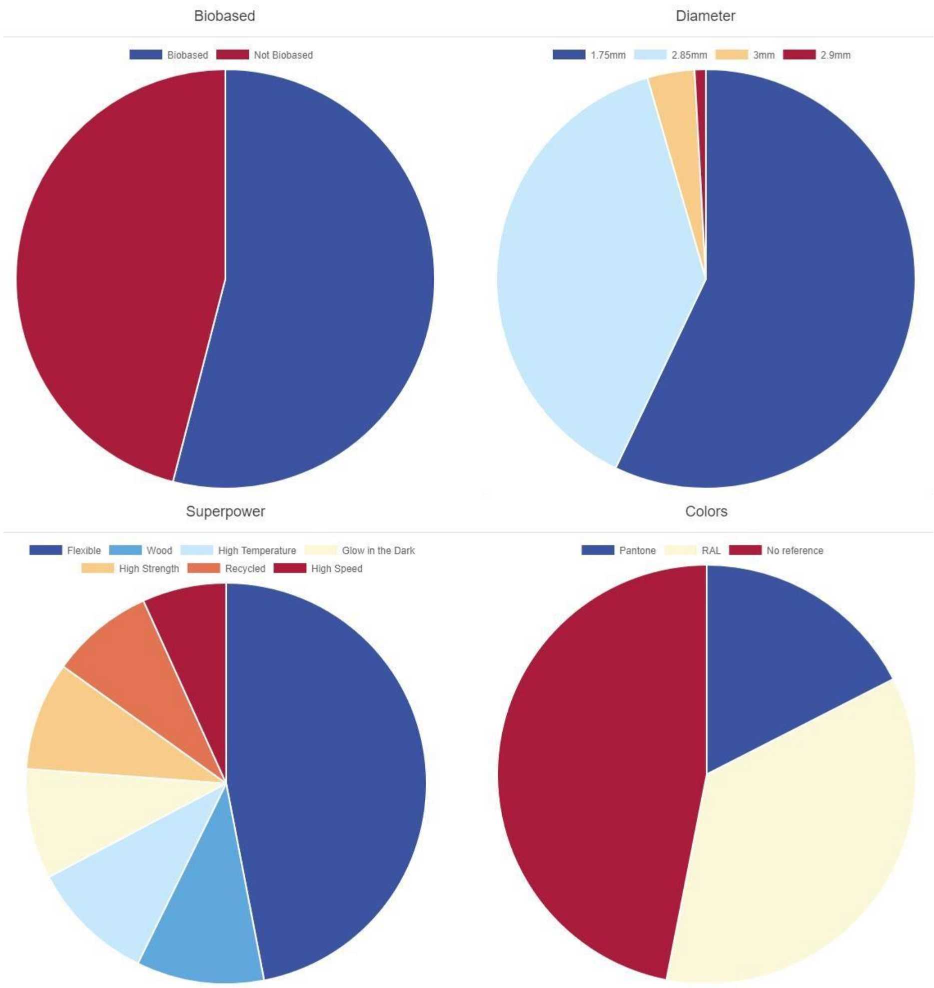


Figure 6: 3D Printer Filament Trends: November 2017. [11]

I.3.2. FDM 3D Printing Materials

According to the latest trends as of late November 2017, the three most used 3D printing technologies are currently:

1.Fused Deposition Modeling (FDM);

2.Selective Laser Sintering (SLS);

3.Stereolithography (SLA).

For what concerns Fused Deposition Modeling (FDM), some of the most popular materials are:

- **Thermoplastic Filament**

- **PLA:** Easy to print, very accurate, low melting point, rigid. Good for most things, not for warm/hot regions.
- **ABS:** Tends to warp, strong and slightly flexible. Used for many mechanical parts.
- **PETG:** Easy to print & accurate, tends to string, good layer adhesion.
- **TPU:** Flexible polymer; ok to print, kind of like stiff rubber. Best used with direct-drive machines.
- **Nylon:** Strong and flexible; special filament for printers exist. Polycarbonate: Obnoxiously strong, high warp, high temp, bad fumes [Paul Chase, 3D Printing 101. 2016.]

Concerning ABS and PLA, there is no limit that one can do of them, for example they can be mixed together. They represent a much better solution to using pure plastic material; this is, in fact, relatively expensive, with a low strength and durability. Final products can usually be distorted easily. Therefore, plastics do not make FDM cost-effective, nor it allows the technology to be applied in functional and load-bearing applications, especially in a large- scale production.

I.4. Polylactic Acid (PLA)

I.4.1. Poly(lactic acid) :

PLA (Polylactic Acid) is a biodegradable and sustainable polymer derived from organic sources. Widely used in FFF (Fused Filament Fabrication) 3D printers, PLA is known for its ease of use and versatility in various applications, particularly those not requiring high mechanical or thermal demands. It serves as an excellent entry point for individuals learning about the 3D printing manufacturing process.

Derived through the fermentation of starch, PLA exhibits transparency and robustness. The ester bonds in PLA are susceptible to chemical hydrolysis and enzymatic chain cleavage. Notably, PLA has gained attention as an alternative biodegradable polymer due to its mechanical properties being comparable or superior to some traditional technical polymers.

In various applications, PLA is often blended with starch to improve biodegradability and reduce costs. However, the brittleness of the starch-PLA blend presents a challenge. To address this, low-molecular-weight plasticizers like glycerol, sorbitol, and triethyl citrate are utilized.

The synthesis of PLA dates back to 1932, with Carothers producing low-molecular-weight PLAs. High-molecular-weight PLA synthesis emerged later in 1954. [12 , 13]

Overall, PLA is a linear aliphatic polyester composed of lactic acid building blocks, making it a biodegradable and compostable thermoplastic derived from renewable resources such as starch or sugar. [14 , 15 . 16. 17]

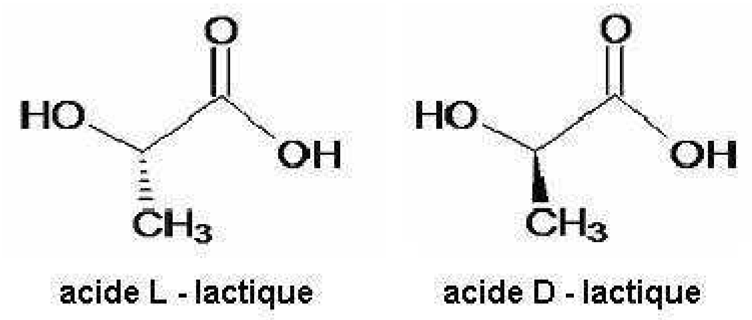


Figure 7: Representation of the two enantiomers of lactic acid: L-lactic acid and D-lactic acid. [12]

I.4.2 PLA Properties

Table 1:PLA Properties [18. 31.34]and Printing settings[19]

Thermal properties		
	Typical value	Test Method
Melting temp	230-250 °C	-
Vicat softening temp	111.9°C	ISO 306
Mechanical properties		
Mechanical properties	Typical value	Test Method
Tensile strength at yield	21-60 Mpa	ISO 527
Strain at yield	2.5-6 %	ISO 527
Tensile Modulus	350-3Mpa	ISO 527
Hardness Shore D	75	ISO 62
Filament specification		
Filament properties	Typical value	Test Method
Diameter	1.75 mm	
Density	1.21-1.25 g/cm3	

Printing settings	Test Method	Test Method
Extruder temperature	190°C – 220 °C	
Bed temperature	65 °C	
Speed	10-70 mm/s	
Retraction Speed	40 mm/s	
Retraction distance	4 mm	
Cooling fan	Yes	
Minimum layer height	0.05mm	

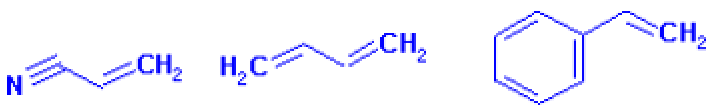
I.5. Acrylonitrile-Butadiene-Styrene (ABS)

I.5.1. ABS Description

ABS (acrylonitrile butadiene styrene) is one of the most common technical materials in several industries around the globe. It's great mechanical and thermal behavior makes ABS the ideal polymer for countless applications.

Traditionally a challenging material to print with FFF printers, it has been re-formulated to ensure good interlayer adhesion and to reduce warping.

ABS is a terpolymer obtained by copolymerization of styrene, butadiene, and acrylonitrile. It comprises two essential elements: a copolymer of acrylonitrile/styrene (SAN), which forms the matrix, and rubber nodules (butadiene grafted with copolymers of styrene/acrylonitrile). The formula for ABS is provided in Figure 6. The grafts on the butadiene nodules ensure good compatibility with the matrix, providing the polymer with excellent mechanical properties, particularly outstanding impact resistance. Alongside High-Impact Polystyrene (HIPS) and PVC/nitrile rubber blends, ABS historically becomes the third member of a family of multiphase polymers, exhibiting high impact resistance and consisting of a thermoplastic matrix and a dispersed rubbery phase [20].



Acrylonitrile Butadiène Styrène

Figure 8 : Structural chemical formula of ABS

I.5.2. ABS Properties

Table 2:ABS properties [21, 32] and printing settings [22]

Thermal properties		
	Typical value	Test Method
Melting temp	230-250 °C	-
Vicat softening temp	111.9°C	ISO 306
Mechanical properties		
Mechanical properties	Typical value	Test Method
Tensile strength at yield	39 Mpa	ISO 527
Strain at yield	3.5 %	ISO 527
Tensile Modulus	1681.5Mpa	ISO 527
Hardness Shore D	76	ISO 62
Filament specification		
Filament properties	Typical value	Test Method
Diameter	1.75 mm	
Density	1.05 g/cm3	

Printing settings	Test Method	Test Method
Extruder temperature	240°C – 260 °C	
Bed temperature	90 °C	
Speed	20-60 mm/s	
Retraction Speed	40 mm/s	
Retraction distance	4 mm	
Cooling fan	10-15%	
Minimum layer height	0.1 mm	

I.6. Polyethylene terephthalate PET

I.6.1. PET Description

Polyethylene terephthalate (PET) is a widely used polymer in numerous applications. It is obtained either through a slow esterification process between terephthalic acid (TA)

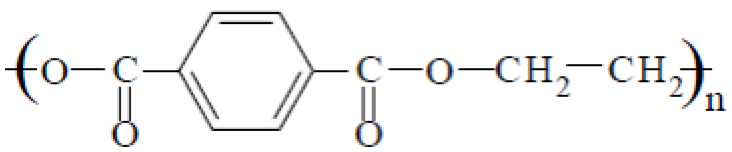


Figure 9:Polyethylene terephthalate motif in its molecular structure. [24].

and ethylene glycol (EG) or through catalyzed transesterification between dimethyl terephthalate (DMT) and EG [23]. DMT must be purified beforehand by recrystallization to obtain, through transesterification, a high molecular weight PET (>20000g/mol). This molecular weight threshold is essential for optimal mechanical properties of the polymer [25].

I.6.2 PET Properties

Table 3: PET properties [26]

Thermal properties		
	Typical value	Test Method
Vicat softening temp	79 °C	ISO 306
Mechanical properties		
	Typical value	Test Method
Tensile strength at yield	57 Mpa	ISO 527
Elongment at break	-	ISO 527
Tensil Modulus	2400 MPa	ISO 527
Hardness Shore	78	ISO 868

CHAPTER II

PET Machine Components and Assembly

II.1. The new proposal material

Used plastic water bottles are a constant problem in developing countries. The plastic waste litters the streets, or ends up in landfills, as seen in Figure 10.

Figure 10: Photo of plastic waste taken at Bourawi Ammar residence

Utilizing this waste to make 3D printing filament solves two problems at once. It gives entrepreneurs a cheap resource, and removes a damaging element from the environment. A common pitfall that developing countries face is the expensive nature of “green industries.” 3D printing gives them a cheap option without the cost barriers associated with other green technologies.

PET MACHINE is different from other filament production machines on the market. Commercially available machines at this scale require virgin pellets of acrylonitrile butadiene styrene (ABS) or polylactic acid (PLA) plastic. They do not work with recycled or virgin polyethylene terephthalate (PET). Recycled plastic is cheaper and more accessible than factory produced pellets. PET MACHINE allows workers to create their own filaments at a much lower cost than what is currently available on the market.

Small business development is the key to improving the lives of people in developing countries. 3D printing is a versatile process that simplifies existing manufacturing methods. Its simplicity allows for developing countries to grow their own manufacturing base, instead of relying on foreign countries. They can create local sustainable businesses to increase prosperity. 3D printing is the key that unlocks opportunities for workers and entrepreneurs in developing countries. PET MACHINE moves one step closer to that goal by giving them new options at a low cost.

II.2. The PET machine components

The PET filament recycling machine is an innovative device designed to address the environmental challenge posed by plastic bottles, specifically those made of Polyethylene Terephthalate (PET). This machine serves as a crucial component in the recycling process, transforming discarded PET bottles into usable filament for 3D printers. This sustainable approach not only reduces plastic waste but also provides a cost-effective resource for 3D printing enthusiasts.

Figure 11: PET Machine

II.2.1. The parts of the Machine

II.2.1.1 The 3D Printed Parts

The machine is made of 80% from 3D printed parts. The specially designed casing has a modular structure, so every part of the machine is fully changeable. Every part is mounted to the machine by screws in properly designed places. Dimensions and designed model of the machine are shown in the picture below [Fig. 12].

