



Testing of Multi Material Printing by FLM Additive Manufacturing

Master Thesis

Study programme: N2301 Mechanical Engineering
Study branch: Manufacturing Systems and Processes

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Master Thesis Assignment Form

Testing of Multi Material Printing by FLM Additive Manufacturing

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Rules for Elaboration:

Perform the testing of the FLM Rebel II 3D printer for printing of parts from two different materials (eg ABS and TPU, ABS and Iglidur, two colors of the same material, etc.). Design a calibration procedure and print settings, and if necessary, make changes of the printer design (such as head cleaning during printing, etc.).

Recommended methods of elaboration:

1. Become familiar with the existing 3D printer Rebel II in the lab.
2. Make research of used materials for FLM technology and print requirements for these materials.
3. Design a suitable shape of the testing part, as assembly of two parts where each part will be printed from different color / material. Select at least three different combinations of materials and perform experimental 3D printing.
4. Design calibration procedure for printer setting and if necessary make changes of the printer design, typically some mechanism for cleaning heads during printing.
5. Evaluate the results and conclusions.

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- [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. 2019-09-23]. Available from: <http://forums.reprap.org/index.php>
- [5] STRATASYS LTD. *Professional 3D Printing*. [online]. 2015 [cit. 2019-09-23]. Available from: <http://www.stratasys.com/>

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Abstract

This thesis work depends on the simple 3D printer REBEL II based on the FLM technology. It is equipped with multiple extruders. This makes REBEL II a printer which is able to print two different materials. The main work is to increase the quality of the print by changing the settings of both printer and extruders and designing an attachment to clean the nozzles while printing. Also calibrating the nozzle to avoid any defects in the printing process.

Keywords

3D Printer, FLM technology, Rebel II

Abstrakt

Práce se opírá o jednoduchou 3D tiskárnu REBEL II založenou na technologii FLM. Je vybaven více extrudéry. Díky tomu je REBEL II tiskárnou, která je schopna tisknout dva různé materiály. Hlavní náplní práce je zvýšení kvality tisku změnou nastavení tiskárny a extrudéru a navržením automatického čištění trysek během tisku. Kalibraci trysek také předejdete jakýmkoli chybám v procesu tisku.

Klíčová slova

3D tiskárna, technologie FLM, Rebel II

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List of Abbreviation

FFF - Fused Filament Fabrication

FLM - Fused Layer Manufacturing

PLA - Polylactide

ABS - Acrylonitrile Butadiene Styrene.

TPU - Thermoplastic Polyurethane

AM - Additive Manufacturing

SLA - Stereo lithography

SGC - Solid Ground Curing

UV – Ultra Violet rays

DLP – Digital light Processing

FDM - Fused Deposition Modelling

LOM – Laminated Object Manufacturing

TIJ – Thermal Inkjet

SLS – Selective Laser Sintering

SLM – Selective Laser Melting

3DP – Three Dimensional Printing

CAD – Computer Aided Design

STL - Standard Triangle Language

PET – Polyethylene Terephthalate

PETG - Polyethylene Terephthalate Glycol

PC – Polycarbonates

HC – Hydro Carbons

°C – Degree Celsius

Sec - Seconds

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1) INTRODUCTION

The topic is '**Testing of Multi Material Printing by Additive Manufacturing**', which is tested in Rebel II. Rebel II uses Fused Filament Fabrication (FFF) method also known as FLM (Fused Layer Manufacturing), one of the Additive Manufacturing technology. The term Fused Filament Fabrication is coined by **RepRap** Project. Fused Layer Manufacturing is developed by S. Scott Crum in 1988. The process of the printing is done one layer at a time. Fused Filament Fabrication is a process of printing an object layer by layer of molten material. The FFF process follows two process which is extrusion of the material which is followed by the process of printing itself. Printer head has the heating element which melts the material before oozing out through the nozzle. Most often used material for Fused Filament Fabrication are Polyactide (PLA) and Acrylonitrile Butadiene Styrene (ABS).

First part of the thesis depends on the printer setting such as including a cleaning mechanism either continuously between layers or periodically changing the printer setting. Various setting in printer such as ooze prevention, feed rate and internal material fill percentage etc. also cleaning the nozzle periodically after each layer or during the material change shows a significant change in quality of the layers. This involves in increasing the quality standard of the printer layer.

Second part of the thesis involves calibration of the multiple nozzle while printing different materials such as ABS, TPU and Iglidur or two different coloured filament of same material. This calibration improves the quality of entire print as the nozzles align in same line.

Aim of the Thesis

Main aim of the thesis is to become familiar with Rebel II and research on materials and print requirements of FLM Technology, to experiment printing on combination of two different material or two different coloured filament of same material. Also to design calibration procedure of the nozzle during multi nozzle printing with printer setting or some mechanism for cleaning the nozzle during printing. Also rectifying the compensation error between the nozzle placement.

2) ADDITIVE MANUFACTURING

Additive Manufacturing (AM) is a layer based production technology. It is the process of converting the CAD model into the real time product or object without demanding any product based tool. This technology builds the object by adding layer upon layer of any desired material like plastic or metal. Additive manufacturing is classified into various types based on the process and raw material used as mentioned below[1].

2.1) Types of Additive Manufacturing

Based on the raw material additive manufacturing is classified in to below said types. Each method has varied work process and has limitations.

2.1.1) Liquid based AM

i. Stereo lithography Apparatus (SLA)

SLA is a very advanced technology of additive manufacturing which builds the product or object layer upon layer of liquid resin of photopolymer. A laser is projected in the form of the cross section of the object in the particular layer. The resin which I react to the laser solidifies and forms the layer of the object. The platform which hold the resin lowers into the liquid resin photopolymer and the laser is passed again which builds the next layer over the previous on. This operation takes place until the complete product is done[2].

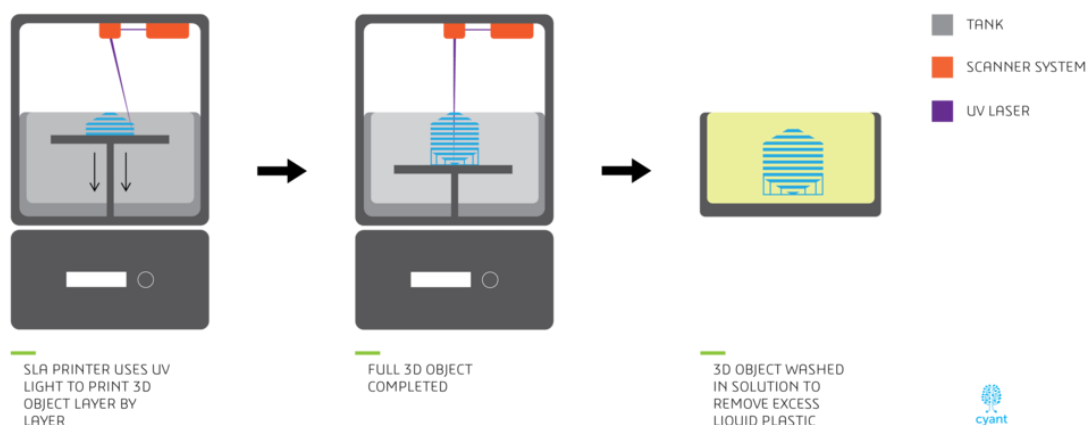


Figure 1 Stereo lithography Apparatus [3]

Material Used:

Liquid resin is used for printing process in SLA. These resin are mostly thermosets which is more brittle. Commonly Used materials are Standard resin, Dental Resin and High Temperature resin[4].

