FACULTY OF MECHANICAL ENGINEERING TUL

Master Thesis

Dual-Material 3D Printing

Study programme:	N0788A270005 Innovation and Industrial Engineering
Author:	**Tamilarasan Amsavalli Ramkumar**
Thesis Supervisors:	Ing. Petr Keller, Ph.D. Department of Manufacturing Systems and Automation

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Master Thesis Assignment Form

Dual-Material 3D Printing

Name and surname:	**Tamilarasan Amsavalli Ramkumar**
Identification number:	S21000173
Study programme:	N0788A270005 Innovation and Industrial Engineering
Assigning department:	Department of Manufacturing Systems and Automation
Academic year:	2022/2023

Rules for Elaboration:

The aim of this work is to find the parameters for two components printing on given 3D printer, based on FFF additive technology. The printed parts will be from two different materials (e.g. PLA and TPU, ASA and Iglidur, etc.). Suggest a procedure for setting print parameters and make changes to the printer design if necessary.
Recommended processing methods:
1. Become familiar with the given dual-head “cube type” 3D printer.
2. Make a research of existing works dealing with multi-component printing using FLM, FDM, FFF technologies.
3. Design CAD models of suitable parts for testing two-components 3D printing, e.g. linear sliding bearing, silent block, etc.
4. Prepare a design of experiments and based on this, perform practical 3D printing tests to obtain the highest quality printing.
5. Evaluate your work.
6. Prepare materials for creating a publication on given topic in a technical journal or at a conference.

Scope of Graphic Work:	according to need
Scope of Report:	approx. 60 pages
Thesis Form:	printed/electronic
Thesis Language:	English

List of Specialised Literature:

[1] GEBHARDT, A. *Understanding Additive Manufacturing: Rapid Prototyping – Rapid Tooling – Rapid Manufacturing*. Munich: Hanser, 2011. ISBN 978-3-446-42552-1
[2] WIMPENNY, D. I., L. J. KUMAR a P. M. PANDEY. *Advances in 3D Printing & Additive Manufacturing Technologies*. New York, NY: Springer Berlin Heidelberg, 2016. ISBN 978-981-10-0811-5.
[3] SRIVATSAN, T. S. a T. S. SUDARSHAN. *Additive manufacturing: innovations, advances, and applications*. Boca Raton: Taylor & Francis, 2016. ISBN 9781498714785.
[4] REPRAP. *RepRap Forums* [online]. 2016 [cit. 2022-09-20]. Available from: http://forums.reprap.org/index.php
[5] STRATASYS LTD. *Introduction to Fused Deposition Modeling Technology – FDM – Stratasys* [online]. 2022 [cit. 2022-09-20]. Available from: https://www.stratasys.com/en/guide-to-3d-printing/technologies-and-materials/FDM-technology

Thesis Supervisors:	Ing. Petr Keller, Ph.D. Department of Manufacturing Systems and Automation
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L.S.

doc. Ing. Jaromír Moravec, Ph.D.
Dean

Ing. Petr Zelený, Ph.D.
Head of Department

Liberec November 20, 2022

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May 22, 2023 Tamilarasan Amsavalli Ramkumar

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Abstrakt:

Tato práce se zaměřuje na nastavení 3D tiskárny typu Cube s duální tiskovou hlavou pro tisk dvou různých materiálů, tedy termoplastů, pomocí technologie FFF/FDM. Pro danou tiskovou hlavu je třeba najít nejlepší parametry pro příslušné materiály, jako je vhodná teplota extruderů a trysek, rychlost tisku, délka retrakcí. Dále se práce zabývá snížením úniku materiálu z nepoužívané trysky. Pro splnění těchto věcí byly provedeny některé hardwarové změny v tiskárně a provedeny úpravy G-kódu v softwaru Repetier Host.

Klíčová slova:
FFF technologie, Více-materiálový 3D tisk, Termoplasty, Vytékání materiálu.

Abstract:

This thesis focusses on the setup of dual head cube type 3d printer for printing two different materials i.e., thermoplastics based on the technology of FFF/FDM technology. In addition to that for the prepared nozzle we have to find the best parameters for the respective materials like suitable temperature of extruders as well as nozzle, speed of printing, retraction length. Furthermore, the thesis talks about the reduction of material oozing from the unused nozzle. For these things, we have done some hardware changes in the printer and G – code modifications in the Repetier Host software.

Keywords:

FFF technology, Multimaterial 3D printing, Thermoplastics, Oozing.

CONTENTS

List of Abbreviations and Symbols

ABS - Acrylonitrile Butadiene Styrene

AM – Additive Manufacturing

CM – Conventional Manufacturing

DIW – Direct Ink Writing

DLP – Digital Light Processing

DMD – Digital Micrometer Device

FEF – Free form Extrusion Fabrication

FFF – Fused Filament fabrication

FDM – Fused Deposition Modelling

HIPS - High Impact Polystyrene

LOM – Laminated Object Manufacturing

MJM – MultiJet Modelling

PEEK - Polyetheretherketone

PLA - Polylactic Acid

STL – Standard Triangle Language

SLA – Stereolithography

TPU - Thermoplastic Polyurethane

TPE - Thermoplastic Elastomer

^{0}C – Degree Celsius

1. INTRODUCTION

The topic of the work is **"Dual – Material 3D Printing Using Additive Technology".** The principle behind this is Fused Filament Fabrication (FFF) which is also known as Fused Deposition Modeling (FDM). The Fused Deposition Modeling is one of the Additive Manufacturing Technology which was developed by S. Scott Crump with Stratasys in 1988. After the expiration of the patent in 2009, Stratasys have released it to open source for the public [1]. FDM is the process where the melted filament material is deposited over a build platform in layer by layer until we get the required part. The extrusion process is led by the pre-fabricated thermoplastic material. The goal behind this printing technology was the rapid production of complex designed objects with cost efficient and high-grade tools. The printer which we used of the work is a Cartesian Printer. The print head of this printer moves along X and Y axes, whereas the print bed moves in the Z-axis. Most often used Materials in FDM are PLA (Polyactide), ABS Polymer, engineering materials like PA (Nylon), TPU, and PETG [2].

Firstly, our thesis moves on to the fine tuning of cleaning mechanism such as cleaning the nozzle such as ooze prevention, material fill, temperature and after each layer is printed thus increasing the quality of the printed material.

Secondly, our thesis focuses on calibrating the nozzle with different materials or two different colored materials by including the necessary Hardware and Software modifications of the Printer.

2. MOTTO OF THE THESIS:

The main motto of the thesis is to carryout test in dual head cube type 3D – printer by using various materials and to find the printing requisites for those materials to get good quality printing parts. These requisites play a major role in printing process and the best suitable materials is pointed out. Research also carried out on materials in FDM/FFF Technology to get familiar with it. The necessary hardware and software modifications for cleaning mechanism as well as for the slicer should be carried out. The materials were tested in various specifications like printing speed, feed rate, temperature to get the high-quality print.

3. ADDITIVE MANUFACTURING (AM):

3.1. Evolution of AM

Additive Manufacturing (AM) is a technology of producing an object in layer by layer at a time. On the other hand, Subtractive manufacturing refers to an object is created by cutting away a solid block of material until the final product is complete, is the polar opposite of additive manufacturing. In earlier 1980's this process was known as Rapid prototyping because it allows individuals to create a scale model of the final product rapidly without using classical setup process and the expenditures associated in bringing prototype [3].

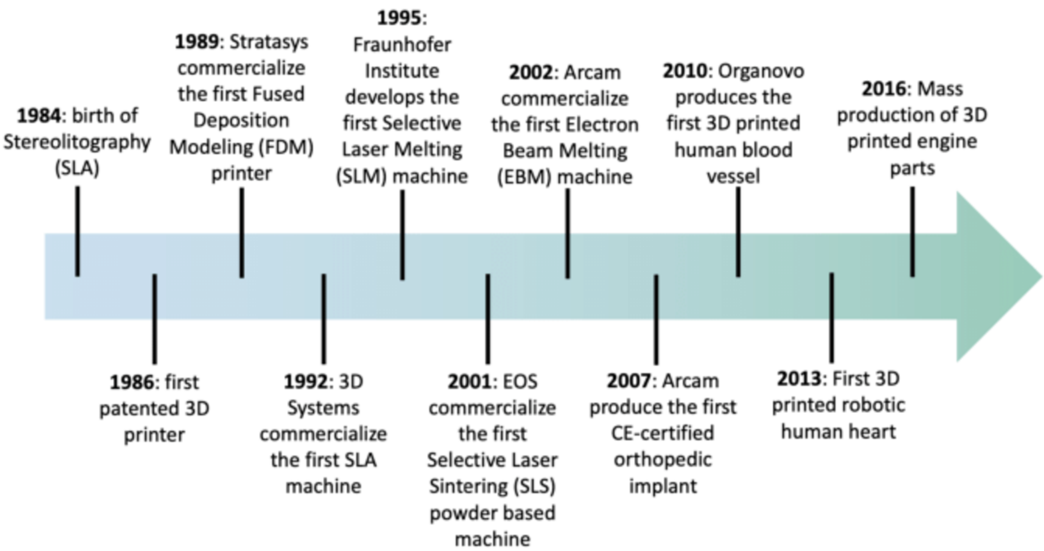


Figure 1: Historic Timeline of Additive Manufacturing [4]

The evolution of Additive Manufacturing which is shown above (Figure 1) [4] came out along with the numerous findings such as for the process of printing we can use any number of materials, polymers, metals and ceramics to foam gels. This greatest finding was now heading into human cells establishments.

3.2. Additive Manufacturing vs Conventional Manufacturing:

It is also necessary to state that Conventional Manufacturing (CM) were still in the case. It is still raising in their own technology. But these were only used when the demand or lot sizes were huge in numbers. Additive Manufacturing (AM) is used when there is a sudden demand in specific product or object in a minimum value instead of creating excess inventory.

4. AM TYPES AND METHODOLOGIES:

4.1. Process Methodology:

This process involves seven key stages, with the quick swift in advancement of computers and software for CAD product design and 3d modelling of the required final product has been rapidly accelerated. Typical process steps for additive manufacturing were shown below (Figure 2) [5].

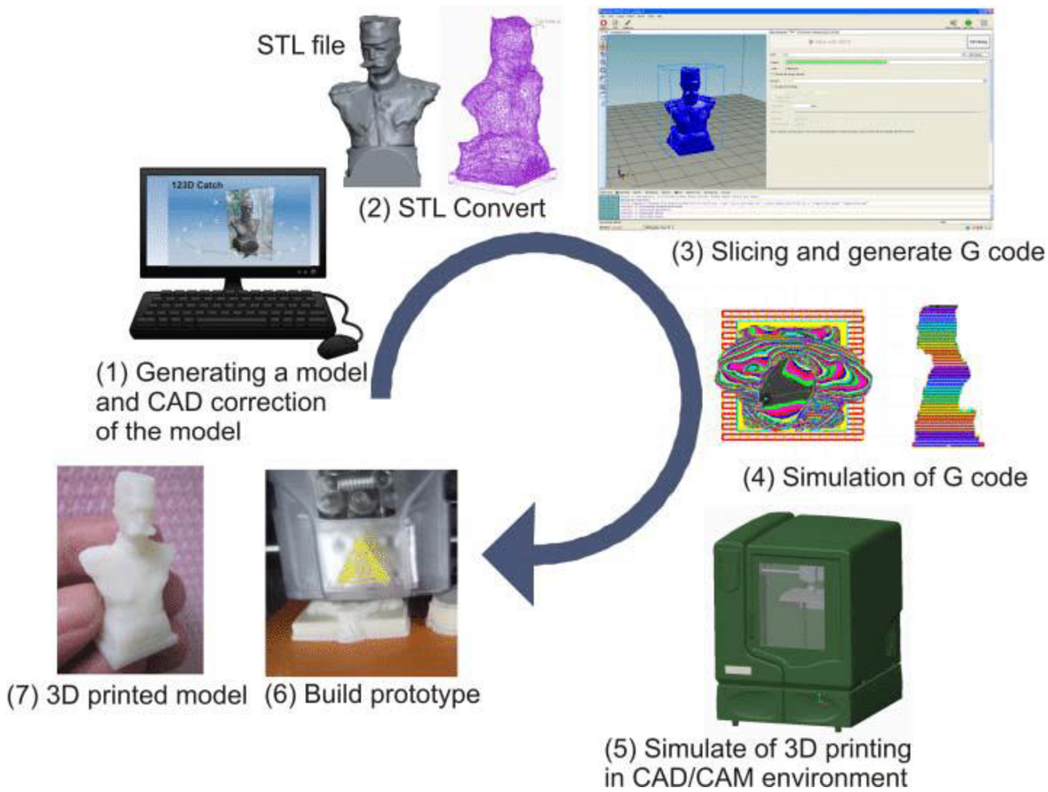


Figure 2: Stages in Additive Manufacturing [5]

Step 1: CAD Model

At first a generic 3d model has to be created with all the specifications run down.

Step 2: STL file

Next is to convert the 3d model to a Stereolithography (STL) file and to check for defects.

Step 3: Generating G-code

The STL files were used as the input for generating G-codes.

Step 4: Simulation of G-code

The generated G-code were simulated and analyzed in the slicer software before prototyping.

Step 5: Machine Setup

Before preceding to build the part, the machine must to required criteria such as material, temperature or energy supply, layer thickness, feed rate and so on.

Step 6: Building Prototype

For building the prototype, the machine is fully automated and there is no requirement of human intervention.

Step 7: Post processing and Finishing

Before getting the finished part, it requires post processing treatments like surface cleaning, curing has to be done.

4.2. Classification and phases in AM:

There are different sorts of Additive Manufacturing (AM) process based upon the type of material infill, generation of layers, phase change phenomenon and application requirements. The process involves three main phases which are shown below (Figure 3).

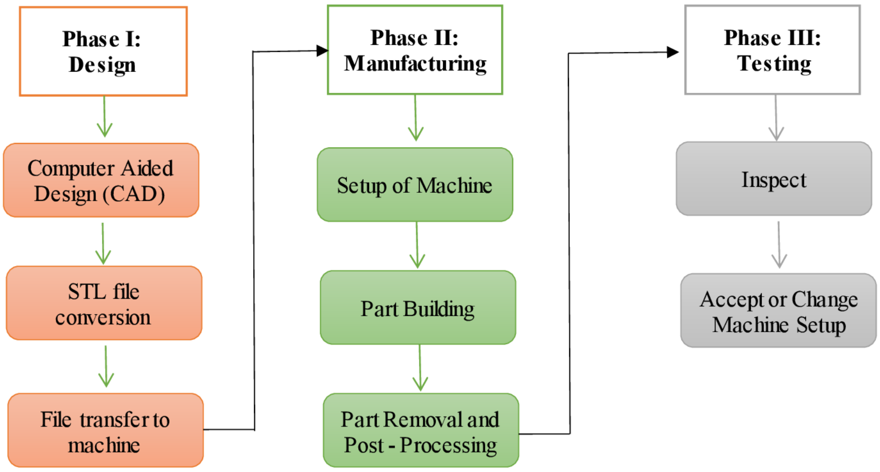


Figure 3: Phases in Additive manufacturing (AM)

The machines used in Additive manufacturing (AM) technology can also be distinguished based on machine dimension, nozzle dimension, nozzle speed and workspace dimensions. Anyhow it also depends on the type of material or composition and the support structure. Based on that it is classified into three major types [6]: Liquid based, Solid based and Powder based techniques.