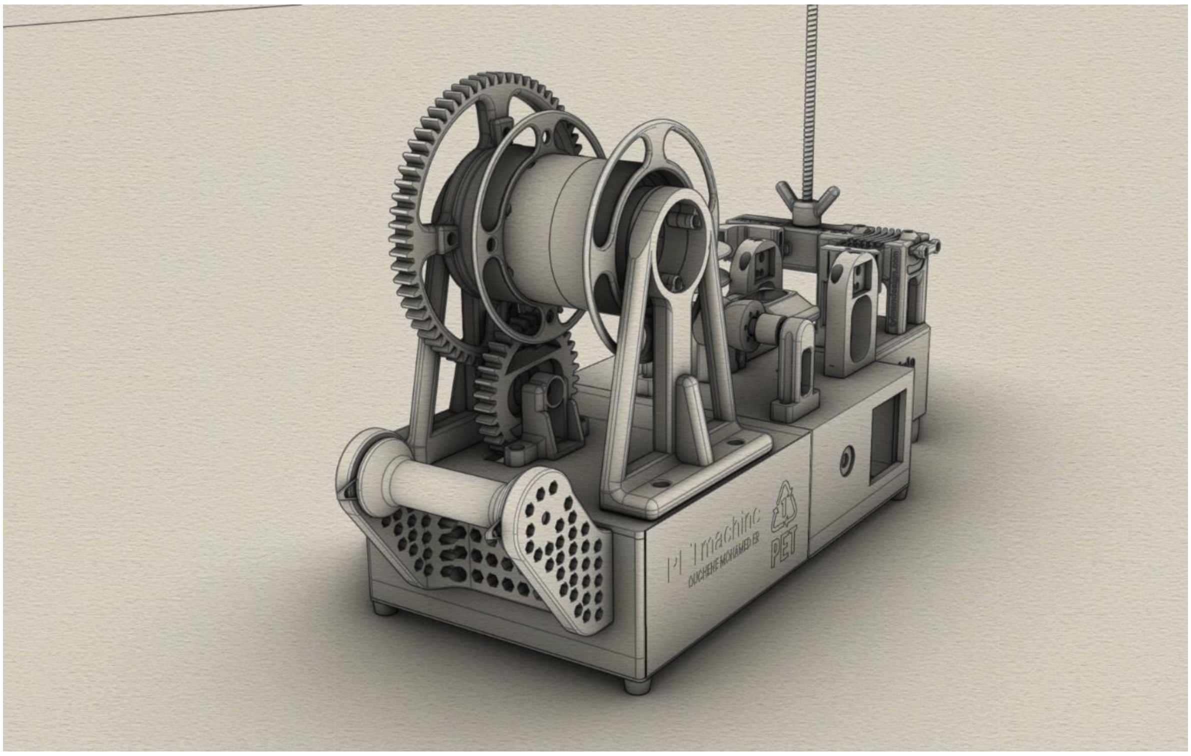
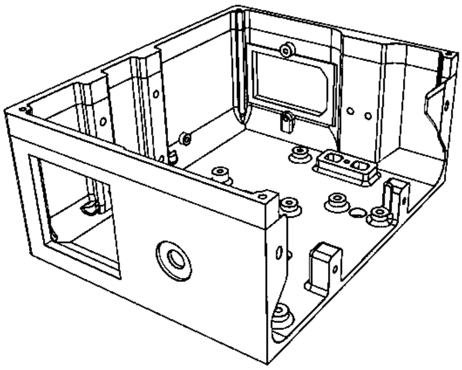
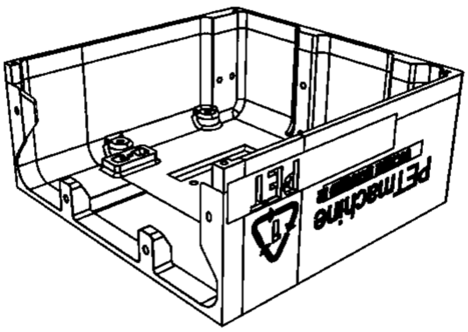
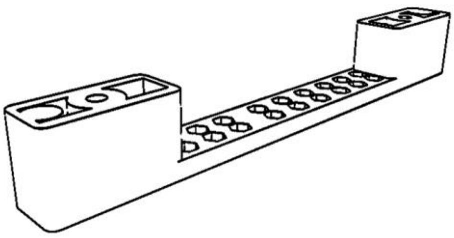
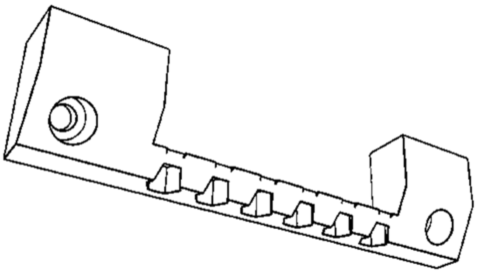
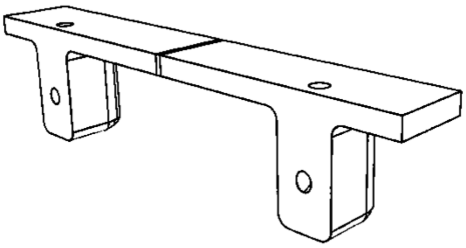
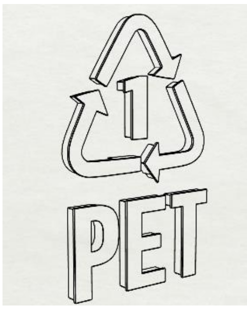
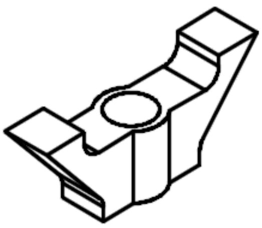
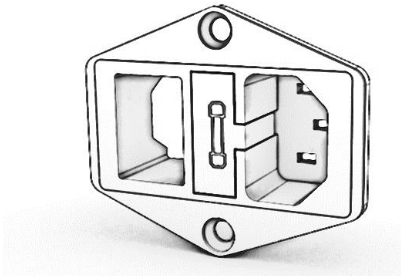
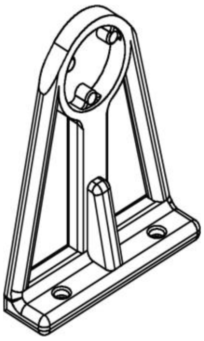
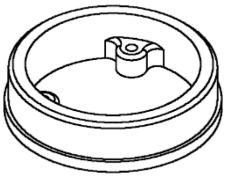
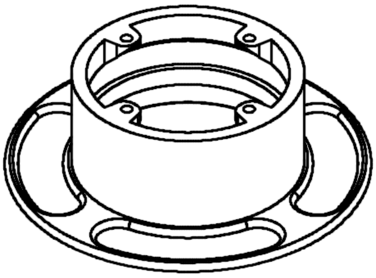


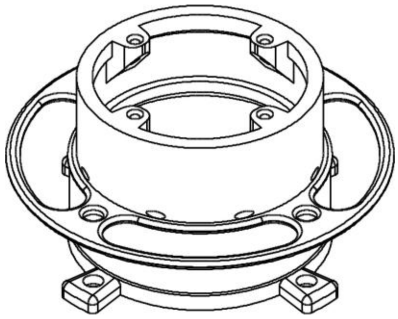
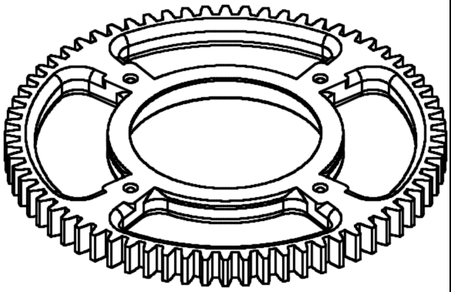
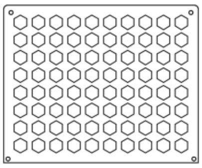
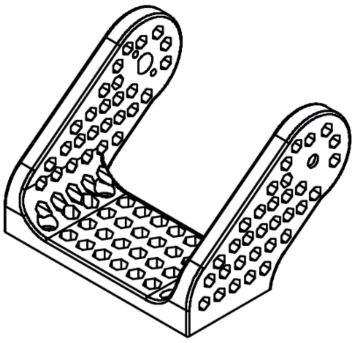
Figure 12: Perspective drawing technique of PET machine

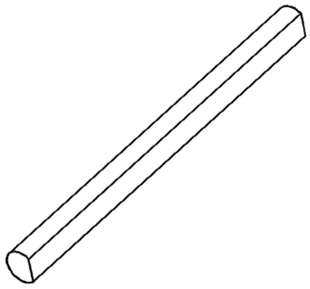
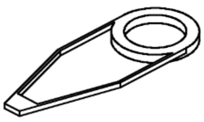
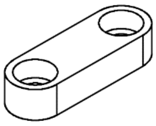
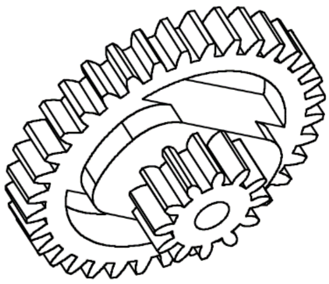
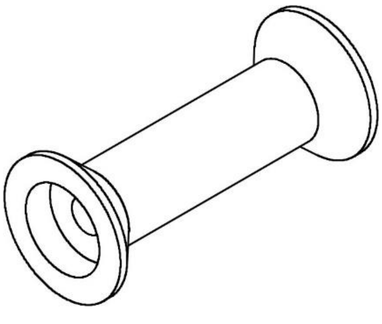
Table 4:3D Printed parts of the machined

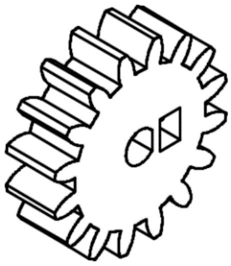
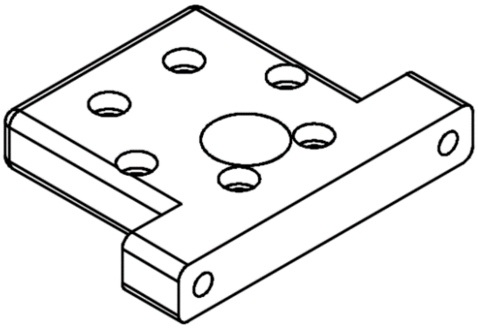
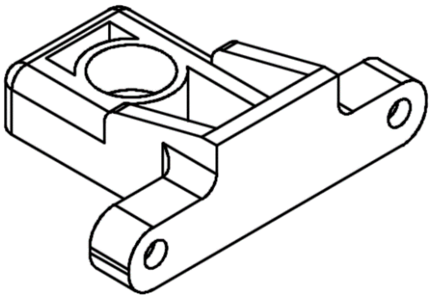
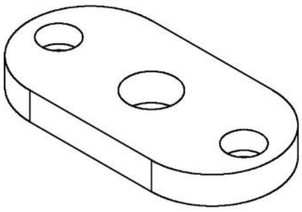
N°	Pice name	Pice image	Description
1	Housing A		Dimension : High : 70 mm Lenght : 130 mm Width : 161 mm
2	Housing B		Dimension : High : 70 mm Lenght : 159 mm Width : 161 mm
3	Power supply adapter		Installed the power supply components securely within the body of the machine

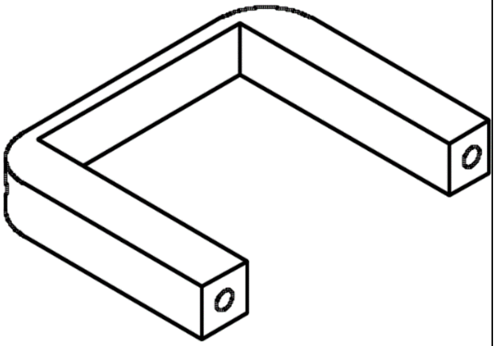
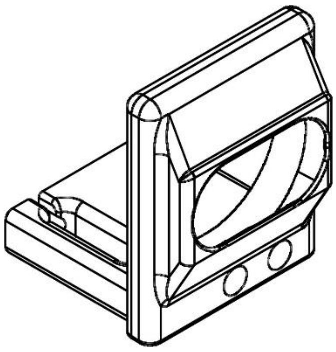
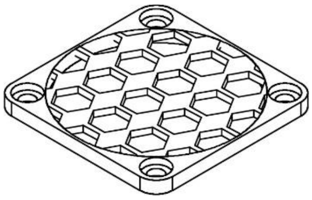
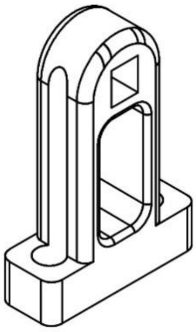
4	Housing A support		Ensured connection between Housing A and B.
5	Housing B support		Ensured connection between Housing A and B.
6	PET logo		Recycling PET Logo
7	PWM controller support		PWM Support Bracket

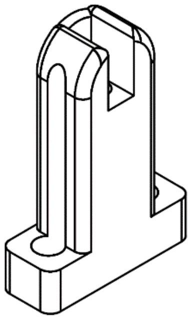
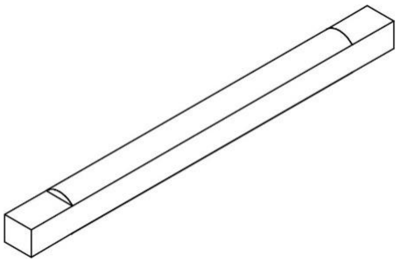
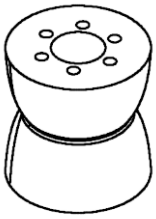
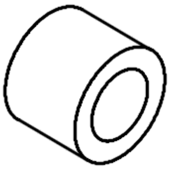
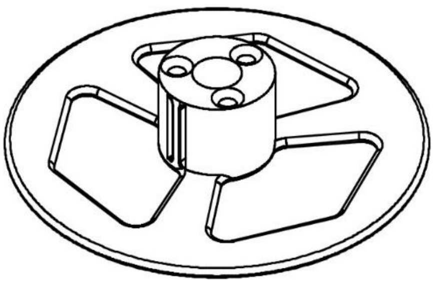
8	AC power Socket		It serves as the holder for the on/off switch button and the input for the cable
9	Spool base part1		the holder of the entire bobbin system
10	Spool base part2		Fixed component interacting with the bearing
11	Spool A		Component for filament collection.

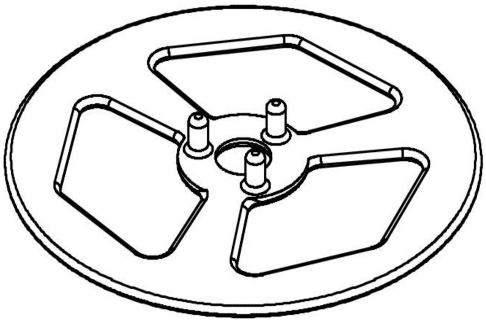
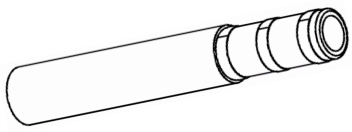
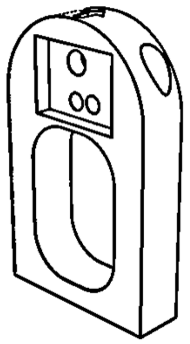
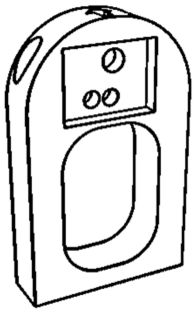
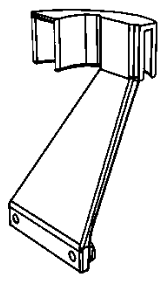
12	Spool B		The second component for filament collection, also attached to the gear.
13	Spool C		Gear 3: Transmission component facilitating movement from the motor to the bobbin, featuring 68 teeth. Each tooth imparts a 5.5° rotation to the bobbin.
14	Bottom cover		Protection of electronic components from the bottom.
15	Guiding roller base		The bracket for the roller guide

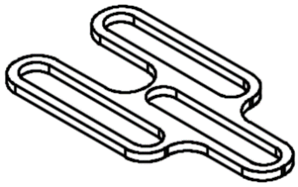
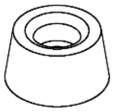
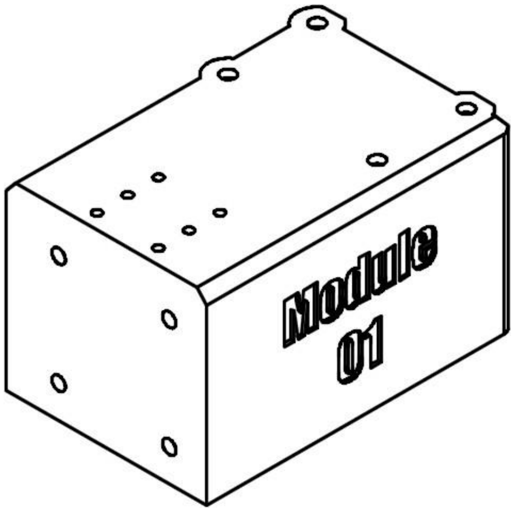
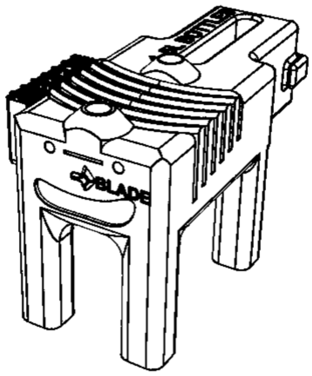
16	Guiding roller rod		The rotational axis of the roller guide.
17	Guiding roller distancer		This piece creates space between the guiding roller and the roller base.
18	Guiding roller blockade		The locking mechanism of the roller system.
19	Double gear1		The initial stage of the transmission movement from the motor gear to spool C involves a small gear with 12 teeth and a larger one with 34 teeth.
20	Guiding roller		The guiding roller has direct contact with the filament.