Advantages:

- High accuracy in dimension.
- Surface finish in this technology is very smooth.
- The application range of this technology is vast.

Disadvantage:

- Could only be use Laser which is costly. This technology could not use UV radiation.

ii. Solid Ground Curing (SGC)

SGC is similar process where the layers are formed with the photopolymer resin as in SLA, but uses the ultraviolet (UV) light source rather than the laser. The layer of resin is placed and the layer is hardened by UV radiation and the remaining resin is vacuumed. The process has the advantage over SLA which is it needs no post processing for each layer. Resin is filled for one layer and UV radiation is passed and the layer is hardened. The remaining unprocessed resin is collected and reused. Since the resin is hardened the layer needs no post processing or curing like SLA[5].

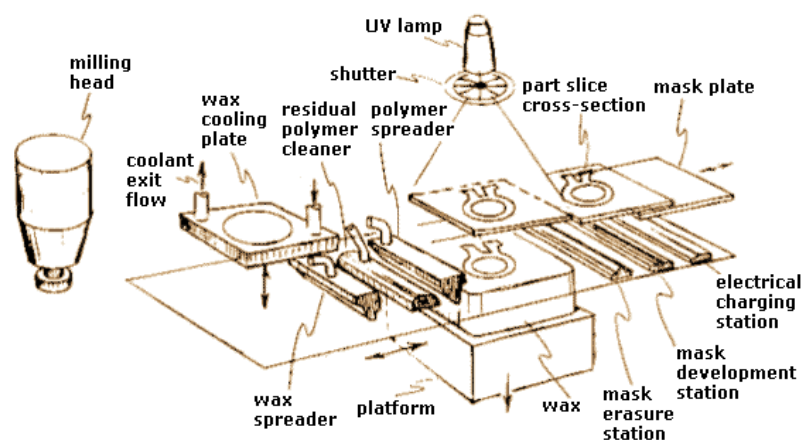


Figure 2 Solid Ground Curing [6]

Materials Used:

Liquid Resin with better mechanical properties like ABS are used for this process. The main property considered are higher solidness and viscosity.

Advantages:

- No need for support structures while printing.
- Higher efficiency, the printing is more accurate.
- Lowest cost for printing.

Disadvantages:

- Produces waste while printing.
- Process produces high noise.

iii. Digital Light Processing (DLP)

DLP is a similar process like Stereo Lithography Apparatus which uses the photopolymer resin to form the layers. While the difference is the light source. The DLP uses a conventional light source like arc lamp. This process is faster than SLA and more accurate dimensionally. The resolution of the layers is high using this process. Similar as all Stereo Lithography process DLP also requires support structures, especially in hollow and hanging structures[7].



Figure 3 Digital Light Processing [8]

Materials Used:

- R5 and R11 are liquid photopolymer used for its better mechanical properties like accurate functional properties like high robust.
- RCP 130 Photo silver is a high temperature resistant material used for achieving high accuracy as it is a ceramic filled polymer[9].

Advantages:

- High Speed Printing Process
- High Accuracy of layers
- Low cost of printing process

Disadvantages:

- Material consumption is higher cost.

iv. Poly jet Printing

Poly jet printing a type of 3D printer which shoots a jet of liquid which is solidified by the ray of UV light. As all other printer poly jet printers also deposit a single layer of material which is hardened by passing UV light and the second layer is deposited. Since the material is in liquid form it can be reused. The liquid which is released immediately hardens and forms the layer. Raw material is available in the form of cartridges which can be attached to the nozzle itself.

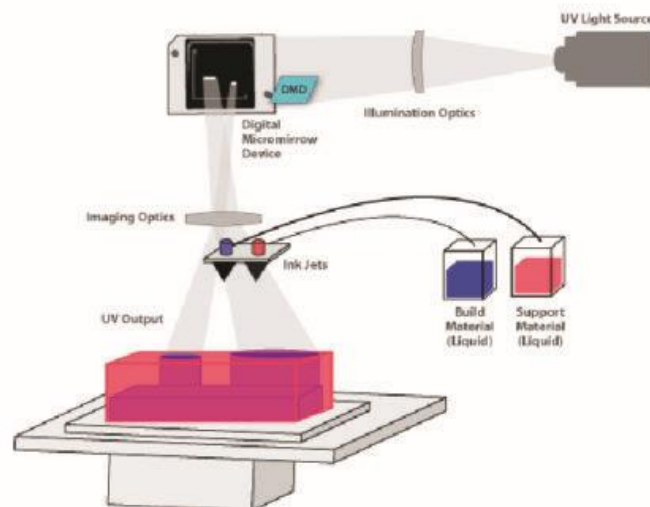


Figure 4 Poly Jet Printing [10]

Materials Used:

- Digital ABS is designed to replicate the properties of the ABS with higher rigidity and toughness.
- Polypropylene is most common material used. Endur and Durus is most commonly used polypropylene for its high elongation properties[11].

Advantages:

- More accurate
- Faster than other technologies
- Can use more colours

Disadvantages:

- Mechanical properties of the print are poor when compared to other technologies.
- Cost of the printers are very expensive.

2.1.2) Solid based AM

i. Fused Layer Manufacturing (FLM)

Fused Layer Manufacturing is a technology which uses material in filament form. The filament is let through the extruder which is heated and melt and the printing process is done. The melted filament is formed by the movement of the extruder head. For each layer the extruder head moves in upward direction. The heating temperature depends on materials which is used. For example, the material used in Rebel II is PET-G which melts and forms a correct consistency at 250°C[12].

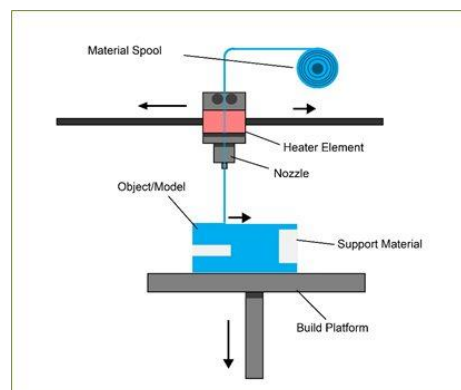


Figure 5 Fused Layer Manufacturing [13]

Materials Used:

- PLA is a basic filament used commonly due to its biodegradable properties and used in printing prototypes as it can handle extreme stress.
- ABS it is most common material used in daily life. It is recycled from itself and used in FLM commonly.
- PET is a thermo polyester used in printing technology in various field due to its properties like food safe material[14]

Advantages:

- Faster technique when compared with SLA and SLS
- Lost working cost
- Machines are consumer friendly and cost efficient.