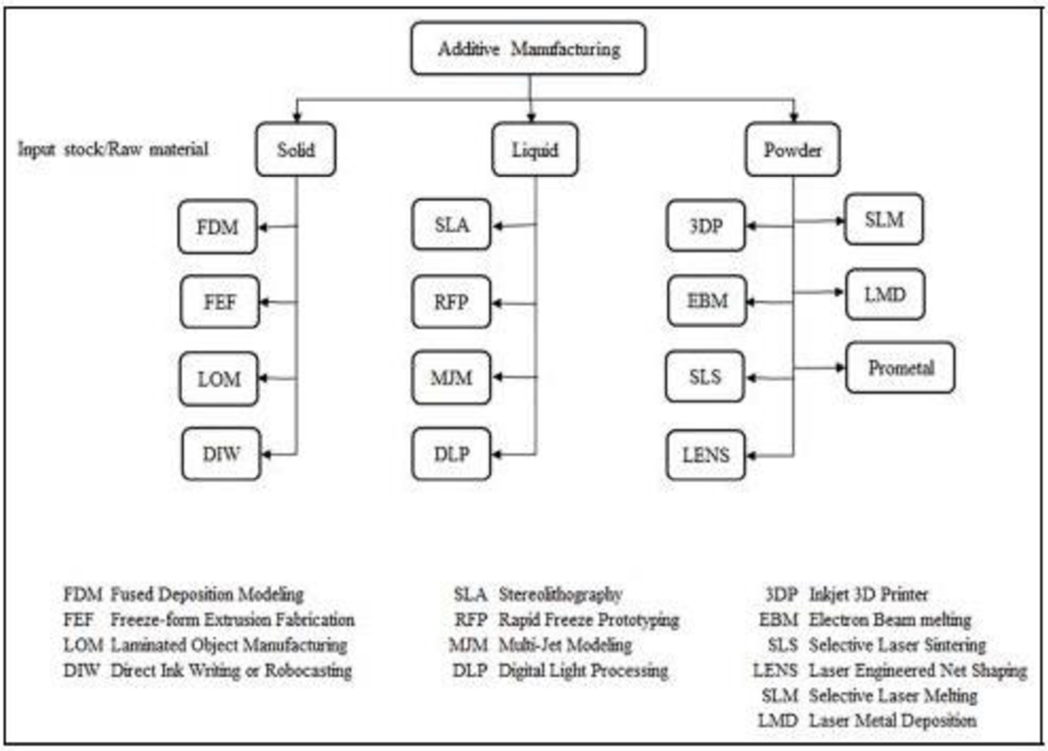


Figure 4: Classification of AM process [6]

4.2.1. Solid Based Additive Manufacturing:

4.2.1.1. Fused Deposition Modelling (FDM):

Fused Deposition Modelling (FDM) is one of the most used 3d printing technology in this modern industry. It’s a system of nozzle-based deposition process. It consists of filament spool, nozzle, extruder, build plate etc.,

The printer (Figure 5) runs on three combinational axes, whereas the build plate moves in y – axis and the extruder head move through x and z axes. It has a heating chamber and a nozzle for material extrusion. The z directional movement of the print head helps to maintain the distance between the nozzle and upper surface of the object [7].

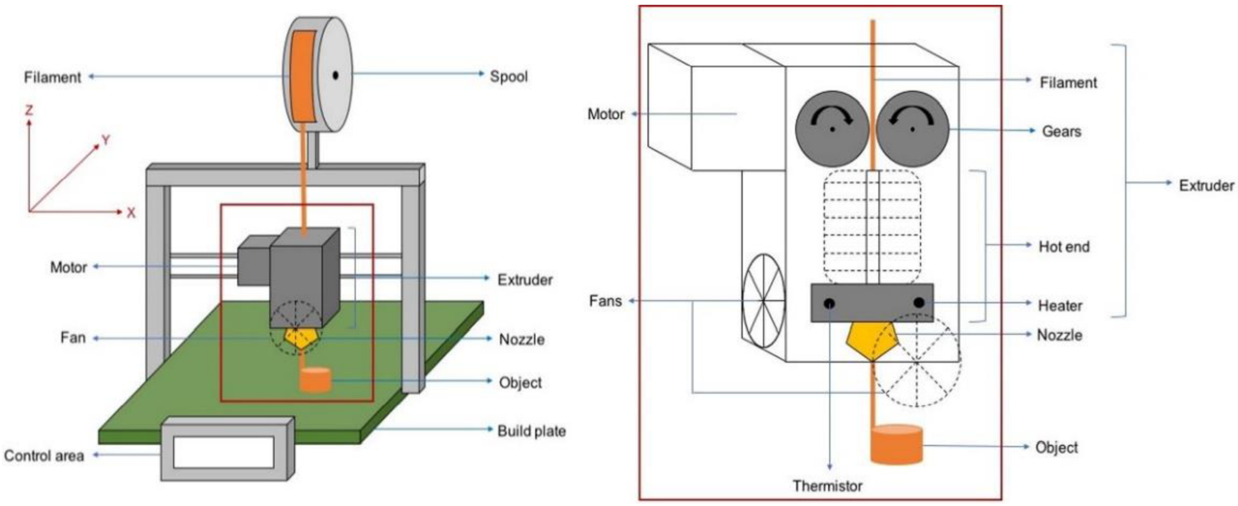


Figure 5: FDM Process and Technique [7]

First the filament is fed into the extruder to melt the material for the process of extrusion. The extruded material is fed in layer by layer through nozzle to get the required object. The printed object is then processed by cold end to get the final part.

Materials used in FDM: The most widely used materials in FDM are acrylonitrile butadiene styrene (ABS), polyamide (PA), polylactide (PLA).

Advantages of FDM:

- ✓ The cost of technology for printing is low.
- ✓ Possibility of Rapid manufacturing which means that low time is required.
- ✓ Since there are no toxic materials were used it is safer.
- ✓ With the use of thermoplastic materials, we can have different colored materials in manufacturing.

4.2.1.2. Free Form Extrusion Fabrication (FEF):

The Free Form Extrusion (FEF) is the first method to use ceramics as an extrusion material by slurries to make 3d components. It uses plastic materials like amorphous polymers, semi – crystalline polymers, thermosets and with combination of liquid pastes.

The nozzle attached with this type of printer is also capable of moving in X, Y and Z directions. The extruded material is deposited on a surface which is in a liquid medium. The object is done in a layer-by-layer fabrication method. To regain and maintain the deposited shape it uses infra-red radiation to dry it. This method requires Post processing and sintering for finishing. The schematic process is shown below (Figure 6) [8].

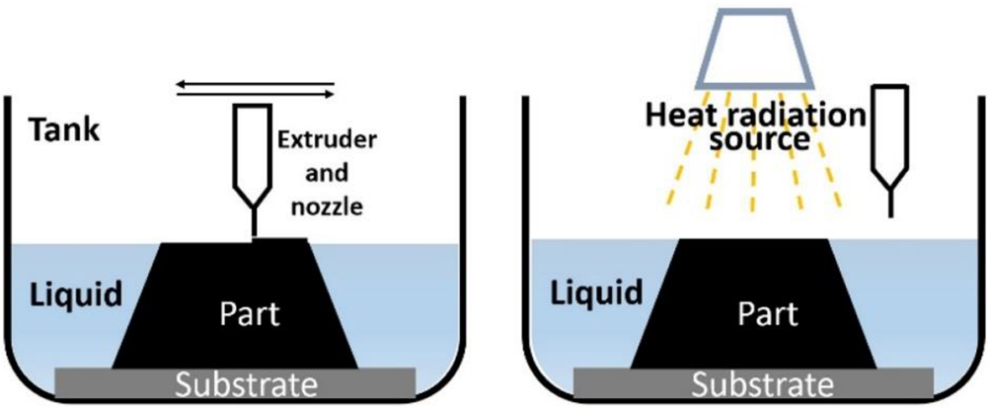


Figure 6: Free Form Extrusion Fabrication [8]

5. COMPONENTS OF FDM PRINTER:

5.1. Material Extruder:

It is also known as the cold end of the printer and it is the upper portion of the assembly. It carries out the filament to the hot end for melting. The cold end of the printer has the spool where the feedstock material is loaded. It consists of three main parts which are a stepper motor, a drive gear and an idler (bearing).

To feed and extract the filament precisely, the extruder uses a torque and pinch system. The drive gear and the bearing grab the filament and passes it through the hot end. They both hold the filament and ensuring the straight path to the hot end. There are two types of extruders [9]:

- Bowden Extruder
- Direct Drive Extruder

Bowden Extruder:

The hot end is not directly connected to the Bowden extruder. Instead, a Bowden tube is used to connect the main extruder body to the hot end once it is placed some distance away.

Teflon is frequently used to make Bowden tubes because of its low friction qualities. Faster and more precise printing is possible but filament control is difficult.

The issue arises in the distance between the extruder and hot end where it can cause retraction issues like stringing and oozing and the friction also increases the motor load.

Direct Drive Extrusion:

In this the extruder is directly mounted on top of the hot end. The filament is sent through the nozzle with the aid of the motor. Since the distance between the extruder and the hot end is small and thereby reduces the friction and provides and greater filament control for flexible printing [9].Both were shown in the below (Figure 7) [10].

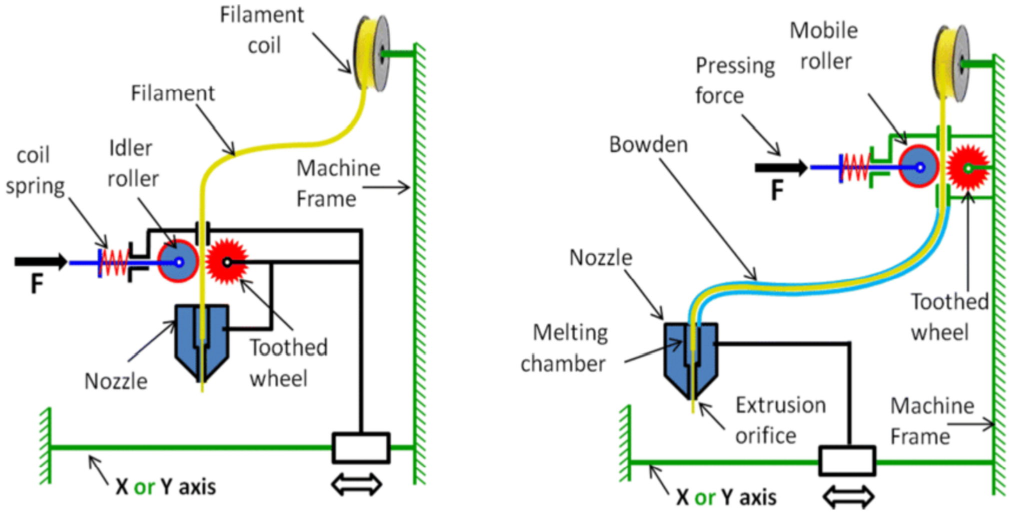


Figure 7: A) Direct drive extruder B) Bowden extruder [10]

5.2.Nozzle:

The diameter of the material filament is determined by the nozzle. It is in the extrusion assembly. Nozzle made of diverse materials can be found just as the furnace block. In most cases brass nozzles are used because it is less expensive. Nozzles with different thread types can be utilized with different extruder models. It is possible to create smaller details using finer nozzles. With larger nozzles, you can extrude more material in a single pass and print more quickly.

5.3.Print Bed:

The platform on which the filament is placed to create the print is referred to as the 3D printer's build surface. The build surface may move in a predetermined direction or remain stationary, depending on the printer's model. The first layer and the adherence of the build plate have a significant impact on the quality of the 3D print. Therefore, the build surface is crucial to the printing process. There are different things to ensure when using the bed. These include:

Heating: Some print beds include a heating pad attached to them so that the printing surface could be heated. The initial layer adhesion and warping are improved by the higher temperature, especially when printing materials like ABS and polycarbonate.

Material: The performance of the construction plate is also influenced by its material. It establishes how heat-resistant the build plate is and how effectively the filament will adhere to it. Some of the print bed materials are Glass, BuildTak, PEI, Aluminium [9].

5.4. Motor:

In addition to extruding and retracting filament through the extruder, motors also provide the power for moving the print bed, print head as well as extruding and retracting the filament through the extruder. Normally 3d printers uses Brushless DC Stepper motor called a stepper motor. They run in small rotational intervals called steps. Each input pulse from the controller turns the shaft one step until it reaches the position. The image of stepper motor is shown below (Figure 8) [9]

Figure 8: Stepper Motor [9]

6. MULTIMATERIAL VS MULTICOLOR:

One of the fundamental features of additive manufacturing that can maximize its potential way beyond that of traditional manufacturing techniques is multi-material 3D printing, which includes employing more than one type of material in a single build. It is possible to implement additive manufacturing of multimaterial through techniques including FFF or FDM, SLA, and inkjet (material jetting) 3D printing.

The possibility of producing 3D printed items with various colors or distinct material qualities, such as elasticity or solubility, is established by extending the design space to other materials [11].

Multimaterial printing is totally different from Multicolor printing, because the use of various colors of a single type of material is all that multicolor printing solutions can offer; multiple types of material could not always be enabled by these methods.

This means that while a printer capable of printing on many materials will also be able to print in multiple colors, not all multicolor solutions can be used for printing on multiple materials [12].

6.1. Advantages of Multimaterial Printing:

- In this we can choose two or more materials for the whole model. It eliminates the need for post-print assembly, which is beneficial because assembly may be time-consuming and models are frequently vulnerable to breakage at the joints where two sections link.
- It can print soluble material like PVA where they require supports or else it is tough to remove the surface of a model. With this we can better surface finish.

6.2. Challenges on Multimaterial Printing:

- It's not as easy to change materials as it is to change a spool. Think about PLA and TPU as two examples. To print successfully with these materials, significantly different slicer settings must be used. You would have to alter the print speed, retraction settings, nozzle and bed temperatures, and other parameters to switch between them.
- Additionally, we must make sure to completely remove one material from our printer's nozzle before printing with another. Otherwise, the new, lower temperature will prevent the small pieces of ABS from exiting the nozzle and may result in blockages if we try to print PLA while still having some ABS in your nozzle [12].

6.3. Printing Methods:

It is based on the type of approach, because each has its own flaws. Generally, there are two types:

Single Extruder - Single Nozzle design:

- These are done in a standard printer. With some modifications in the printer accessories, we can pursue multimaterial printing.
- In these multiple materials are combined in the single nozzle design either before or during the melting phase of the print head so that they may all be extruded through the same nozzle. For examples multiple filaments can be cut and attached to make a single filament of mixed type.
- For this type most of them uses Bowden extruder type and the name of this technique is done with the help of Mosaic Palette. The design of this type is shown on below (Figure 9) [11].

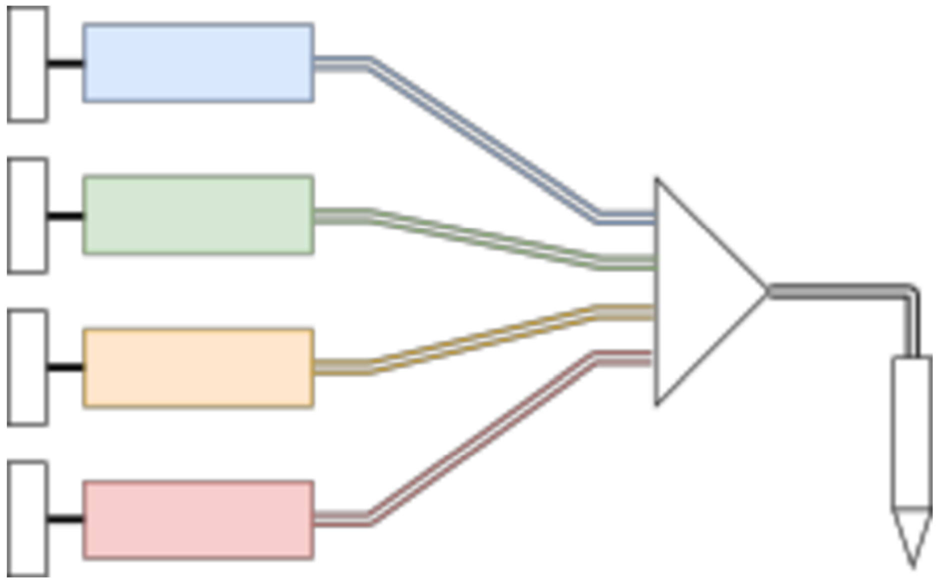


Figure 9: Single Extruder - Single Nozzle design [11]

- There are many impurities since it is because of material mixing before the new material comes in to the extruder. Theses impurities were driven into infill printing or in some cases it has solved through wipe tower.
- The main disadvantages of this type are the purging of color material in the extruder which is previously printed and which is overlapped by the current color material which is quiet devastation.
- But the advantage is we don't need to setup different temperatures for each of the filament either if it is a different material. There is also no need for setting different print bed temperature.