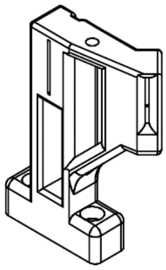
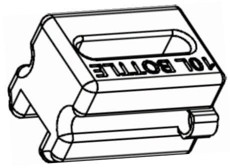
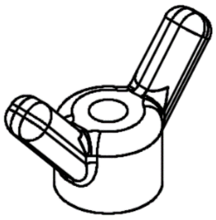
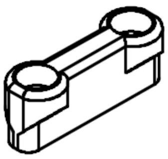
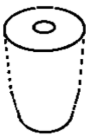
21	Motor gear		The first gear has direct contact with the motor and connects to the double gear.
22	Motor bracket		Attach the motor gear to the interior of the fuselage of the machine.
23	Double gear3		Attach the motor gear externally and also connect it to the double gear.
24	Double gear2		Protection cover for double gear 1.

25	Controller clamp		Support bracket for the REX C100.
26	Cooling fan casing		The bracket of the cooling system.
27	Fan cover		Fan cover.
28	Tensioner base L		The left bracket of the tensioner system.

29	Ensioner base R		The right bracket of the tensioner system.
30	Tensioner rod		The rotation axis for the tensioner system.
31	Tensioner roller		The roller guide of the tensioner system.
32	Tensioner distancer		This piece creates space between the bases and the tension roller.
33	Small spool A		The upper section of the ribbon storage.

34	Small spool B		The lower section of the ribbon storage.
35	Small spool base		The axe of rotation
36	Heater base A		The left bracket for the entire heat block system.
37	Heater base B		The right bracket for the entire heat block system.
38	Ribbon guide		It guides the ribbon from the spool ribbon storage to the heat block.

39	Motor distancer		Specify the distance between the motor and the gear motor.
40	Leg		Supports the entire machine above the ground.
41	Module_01		The enclosure that houses the cutting system.
42	Cutting device		The component where all the cutting operations take place includes the blade for severing the bottle and channels designed for various wall thicknesses. These channels ensure consistent filament structure irrespective of the bottle type.

43	String guide		Guide the ribbon, cut by the cutting device, to the heat block.
44	Ext module		The component used for bottles larger than 5 liters.
45	M6 nut knob		It is utilized to secure the M6 threaded rod, measuring 43cm in length.
46	Blade cover		Blade protection cover.
47	M6 rod cap		Securely fasten the M6 threaded rod, 43cm in length, from the top.
48	Leg tall		Support the cutting system above the ground.

The model was designed in Rhino 3D modelling software. The material used to create parts is PLA (polylactide), it has no contraction during printing, and it's easy to use because desirable dimensions of designed parts are different. In fact, so the designer must correct and optimize all dimensions so that this difference is as small as possible. PLA material is easy to make it. For example, 3mm hole in real print has ~2.9mm, so designer should change dimension in modelling program to 3.1mm and the printed part will match the assumed dimensions. In the picture below the CAD model of machine is shown [Fig. 13].

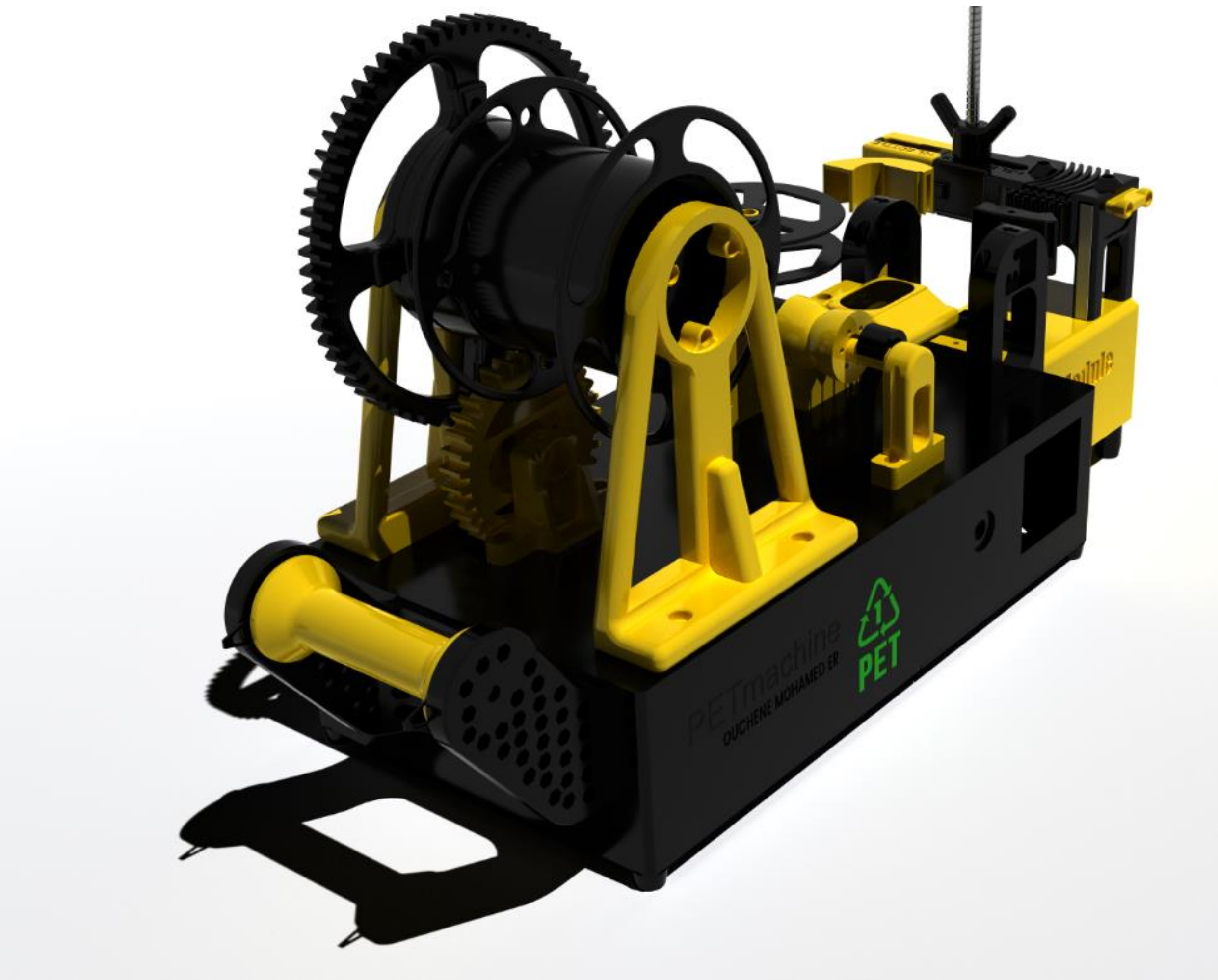
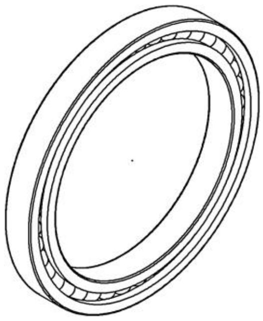
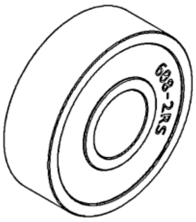
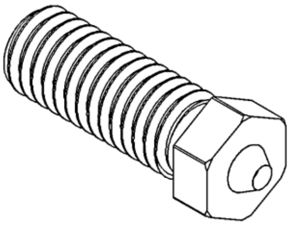
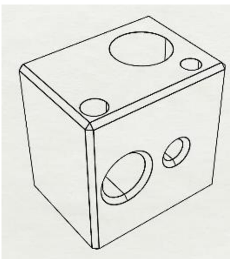
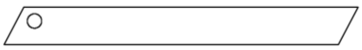


Figure 13: 3D CAD machine assembly

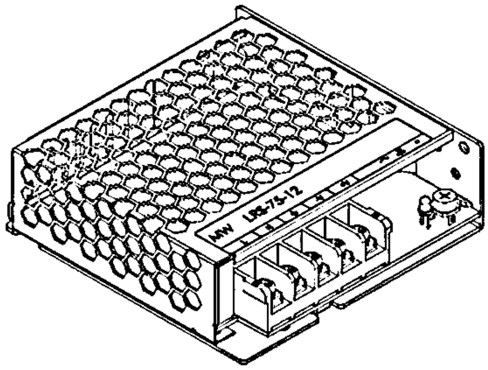
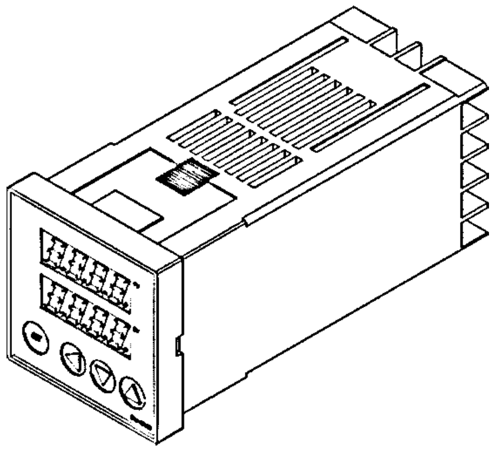
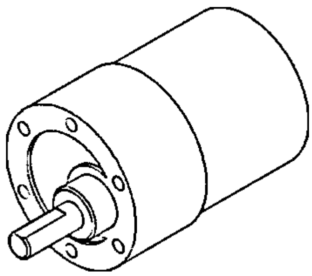
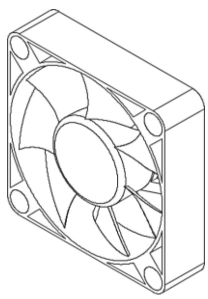
II.2.1.2. The Non-3D Printed Parts (SOLID)

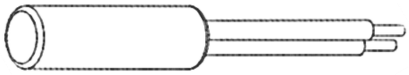
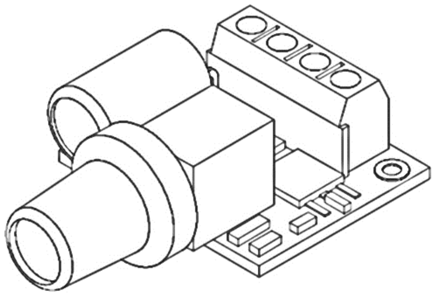
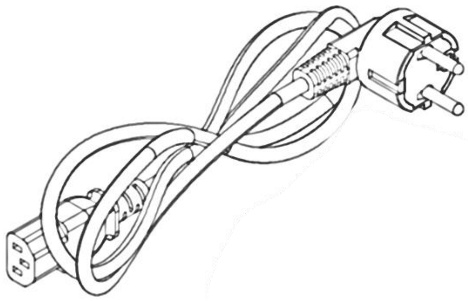
Table 5:The Non-3D Printed Parts (SOLID)

N°	Component Name	Component Image	Description
49	6810 bearing		Friction Reduction Load Support Efficiency Improvement Precision Movement Durability Enhancement: lifespan. Shock Absorption Versatile Motion Rigidity Maintenance
50	608 bearing		The same as the previous.
51	Modified Volcano nozzle		After being heated by the hot end block, it can transform the ribbon bottle into a 1.75mm filament.
52	STANDARD V5 Hot end block		The hot end is heated by the heater resistance, which transfers heat to the nozzle.
53	9mm blade		To sever the bottle.

II.2.2. The Non-3D Printed Parts (Electronic)

Table 6:The Non-3D Printed Parts (Electronic)

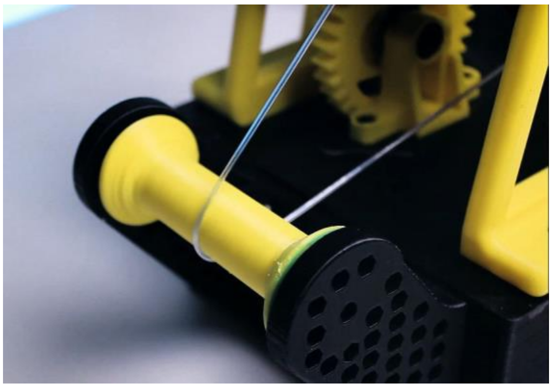
N°	Component Name	Component Image	Description
54	MeanWell LRS 75-12		Convert 220V AC to 12V DC with a current rating of 10A.
55	REX C-100 PID temperature controller		Control the temperature by sensing the instantaneous temperature from thermocouple K and issuing commands to increase the temperature to the heater resistance.
56	Gearmotor		Gear motor 12 V 60RPM
57	Fan		40x40x10 12V

58	Heater		12V 40W
59	PWM motor controller		Control the velocity of the gear motor.
60	Thermocouple K		Display the instantaneous temperature of the heater block.
61	AC power cable		Connect the power between the energy source and the machine.

II.3. Assembly and Purpose of each Parts :

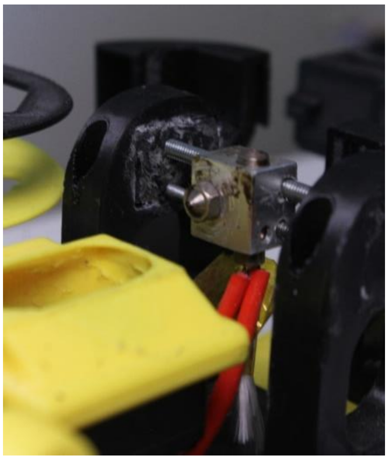
II.3.1 Mechanical Parts:

Table 7:Mechnical Parts Assembly

The Assembly Process / Parts necessary	The purpose of each assembly
1. Housing Parts necessary : housing_A housing_B	The housing serves as the fuselage of the machine, accommodating all components. Internally, it integrates electronics and supports, while externally, the boboines, hotend, and fan are in external. 
2.Guiding roller Parts necessary : guiding_roller_base guiding_roller guiding_roller_distancer (x2) guiding_roller_rod guiding_roller_blockade 608 bearing (x2)	The guiding roller enables the application of force to the filament, changing its pulling direction and ensuring stretching for extrusion through the nozzle. 