Disadvantages:

- Has low accuracy
- Low details

ii. Laminated Object Manufacturing (LOM)

Laminated Object manufacturing is a 3D printing technology which uses layers of plastic paper to for the prototype or product. The CAD file of the object is used and multiple layers of plastic papers are bonded or laminated over each other. Now a laser cutter is used to cut the required shape of the layer. Once cutting is done the layer is lowered to the thickness of the layer and next layer of plastic paper is placed and heated[15].

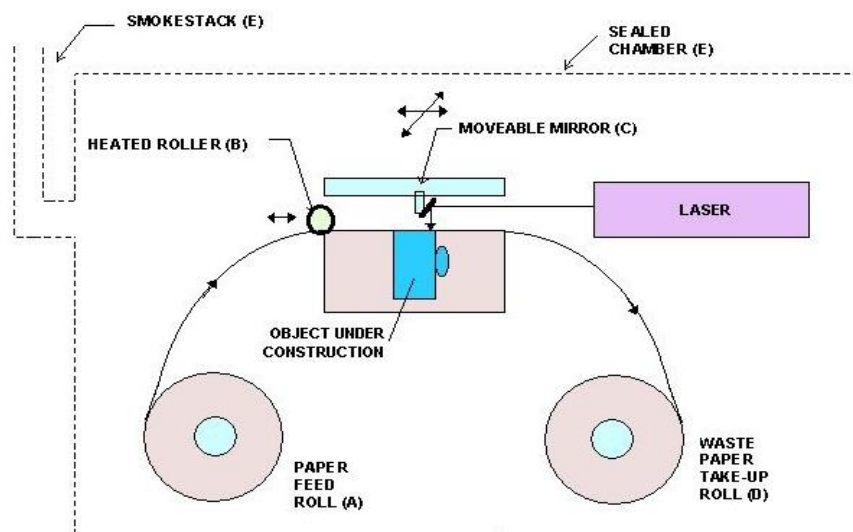


Figure 6 Laminated Object Manufacturing [16]

Advantages:

- Quick process for prototyping
- Low cost when compared to any other technologies.

Disadvantages:

- Low Mechanical Properties.
- High wastage of paper which cannot be reused.
- Post processing is required for the objects.

iii. Thermoplastic Ink Jet (TIJ)

The Inkjet technique is similar to any 2D printing, which sprays the ink. In inkjet printing the nozzle uses the thermoplastic or wax. The liquid thermoplastic is sprayed as droplets. These materials solidify as soon as it is sprayed and layer will be formed immediately. This technology depends on the thermal phase of the materials[17].

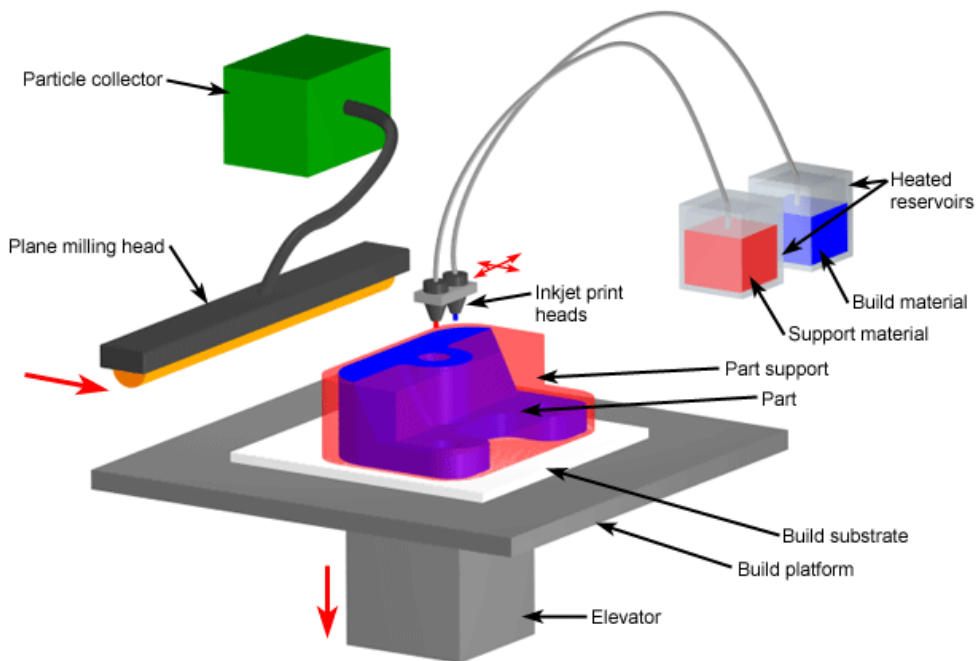


Figure 7 Inkjet printing [18]

Materials Used:

- TIJ unit that uses alcohol or other solvent is suitable for printing on a wide range of materials that include PVC, PET, blister foils and varnished coated cartons. Recent advances in both solvent ink and print heads technology are rapidly expanding the range of compatible materials that can be printed [18].

Advantages:

- Low cost of printing
- Possibilities of various colours in printing
- Output product is of high quality.

Disadvantages:

- Printer head is prone to damage easily
- Printing material is of high cost, available only in cartridges.

2.1.3) Powder based AM

i. Selective Laser Sintering (SLS)

Selective laser sintering is a 3D printing technology which uses a laser beam to solidify or fuse the powdered material to form a solid material. This technology only depends on the intensity of the laser thus uses pulsed laser. Unlike melting SLS only sinters the powder into a solid, the product is a porous solid. Once a layer is formed the bed is lowered and material is filled and process is repeated until the product is finished. Since the powder is sintered there is no need for support material as the powder itself acts as support material[19].

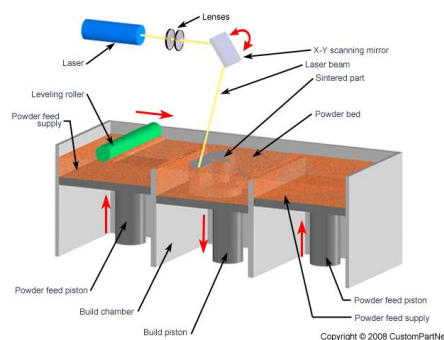


Figure 8 Selective Laser Sintering [20]

Materials Used:

- SLS technology mainly focus on nylon products such as ALM PA650 and ALM FR106 which both has high tensile strength and high percentage of elongation at break properties[21].

Advantages:

- No separate support material needed this allows complicated and overhanging structures.
- Output products have high strength and stiffness

Disadvantages:

- Need post processing as the output product is porous and need to be sealed for better properties.

ii. Selective Laser Melting (SLM)

Selective laser Melting is a technique whereas all 3d printing process starts from the 3D design which is sliced into multiple layers and each layer is printed by melting and fusing the powdered material probably metal. The thin layer of metal powder is spread and the information for the sliced CAD model is used for projecting the laser. The laser used is so intense to melt and bind the powder into a solid structure. The whole setup is contained under an inert gas environment to avoid unwanted reactions[22].