Multi Extruder – Multi nozzle design:

- In this each one of the extruders has a separate nozzle which the materials do not interfere with each other. Either the same print head or separate print heads can accommodate the nozzle.
- For this method each nozzle has to be calibrated separately in order to achieve precise printing. In addition to that one of the main advantages is

materials don't mix with each other. This main helps in reducing the wastage of material.

- When we compare with the single extruder – single nozzle design it is not necessary to use infill patterns for mixed materials and a wipe tower. The design of this type is shown below (Figure 10) [11].

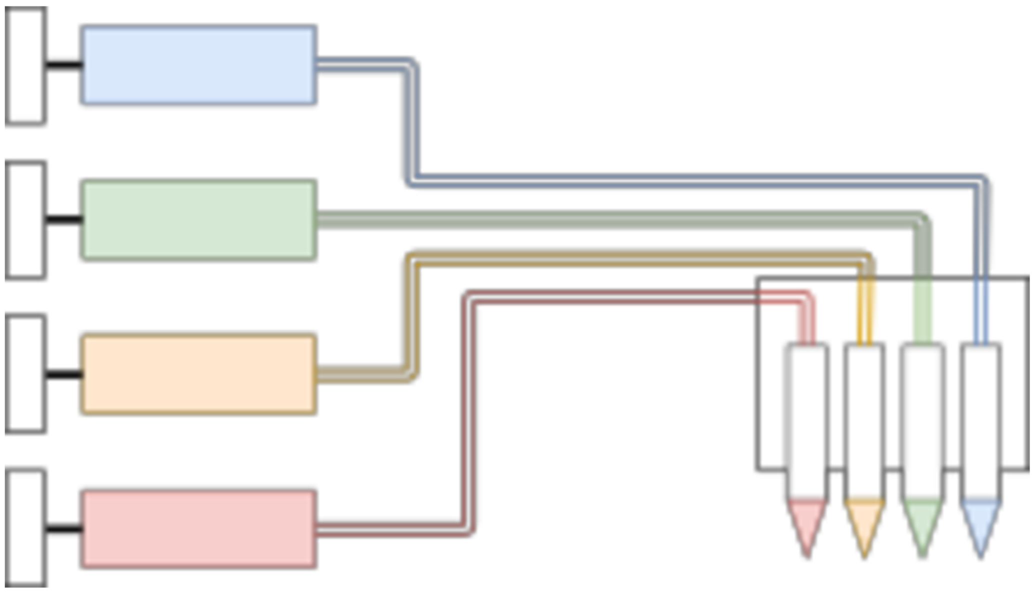


Figure 10: Multi extruder - Multi nozzle design [11]

- Furthermore, for this type, each extruder has to be controlled separately by the use of G – code in order to attain the good quality parts.
- The main advantage of this type is the time requires for swapping between filaments is no longer here so that the processing time reduces. With this we can also print structures with lighter and harder materials at the whole. We can also set different parameters for each nozzle with respect to distinct materials or structures.

6.4. Multi Material Slicing:

6.4.1. Design of CAD part:

- Before importing a CAD model, it should be designed as two or more parts and then we need to assemble. Since we need to assign materials and the extruders for the parts respectively. The model was shown on the below (Figure 11, 12). At that time, we can also select suitable temperatures and location of the parts separately.
- With the help of this we can also assign colors for the respective parts in the software for slicing of the material.

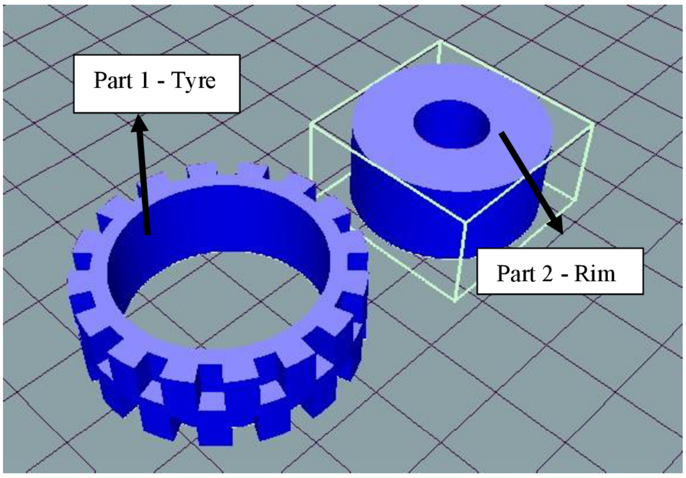


Figure 11: CAD model

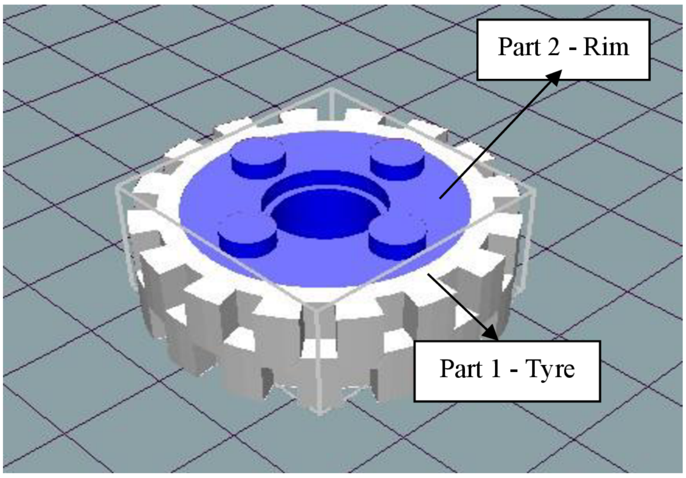


Figure 12: During Slicing

6.4.2. Setting Extruder Sequence

- This has to be done for the use of assigning colors for the parts i.e., up to which layer or how many layers it will print with the color and after that which extruder has to follow up that.
- This also done by customizing the G – code in the slicer software. By setting up G – code we also fix the suitable temperature for the respective extruders. [13].

6.4.3. Wipe tower:

- These wipe towers are used for the continuous flow of filaments of different materials in the extruders. It also used for the color transitions in the extruder. These are disproportional to the size of the object to be printed. It is shown on the below (Figure 13) [14]. We can use the wipe infill option for printing without the use of tower. In these darker colors of material are used in the center of the object by using the slicer software infill settings.

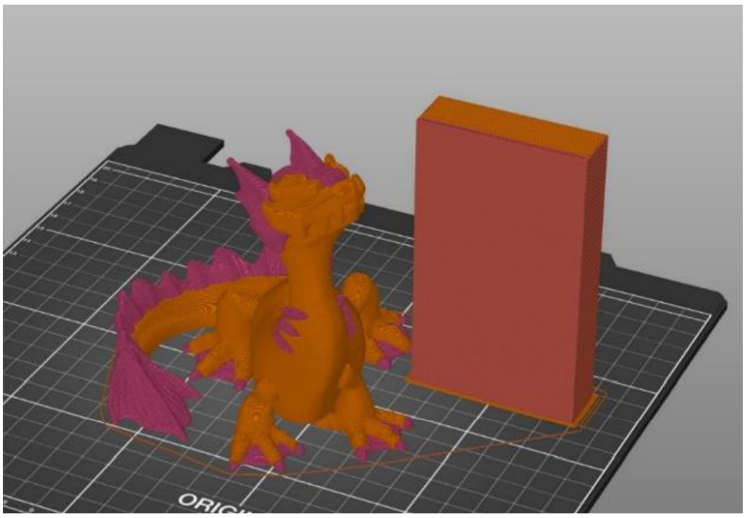


Figure 13: Wipe tower [14]

6.5. Solutions for printing Multimaterial:

6.5.1. Filament Swapping:

It is the most common method in 3d printing for printing multicolor with a single extruder. The print must be halted halfway through so that a new filament can be changed. It will require a lot of work because you'll have to keep an eye on the 3D printing process and sometimes assist.

The other method of approach is including commands in the model's G-Code. It is more flexible than the manual method but it requires the knowledge to write and manipulate G-Code commands. The complexity of your design will determine how frequently you'll need to swap out another filament. By changing the orientation of the model in the slicer program so that color transitions take place precisely on layer boundaries, we may optimize this procedure [15].

6.5.2. Mosaic Palette:

In order to feed the printer a single, continuous length of filament that is created similarly as if you were using a single material, the Palette carefully cuts and inserts a variety of materials. The palette was shown below (Figure 14).

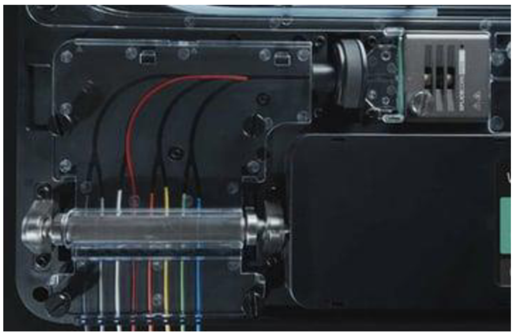


Figure 14:Palette [12]

One drawback is that it prints a purge block to make sure the print doesn't use the area where the materials were fused—which would have mixed with both materials. It is quite wasteful when printing small object because the purge block can consume more material than the print itself. It is also suitable for single extruders [12].

6.5.3. Slicer Configuration:

If we have multi part model which defines the regions we can assign each one of them to extruder. This can be done through printer settings by incrementing the number of extruders. It also adds that customizing G-Codes between the tool changes followed by the assigning the type of filament and the material associated with it.

6.5.4. Choosing the best type of extruder:

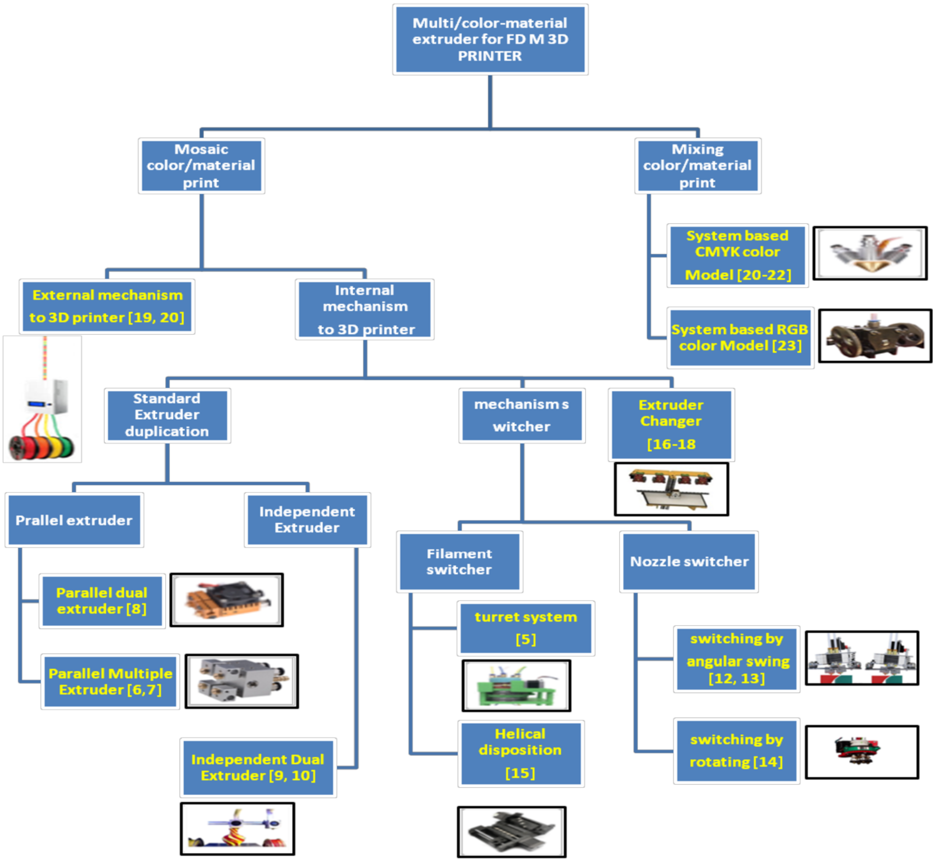


Figure 15:Structure of extruders of FDM 3D printer [10]

Selecting the best combination of extruders based on the effectiveness of the additional features they provide for the multi-material/color function, is quite intriguing. Multi-color/multi-material extruders can be divided into two categories: Mosaic print model and Full mixing print model.

In the mosaic print model, the object is segmented with extensive patterns that are made of the same material or color, while the full mixing color print is made by continuous fading of the shade or color. The picture above shows the type of extruders available (Figure 15) [10].

6.5.4.1 Mosaic color/material print:

These types of systems are based on the replica of the extruder and operate according to the single extruder principle for all the other extruders fitted in the head carriage. The multiple extruders fitted in the carriage can be of parallel or independent type as in the (Figure 16) [10]:

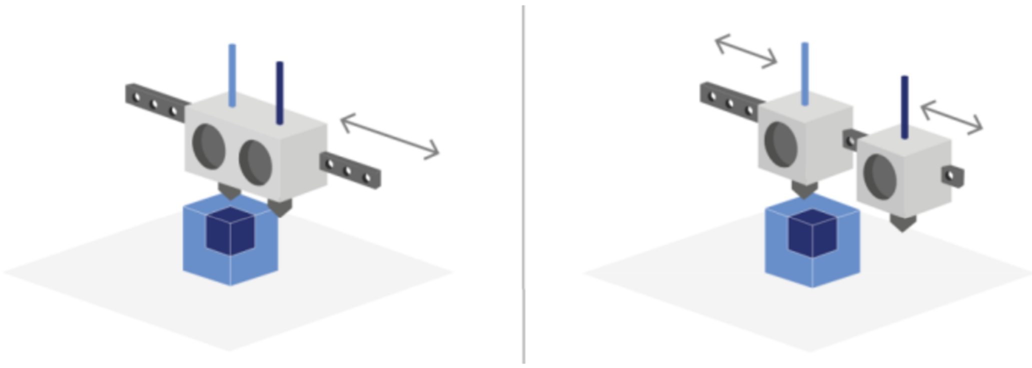


Figure 16:A) Parallel type B) Independent type extruder [10]

The parallel standard extruder contains two or more print head on the same carriage. Then they eventually describe the parallel patterns, whereas in independent dual extruders each of them moves along the x – axis.

The parallel type extruders are bulky and adds excess weight to the machine. It uses single wire drive system similar to clutch gear box and it has the ability to print numerous materials with varied melting temperatures and colors is a benefit of having multiple independent nozzles.

To escalate the productivity, independent extruders with different extruders. Due to the difficulty in calibration these types of extruders are limited to two because of their placement. This type of approach can facilitate collaborative working during the deposition process of the same object while also being suitable for cloning components [10].

6.5.4.1.a). Filament Switcher Mechanism:

This design uses single extruders capable of printing multicolor or multimaterial. It has a switcher mechanism which allows the active filament to switch to standby mode automatically. It is described in below (Figure 17) [10]:

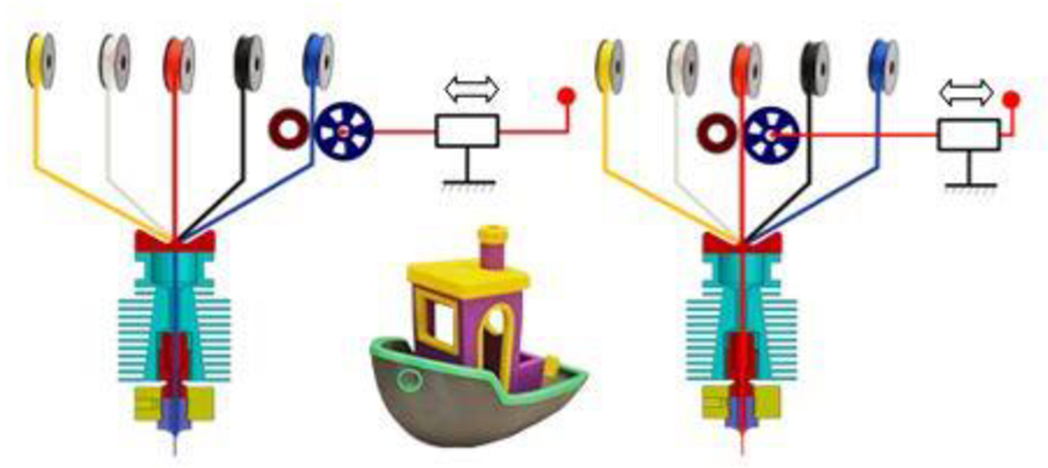


Figure 17:Switcher mechanism from blue color to red color [10]

6.5.5. Multi – extruder electronic control of FDM 3d printers

Apart from the mechanical design of multi extruders it relies on the electronic part and software which controls it. Normal electronic boards are built for single extruders while for the multi extruders it has to be redesigned for our needs. The table 1 below shows the available electronic boards [10].