<table>
<tr><td>3. Cooling fan

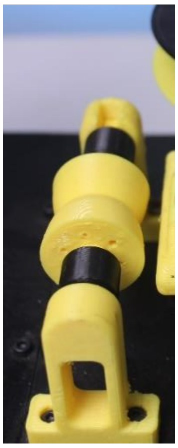
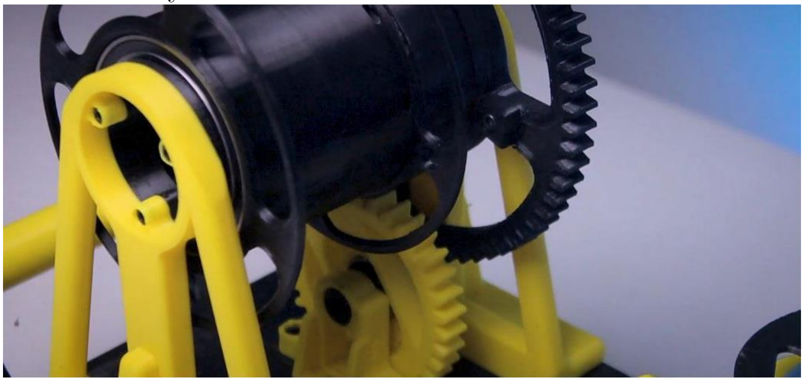
Parts necessary :
cooling_fan_casing
27 fan_cover
40x40x10 12V fan</td><td>The filament is subjected to stretching through the gear system during application. The role of the fan is to reduce the temperature of the extruder filament, making it more solid. This helps prevent tearing.
</td></tr>
<tr><td>4.Extruder

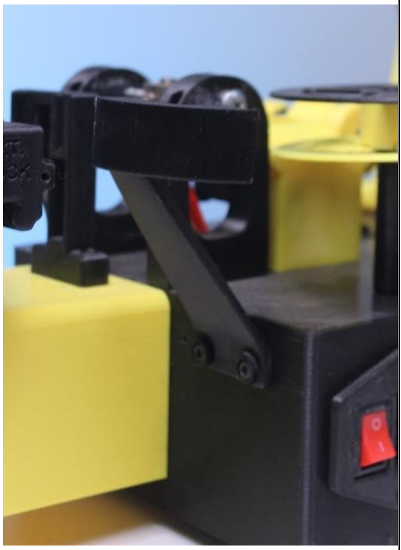
Parts necessary :
heater_base_A
heater_base_B
standerd V5 hotenblock Volcano</td><td>The heating block is made of regular 3D printing heating block, specially drilled nozzle allows extrusion of filaments with a diameter of 1.75mm. A plastic string passes through the heating block, which is plasticized and then formed by a nozzle into a filament.


The heater block is supported by tow base .</td></tr>
<tr><td>5.String spool

Parts necessary :

small_spool_A
small_spool_B
small_spool_base</td><td>We can cut the bottle and place it in a string spool. This will decrease the energy consumed by the motor. And make the process more faster
</td></tr>
</table>

6. Tensioner Parts necessary : tensioner_base_L_FEDS tensioner_base_R_FEDS tensioner_rod_FEDS trigger_rod_FEDS tensioner_roller_distancer tensioner_roller	Guide the filament to the guiding roller 
7. Winding spool system Parts necessary : spool_A spool_B spool_C spool_base_V2_1 (x2) spool_base_V2_2 (x2) double_gear_1 double_gear_2	The big bobbin is set in motion by two-stage gear transmission with 1:10 gear ratio powered by DC motor . The motor has 12V and torque of 2Nm, and the rotational speed is 60 rpm/min.After taking the losses into account, we have 18Nm and 0.5-3 rpm/min on the bobbin. This amount of torque is necessary for the machine to work properly because pulling the filament requires very high force. Big bobbin and gears are bearing, which significantly reduces friction and increases the efficiency of the entire transmission. 
8.Bottom covers Parts necessary : leg (x4) bottom_cover (x2)	Protection 

9.Ribbon_guide Parts necessary : ribbon_guide	Guide the ribbon cut bottle to the heat block 
10.Cutting Module Parts necessary : cutting_device module_01 string_guide ext_module M6_nut_knob blade_cover M6_rod_cap High leg (x2) 9mm blade	The primary function of this component is to precisely section the bottle into slender slices capable of seamlessly navigating the heat block. Meticulously designed, this part serves the crucial purpose of ensuring a consistent flow of material through the nozzle. This design philosophy is aimed at achieving uniform density, thereby guaranteeing a steadfast commitment to high-quality printing standards. The nozzle, with a specific diameter of 1.75mm, plays a pivotal role in this intricate process. Notably, the filament doesn't attain the temperature required for melting; instead, the temperature is meticulously controlled to soften the ribbon. Subsequently, the softened ribbon is expertly folded to craft the filament. It's imperative to highlight that the composition comprises 85% PET, with the remaining 15% being empty space. To precisely calculate the requisite surface area that should traverse the nozzle, a dedicated formula is employed, ensuring a systematic approach that upholds standardized processes. This meticulous approach,

centered around a sophisticated design and controlled material composition, is instrumental in consistently delivering superior printing quality.

$\boldsymbol{S = 0.8\pi \frac{D^2}{4}}$=$\boldsymbol{0.85\pi \frac{1.75^2}{4}}$=2.04 $\boldsymbol{mm^2}$.--------(1)

In order to ascertain the thickness of the bottle, we employ the parameter of caliber, denoted as "T." Subsequently, the selection of filament width, designated as "W," allows for the systematic design of the cutting device through this established methodology.

So the S^1 will be the surface of the ribbon

$\boldsymbol{S^1 = W \times T}$--------*(2)*

By make (1)=(2) $S^1 = S$

In pursuit of achieving the desired width, we employ a methodical approach to determine and control the filament width, denoted as "W."

$$\boldsymbol{2.04 = W \times T}$$

$$\boldsymbol{W = \frac{2.04}{T}}$$

To generate the relevant data, we can compile and organize the information systematically, resulting in the creation of a comprehensive table.

Thickness "T" (mm)	Width "W" (mm)
0.35	6
0.3	7
0.25	8
0.2	9
0.15	10
0.1	12

II.3.2 Electrical Parts :

Electronic circuit :

In the image below, the electronic circuit comprises essential components. The Mean Well serves as the generator, seamlessly connected to the AC socket via a 220V AC to 12V DC and 10A wire converter. This setup ensures efficient power conversion for operational stability.

To regulate the motor, a PWM (Pulse Width Modulation) controller is employed. It facilitates precise control over the motor's velocity, enhancing operational flexibility. The PWM controller is connected to the generator, enabling seamless integration.

For effective cooling, a fan is incorporated, directly linked to both the positive and negative terminals of the generator. However, it's noteworthy that the fan operates continuously, lacking variable control.

The operator panel features a REX C-100 temperature PID controller, drawing power from a 240V source. This controller effectively manages the temperature of the head, as

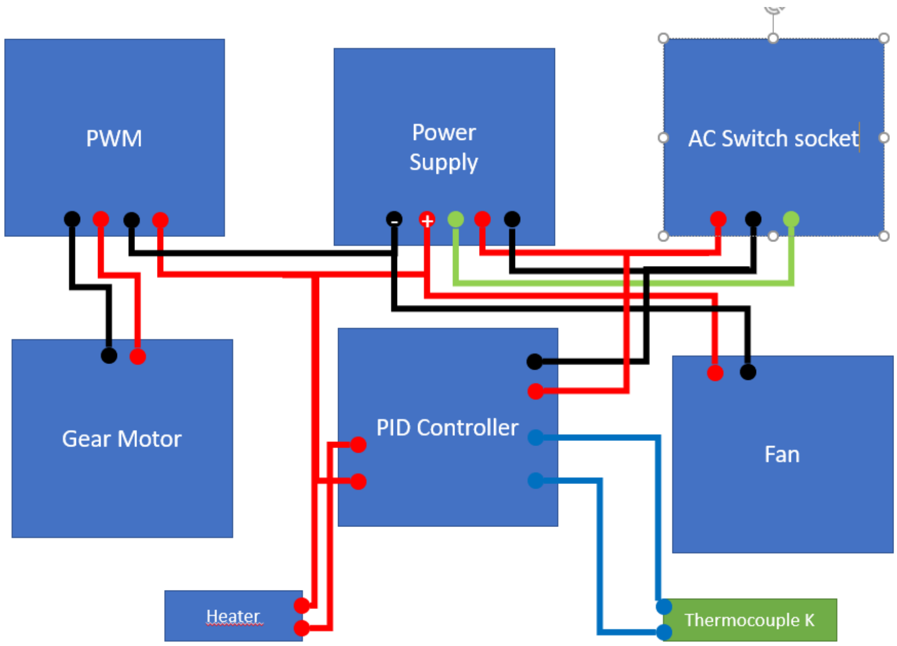
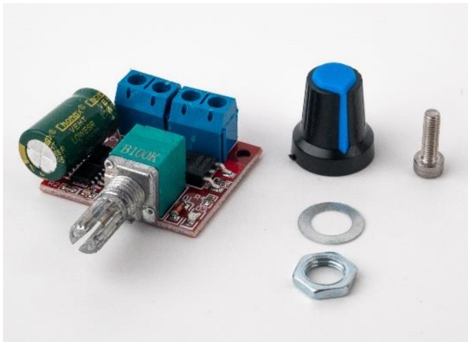


Figure 14:Scheme of electronic circuit

indicated in Figure 14. Temperature feedback is provided by a thermocouple K positioned within the head. The connected 40W heater operates on 12V, enabling the system to achieve temperatures up to 260°C. This meticulous arrangement ensures precise temperature control and reliable performance.

After assembling the housing, the next step involves the installation of electrical components within the fuselage.

Table 8: "Electronics Parts Assembly

The Assembly Process / Parts necessary	The purpose of each assembly
1. Electric motor installation Parts necessary : Motor bracket Double gear3 Motor distancer Motor gear Gear motor	The motor generates rotational movement, and the gear system facilitates the transmission of this movement. The motor bracket serves as a support structure, securing the entire system within the fuselage. 
2. PWM motor controller installation **Parts necessary :** • PWM controller • support	It is used to control the velocity of the geared motor. 

3. Power supply installation **Parts necessary :** • Power supply adapter • Mean Well LRS-75-12	The power supply serves as the energy source for the entire system. It obtains energy by converting 240V to 12A. The power supply is integrated into the system and securely fixed to the fuselage of the machine through an adapter. 
4. REX C100 – installation **Parts necessary :** • REX C100 temperature controller • Heater 12V 40W • Thermocouple K	The operator panel consists of REX C-100 temperature PID controller powered by 240v, that is controlling the temperature of the head. Temperature data is provided by thermocouple K placed in the head. The heater of power 40W is connected to this device and powered by 12V. This allows reaching temperature up to 260°C. 

After assembling all the components, the final result is depicted in the image below

Figure 15: The real model of the Pet machine after assembly

II.4Machine technical datasheet

Table 9:Machine datasheet

Characterization	Value
Machine	PET Machine prototype
Demotion	Length : 465 mm Hight : 259 mm Width : 161 mm
Power supply	220V -12 V 10 75W
Machine load	4 kg
Production filament	0.3 m/min
Pulling temperature*	195-215 degree Celsius
Pulling speed	around 50% of the potentiometer's max. range

CHAPTER III

USER GUIDE

III.1. Steps to Create the filament

III.1.1. Preparation the bottle

1. Pour a little bit of water into the bottle, close it and heat it very carefully above the source of heat (stove, hot gun), water inside will evaporate and increase the pressure. The method I will show you here is in my opinion the fastest, easiest and safest one.

2. You can ask a question "Why we should do it?". It helps immeasurable to cut the bottle easily and fast on the entire length. It makes thick bottle walls a little bit thinner as walls, which helps in later processing.
3. Mount the bottle into drill chuck, the driller fits nice there.
4. Rotate the bottle using a drill and spill the boiled water at the same time.

Figure 16 :Mount the bottle into drill chuck

Figure 17:Expose the bottle to a stream of hot air

Figure 18: Final result (smooth bottle)

Around 100-150ml will be enough for 1,5L bottle. You can collect spilled water by placing the dish underneath and use it again for the next bottles (after boiling).
And now you can see the final result it is smooth bottle ready to the next process

III.1.2. Cutting the bottle - creating plastic ribbon

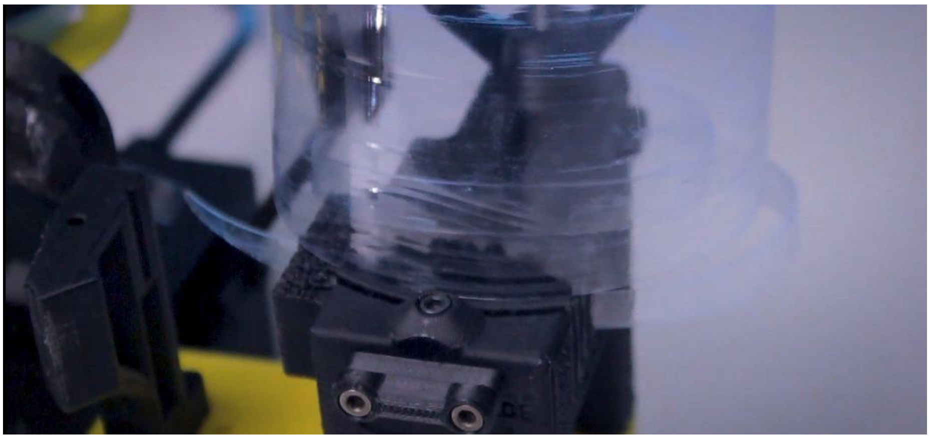


Figure 19 : Cutting the bottle with cutting device

There are 2 ways to cut the bottle. One way is manual, using the power of your hands and Cutting module design. 2'nd method allows you to use the **PET machine** itself to do this for you.

STEP 1 Preparation

1. Preparation for both methods is the same.
2. It's easier to make it when the bottle is closed so walls won't fall inside.

Using a paper towel and acetone remove label glue from the bottle.

Using a hobby knife, remove the bottom of the bottle. Then align the edges using scissors (a really important step).

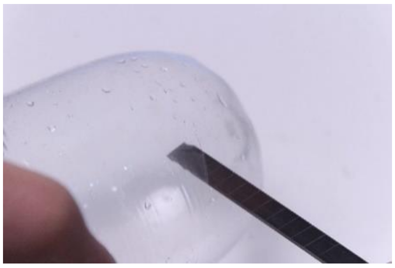


Figure20:Cutting the bottom of the bottle

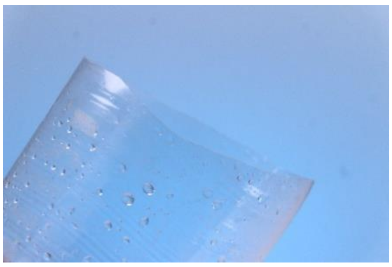


Figure21 : Bottle after cutting

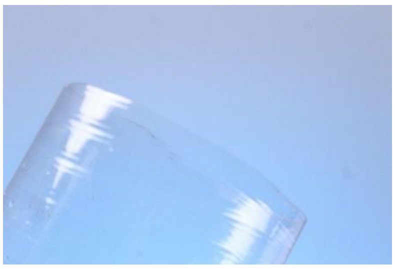


Figure 22: Bottle after align the edges

Using scissors cut 15cm long a really narrow strip with an even more narrow end.

Figure 23: Cutting the Stripe

STEP 1.2. Cutting module (manual cutter)

The cutting module has 6 channels, every channel cut your future string to particular width. Using the table below check which channel is correlated with the wall thickness of your bottle. There are marked strip widths on the Cutting module design near every channel.

0,35 mm → 6 mm
0,30 mm → 7 mm
0,25 mm → 8 mm
0,20 mm → 9 mm
0,15 mm → 10 mm
0,1 mm →12 mm

On the left bottle wall thickness, on the right strip width.

Figure 24: Take measurement of the thickness of the bottle

Figure 25: Cutting the bottle with cutting device

Using a caliper measure the bottle wall thickness and choose the right channel. In my case I have to choose a 9mm channel. Set the appropriate position of the rod as well, to allow the bottle to spin freely.

Pull the end of the string, try to do it evenly and as perpendicular as possible.