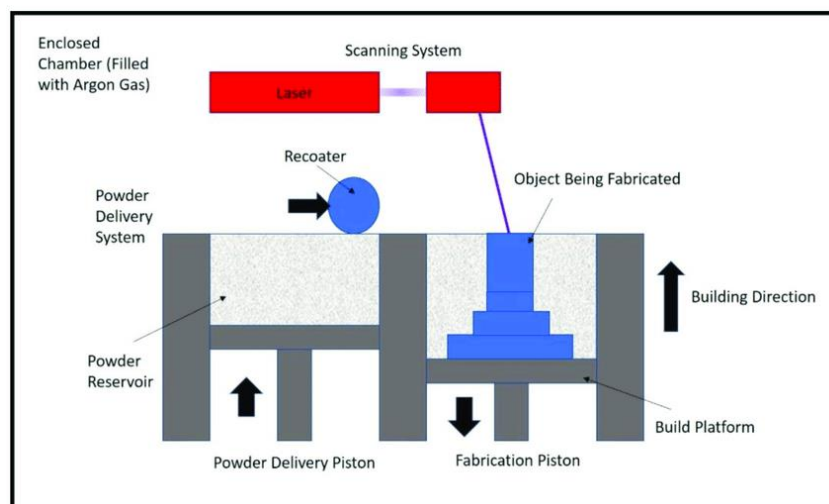


Figure 9 Selective Laser Melting [23]

Advantage:

- Faster process when compared other metal printing technologies.
- It is used for production process in industries.

Disadvantages:

- Have dimensional constrain in z direction.
- Post processing is needed to smoothen the surface.

iii. Three Dimensional Printing (3DP)

Three dimensional Printing is a similar process as Selective Laser Sintering but uses an adhesive fluid to bind the powdered material. This method is a fast phase operation which forms multiple layers in short time. As all method once a layer is formed the material of new material is distributed and adhesive liquid is sprayed again according to the cad model[24].

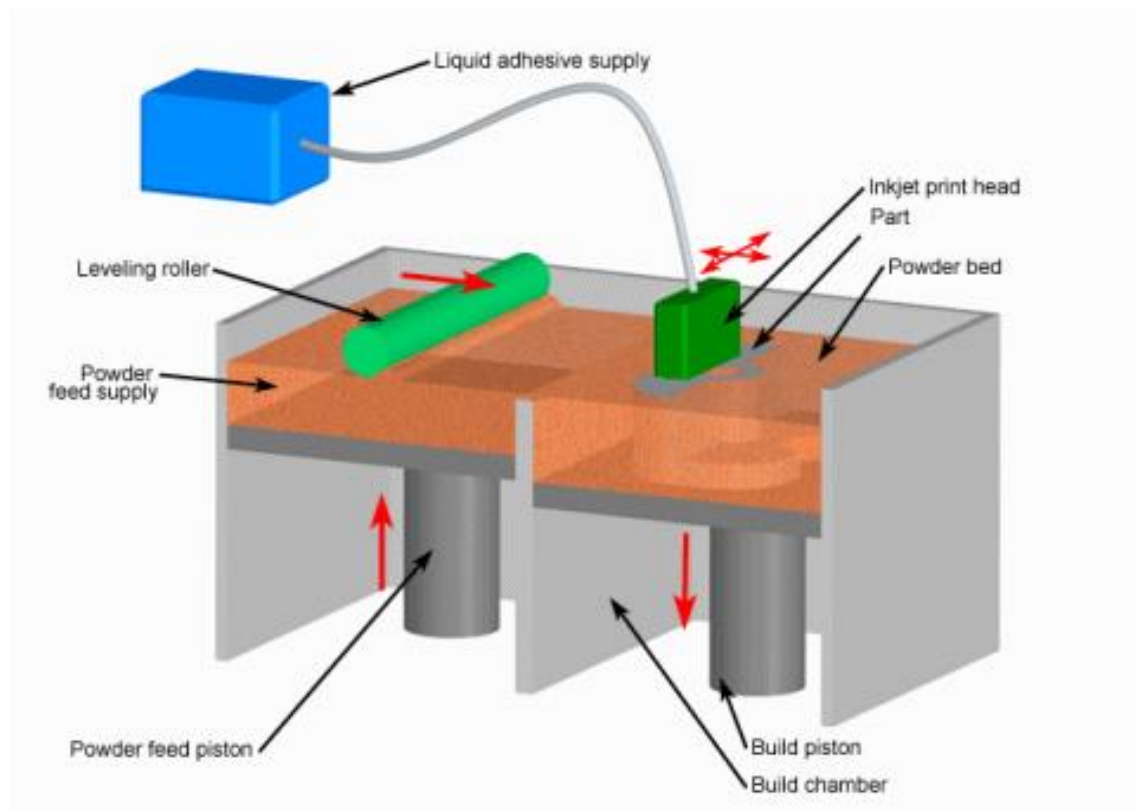


Figure 10 Three Dimensional Printing [25]

Advantage:

- Faster process than any other method.
- Low cost and used for prototyping.
- No need for support material.

Disadvantage:

- The strength of the output product is low and need post processing to increase strength.

2.2) Fused Layer Manufacturing

Fused Layer Manufacturing is a 3D printing technology which uses the material in solid form. The solid raw material is melting and each product is formed layer by layer. The material is usually in the form of filament which is melted and extruded from a nozzle and layer is formed[26].

The extruder head has a heating element which melts the filament and extrudes to form a layer which solidifies. The filament is a thermoplastic material. The filament is melted and extruder moves and forms the product from bottom. The nozzle moves in all three directions in x, y and z direction.

The CAD model is converted in a format which is understood by 3D printers, usually STL files. The STL file is fed to the 3D printer which is sliced or divided into various layers.

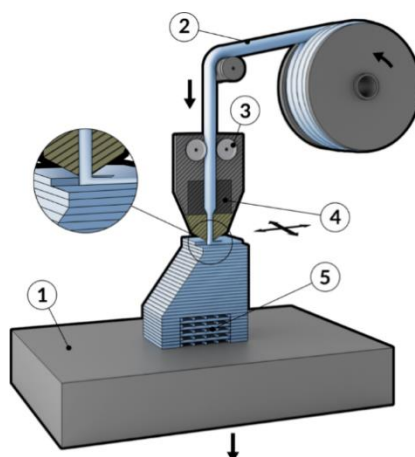


Figure 11 Fused Deposition Modelling extruder [26]

The above figure 11 shows the FLM machine, the product or sample is formed on the bed [1]. The filament in the form of wire [2] is extruded by the

extruder head [3]. The rollers in the extruder head is used to push the filament through the heating element [4] in the extruder where the filament is melted and pushed through the nozzle to form the product [5]. Here the bed or platform remains stable and the product is formed by the movement of the extruder head.