Table 1 Electronic boards for multi extruders [10]

Board Type	**CPU**	**CPU Speed**	**Stepper driver**	**No. of. extruders**	**Expansion possible of extruders**
Electronic boards with 8 bits					
RAMPS 	Atmega 2560	16	4988, panelsPololu	2	**4** with RAMPSXB **4** with CNC Shield
Rumba 	Atmega 2560	16	A4988, DRV8825	3	no expansion found
Megatronics 3.0 	Atmega 2560	16	A4988, Pololupannel DRV8825	3	no expansion found
Azteeg X3 Pro 	Atmega 2560	19	A4988, Pololu boards, digital current control (1/16 µ steps/step)	5	no expansion found

A). Microcontroller based electronic boards:

The most widely used and standard electronic boards which has 2 extruders at a place is RAMPS 1.4. But according to the needs for extruder we can innovate a custom electronic board from many of the open sources that are mentioned in the Table 1. The stepper drivers which control the extrusion system is most important factor for choosing the electronic board [10].

B). By Parallel Process Controlling:

Normally microcontrollers are run by serial connection which executes one input at a time. To make it parallel, there is a need to build a star network configuration where different MCUs make the task to be done. On the other hand, the performance of the Arduino UNO board in parallel connection limits the processing speed, so it is resolved by replacing Raspberry Pi 3. The picture below shows the network (Figure 18) [10].

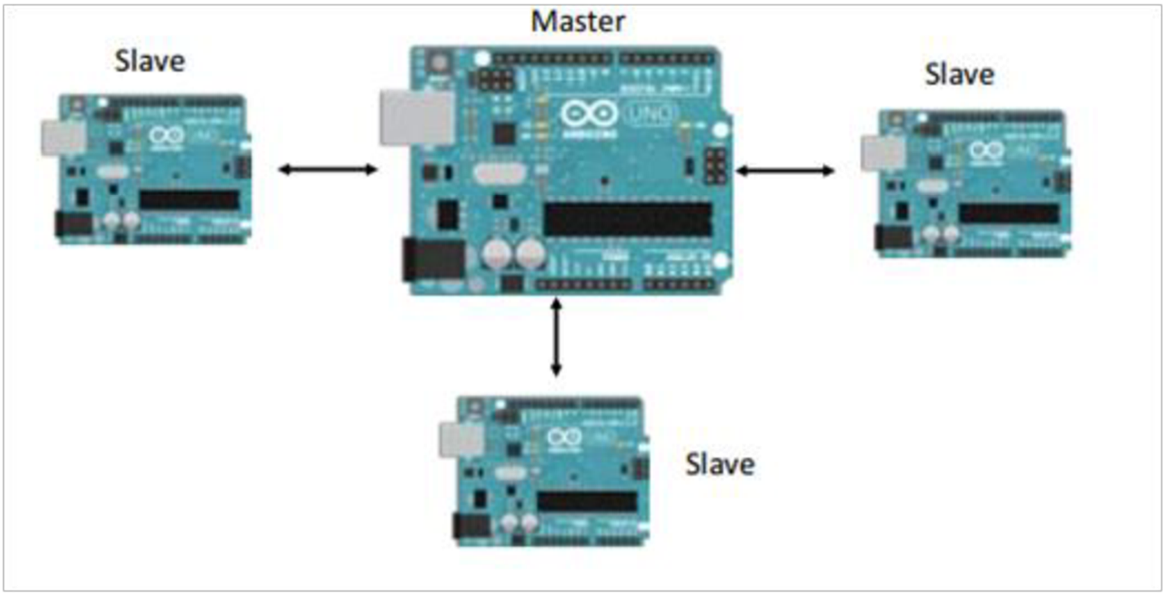


Figure 18: MCU star network for Parallel Connection [10]

C). Control using FPGA board:

The FPGA board has the advantage of associating large number of inputs and outputs with high execution speed while the microcontrollers don't. It is flexible in nature and can be designed according to the need of the application and equipment to be controlled. The structure of FPGA board with host software RepRap is shown below (Figure 19) [10].

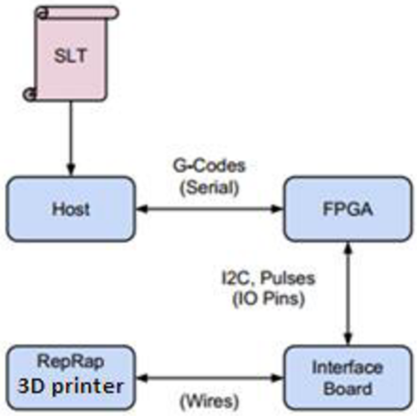


Figure 19: Structure of FPGA card for RepRap 3d printer [10]

7. MATERIAL USED FOR 3D PRINTING:

7.1. Polylactic Acid (PLA):

- Polylactic acid, usually referred to as PLA, is a thermoplastic monomer made from organic, regenerative resources like sugar cane or maize starch. Contrary to most plastics, which are made using fossil fuels by distilling and polymerizing petroleum, PLA is manufactured using biomass resources.
- It is inexpensive and have a low melting point. Printers with an operating temperature between 157 °C and 170 °C are ideal for use with PLA filaments. It works best on 3d printers with a bed temperature of 60 °C. Since it has low glass transition temperature is not suitable for modelling high temperature applications [16].

7.2. Acrylonitrile Butadiene Styrene (ABS):

- One of the earliest plastics to be utilized with commercial 3D printers was this substance. Thanks to its economic cost and strong mechanical qualities, ABS is still a highly well-liked material today, many years after its development.

- ABS is renowned for its durability and resilience to impacts, enabling you to print robust parts that can withstand increased use and wear. Cooling fan is not required for this material.
- It is tough, non-toxic and durable. It has high melting point of 210 – 250 °C. When used on a cold heat bed, this filament has a tendency to distort. So, the print bed should have the temperature of 80 – 110 °C.
- The pungent, disagreeable smell of ABS filament is one of its drawbacks. It is therefore advisable to use this filament in a well-ventilated space with a closed-frame 3D printer [16].

7.3. Nylon:

- A very robust, long-lasting, and adaptable 3D printing material is nylon filament. Nylon lends itself well to things like living hinges and other functional pieces since it is flexible when thin but has a high inter-layer adhesion. It is one of the cheapest filaments since it melts at a high temperature 230 °C, these are only used in 3d printers designed to handle such temperatures. It is also necessary to heat the print bed because nylon tends to curl when printed on a cold bed [16].

7.4. Thermoplastic Elastomers:

- These are nothing but Thermoplastic Polyurethane (TPU) and Thermoplastic Elastomer (TPE) materials that exhibit rubber like characteristics. It has high impact strength and resistance to low and high temperatures of -30 °C – 140 °C and it’s good to abrasion resistance. It has an extruder temperature of 210 – 260 °C and the bed temperature should be kept low as possible [16].

7.5. Polyetheretherketone (PEEK):

- It is a high-performance engineering thermoplastic that can be used as a lightweight alternative to metal since it is extremely strong, heat-resistant, and flame-retardant. PEEK components can weigh up to 70% less than metal components.
- With the help of this material many customizable parts can be created because of its inert properties and it is capable of producing parts for aerospace with mixture of aluminum and titanium alloys [17]. Large generic components that could be produced using less expensive polymers. It has the heat deformation temperature up to 143°C.

7.6. Soluble Filaments (HIPS and PVA):

- High Impact Polystyrene (HIPS) is low in cost and has a great impact resistance, matte texture and has great aesthetic qualities. HIPS becomes a perfect companion for dual extrusion since it shares many of ABS' printing characteristics.
- HIPS is a terrific option for parts that would eventually wear out or be utilized in applications that could benefit from the lesser weight because it is not just excellent for supporting your ABS prints but is also more dimensionally stable and somewhat lighter than ABS. It is best used on a print bed with a temperature of 55 – 65 °C. It has a hot end temperature of 240 °C.
- Polyvinyl Alcohol (PVA) actually dissolves when it comes into contact with water, which makes it an excellent material for 3D printing support structures. PVA supports can be used to print exceedingly complicated shapes or ones with partially enclosed chambers. They are simple to remove by dissolving in warm water. It has a nozzle temperature

of 180 – 200 °C and print bed temperature of 45 – 60 °C. PVA can also be used as a model material if there is a need to make quick prototypes [16].

7.7. Acrylic Styrene Acrylonitrile (ASA):

- It is an ABS-like plastic that can be printed in three dimensions. By altering the type of rubber used in the composition, it was initially designed as an ABS substitute that would be more UV resistant.
- ASA is renowned for its excellent temperature tolerance, high impact resistance, and challenging printing properties. Due to its higher resilience to UV and severe weather, it frequently replaces ABS in outdoor applications[18]. It has a bed temperature of 90 – 110°C and extruder temperature of 230 – 270°C [19]. It has high impact and resistance to wear and it is expensive.

7.8. Iglidur®:

- It is one of the high-performance polymers for 3d printing. The iglidur® 3d printing filament has an extra-ordinary service life. It is 50 times more abrasive resistant than other 3d printing materials.
- Due to their tribological properties, the igus® Tribo – Filaments are best suited for replacing parts like bearings, nuts and gears and it also allow the nozzle temperature to set as constant. Due to their elastic properties, it can be widely used in areas where there were strong bending profiles. Elements like actuators, pneumatic grippers are suited for this type [20]. These filaments are used in the areas where there is single piece production of parts in small volumes, wear resistant parts and in the construction of jigs. It has a nozzle temperature of 240 - 250°C and a bed temperature of about 20 – 60°C. It is easy to process for 3d printing.

8. EXPERIMENTS:

8.1.3D Model of Printer:

This printer is based on the Rep rap technology and is called the dual head cube type 3D printer. It uses Repetier host software for the whole printer functioning. The printer has the co – ordinates of x, y and z axes. Here the X and Y axis corresponds to the extruders and the Z axis corresponds to the print bed which is moving in up and down direction. The dimensions of the printer are 440*395*635 mm and the print bed dimensions are 210*210 mm. It consists of two extruders with a cam mechanism included with the fan for hot end cooling. The diameter of the nozzles was 0.4 mm The material filament spool is kept at the top of the printer. The printing progression was displayed on the small display and also on the software. The printer was shown in the below (Figure 20):

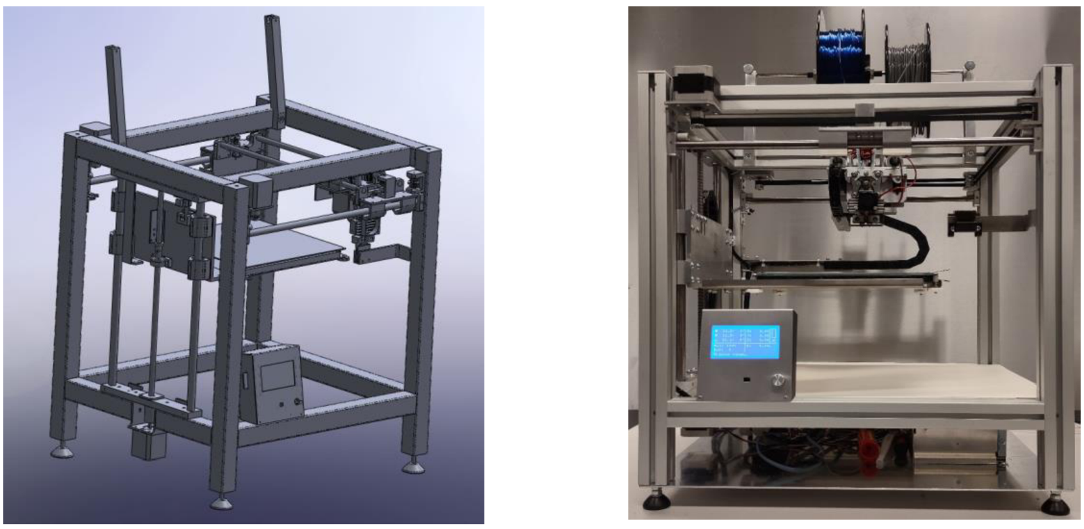


Figure 20: 3d Model of KSA Printer

Output Validation:

The output of the printed part that we going to measure is of visual quality that should not be without oozing of material without any break in between the layers.

8.2. Components Prepared:

Extruder:

As we discussed earlier, there are two types of extruders. We used Bowden type extruder for our printer. This extruder is fitted with the fan and the wheels for filament driving. It uses cam mechanism to enable both the nozzles one after the other according to the need. The image of the extruder is shown below on (Figure 21):

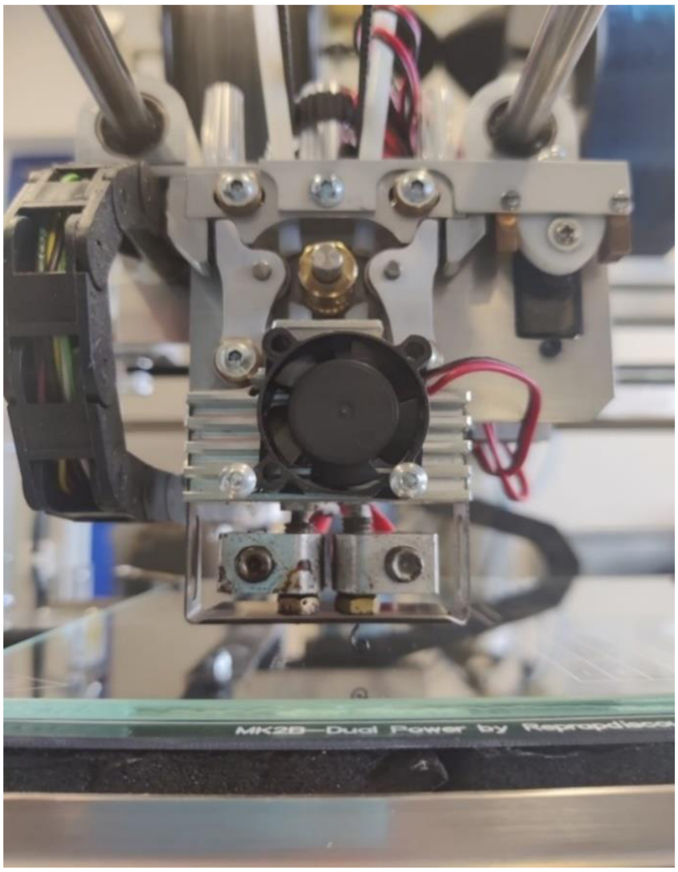


Figure 21: Extruder

Nozzle:

We designed a new nozzle with three converging orifices for the easy flow of melted material. The image of the nozzle with the sectional view is shown below (Figure 22): The whole length of the nozzle is about 12.5mm and the length of each orifice are as follows L1 with 7.5mm which is the input, length of L2 is 4.5mm and the final output orifice L3 is 0.5mm and the diameters are 2mm, 1mm and 0.4mm consecutively.