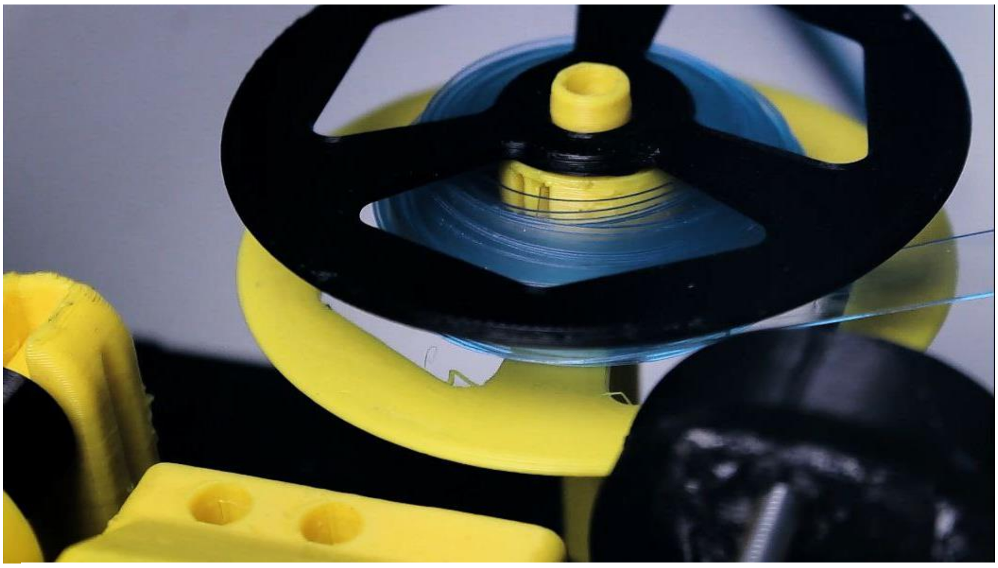


Figure 26:The ribbon on the small spool

Take scissors and align one of the ends of the strip, then pass it through the special slot in the **small spool.**

STEP 2.2. Cutting module (automatic cutter)

The same process, but now the gear motor automates the task, making everything automatic. Use the side slot of the Module01 string guide and pull the string using pliers, 10-15cm is enough.

.

Figure 27: Cutting the bottle using gear motor

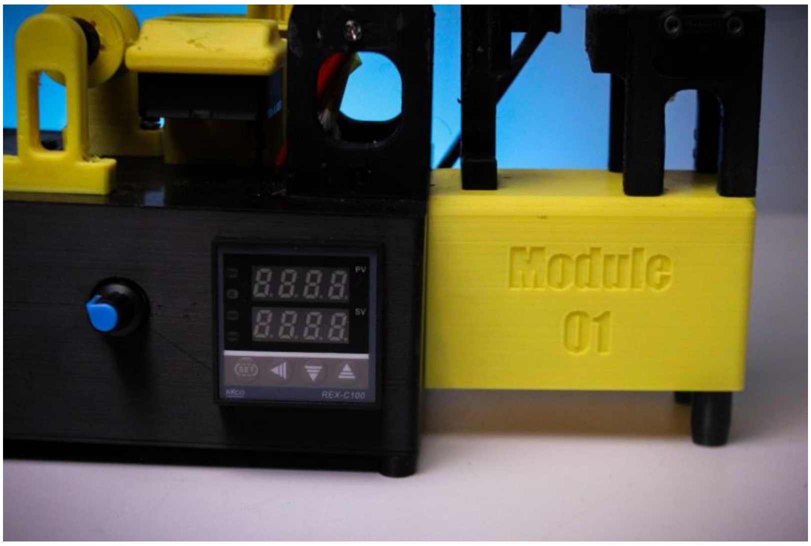


Figure 28: Module 01

III.1.3. Creating the filament

Pass the end of the strip through the ribbon guide and COLD nozzle.

Turn the potentiometer of the PWM motor controller maximally counter clockwise.

Figure 29: Turn on the machine

Connect the **PET machine** to the mains and turn it on.

Figure 30: Set the temperature

PV is your actual/real hot end temperature. SV your desired temperature.

Set the temperature of 207 degree Celsius on the REX-C100 temperature controller, to do this:

Click the “SET” button, then use left arrow to choose particular column

[0 , 0 , 0 , 0] and down/up arrow to increase/decrease the number in this column from 0 to 9.

To accept the value click the “SET” button again.

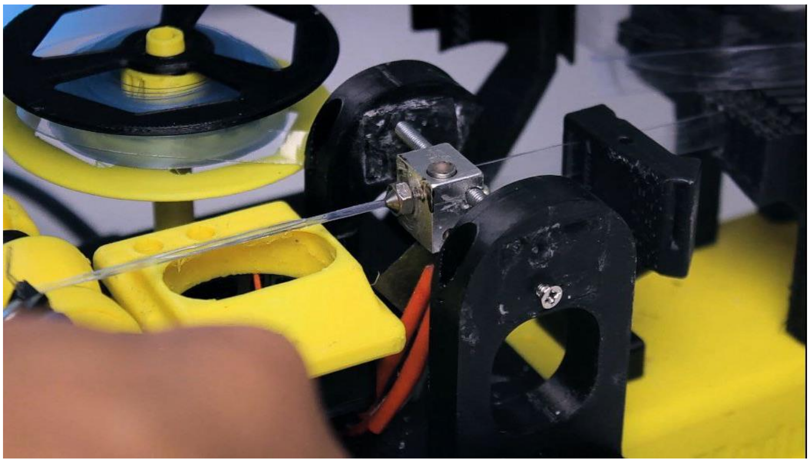


Figure 31: Pulling the strip manually throw the heat block

When the temperature reaches 100 degrees Celsius, pull the end of the strip a little bit. It will prevent the string from retracting and popping out from the back of the hot end.

When the temperature reaches 207 degrees Celsius, pull the filament through the whole machine

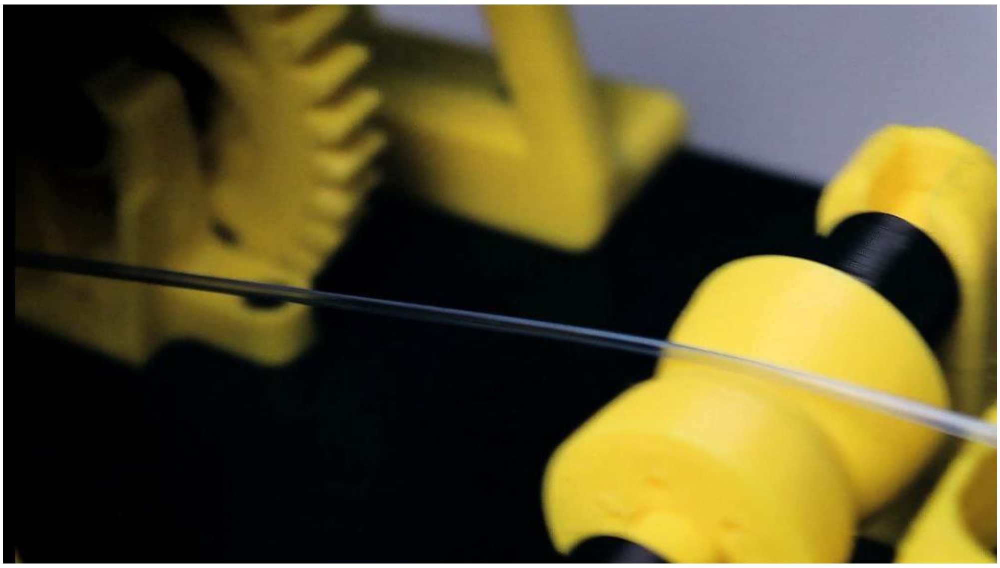


Figure 32: Pass the filament around the tensioner roller

Pass the filament around the guiding roller like in the picture.

.

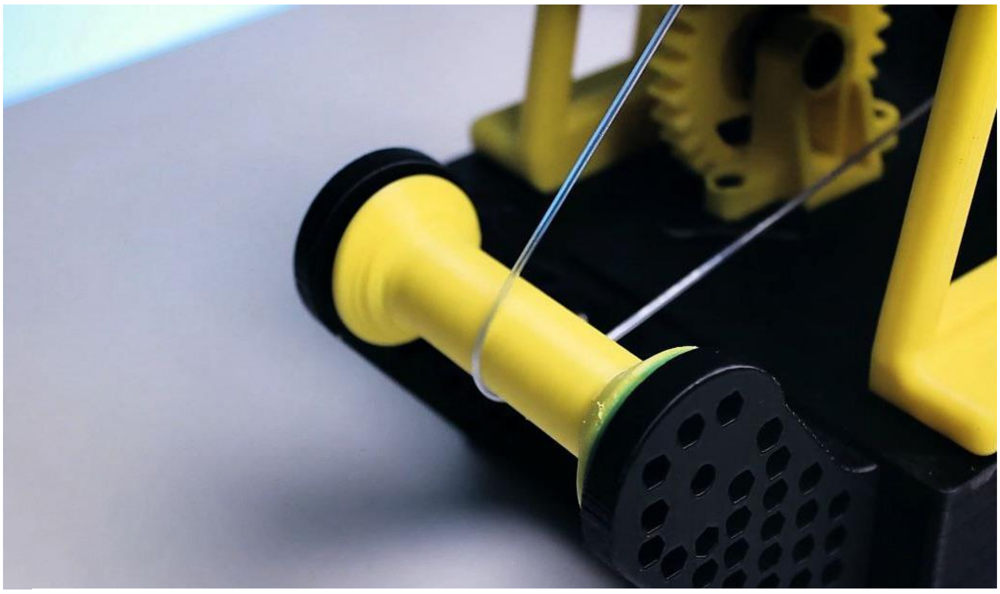


Figure 33: Pass the filament around the guiding roller

Pass the filament through the special tunnels in the winding spool.

Make a loop, tighten firmly (it will be easier using pliers) and cut the end of the unwanted filament.

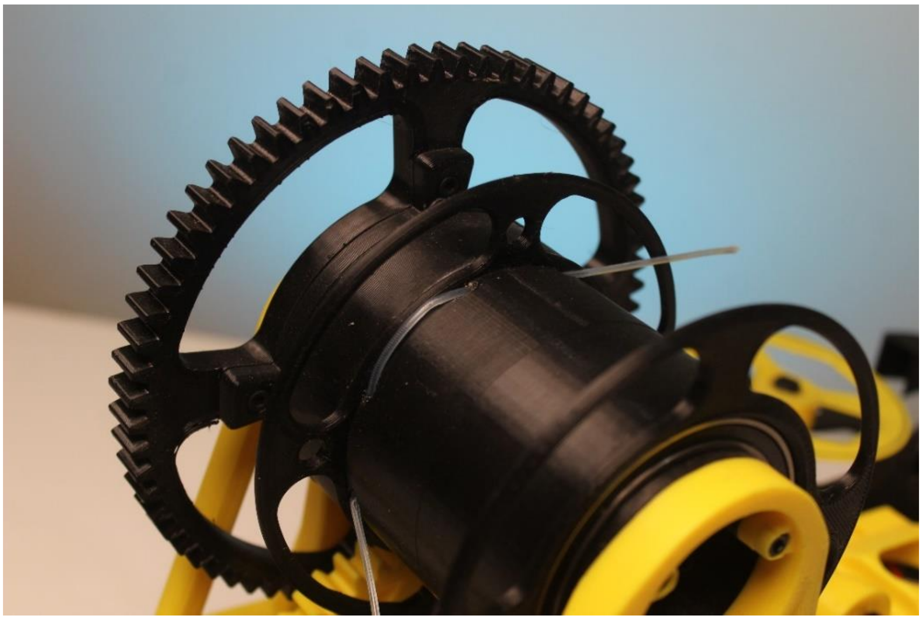


Figure 34: Pass the filament around the winding spool

Make sure that filament is placed on the tensioner roller. Then turn the potentiometer of the PWM motor controller clockwise till the winding spool will start to move slowly. Later you can speed it up to around 70% of power.
Sometimes you can align the filament on the spool with your finger.

Figure 35:Control the velocity of the motor

Figure 36:The filament through the hot end autom

Figure 37:Storage the filament in the spool

When the plastic strip is finished, turn off the motor. Cut off the end of the filament and take it off from the winding spool Now the filament is ready to print!

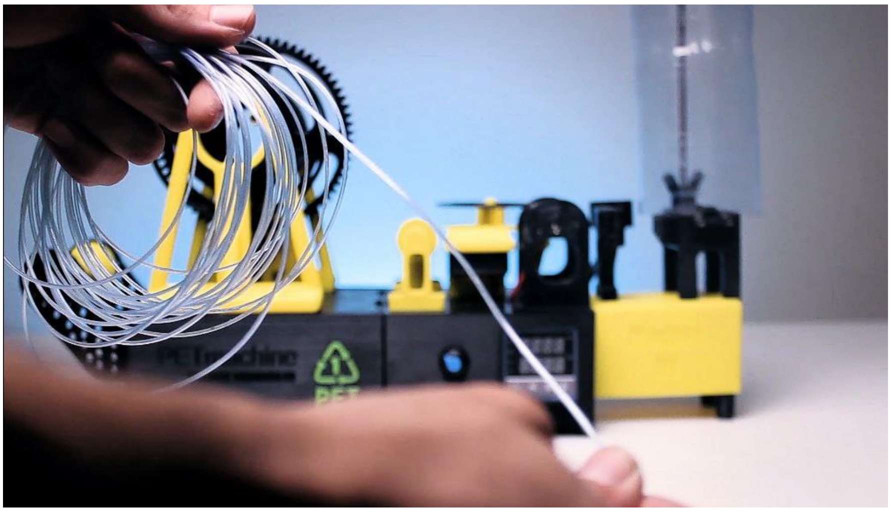


Figure 38: PET filament ready for printing

CHAPTER IV

MATERIAL PROPERTIES AND COMPARISON

IV.1. Introduction:

In this chapter, our focus is on thoroughly characterizing the produced PET filament to evaluate its properties and optimize parameters for practical reel applications. We start with a detailed assessment of printing quality, using rigorous testing to refine PET-specific printing parameters. We then conduct a comparative analysis involving PET, PLA, and ABS filaments to highlight their respective strengths.

Our approach includes structural analysis of PET filament composition and iterative adjustment of printing parameters to achieve optimal results. We also assess post-printing characteristics like tensile strength and hardness, providing a comprehensive view of the material's mechanical properties.

This chapter offers a systematic exploration of PET filament, blending scientific rigor with practical insights from extensive testing. Our goal is to highlight the unique attributes that make PET filament a compelling choice in practical applications.

IV.2. Methodology

IV.2.1. Examination of Filament

A. Macroscopic scale:

Let's start our characterization by comparing the general aspects of different types of polymers (PLA and ABS) to the produced on (PET). For this reason, samples of standard PLA and ABS filaments available in the market, alongside PET filament, were generated [Figure 39]. Visually, the PET filament showcases significant transparency, setting it apart from the opaque nature of PLA and ABS counterparts.

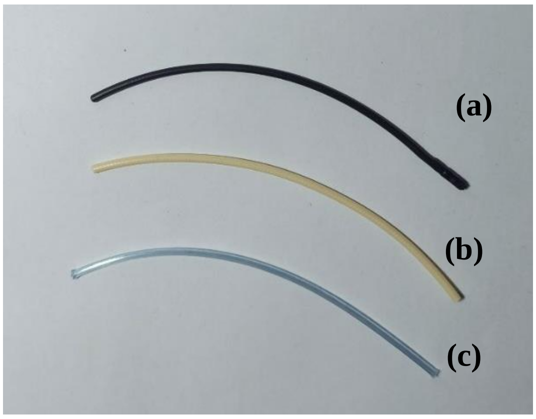


Figure 39: Visual aspects of (a) PLA (b) ABS and (c) PET

B. Microscopic scale:

To obtain a comprehensive understanding of the materials and the necessary printing conditions, we employ a microscope with a 10x zoom to scrutinize the structure for potential internal defects that might contribute to the production of faulty parts. Additionally, we investigate the printing settings to ensure optimal performance and reliability in the 3D printing process.