The Cartesian 3D printer is classified based on the working principles of the and movement of the extruder head. The types are as follows,

2.2.1) Cartesian 3D printer

It is a common 3D printer found in market. It is a Cartesian coordinate system. It uses three axes: X, Y and Z axis. All three axes are used to determine the correct position of the extruder head. The X and Y axes are the main axis in which the bed moves to form the layer. The Z axis is used to determine the layer height[27].

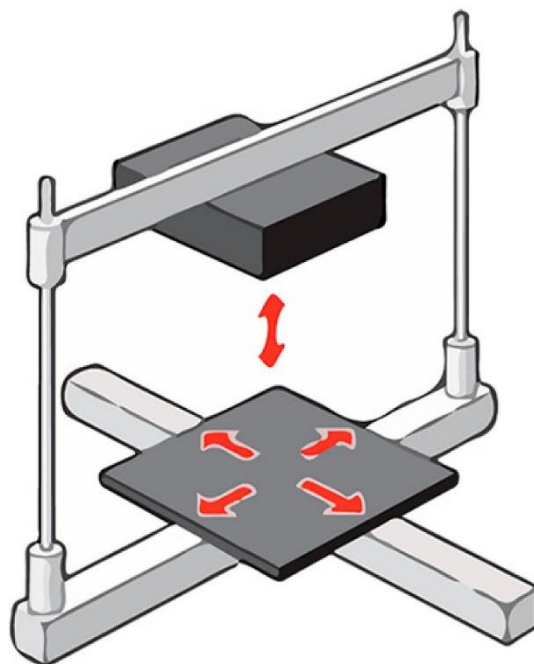


Figure 12 Cartesian 3D printer frame [27]

2.2.2) Delta 3D printer

Delta 3D printers are similar to Cartesian printers; it has the same three Cartesian coordinates in addition with other three coordinate. The extruder is attached with rods fixed in three triangular points. All these points move in up and down direction to determine the position of the extruder and nozzle. This method is similar to Cartesian printer with addition to rotating platform or bed[27].

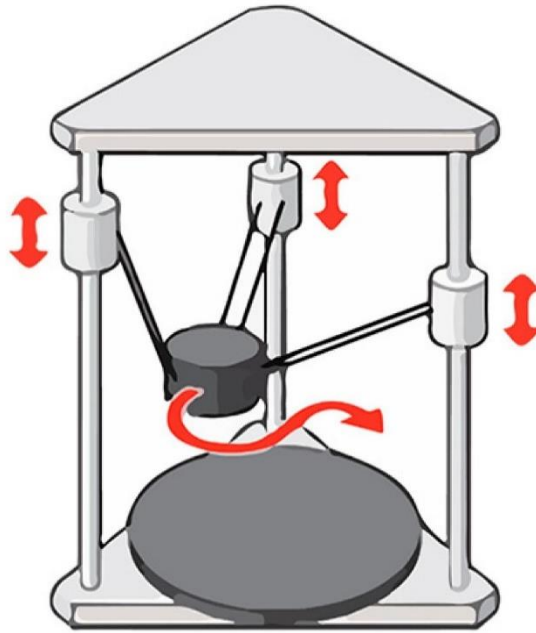


Figure 13 Delta 3D printer frame [27]

2.2.3) Polar 3D printer

Unlike Cartesian and delta printers, polar printers have only 2 axes or coordinated. It is only described in the form of length and angle. The advantage of polar printers is it only need two motors unlike other printers and is classified as the most efficient in long time run[27].

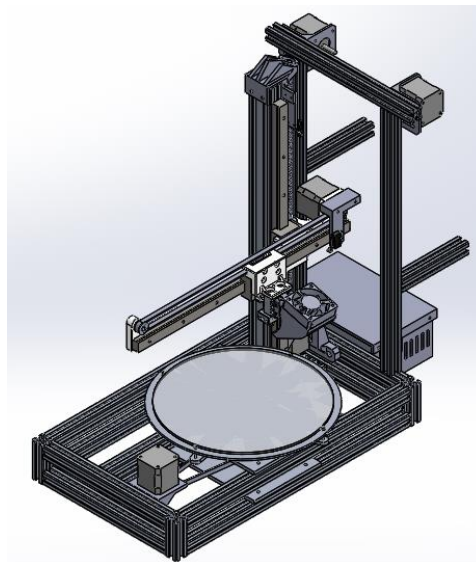


Figure 14 Polar 3D printers [27]

2.2.4) Robotic 3D printers

Robotic arms are industrial equipment which are incorporated with the 3D modelling to experiment. It is used to build models in big scale like walls and buildings. Although it is not reliable as other printers the technology is in development phase. Extruder is fixed in the end of the arm at wrist. The arm is able to determine the position. This type of printers is able to handle complicated structures[27].

2.3) FLM procedures

2.3.1) Loading of Polymer

The materials used in FLM is mostly thermoplastic polymers like Polylactic acid (PLA), Acrylonitrile butadiene styrene (ABS), Polyurethane etc. the materials are usually in pre-extruded filament form. It is loaded in the material loading deck[28].

2.3.2) Melting of Material

The loaded material is extruded by the extruder head which pushes the material into the melting zone in the extruder head. The heating element is able to be controlled and temperature is set according to the material used.

2.3.3) Application of pressure

The molten material is pushed through the nozzle. The pressure needed to push the molten material through the nozzle is produced by adding more material by extruder gears located in the extruder head.

2.3.4) Extrusion and Plotting

The material is extruder to form the layer upon layer by the movement of the extruder head which can be programmed. the extruder has two axes in x and y axes. The height is adjusted my movement of the head in z direction.

2.4) Materials Used for FLM

Materials used in Fused deposition modelling is usually thermoplastic polymers. PLS and ABS are two main polymers used widely. The material is chosen based on the required properties need for printing.

2.4.1) Basic properties of Printing Material

- Printability – The ability to be printed or to form the desired layers. The easier the material is printable it is selected for the FLM process. PLA is best material with higher chance of printability[29].
- High Strength – Strength in FLM process is defined as the maximum stress which the material undergoes when tension is applied before breakage. PC is high strength material whereas the TPU nylon and PET have low strength.
- Layer Adhesion – This is the main property which is responsible printing. Due to this property printing is possible. PLA is more adhesive and nylon is less adhesive.
- Heat resistance – Heat resistance is the property which shows the highest temperature reached by the material before deformation. ABS and PC has high heat resistance and PLA and nylon has low heat resistance.

2.4.2) Material used in 3D printing

With all the above said properties various thermoplastic polymers are chosen. Most suitable polymers which can be used for printing are,

- PLA (Polylactic acid)

PLA is one of the easiest polymer to be printed with high accuracy or visual quality. The physical property of PLA is strong but brittle. The material is biodegradable, odourless and has UV resist

- ABS (Acrylonitrile Butadiene Styrene)

ABS is more preferred than PLA due to its high heat resistant and higher toughness. ABS is suitable post processing after printing due to its strength. It can also be glued easily with acetone unlike PLA. ABS is UV sensitive thus exposing it to UV radiation can change its properties.