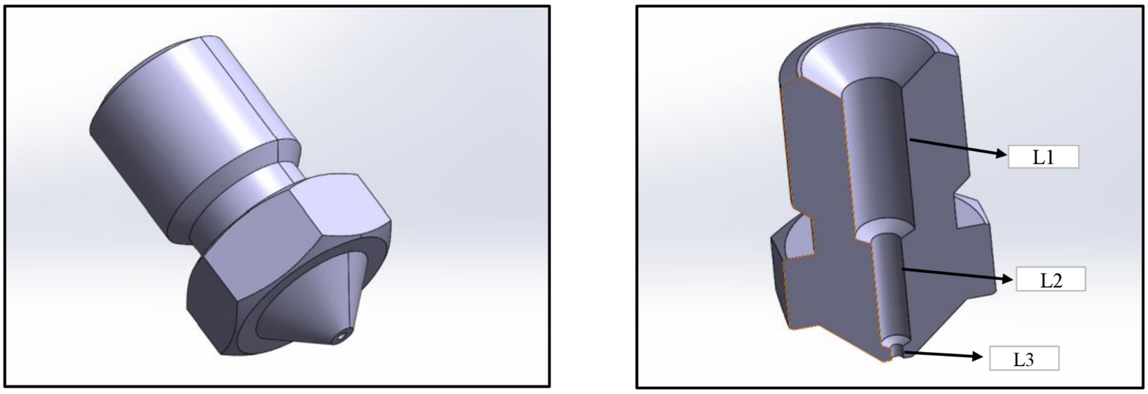


Figure 22: New Nozzle

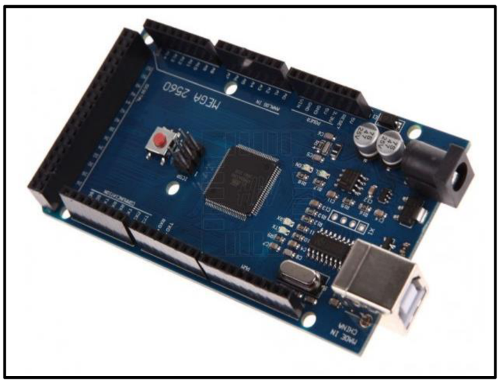
Print bed:

It is one of the important components for creating a 3d printed part. It has two main elements heating pad and the construction plate. Our heating bed can produce power of about 120 watts for 12V and so it is insulated and the construction plate we use is glass. Before starts printing we need to apply a glue so that the printed part can stick to the construction plate firmly forming a base layer. The image of the heating pad and the plate is show below on (Figure 23):

Figure 23: Construction plate and heating pad

Micro controllers:

Since micro controllers acts as a central processing unit, we used Arduino board of type Mega 2560 with the synchronization of Ramps 1.4. The image is shown below (Figure 25)[21]:



Arduino Mega 2560

Ramps 1.4

Figure 24: Micro controllers [21]

8.3. Printer Setup:

To setup the printer for printing, Go to Repetier host software – config – printer settings [22].

Printer Connection:

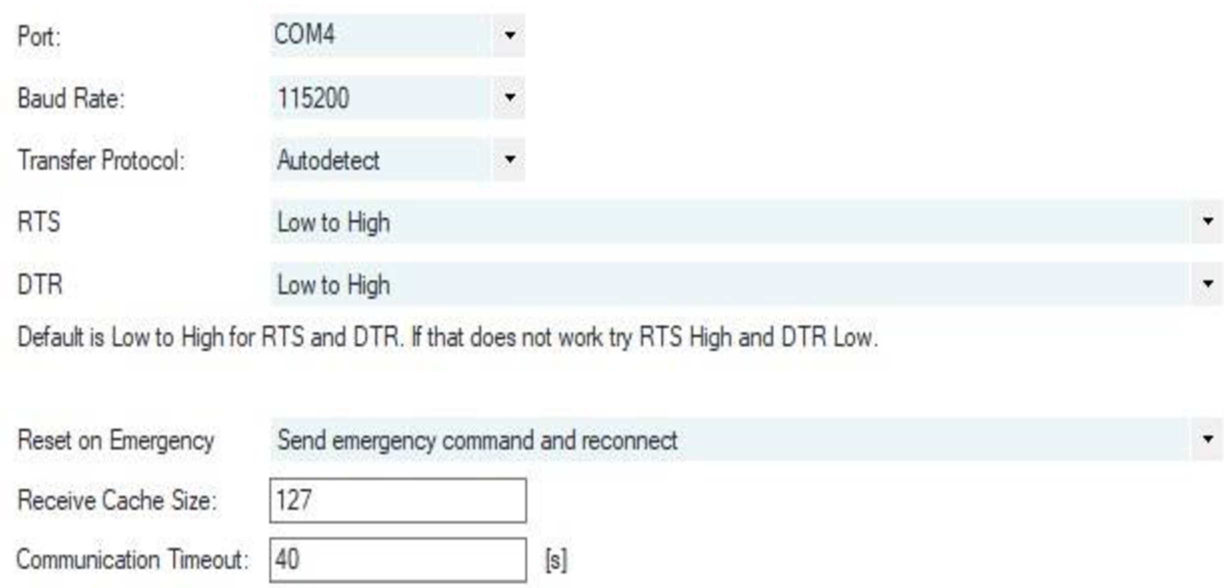


Figure 25: Printer connection settings [22]

The port for connection is selected as COM4. Then the baud rate was detected automatically detected from the firmware settings. Baud rate is about 115200 which is nothing but the speed at which the transfer of G – codes shifts. Transfer protocol is set as autodetect to communicate with the printer to get the data in the binary form.

Printer Setting:

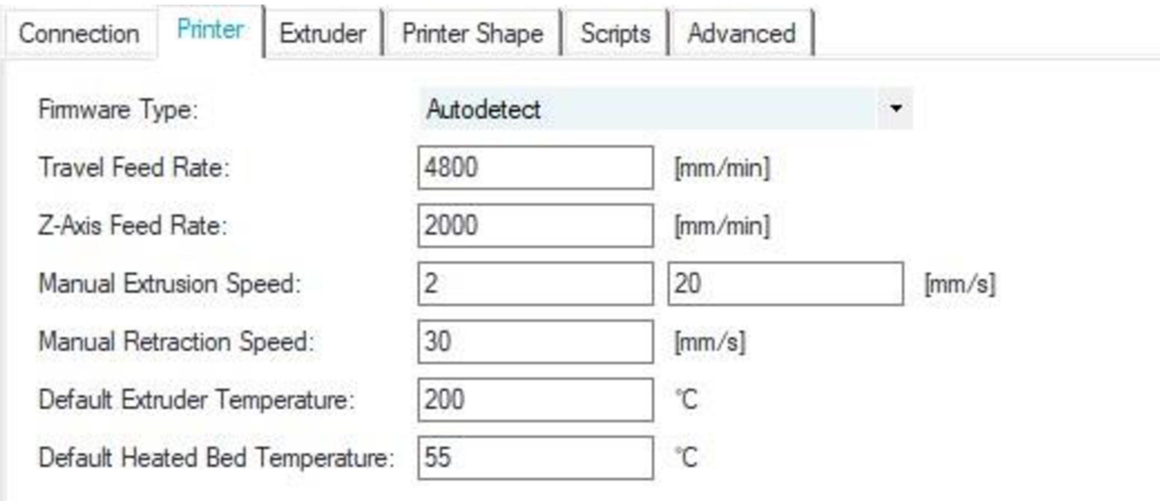


Figure 26: Printer Setting [22]

In the printer tab we can see the parameters like feed rate, extrusion and retraction speed, extruder and heat bed temperature[22]. These are some of the default units which we can change according to the need.

Extruder configuration:

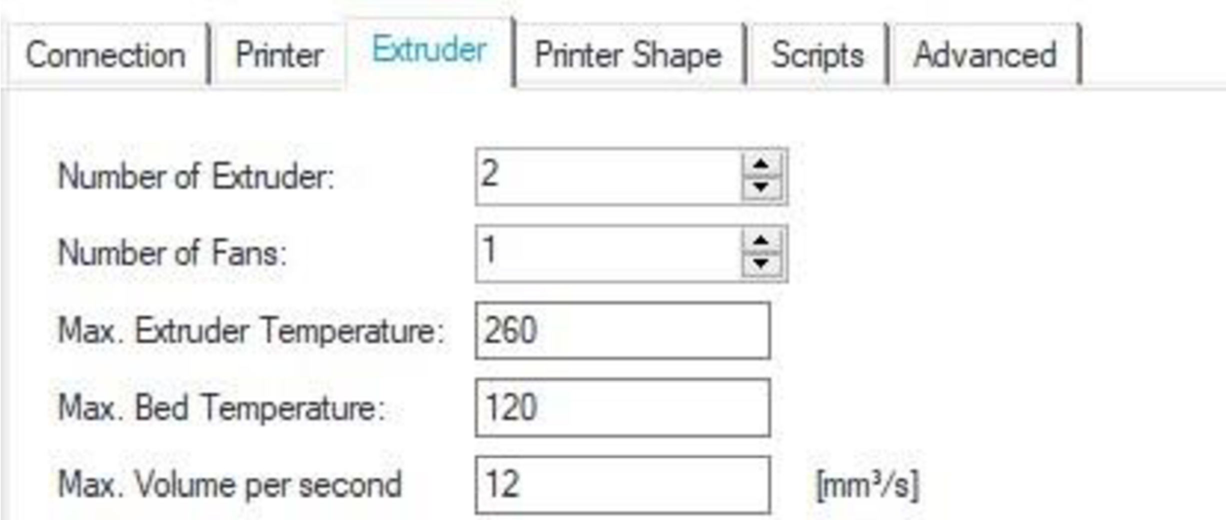


Figure 27: Extruder setting [22]

These are the major settings in the extruder tab. As for our design we will have two extruders and the maximum bed temperature as 120 ^{0}C and the maximum extruder temperature as 260 ^{0}C, maximum volume per second is 12 mm^3/s.

Printer shape configuration:

In this for our printer shape, the X – axis limits were set from 0 mm to 238mm. Y axis limits were set as 0 mm to 200mm. the print area width, depth and height were 200mm*200mm*150mm[22].

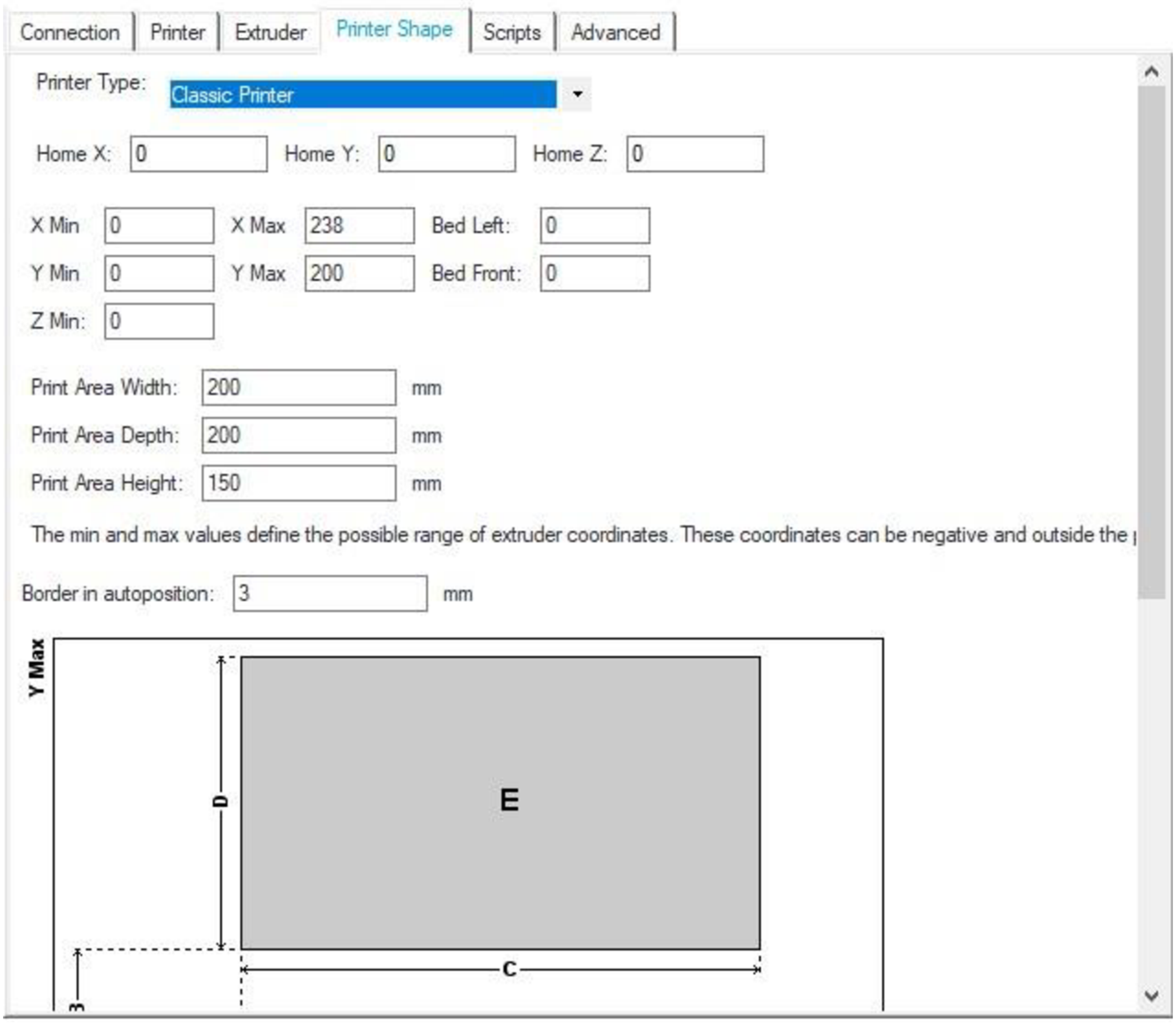


Figure 28: Printer shape configuration [22]

8.4. First trail:

For the first trial of our part, we used black PLA material and blue PETG material. For the outer part we used extruder 1 and PLA corresponds to it and for the inner part extruder 2 is used with PETG material.

The temperature for PLA is 220 ^{0}C.
The temperature for PETG is 245 ^{0}C.
Bed temperature is 60 ^{0}C.

On this trial run we faced so many flaws like incorrect nozzle placement, nozzle oozing etc., were shown in below (Figure 29):

Figure 29: First trial

8.5. Calibration tests:

Since we found that there is an incorrect setting of nozzle co – ordinates. By changing the extruder offset steps in the Firmware EEPROM settings we can calibrate the nozzle. The calibration tests and the results were discussed below.

Test 1:

When we test it, we found that there is problem with the extruder 2 which is blue PETG. For every 1mm it corresponds to 320 steps. For the first one the firmware setting and the test result were shown below (Figure 30):

Figure 30: Calibration test 1

Extr.2 PID I-gain	2.0000	
Extr.2 PID D-gain	40.0000	
Extr.2 PID max value	255	0-255
Extr.2 X-offset	3200	steps
Extr.2 Y-offset	0	steps
Extr.2 Z-offset	0	steps

Figure 31: Firmware EEPROM setting 1

Test 2:

In this we corrected in both the x and y offsets of extruder 2. The steps of about 64 are for the x axis and for y it is about 3264 steps. The test result was shown below (Figure 32).