Figure 40 below shows us a cross section of ABS filament compared to the PET filament. We can see on the microscope that the first one has a full structure with no defects or cavities

For the PET filament, it is seen on the figure that it has a smooth external surface while its internal part has some defects, likely resulting from empty spaces created during the processing. We plan to address this issue by adjusting the printing flow to ensure a consistent quantity of material, enhancing the overall professionalism of the product.

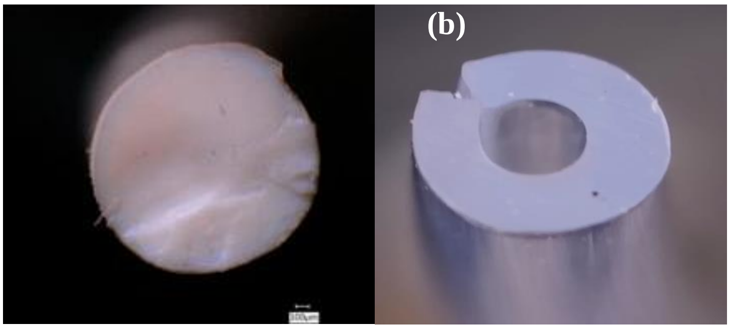


Figure 40: Microscopic comparison between (a) ABS and (b) PET

IV.2.2. Printing configuration:

As we mentioned in the previous paragraph, printing configuration and filament flow should give us a smoother structure of PET sample. In order to determine these parameters, calibration cubes of PET filament were printed using the 3D printing technology, they were subjected after that to some tests to verify the success for each set. These tests rely mainly on comparing hardness and structure, aiming for hard and shiny samples.

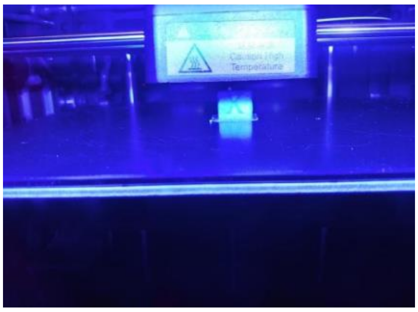


Figure 41: Printing cubic test with PET filament

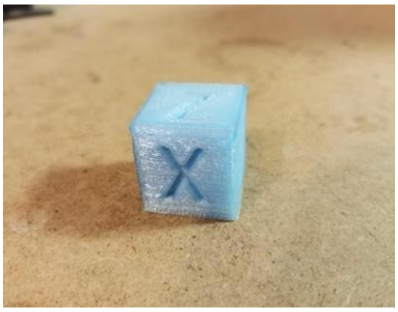


Figure 42: Cubic calipration final result

At the end of these tests, it was shown that satisfactory results are achieved at a temperature of 260°C, bed temperature of 80°C and printing speed 35mm/s. Table 10 below shows all the parameters that need to be followed to have such results.

Table 10: Slicing Setting for PET filament

Setting	Value
Layer height	0.15-0.3mm
Nozzle temperature	250-260 degree Celsius**
Bed temperature	75-85 degree Celsius
Flow	115-130%
Printing speed	30-50mm/s
Retraction distance	2-3mm*** (bowden extruder)
Retraction speed	20mm/s (Bowden and direct drive extruder)
Cooling fan speed	10-15%

IV.2.3. Density:

The density of materials is a key parameter when determining the weight of finished and semi-finished products. It also provides information on technical properties such as stiffness and can be used for quality control of foamed or crystallized plastics.

The physical properties of a material are directly related to its density, which allows for indirect measurement of material changes, like crystallinity. Crystallinity not only influences the previously mentioned stiffness but also thermal stability.

The density (ρ) of a material is the quotient of the weight (m) and the volume (V):

$$.\rho = \frac{m}{V}$$

To obtain the mass, a balance is used. As for the volume, it is determined using the Rhino3D software, as illustrated in the figure above. the volume (V) is 8.34 cm^3.

Figure 43:Accurate balance

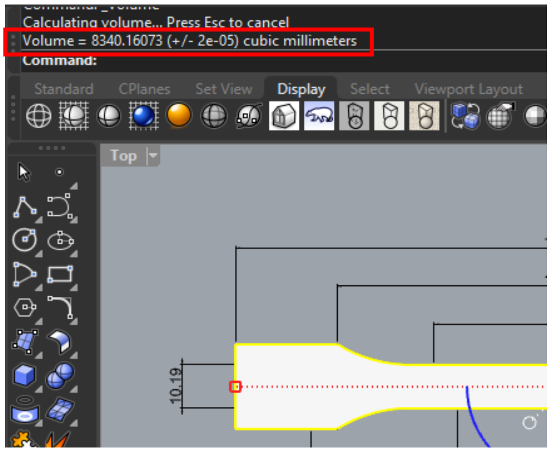


Figure 44: Volume of specimen calculate with Rhino 3d CAD Software

IV.2.4. Tensile test:

A. Machie description:

To run the tensile test, we used the universal ZWICKROELL Z050 testing machine (figure 45) the maximum applied force can reach 50kN with an accuracy of crosshead up to 0,1N and drive speed that can be set on 0,01mm/s. [27]

Figure 45:Tensile test machine with computational treatment

B. Standard specifications :

A series of characteristic values are determined to describe the essential mechanical properties of a molding and extrusion material. These characteristic values are mostly used for comparison purposes. Typical characteristic values are:

- **Tensile stress:** force related to the initial cross section of the specimen
- **Strain:** change in gauge length with reference to the initial gauge-length
- **Tensile modulus:** gradient of the curve in the stress-strain diagram
- **Yield point:** stress and strain at the curve plot point at which the gradient is zero
- **Point of break:** stress and strain at the moment of specimen break
- **Poisson's ratio:** negative ratio of transverse strain to axial strain

Both ISO 527-1/-2 and ASTM D638 define test methods for tensile tests. The two standards are technically equivalent but do not provide fully comparable results, because specimen shapes, test speeds and the method of result determination differ in some respects.

In the standardized tensile test, results are based on a defined specimen pull-off speed on the specimen. However, the loads on a component or structure in actual service may lie within a very wide range of the deformation rate. Due to the viscoelastic properties of polymers, mechanical properties different from those measured on a standardized test specimen normally result under altered strain rates. For this reason, the characteristic values determined in a tensile test are only of limited suitability for component design but represent a very reliable basis for material comparisons .[28]

Specimen types / specimen shapes:

The overriding goal of testing molding and extrusion materials is to achieve a high degree of reproducibility. This requires you to limit the number of specimen types. The shape and dimensions of the specimens are defined in ISO 527-2. The preferred specimens are type 1A (injection molded) and type 1B (pressed or mechanically machined):

- **Specimen type 1A to ISO 527-2**

The specimens are usually produced by injection molding. Type 1A specimens as defined in ISO 527-2 are used; in ISO 3167 these are designated as type A specimens and are additionally restricted to a specified thickness of 4mm. This specimen is also included in ISO 20753 as specimen A1.

Injection molded specimens display decreasing orientation as the distance from the feed point increases, leading to non-constant mechanical property curves along the length of the specimen, and therefore frequently resulting in specimen break on the side away from the gate.

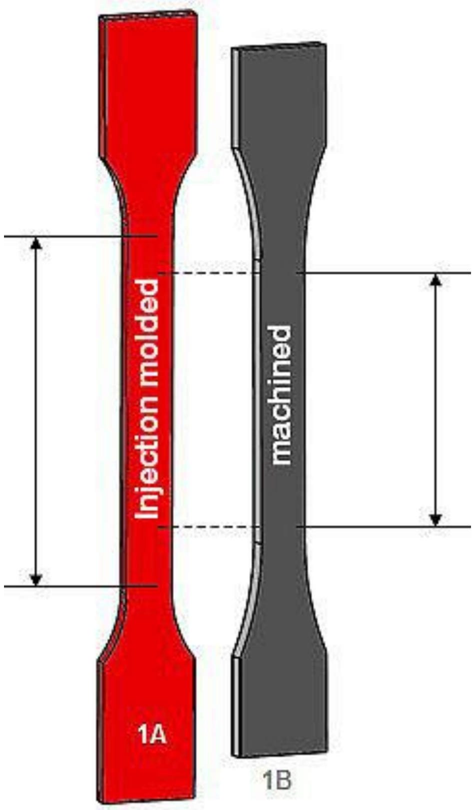


Figure 46: ISO 527 Specimens

The preferred gauge length for the specimen is 75mm, or alternatively 50mm.

- **Specimen type 1B**

As an alternative, type 1B specimens can be used; these are designated as type B in ISO 3167 and as type A2 in ISO 20753.

They are generally machined from pressed or injection molded sheets. The orientations of the polymer normally differ significantly from those in injection molded specimens. Comparability of results obtained using different specimen shapes is not guaranteed.

A gauge length of 50 mm is specified for type 1B specimens due to the larger radius and therefore shorter parallel area.

Table 11:ISO 527 specifications for specimens

Size	1A Specimens		1B Specimens
Full length, l3	170		150
Parallel length, l1	80		60
Gauge length, L0	75	50	50
Parallel section width, b1	10		10
Thickness, h	4		4
Grip section width, b2	20		20
Grip face length, L	115		115

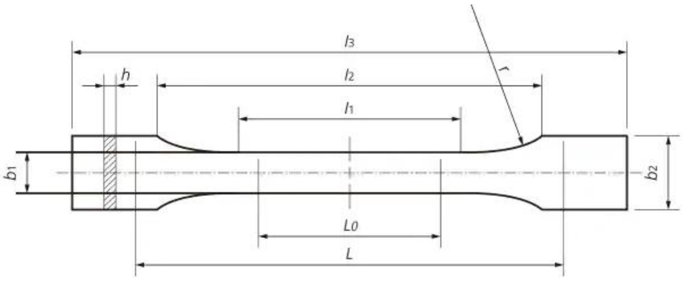


Figure 47:Schematic representation of standard tensile test specimens

Figure 48:Tensile test specimens’ elaboration

In our test, we will use **Specimen type 1B**. Figure 48 shows their elaboration process, while table 12 shows the selected parameters to get test specimens for the three materials.

Table 12 :Printing parameters for specimens of (1) PLA, (2) PET and (3) ABS

1	• **Material used:** PLA • **Layer Hight:** 0.2 mm • **Nozzle temperature:** 210 °C • **Bed temperature:** 60 °C • **Printing speed:** 30 mm/s • **Fan speed:** 100% • **Orientation:** Vertical 30°	
2	• **Material used:** PET • **Layer Hight:** 0.2 mm • **Nozzle temperature:** 250 °C • **Bed temperature:** 80 °C • **Printing speed:** 30 mm/s • **Fan speed:** 15% • **Orientation:** Vertical 30°	
3	• **Material used:** ABS • **Layer Hight:** 0.2 mm • **Nozzle temperature:** 240 °C • **Bed temperature:** 75 °C • **Printing speed:** 30 mm/s • **Fan speed:** 0% • **Orientation:** Vertical 30°	

Test processing:

The specimens are carefully positioned within the machine, and subsequent configurations are applied on the computer using the TESTEXPERT III program (figure 49). These settings are tailored to meet the ISO 527 standards.

The testing process is initiated, with the graph being generated in real-time as the machine applies tension. In figure (50,51), the specimens are shown before and after the test, providing a comprehensive view of the testing procedure. This systematic approach ensures precision and adherence to standardized testing protocols.

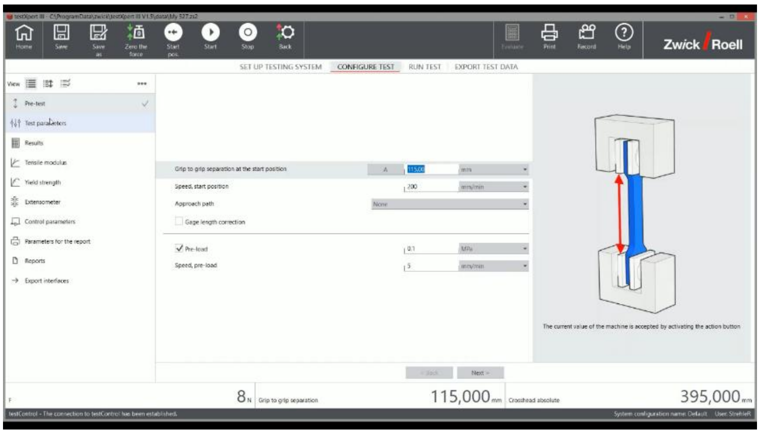


Figure 49: Set settings for the tensile test

Figure 50: Specimen before tensile test

Figure 51: Specimen after tensile test

Figure 52: PET specimen after tensile test

IV.2.5. Hardness test:

Hardness tests were conducted on the samples using the ball-pressing method. These tests were performed using the INSIZE ISH-PHB device as shown in (Figure 53).

To ensure the accuracy of the hardness results, each specimen was tested at three different locations. The average of these three measurements was then calculated to provide a representative hardness value for each specimen.

Figure 53: INSIZE ISH-PHB Hardness measurement device

The INSIZE ISH-PHB device, which is primarily designed for measuring the hardness of metals, was utilized for these tests. This device provides hardness values in terms of the Leeb scale. However, to make these results more relevant in the context of polymer materials, we converted the Leeb hardness values to Shore hardness values. This conversion was performed using a standard Hardness Conversion Table. [29]

It’s important to note that the results obtained through this conversion process are approximate and may lack the precision of direct Shore hardness measurements. Therefore, while these results provide a useful indication of the relative hardness of the tested materials, they should be interpreted with caution in applications where precise hardness values are required.

IV.2.6. Heat resistance test :

For the quantitative aspect of this test, conducting experiments was not feasible due to the need for specialized equipment such Vicat temperature test machine, which is currently unavailable. Therefore, the test will not be executed, and we will instead elucidate the methodology. The values for each material will be obtained from their respective data sheets. NF EN ISO 306

IV.2.6.1. Principle :

Determination of the temperature at which a standardized penetrator, subjected to a standardized load, penetrates 1 mm into the surface of the plastic specimen when the temperature is raised at a constant rate. The temperature at which the penetration is 1 mm is called VST, in degrees **Celsius.**

IV.2.6.2. Apparatus :

The apparatus consists of:

1. A rod equipped with a weight-bearing plate, mounted in a rigid metal assembly in such a way that it can move freely in a vertical direction, with the base of the assembly serving as support for the specimen under the penetrator tip at the end of the rod.

2. A penetrator tip, made of hardened steel, with a length of 3 mm and a circular section, with an area of 1,000 $mm^2 \pm 0.015\ mm^2$, fixed at the end of the rod.

3. A calibrated dial micrometer, to measure the penetration of the penetrator tip into the specimen to 0.01 mm accuracy.

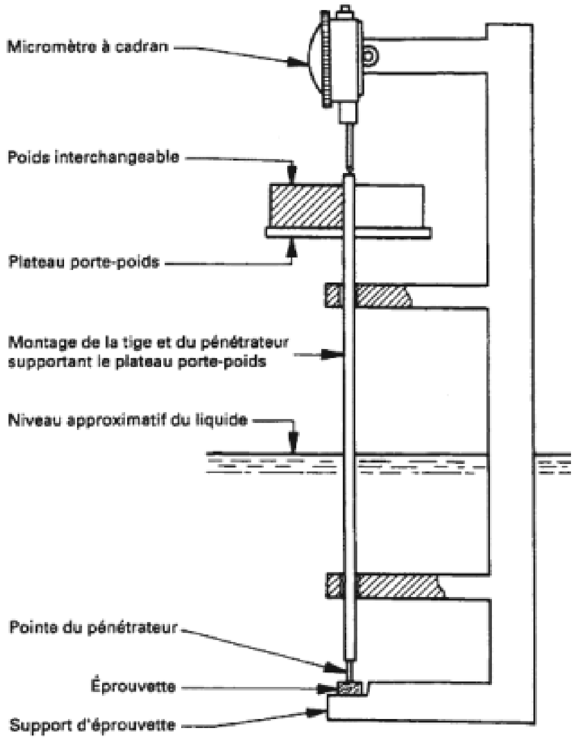


Figure 54: Vicat temperature test machine

4. A weight-bearing plate, attached to the rod, and appropriate weights, such that the total force applied to the specimen can be adjusted to

- 10 N ± 0.2 N for methods A50 and A120, and
- 50 N ± 1 N for methods B50 and B120.