- PET (Polyethylene Terephthalate)

PET is a softer polymer which can be used for printing. It is easier to print than ABS. It has high resistance to chemical and humidity which makes it safe to food items. It is also recyclable and can be post process by acrylics. It is heavier when compare to ABS or PLA.

- Nylon

Nylon is a material with High mechanical properties and has good impact resistance. Nylon is known for its high chemical resistance and strength. It also has a disadvantage of releasing potentially harmful fumes when heated.

- TPU (Thermoplastic Polyurethane)

TPU is the most flexible material used in printing technology and is also known for high impact resistance. It has a good abrasion resistance and also do not react with oils. But to its properties the post processing the TPU is difficult.

- PC (Polycarbonates)

It is an alternative of ABS which has similar properties and it is strongest polymer in the above list. It is similar to ABS easy to post process and can be sterilized unlike any other, but is sensitive to UV radiation which affects its properties.

Choosing the polymer for 3D printing is a main process and it depends on the type of the printer, functions of the print etc. Functional parts are to printed with high strength material like ABS and PC whereas the prototypes can be printed with low strength material which could save cost and power.

2.4) Applications of FLM

ABS

- Concept parts and prototypes production,
- Production tools and thermoform tools,
- Electronic components,
- Food and medical components handling tools,
- Functional Prototypes for testing purpose.

PC

- Rapid tools,
- Jigs and fixtures
- Industrial Equipment
- Low volume production parts

Resin

- Aerospace equipment
- Composite tools and metal forming tools
- Medical applicants

Nylon

- Ducts and vents
- High vibration resistance components
- Panels and covers
- Drill guides.

Various materials are used in FLM technologies and is used based on the need. Each material mention above is capable of 3D printing. Some other materials are PET and Iglidur.

3) PRACTICAL WORK

3.1) Rebel II - Printer

Rebel II is a printer primarily designed to print basic designs using a single nozzle. It is a FLM technology which uses the solid material filament in wire form which is melted and layer is printed. It is redesigned to print the complicated shapes using two nozzles at same time. Material used to print the parts is ABS and PETG (Polyethylene Terephthalate). PETG is a thermoplastic which is reusable.

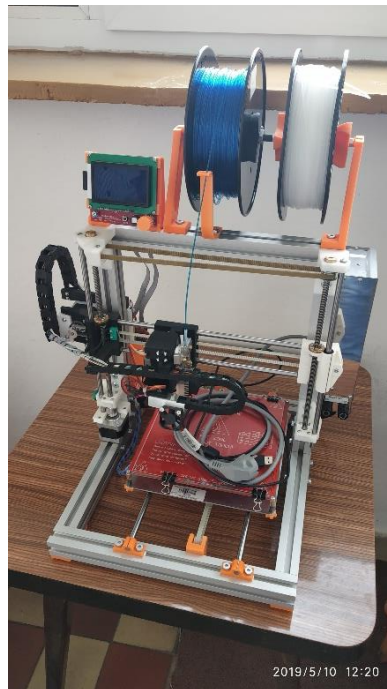


Figure 15 Rebel II

3.1.1) Specifications of Printer

Rebel II is a small printer having a print area of 200*200*140 mm. It consists of two independent nozzles which can operate on their own as each nozzle is equipped with extruder gears for each which provides extrusion pressure.

Input for the Rebel II is provided either by a computer connected by the USB connection available or by SD card which can be directly connected to the printer itself. The input files should be in STL format to be read by the printer.

Printer is controlled by Repetier Host for inputs and manual controls. Printer specifications are shown in the below table which includes federate and allowable temperature.

Working Space	200 *200 * 170 mm
Axis Range	X-218 (18 mm space for nozzle cleaning), Y- 200, Z-170mm
Print head	Two direct independent extruders

Extruders	Metal, max temperature 300-degree Celsius
Nozzle	Brass, diameter 0.4 mm, replaceable.
Heated bed	Maximum 110 degree Celsius
Federate in X and Y axes	Maximum 7200 mm/min
Federate in Z axis	Maximum 600mm/min
Control board	Arduino Mega 2560 + RAMPS v.1.4 + LCD display + SD card/USB connection

Table 1 Rebel II Specifications

3.1.2) Working Process in REBEL II

Printing process in Rebel II is similar process as in all 3D printers. The printing process is classified into three different process as explained in above topics.

Pre-printing process

- Printer is switched ON and connected to the computer with Repetier Host.
- The STL files of the printing object is loaded and checked.
- Temperature of both extruder head and bed is set according to the need.

Printing Process

- Loading of material is done. Material used here is in filament form and is loaded in it is placed and connected to the extruder.
- Melting of material is done using the heating element in the extruder head. The temperature is controlled by the software and temperature maintained in Rebel II is around 250 degrees Celsius which is optimal for PETG.
- Once the material is melt to the required form the required pressure is applied by the extrusion gears present in the extrusion head by adding more material which extrudes the molten material through the nozzle.
- When extrusion of material starts the extruder head moves in the designed or programmed direction to print the material. The plotting process is a software work which is performed on the STL files and provide as an input for the printer.

Post –Printing Process

- Once printing is finished the printer is turned OFF.
- The extruder and bed are left to cool down and when temperature drops to a certain level the print is ready to be removed and used.

3.1.3) Material Used - PETG

PET is a thermoplastic polymer. It comes under polyester group. PET is the most used polymer due to its recycle properties and its physical, chemical, mechanical and thermal properties. PET is considered as food safe polymer. It is colourless and odourless naturally can be modified as per the need by processing based on the need.

Material used in Rebel II is PET-G or Polyethylene Terephthalate Glycol. Ethylene Glycol present in Pet provides PET good thermal properties which makes it popular for all FLM printing worldwide. Glycol avoids the property change due to high temperature. PETG has similar properties like ABS and considered as a good replacement. PETG is resistant to most of the alcohols, oils, HC and diluted acids[30].

Advantages:

- Has considerable strength and stiffness as most of the polymers.
- It is known for high strength to weight ratio.
- Has high working temperature range of -60 to 130 degrees Celsius
- Food safe and recyclable.

Limitations:

- Low impact strength.
- Reacted with concentrated acids
- Reacts with boiling water.

3.2) Printing Process

Rebel II is controlled or the input feed is given using the software called Repetier-Host (V2.1.6). the interface of the software is given below in figure 16.