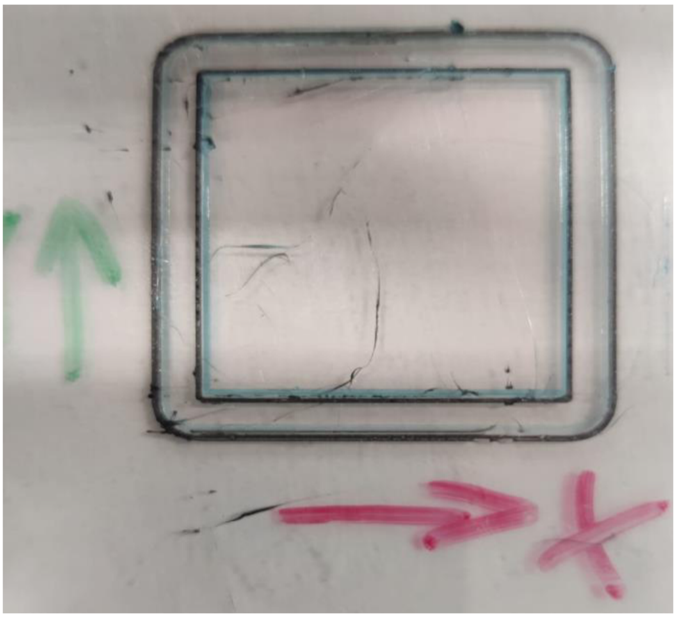


Figure 32:Calibration test 2

Extr.2 PID I-gain	2.0000	
Extr.2 PID D-gain	40.0000	
Extr.2 PID max value	255	0-255
Extr.2 X-offset	3264	steps
Extr.2 Y-offset	64	steps
Extr.2 Z-offset	0	steps

Figure 33:Firmware EEPROM setting 2

Test 3:

In this the x offset was good but in the y direction the offset is changed to 128 steps. Hence, we get the good results as shown below (Figure 34) and the part result were shown on (Figure 36):

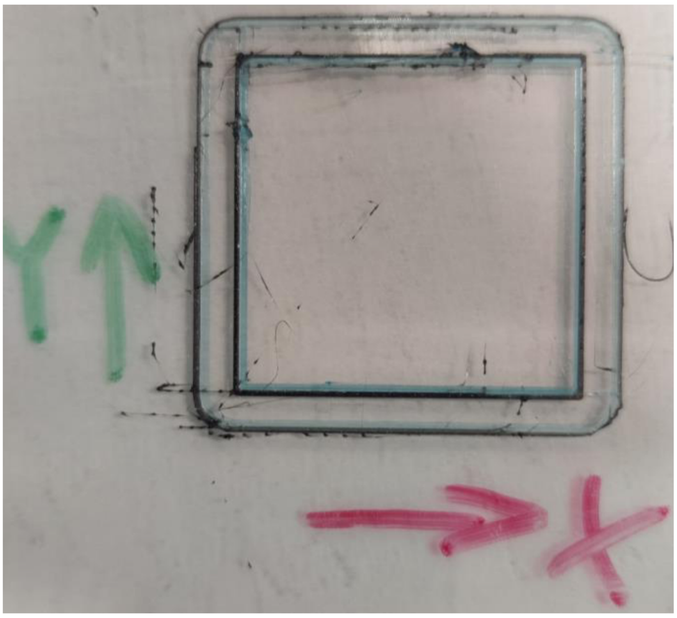


Figure 34:Calibration test 3

Extr.2 PID I-gain	2.0000	
Extr.2 PID D-gain	40.0000	
Extr.2 PID max value	255	0-255
Extr.2 X-offset	3264	steps
Extr.2 Y-offset	128	steps
Extr.2 Z-offset	0	steps

Figure 35:Firmware EEPROM setting 3

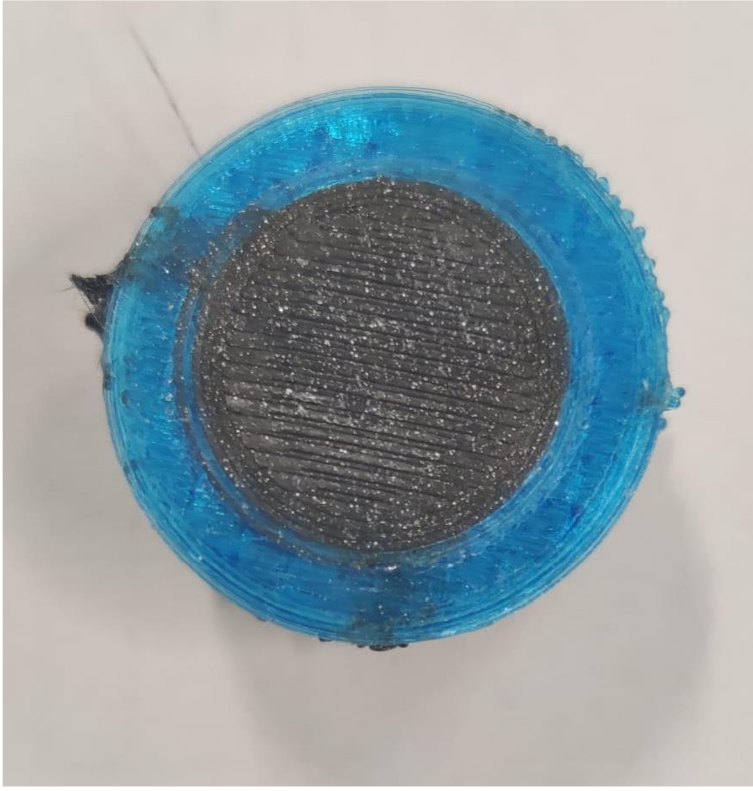


Figure 36: Result of calibrated nozzle

8.6.PLA vs PETG:

As we seen from the above trail tests, we get to know there is a main problem called oozing. To overcome that we introduced the tool change G – code. The new set of G – codes will reduce the temperature of the idle nozzle to 15 ^{0}C and vice versa. At the same time brush is introduced and for every layer the nozzle is cleaned using brush (Figure 37) with the G – code. The Figure and G – code is shown below.

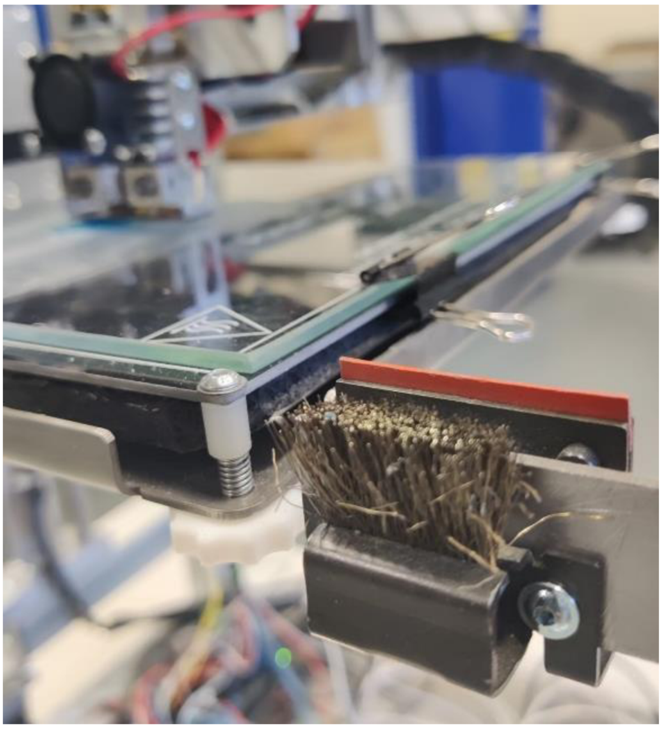


Figure 37: Cleaning brush and Silicone rubber

We can edit this G – code by Prusa slicer – Printer settings – Custom G code – Tool change G code.

```
G92 E0
{if previous_extruder>=0}M104 S{temperature[previous_extruder]-15}
T[previous_extruder]{endif}
M104 S[temperature[next_extruder]] T[next_extruder]
G1 E-5 F1500
G1 Y0 F10800
G1 X214
T[next_extruder]
{if next_extruder==0}G1 X224{else}G1 X234{endif}
M109 S[temperature[next_extruder]]
G4 S1
G92 E0
G1 E8 F500
```

```
G4 S1
G1 Y18 F500
G1 Y0 F3500
G1 Y18
G1 Y0
G1 Y18
G1 Y0
G1 X100
G92 E0
```

Table 2:Parameters for test samples

Parameters\Tests	**Test 1**	**Test 2**	**Test 3**
Extruder 1 material	PLA	PLA	PLA
Extruder 2 material	PETG	PETG	PETG
Extruder1 temperature	220 ^{0}C	220 ^{0}C	220 ^{0}C
Extruder 2 temperature	245 ^{0}C	245 ^{0}C	245 ^{0}C
Bed temperature	60 ^{0}C	60 ^{0}C	60 ^{0}C
Feed rate	100 %	100 %	100 %
Flow rate	100 %	100 %	100 %
Retraction	Only for PETG	Both the filaments	Retraction for PLA is disabled
Speed of printing	60 %	60 %	40 %

The results of all the above three tests were discussed below:

Sample Test 1:

For the above parameters for test 1 we faced the results with oozing of the nozzle and improper cleaning of the nozzle. Since there is an oozing, we introduced filament retraction for the PETG material. The retraction length is about 3mm, so the oozing is reduced on the extruder 2. The result of this test is shown below (Figure 38):

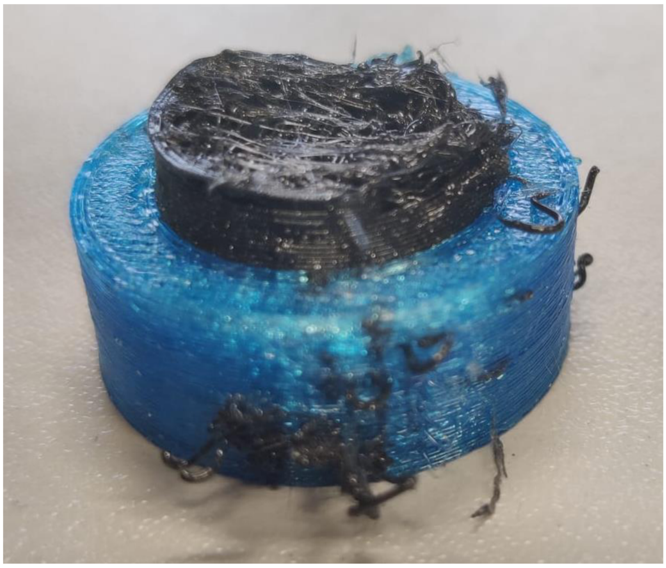


Figure 38: Sample test 1

Sample test 2:

In the second test same testing of temperature is used. In the nozzle cleaning area silicone rubber is kept a bit lower than the brush. The filament retraction is switched on for both the PLA and PETG filaments. At that time the print quality is very poor when compared with the Sample 1 because the retraction of the PLA filament gets stucked inside the nozzle and then the flow of material interrupted. Oozing also continues in this test. The results were shown on below (Figure 39):

Figure 39:Sample test 2

Sample test 3:

Temperature settings are also same on this test. Filament retraction for PLA is again disabled here. The main change here is we decreased the speed of the printing to 60 % to 40 %. Hence the time for printing is increased gradually. But the oozing continues. The results were discussed on below (Figure 40):

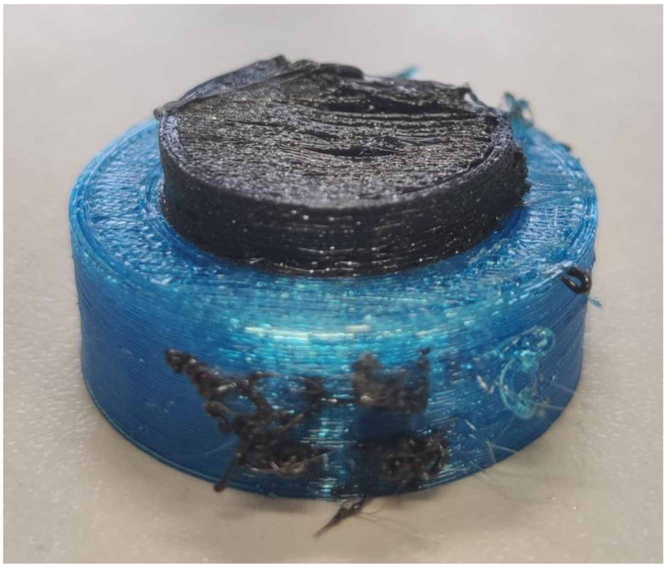


Figure 40:Sample test 3

8.7. Multicolor PETG:

For getting good results in the printing, we used multicolor in the same material.

Sample Test 1:

Extruder 1 – PETG – yellow (245 ^{0}C – 15 ^{0}C)

Extruder 2 - PETG – Blue (245 ^{0}C – 15 ^{0}C)

Feed rate – 100 %

Flow rate – 100 %

Bed Temperature – 60 ^{0}C

We printed with this configuration by switching on retraction for both the extruders. We also reduced the temperature in the unused nozzle by 15 ^{0}C to defend oozing of the material. But the oozing continues in the yellow PETG, the result was shown below (Figure 41):

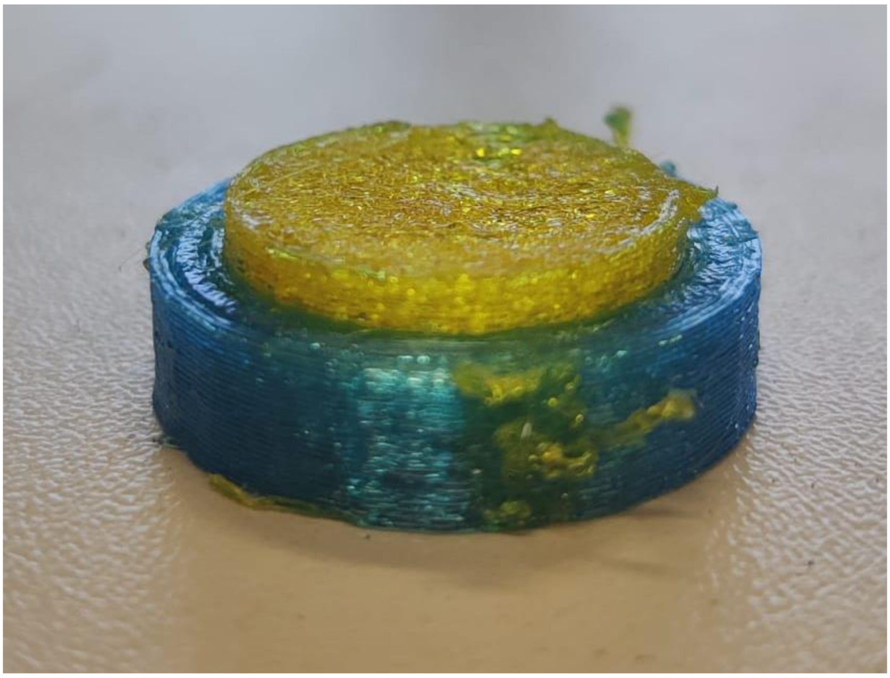


Figure 41: Multicolor Test 1

Sample Test 2:

Extruder 1 – PETG – yellow (235 ^{0}C – 15 ^{0}C)

Extruder 2 - PETG – Blue (245 ^{0}C – 15 ^{0}C)

Feed rate – 100 %

Flow rate – 100 %

Bed Temperature – 60 ^{0}C

To reduce the oozing problem in the yellow PETG we reduced the temperature to 235 ^{0}C. Oozing in the material is only somewhat reduced. The problem is before cooling down the temperature to -15 ^{0}C the extruder starts to printing in the case the material left off in the nozzle becomes problem while printing. The result is shown below (Figure 42):

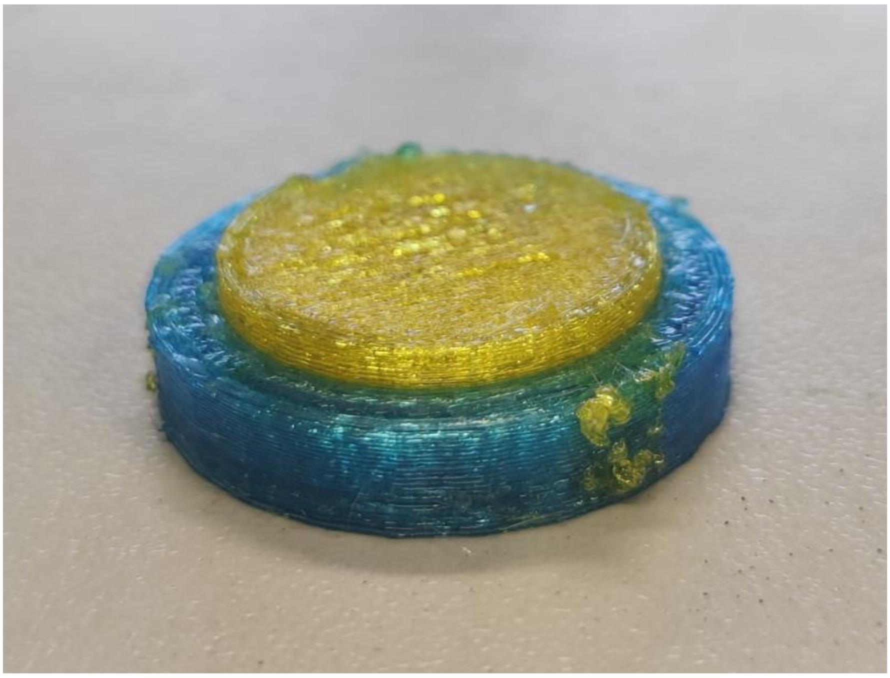


Figure 42:Multicolor Test 2

Sample Test 3:

Extruder 1 – PETG – yellow (235 ^{0}C – 15 ^{0}C)

Extruder 2 - PETG – Blue (245 ^{0}C – 15 ^{0}C)