5. A heating bath containing a liquid as a heat medium. This can be water, oil, silicone oil, but other liquids may also be suitable. Ensure that this liquid is stable at the temperatures used and does not alter the tested material. Air can also be used as a heat medium if necessary.

6. A regulation system that can gradually increase the temperature by 50°C or 120°C per hour.

IV.2.6.3. Specimens:

Generally, parallelepiped specimens are used with the following dimensions:

- Length = 10 mm or more
- Width = 10 mm or more
- Thickness = 3 to 6.5 mm

Use two specimens for each test, but prepare additional specimens in case the deviation between the results is too significant. [30]

Consequently, the values will be sourced from the technical data sheets provided by each material's specifications.

Table 13: Value of Vicat temperature obtenida form Technical datasheet

Materials	**PLA[31].**	**ABS[32].**	**PET[26].**
Temperature °C	60	111.9	79

IV.2.6.4 Interpretation :

The differences in Vicat temperatures between PLA (60°C), ABS (111.9°C), and PET (79°C) can be attributed to their different chemical structures and properties:

The chemical structures of PLA, ABS, and PET significantly influence their properties.

ABS (Acrylonitrile Butadiene Styrene) exhibits the highest temperature resistance among the three polymers discussed. This attribute is attributed to its chemical structure, represented as $(C_8H_8 \cdot C_4H_6 \cdot C_3H_3N)n$. ABS is a terpolymer formed by polymerizing styrene and acrylonitrile in the presence of polybutadiene. The polar nitrile groups from neighboring chains attract each other, enhancing the strength of ABS compared to pure polystyrene. Acrylonitrile contributes chemical resistance, fatigue resistance, hardness, and rigidity, while also increasing the heat deflection temperature. [33]

In contrast, PET (Polyethylene Terephthalate) ranks second in temperature resistance, with a Vicat temperature of 79°C. PET is produced through the polymerization of ethylene glycol and terephthalic acid. Ethylene glycol, a diol, and terephthalic acid, a dicarboxylic aromatic acid, react to form ester groups under heat and catalyst influence. The presence of a large aromatic ring in the PET repeating units imparts notable temperature resistance to the polymer.

PLA (Polylactic Acid) has a chemical structure of $(C3H4O2)n$ and is a biodegradable thermoplastic derived from renewable resources like corn starch or sugar cane. The monomer is typically obtained from fermented plant starch. While PLA is environmentally friendly due to its ability to degrade under certain conditions, it has a lower melting point and is less heat-resistant compared to ABS and PET. [23]

In summary, the presence of different functional groups and the arrangement of these groups within the polymer chain can affect the polymer’s heat resistance, and other physical and chemical properties. The Vicat temperature is a critical property of plastic materials, especially in applications like 3D printing, where heat is applied to melt and extrude the plastic. The differences in Vicat temperatures between PLA, ABS, and PET reflect their different chemical structures and the varying degrees of heat required to soften them.

IV.3. Results, Validation and Interpretation:

IV.3.1. Density:

The density results are presented in the table below, along with a corresponding graph. with a volume (V) is 8.34 cm³.

Table 14: Density result of experimental and technique datasheet [18, 33,26]

Material	Mass (g)	Experimental Density (g/cm³)	Data Sheet Density (g/cm³)
PLA	10.5	1.25	1.24
ABS	8	0.96	1.05
PET	11	1.32	1.335

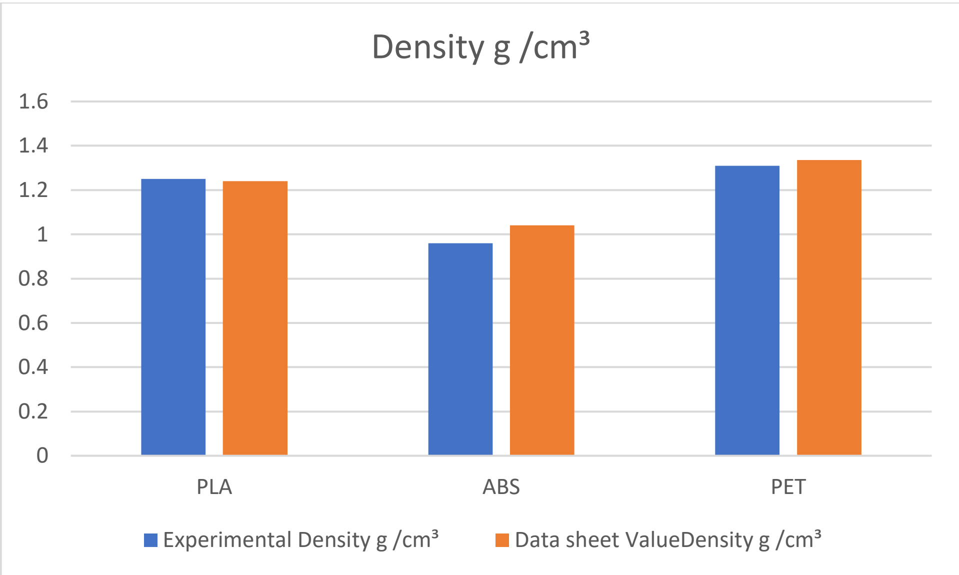


Figure 55: Clustered column of density

This phrasing provides a clear and concise introduction to the presentation of density results in both tabular and graphical formats.

Validation of results:

The experimental density for PLA aligns consistently with the values specified in the datasheet.

For **ABS**, experimental density is also **lower** than the data sheet value. This could be due to factors such as the presence of additives or variations in the manufacturing process. The type of 3D printer used can indeed influence the density of the printed material. Closed 3D printers like Zortrax often have more controlled environments, which can lead to more consistent results. On the other hand, open 3D printers may be subject to environmental factors such as temperature and humidity, which can affect the printing process and the properties of the printed material. In my case, the lower experimental density of ABS could be due to the open 3D printing environment. Factors such as cooling rate, extrusion temperature, and filament quality can vary more in an open printer, potentially leading to less dense prints.

For **PET**, the experimental density is **very close** to the data sheet value, indicating that the experimental setup and procedure are likely accurate for this material.

Interpretation:

The density of a material is determined by its mass per unit volume. Several factors can influence the density of a material, including its chemical composition, degree of polymerization, crystallinity, and the presence of additives or fillers

IV.3.1. Tensile test:

Tensile test results are generally represented as stress-strain curves, with the stress representing the load applied on the sample, and the strain being the elongation. Figure 56 shows the results we got for the three tested materials.

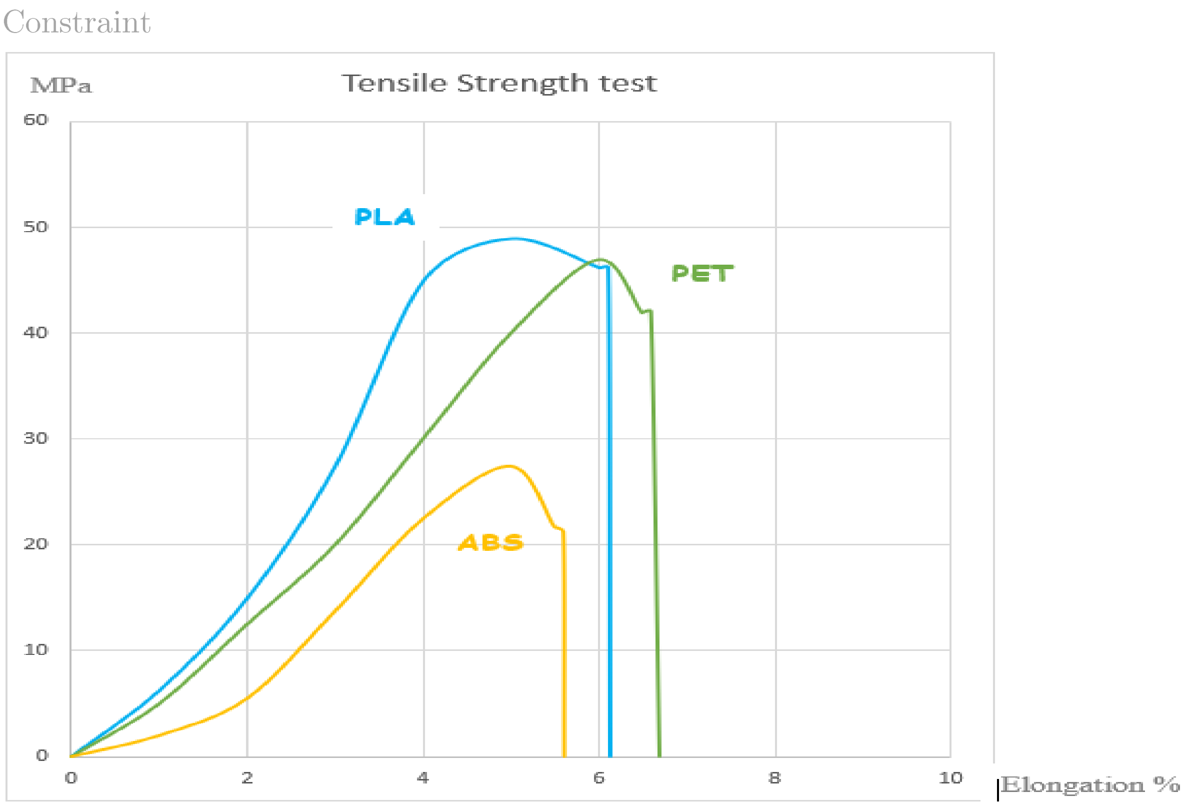


Figure 56: Tensile test curves

Interpretation :

The graph shows that samples from PLA, ABS and PET broke brittle, The results shown on the graph are typical for hard plastics

we also observe that PET, PLA, and ABS exhibit minimal elongation under stress. Among the samples, ABS displayed the lowest strength, being only half as strong as the PLA sample. This discrepancy can be attributed to various factors including filament composition, presence of fine inclusions, moisture content, and formation of air bubbles during filament creation, all of which substantially compromise its structural integrity.

The underlying reason for this difference lies in the bonding quality established between layers during the manufacturing process of the samples, which is superior in the case of PLA and PET materials compared to ABS samples.

The strength of a material is primarily determined by its tensile strength, which is the maximum amount of tensile (pulling) stress that it can take before failure, such as breaking or permanent deformation.

From our experimental results, it appears that PLA has the highest tensile strength at yield (49 MPa), followed by PET (47 MPa), and then ABS (29 MPa). This suggests that PLA is the strongest material among the three, in terms of tensile strength.

Several factors can influence the strength of a material:

Chemical Structure: The chemical structure of a polymer, including the types of monomers it contains and the way they're arranged, can significantly influence its strength. [37]

Degree of Polymerization: The degree of polymerization, or the number of repeating units in a polymer chain, can also affect a material's strength. Generally, polymers with a higher degree of polymerization (longer polymer chains) have greater strength. [38]

Crystallinity: Polymers can be either amorphous (randomly ordered) or crystalline (highly ordered). Crystalline regions in a polymer are typically stronger than amorphous regions. Therefore, polymers with higher crystallinity usually have higher strength. [39]

Processing Conditions: The conditions under which the materials are processed can also affect their properties. For example, the temperature and speed of the 3D printer, the cooling rate, and the environment in which the printing takes place can all affect the final properties of the material.

Density: tensile strength of polymer grouting materials increases with the density . [40]

PLA (Polylactic Acid): PLA is a semi-crystalline (Figure 57) polymer and linear aliphatic polyester. Its structure contains large, cyclic molecular units, which makes it rigid and brittle. The rigidity contributes to its high tensile strength and modulus, but the brittleness means it can break more easily under strain, which is reflected in its lower elongation at yield compared to PET and ABS. The degree of crystallinity in

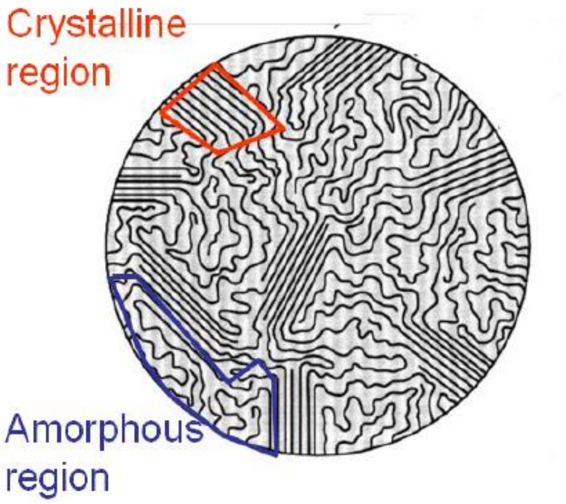


Figure 57: Semicrystalline polymer structure. Photo courtesy of Journal of Chemical &Research [41]

PLA can also influence its properties; higher crystallinity usually leads to increased stiffness and strength but decreased toughness. [42]

PET (Polyethylene Terephthalate): PET is a semi-crystalline polymer. It consists of repeating units of an ester functional group, which is responsible for its characteristic properties. The presence of a large aromatic ring in the PET repeating units gives the polymer notable stiffness and strength. This contributes to its high tensile strength and modulus. However, PET's semi-crystalline nature means it has both stiff, strong crystalline regions and more flexible, less strong amorphous regions, which can lead to variability in its properties. [43]

ABS (Acrylonitrile Butadiene Styrene): ABS is an amorphous (Figure 58) polymer created through the polymerization of styrene and acrylonitrile in the presence of polybutadiene. This composition imparts properties that make ABS less brittle compared to PLA and PET.