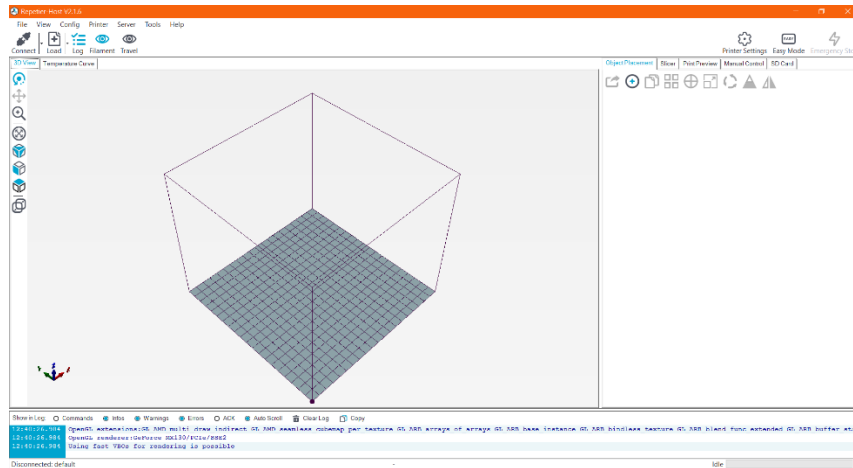


Figure 16 Repetier Host Home Screen

The STL (Stereo lithography or Standard Triangle Language) file of the Sample to be printed is opened in the software and required setup is done in the software. STL file is obtained from various design software like CATIA or CREO. For instance, in the case of the practical work in order to test the performance of the printer with two nozzles a cube is printed. A dice designed with two parts are used to test the printer.

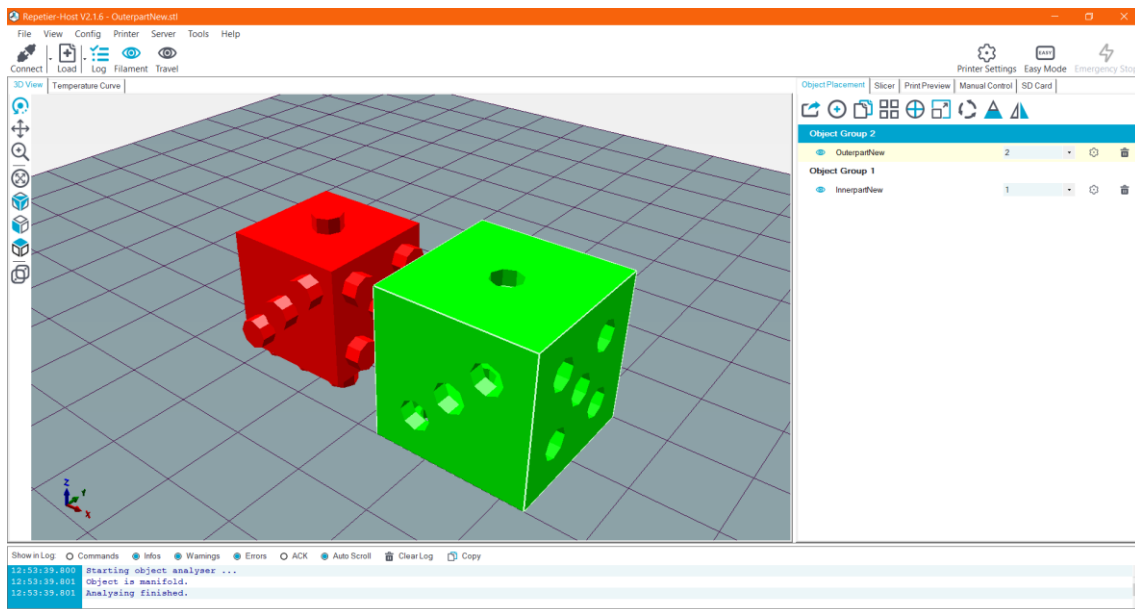


Figure 17 Host Samples

The dice is designed as two parts as outer and inner parts as shown in the image. Each part is assigned to different nozzle and placed in centre. The work place shown in the software represents the workspace in the printer. The parts are

printed as shown in the software, thus the two different parts are placed in centre or same axis. Once parts are aligned now slicer in Repetier host is used. Various slicer option is available such as Cura Engine, Slic3r and Prusa Slicer. The slicer used for the work is Prusa Slicer.

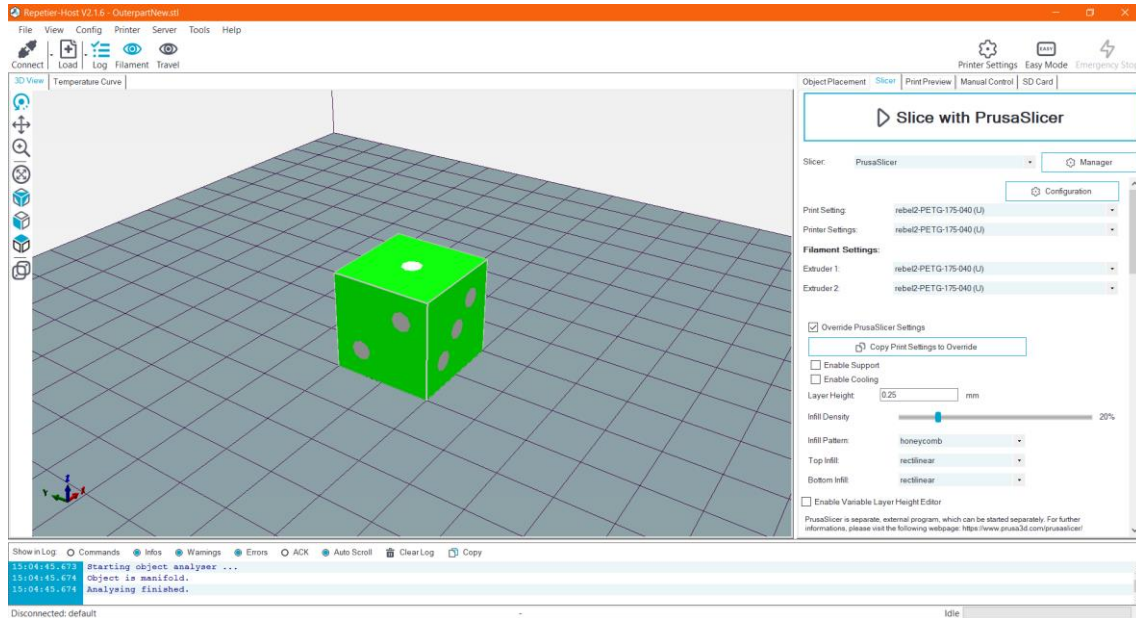


Figure 18 Host Samples position

When the command Slice with PrusaSlicer, Printer setting are changes or altered as per our need in this window. Parameters like the material density and infill pattern are set to our requirements. Layer height is also adjusted. Here layer height is set to 0.25mm and infill density is mainted at 20 % and infill pattern is set to honeycomb shape. Once all parameters are defined slicing in performed and the part is sliced and the resultant model is displayed.