Feed rate – 100 %

Flow rate – 100 %

Bed Temperature – 60 ^{0}C

To overcome the cooling down problem in the extruder, we solved by changing the G – code in the printer configuration. The result is good compared to previous one. It is in the below (Figure 43):

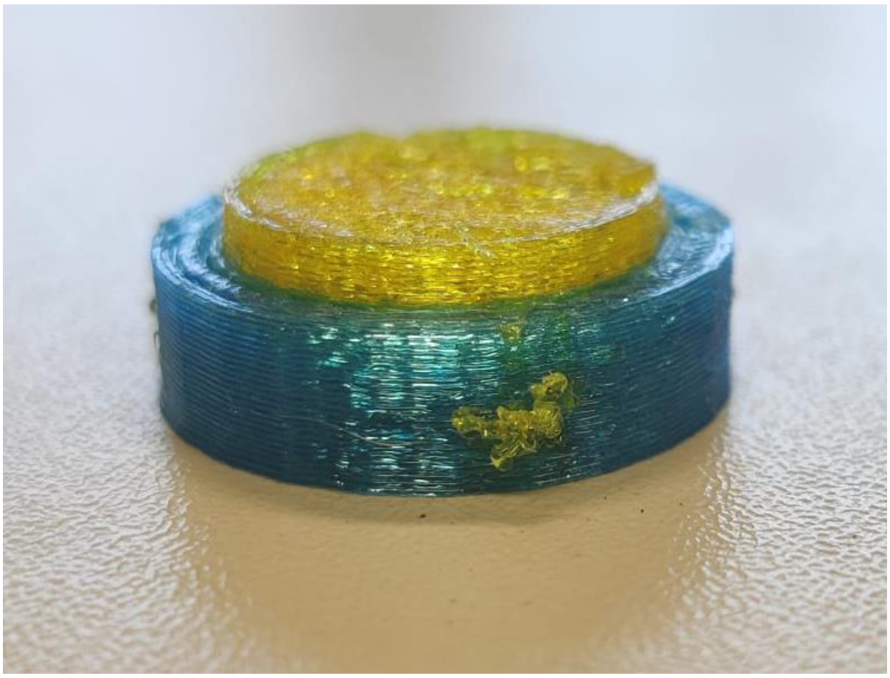


Figure 43:Multicolor Test 3

Sample Test 4:

Extruder 1 – PETG – yellow (235 ^{0}C – 15 ^{0}C)

Extruder 2 - PETG – Blue (245 ^{0}C – 15 ^{0}C)

Feed rate – 100 %

Flow rate – 100 %

Bed Temperature – 60 ^{0}C

In this test we installed a fan for cooling the extruder end. Same material and temperatures were used as shown. We changed the tool path of the hot end for cleaning. Previously after finishing one layer, it travels in Y – X direction to reach the brush, but now it changed to X – Y direction to reach the silicone rubber. The result was so much improved and oozing is also reduced. Only a small amount of filament pieces was left off in the printed part. The result is shown on the below Figure (44):

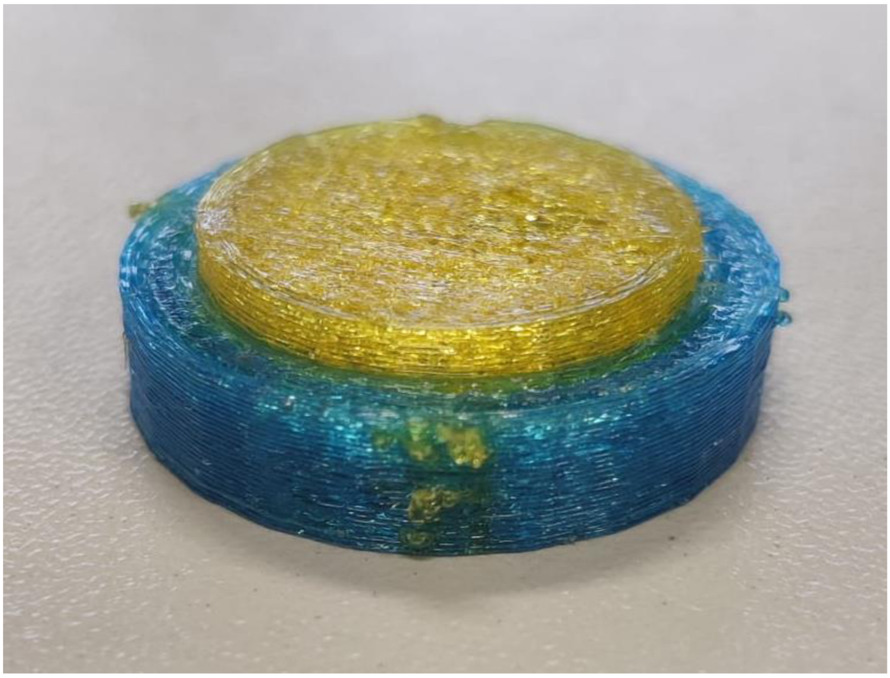


Figure 44:Multicolor Test 4

8.8. PLA vs PETG

Now we found some of the best parameters for both the materials. So, we proceed with those parameters to get the good result.

Sample Test 1:

Extruder 1 – PETG – Blue (245 ^{0}C – 15 ^{0}C)

Extruder 2 - PLA – Grey (200 ^{0}C – 15 ^{0}C)

Feed rate – 100 %

Flow rate – 100 %

Bed Temperature – 60 ^{0}C

Here we used Grey PLA and Blue PETG for printing. The suitable temperatures were shown above. Fan is enabled for cooling of the hot end. Oozing occurs at the PETG end due to high temperature setting of the filament material. It is shown on the below (Figure 45):

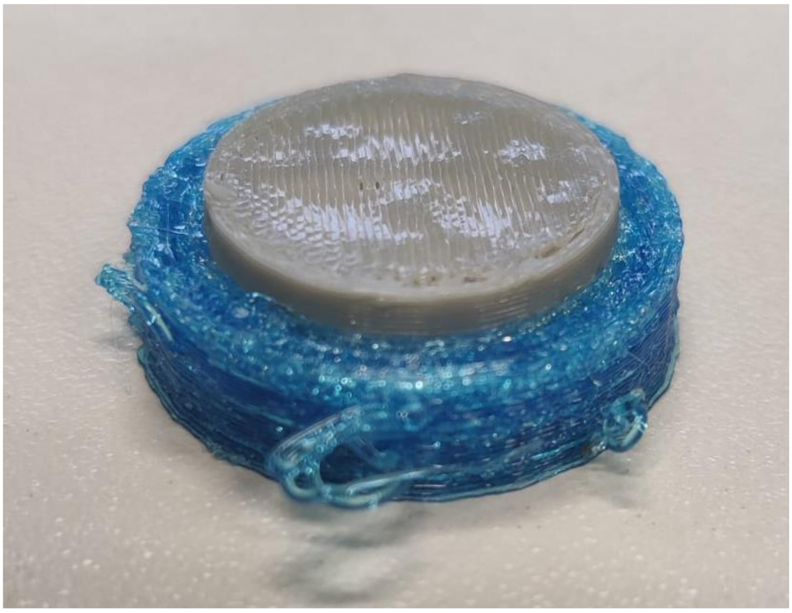


Figure 45: Multimaterial Test 1

Sample Test 2:

Extruder 1 – PETG – Blue (230 ^{0}C – 15 ^{0}C)

Extruder 2 - PLA – Grey (200 ^{0}C – 15 ^{0}C)

Feed rate – 100 %

Flow rate – 100 %

Bed Temperature – 60 ^{0}C

In this sample the main difference is reduction of temperature in Extruder 1 PETG material to 230 ^{0}C. The length of the retraction is changed to 10mm for both the extruders for PETG filament. Z lift is increased from 1mm to 3 mm. The result is considerably improved on both the filaments as shown on the below (Figure 46): The quality of the printed part is also improved.

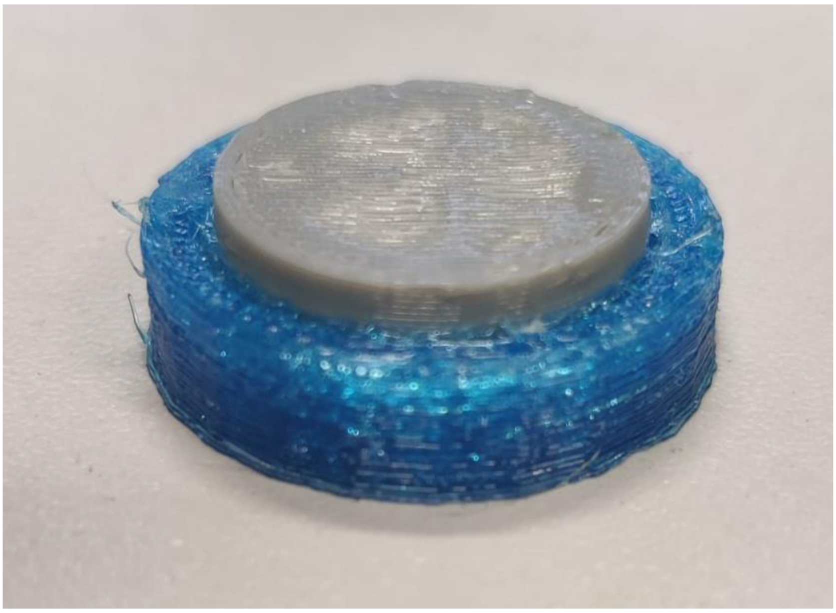


Figure 46:Multimaterial Test 2

Sample Test 3:

Extruder 1 – PETG – Blue (230 ^{0}C – 15 ^{0}C)

Extruder 2 - PLA – Grey (200 ^{0}C – 15 ^{0}C)

Feed rate – 100 %

Flow rate – 100 %

Bed Temperature – 60 ^{0}C

To get some more better results, same temperature settings were used as in the previous case. Cleaning mechanism were changed by modifying the co – ordinates to reduce oozing. The position of hot end on the silicone rubber is changed to Y 28 from Y 30 and for brush it is from Y 19 to Y 15. The result is quality of the part is good with minor flaws in oozing as shown on the (Figure 47):

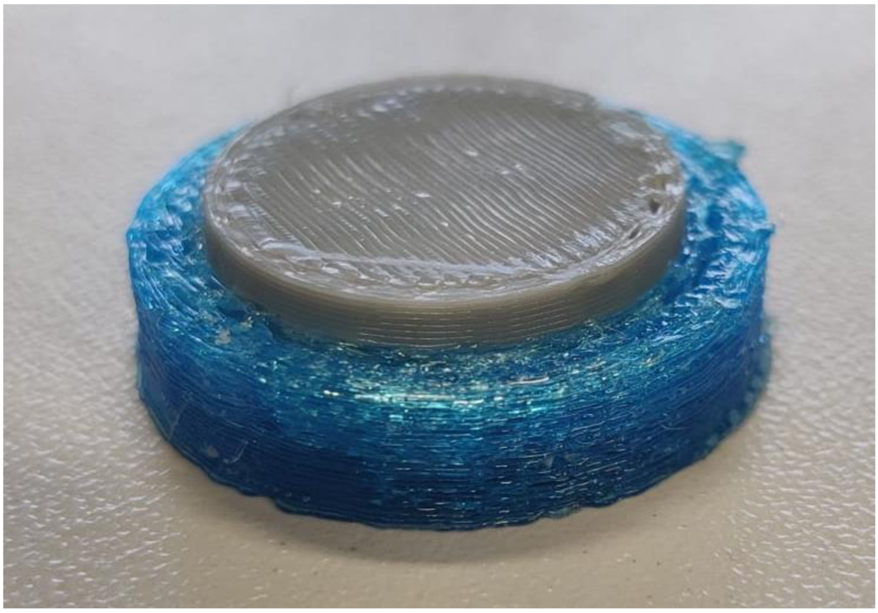


Figure 47:Multimaterial Test 3

Sample Test 4:

Extruder 1 – PETG – Blue (230 ^{0}C – 15 ^{0}C)

Extruder 2 - PLA – Grey (200 ^{0}C – 15 ^{0}C)

Feed rate – 100 %

Flow rate – 100 %

Bed Temperature – 60 ^{0}C

To get best quality of the print we introduced a new sheet metal design to wipe out the left of material in the nozzle. The parameters are likely to be same as in the previous case. The sheet metal design was shown on below (Figure 48) and the result is displayed on (Figure 49):

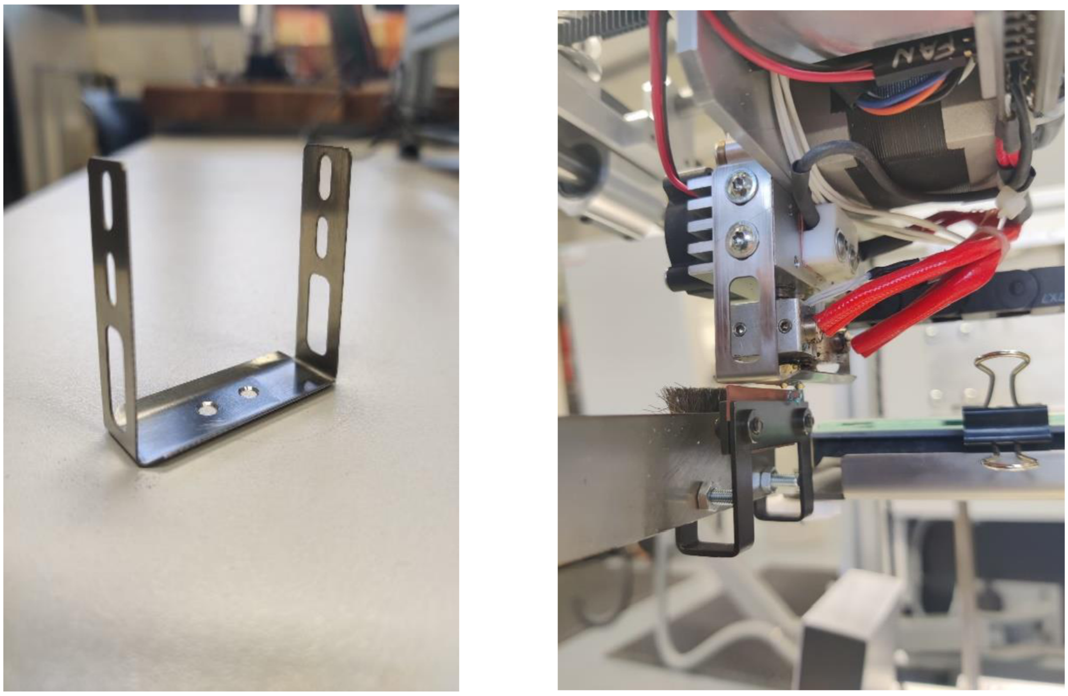


Figure 48: sheet metal design and Placement

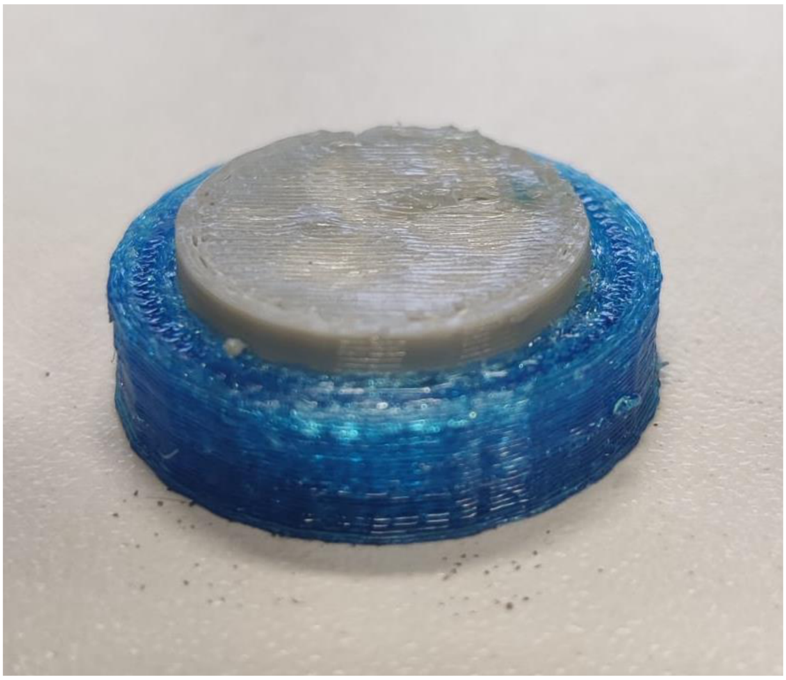


Figure 49: Multimaterial Test 4

8.9.PLA vs TPU:

Next, we move on to the research between PLA and TPU. This time we used the PLA (black) filament from the manufacturer Prusa, and the (white) TPU filament. For the above materials we used some of the parameters for printing that were described below.