Figure 58: Amorphous polymer structure

The information presented in the tensile graph can be represented by the data provided in the following table, illustrating the correlation between the graph and the specified values. [44]

Experimental result:

Table 5: Tensile test experimental results

Materials	**PLA**	**ABS**	**PET**
Tensile strength at yield $\boldsymbol{R_{max}}$ (MPa)	49	29	47
Elongation at yield %	4.9	5	6.1
Tensile module MPa	2322.8	1425.3	2180

Technique data Sheet:

Table 16:Tensile test technique datasheet results

Materials	**PLA**[36]	**ABS**[21]	**PET**[26]
Tensile strength at yield $\boldsymbol{R_{max}}$ (MPa)	49.5	39	57
Elongation %	5.2	3.5	6.1
Tensile module MPa	2346.5	1681.5	2420

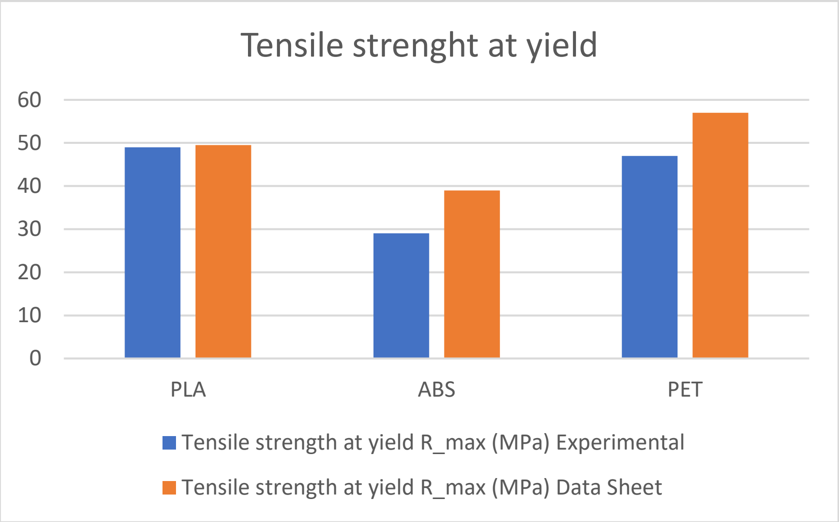


Figure 59: Clustered column tensile strength at Yield

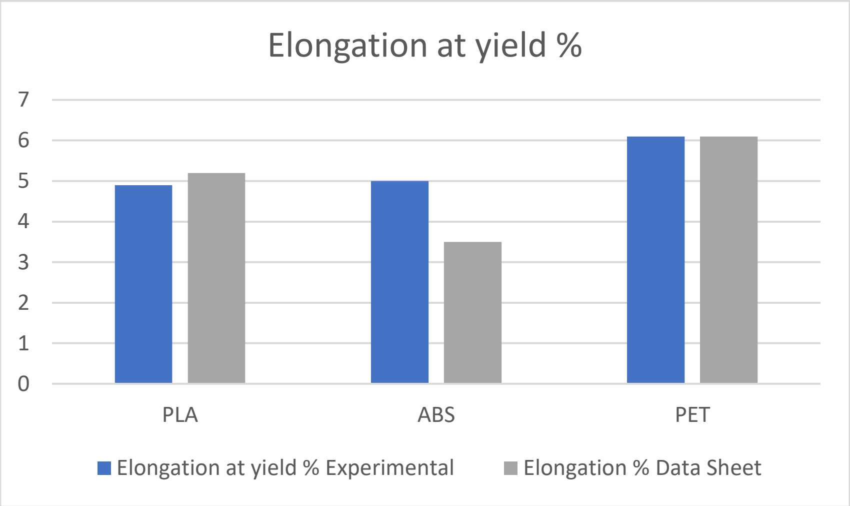


Figure 60: Clustered column Elongation at yield

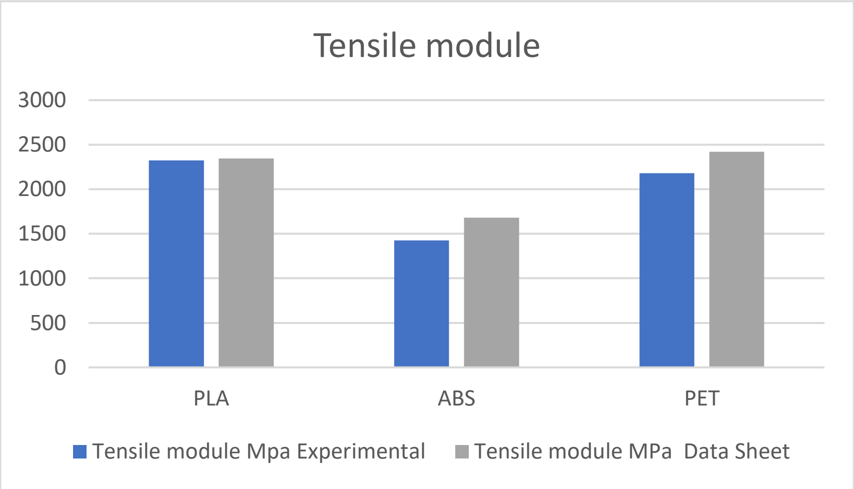


Figure 61 : Clustered column Tensile module

Validation :

PLA: The results for PLA are very close to the datasheet values, which suggests that the PLA filament you tested is of high quality and was processed and tested under appropriate conditions.

ABS: The tensile strength at yield and tensile modulus for ABS are lower in my results compared to the datasheet. This could be due to the ABS being printed in an open environment. ABS is known to be sensitive to changes in temperature and humidity, which can affect its mechanical properties. The open environment could have led to uneven cooling, which can cause residual stresses and reduce the mechanical properties.

PET: The tensile strength at yield for PET is lower in my results compared to the datasheet, while the tensile modulus is close to the data sheet value. This could be due to variations in the quality or processing of the PET filament.

Differences between my results and the data sheet values are not uncommon and can be due to a variety of factors related to the processing and testing conditions and the quality of the material.

IV.3.2. Hardness:

Specimens submitted to hardness test are left with a mark on them. The dimensions of this mark are measured and material's hardness is then calculated. Table 17 below shows the results given for the three materials as LEEB and Shore results.

Table 17 :Scale for Shore hardness, and Leeb Scale

Material	LEEB (HL) Experimental	Shore D Experimental	Shore D Data Sheet
PLA	796	79	75 [**34**]
ABS	688	60	76 [**21**]
PET	746	70	78 [**26**]

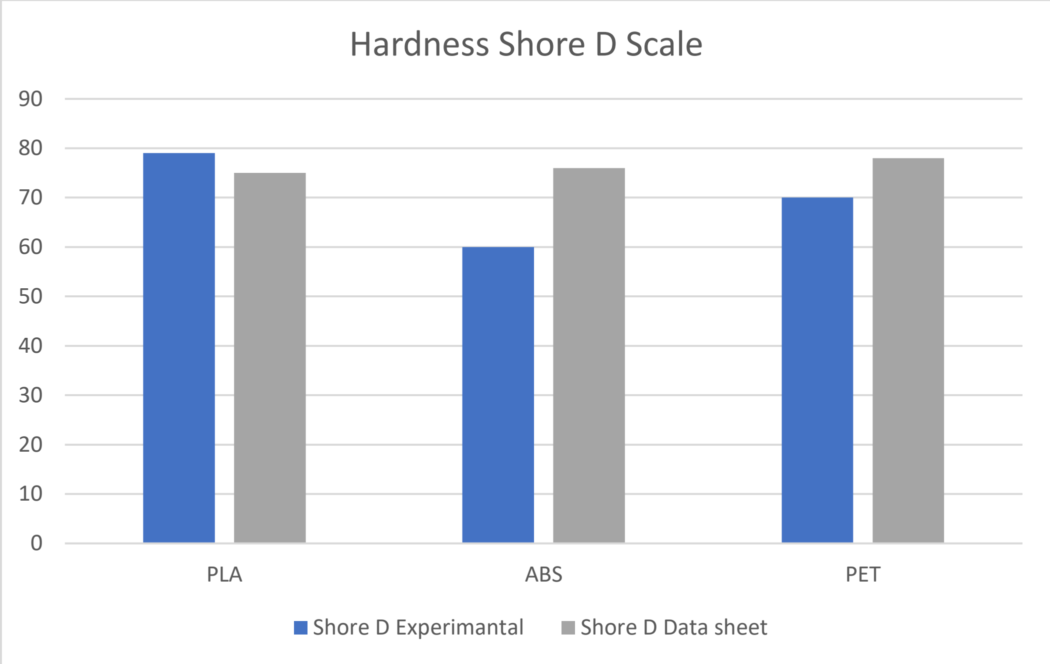


Figure 62: Clustered column Hardness Shore D Scale

Interpretation:

The Shore D hardness values you provided indicate the relative hardness of the three materials: PLA (Polylactic Acid), ABS (Acrylonitrile Butadiene Styrene), and PET (Polyethylene Terephthalate).

PLA (79 Shore D): PLA exhibits the highest hardness among the three materials. This could be attributed to its crystalline structure, which tends to resist deformation, thereby making it harder. However, this also makes PLA more brittle, which means it may break or crack under high stress or impact.

ABS (60 Shore D): ABS exhibits the lowest hardness value among the three materials, suggesting that it is the most pliable. This characteristic may be attributed to its amorphous structure.

PET (70 Shore D): PET has an intermediate hardness value. PET is semi-crystalline, which gives it a good balance between hardness and toughness. It has good chemical resistance, and it is also resistant to UV light.

It's important to note that hardness is just one measure of a material's properties. Other factors such as tensile strength, impact resistance, and temperature resistance also play a crucial role in determining the suitability of a material for a particular application. Therefore, while PLA is the hardest among the three materials, it may not necessarily be the best choice for all applications. Similarly, while ABS is the softest, it may be the best choice for applications that require high impact resistance.

Validation:

The hardness results for PLA and PET show a close similarity. On the contrary, ABS exhibits different values. As mentioned earlier, this discrepancy can be attributed to the challenges associated with printing on an open 3D machine where environmental factors are more difficult to regulate compared to closed machines. ABS, being sensitive to its surroundings, is influenced by these environmental conditions, as explained previously.

The differences between the experimental Shore D hardness values and the values provided in the data sheets could be due to a variety of factors:

Material Variability: The specific formulation and processing of the material can significantly affect its hardness. Even slight variations in the manufacturing process, such as temperature, printing speed , printing orintation, can result in different hardness values.

Measurement Uncertainty: Like in our hardness tsest we use leeb scal and than we convert to shore D scal whch don't give pression resul that can explain the dfrence

IV.4. Conclusion:

After conducting these tests, we can now compare these three types of materials.

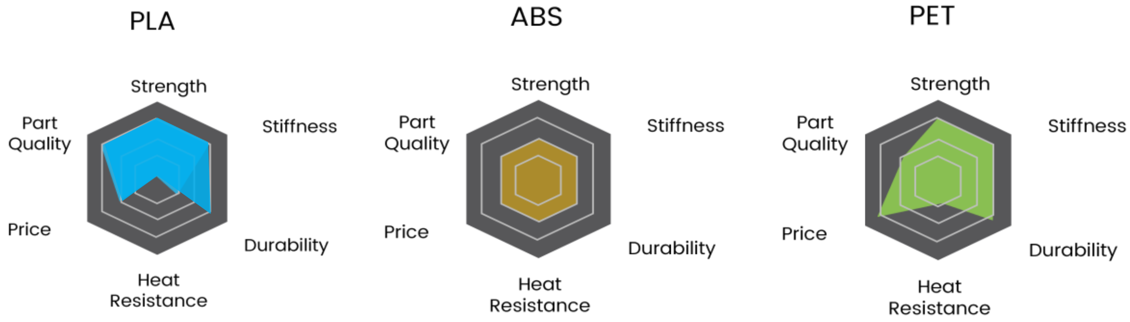


Figure 63:Comparison between Polymer Properties

PLA (Fast, Easy, Rigid)
Best Uses: Concept prototypes

PLA (polylactic acid) emerges as an excellent choice for initial concept modeling due to its user-friendly nature, compatibility with office settings, and efficient utilization with breakaway supports, ensuring quicker printing and removal compared to dissolvable supports. Derived from corn, PLA is acknowledged as biodegradable within industrial processes. Contrary to common perception of its simplicity, PLA exhibits noteworthy tensile strength and modulus among foundational polymers. However, a notable drawback lies in its brittleness—failure results in a catastrophic fracture, distinguishing it from polymers with more flexible properties. In the current market, the cost of 1 kg of PLA filament stands at approximately 3500 DA.

PET (Cheap, Durable)
Best Uses: Functional prototypes

Polyethylene Terephthalate (PET, showcases a tensile strength, indicating a reduced ability to withstand stretching forces compared to PLA. PET exhibits an elongation at break, suggesting flexibility and ductility before failure.

PET's balanced mechanical properties, combining strength and flexibility, make it suitable for versatile applications. With commendable hardness and temperature resistance, PET presents a harmonious array of characteristics.

Widely used in filament manufacturing, PET is a prevalent choice, offering durability with a glossy finish. The introduction of glycol, forming PET, enhances flexibility and impact resistance. PET's unique properties, including resistance to shrinking and strong adhesion to other materials, position it as a reliable and easily printable material. The cost of 1 kg of PET filament stands at approximately 2000 DA.

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ABS (Smooth, Durable, Heat-Resistant)
Best Uses: Functional prototypes, manufacturing tools

ABS (acrylonitrile butadiene styrene) stands out as a premier choice for the fabrication of injection-molded consumer products, prized for its impeccable surface finish, remarkable durability, and robust heat resistance. Its widespread utilization arises from its capacity to faithfully replicate the appearance, texture, and functionality of the final product during the prototyping phase. ABS's exceptional durability and high heat deflection temperature further position it as a material of choice for applications in laboratory settings or on the factory floor. This superior-grade material comes at a cost of 4500 DA.

IV.5. Technique data sheet of Recycling PET:

Table 8: PET properties and priting settings

Thermal properties		
	Typical value	Test Method
Melting temp	230-250 °C	-
Vicat softening temp	75°C	ISO 306
Mechanical properties		
Mechanical properties	Typical value	Test Method
Tensile strength at yield	47 Mpa	ISO 527
Strain at yield	6.1%	ISO 527
Tensile Modulus	2180Mpa	ISO 527
Hardness Shore D	70	ISO 62
Filament specification		
Filament properties	Typical value	Test Method
Diameter	1.75 mm	
Specific gravity	1.3 g/cm3	
Printing settings		
Printing settings	Test Method	Test Method
Extruder temperature	255°C – 260 °C	
Bed temperature	75-85 °C	
Speed	10-50 mm/s	
Retraction Speed	20 mm/s	
Retraction distance	2-3 mm	
Cooling fan	10-15%	
Minimum layer height	0.05 mm	

General Conclusion

General Conclusion:

Embarking on a journey from the exploration of 3D printing technologies to the development of the PET filament recycling machine, this project embodies a comprehensive approach to sustainability in additive manufacturing.

Commencing with an overview of 3D printing technologies and the materials pivotal to industrial applications lays the groundwork for understanding the industry landscape. The subsequent introduction of the PET recycling machine transcends being merely a technological innovation; it represents a strategic response to the challenges posed by plastic waste and the exorbitant costs of traditional filament materials.

The detailed exposition of the machine's functionality, coupled with the systematic process of transforming discarded PET bottles into 3D printing filament, illuminates a pathway towards a circular economy. This sustainable alternative not only offers a cost-effective solution but also significantly contributes to mitigating the environmental impacts of plastic waste.

Comparing PET filament characteristics with industry standards like ABS and PLA serves as a quantitative measure of its viability and competitiveness. The economic and ecological advantages underscore its potential to reshape material choices in the 3D printing landscape.

In essence, this project goes beyond the mere development of a recycling machine; it signifies a conscientious shift towards eco-friendly practices in additive manufacturing. The PET filament recycling initiative aligns with the principles of sustainability and sets the stage for further innovations and considerations of responsible material usage within the 3D printing industry. It stands as a testament to the transformative power of technology when harmonized with environmental consciousness and economic prudence.

In this thesis, we introduced the design and model of a filament machine, proposing an alternative way to create ecological filament. The machine and filament were tested against generally available filaments in simple tests, successfully producing a filament usable in a regular 3D printer from ordinary plastic bottles.

The research presented in the article allows for the analysis of the created material, showcasing its potential, especially in promoting waste recycling and creating durable elements. While creating and using PET filament for printing parts on a 3D printer requires a deeper and more extended analysis, considering it as a prototype, the machine has demonstrated success despite having some drawbacks that need correction.

Various solutions for similar machines are available, and the method presented in the article, although less popular, offers advantages. Unlike more complicated processes involving creating granules and larger machines, the one in this article is composed of 90% 3D printed parts, contributing to its affordability.

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