Extruder 1 – TPU – White (230 ^{0}C – 15 ^{0}C)

Extruder 2 - PLA – Black (210 ^{0}C – 15 ^{0}C) [23]

Feed rate – 80 %

Flow rate – 100 %

Bed Temperature – 60 ^{0}C

To get the best quality printing between both the filaments we used the mentioned temperatures with the feed rate of 80% and flow rate of 100%. Since the TPU filament is so elastic we reduced the feed rate levels and disabled the retraction. Because of new PLA filament from the different manufacturer, we used the temperature at a rate of 210 ^{0}C. At the first time we get the good printing results without oozing of material either at the part or at the nozzle. The image of the printed part is shown below (Figure 50):

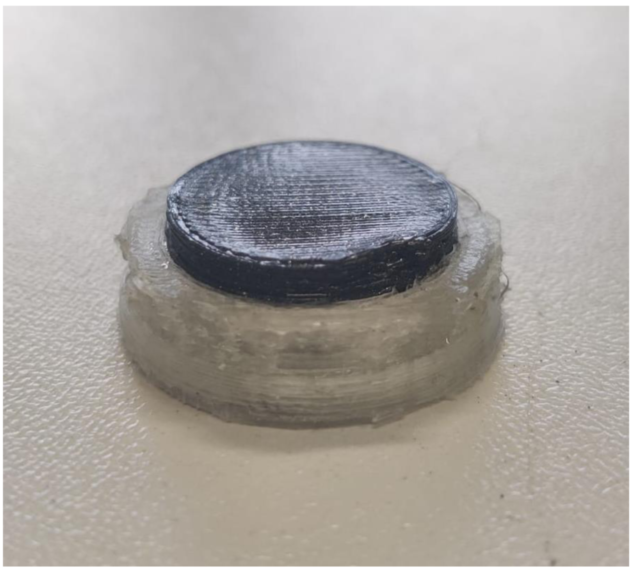


Figure 50: PLA vs TPU

8.10. Test Experiments:

Since we find all the best parameters, we then prepared two models to verify the part which resembles the parameters that we set. First, we designed a spur gear 3d model that we show in the below (Figure 51):

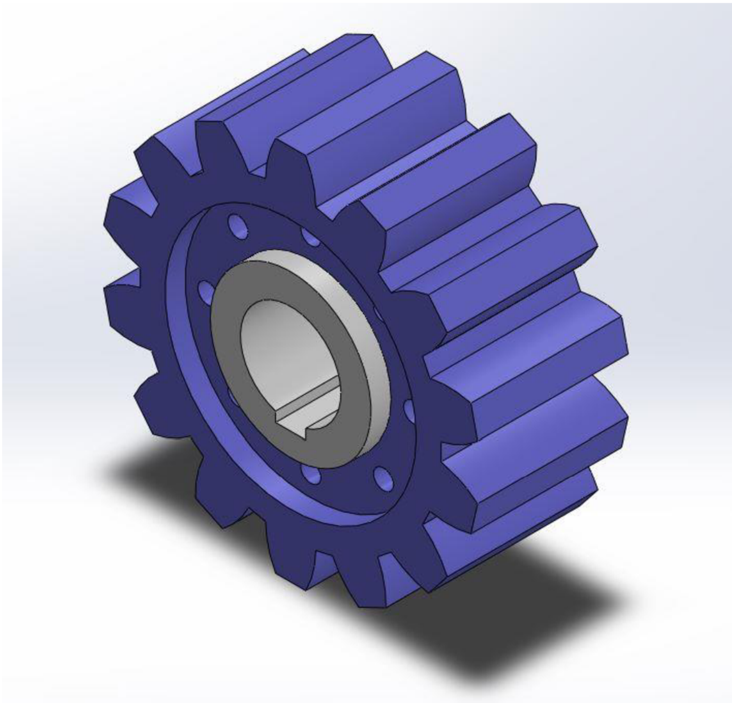


Figure 51: Spur gear 3d Model

Here the outer wheel is printed with Blue PETG material and the inner bearing is printed with Grey PLA material. The output of the part is good and the problem of oozing doesn't appear here. But the details of the part aren't much detailed. The practical time of printing takes about 2 hours 40 minutes but the estimated theoretical time was about 1 hour 13 minutes. The result of the printed part is shown on below (Figure 52):

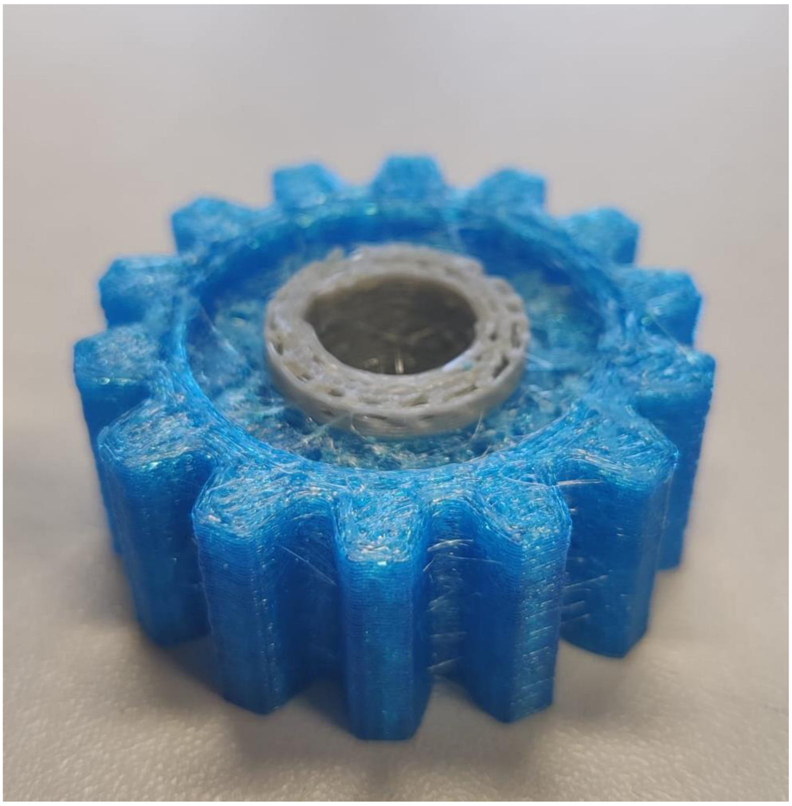


Figure 52: Printed Spur gear

Secondly, we then printed another Lego tyre 3d model. The model is shown on below (Figure 53):

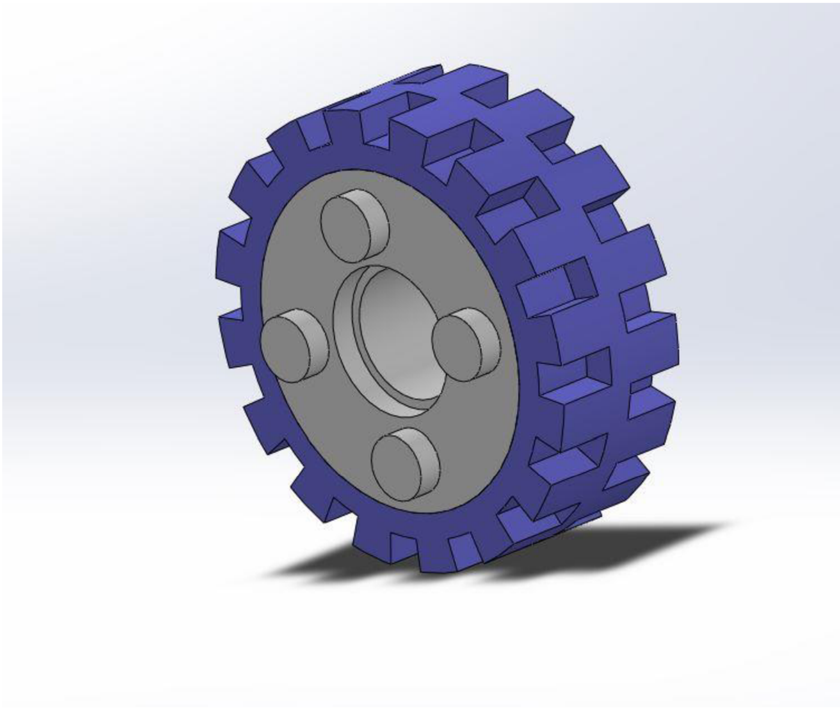


Figure 53: Lego tyre model

In this the inner rim corresponds to the Grey PLA material and the outer tyre was printed with Blue PETG. The design pattern of this model is also intricate when we compare with the previous one. At the end the output is also good and the oozing of the material is totally shut down. Here also the details of the part are not displayed efficiently. In addition to that the estimated theoretical time of the part is 1 hour 10 minutes but the practical time is about 2 hours 20 minutes. The image of the printed part is shown below on (Figure 54):

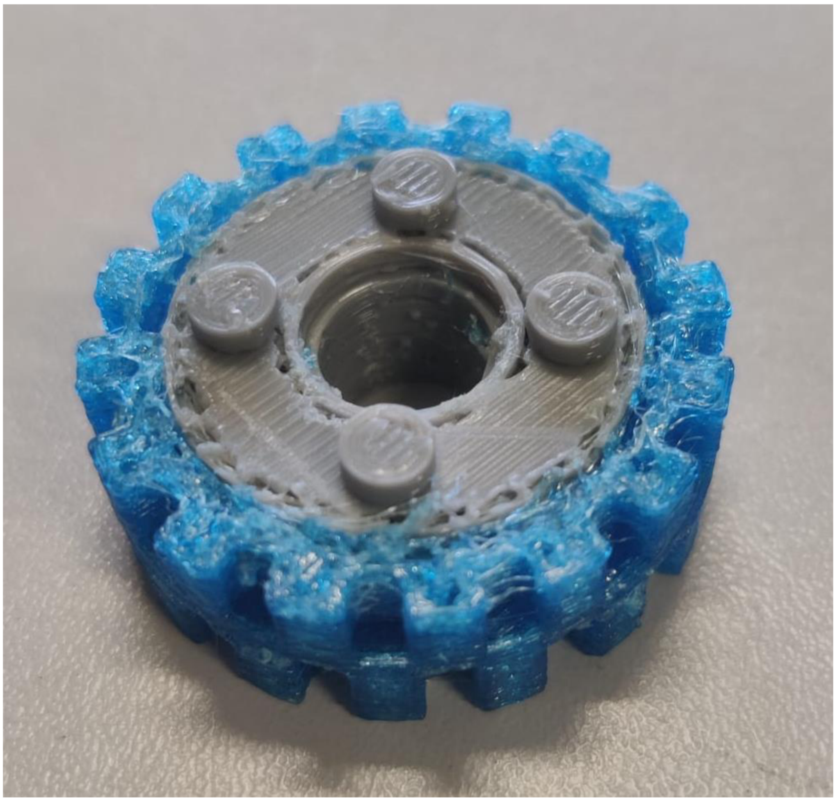


Figure 54: Printed Lego tyre

9. Conclusion:

This thesis presents the output of best parameters that is suitable for printing PLA, PETG and TPU material on the dual head cube type 3d printer. It uses two nozzles for the respective materials to be printed by the use of FFF/FDM technology. We used both the materials as filaments because of the technology of FFF/FDM.

During the time Firstly, we faced the problem of nozzle positioning so that we calibrated the nozzle for three times and found the best position of them.

Secondly, to eliminate the problem of oozing we then designed a cleaning mechanism called brush and a silicone rubber for cleaning the nozzle. We also changed the tool path of the hot end in the X -Y direction to reach the silicone rubber first and then the brush. For this we modified the G – codes in the Repetier host software. In addition to that we also designed a new sheet metal to be placed in the nozzle end to wipe out the left off material completely.

Thirdly, to find the best parameters like temperature, speed for the materials we found several tests. We also enabled retraction length of about 10mm for both the extruders and the z – lift is about 3mm for PLA vs PETG filaments and for the PLA vs TPU the retraction is switched off. The suitable temperatures for the materials were listed below.

For PETG – Blue (230 ^{0}C – 15 ^{0}C)

For PLA – Grey (200 ^{0}C – 15 ^{0}C)

Feed rate – 100 %

Flow rate – 100 %

Bed Temperature – 60 ^{0}C.

Speed of printing – 60 %

For TPU – White (230 ^{0}C – 15 ^{0}C)

For PLA (Prusa) – Black (210 ^{0}C – 15 ^{0}C) [23]

Feed rate – 80 %

Flow rate – 100 %

Bed Temperature – 60 ^{0}C

(For the detailed parameters see the attachment below).

The below (Figure 55) describes the initial and final stages of printing. The (A) describes the initial stages with the problem of oozing and improper temperature settings. (B), (C) and (D) are the final stages of printing without oozing of material. The picture A, B, C describes the filament of PLA vs PETG and picture D describes the TPU vs PLA. Even though the details of the printed part weren't shown much enough but the quality of material oozing is shutdown. Hence for the future cases of printing we can use these parameters to get the best quality printing. Since we need to publish this paper, I have prepared all the materials and we are looking for suitable journal to proceed it.

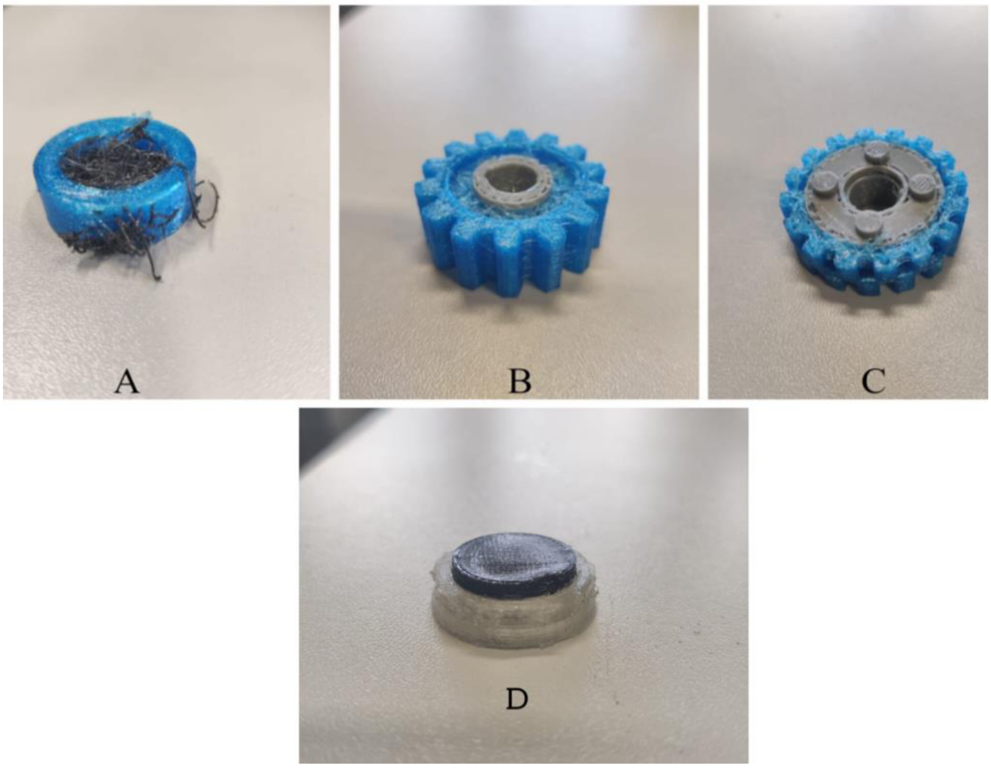


Figure 55: Result Comparison

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ATTACHMENTS:

Prusa Configuration Bundle – you can download it from www.stag.tul.cz