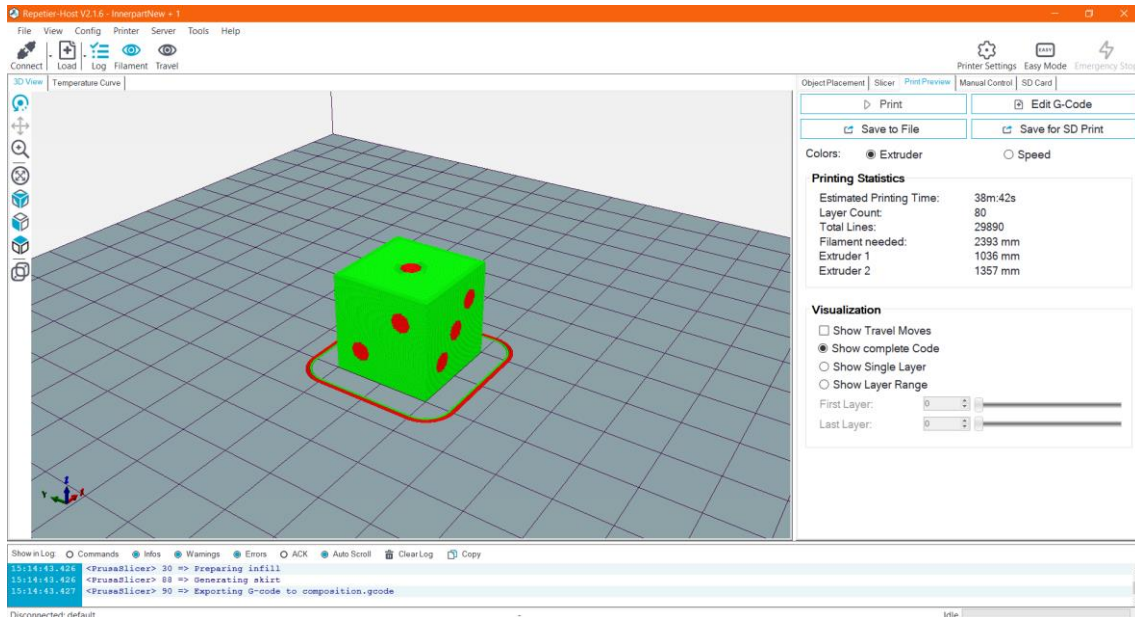


Figure 19 Host Print Preview

While Slicing, the part is being printed and the sample is shown. Details like number of layers, estimated time and amount of material need for printing in each extruder is calculated and shown. It is possible to see each and every layer of the print individually as shown below.

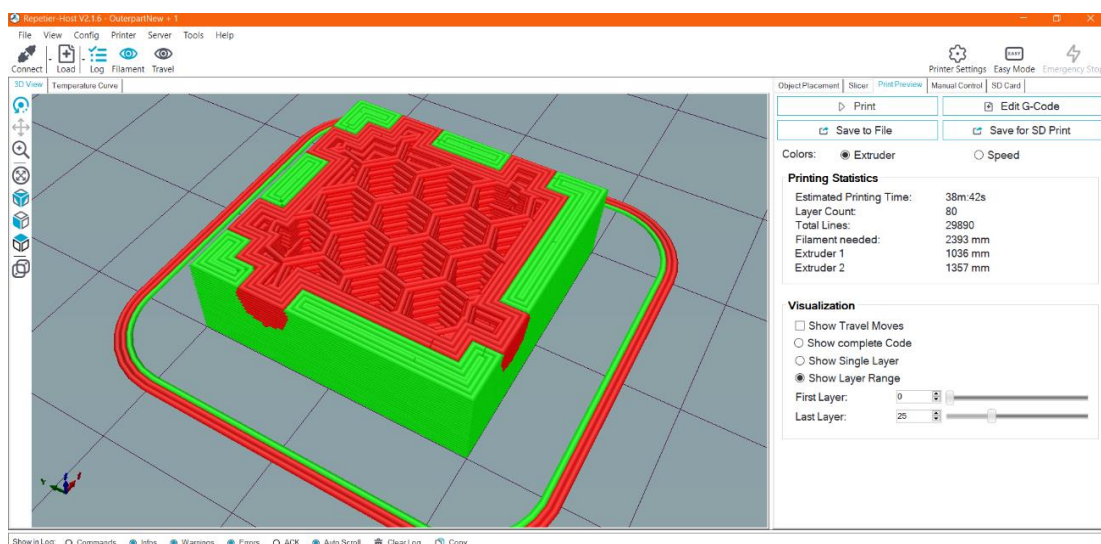


Figure 20 Host Sample Layered-1

Figure 20 shows the print sample of the layer 25, which shows the print of both material 1 and 2 from corresponding extruders. The internal structure is used as honeycomb which makes use of low material with better strength.

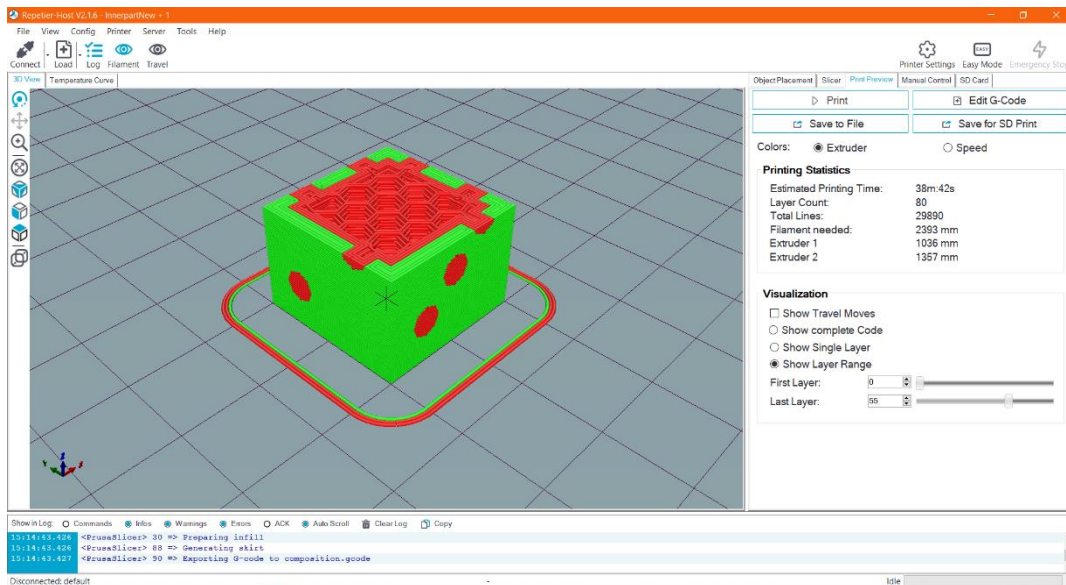


Figure 21 Host Sample Layered-2

Above figure 21 shows the printed layer 55 which has been printed and shows the honeycomb structure again which is maintained throughout the print. Here the input of the print can either be given through the computer or by using the memory card.

Repetier Software provides options to enter manual codes at required places to achieve better quality print. This helps in adding or removing a process. Manual codes can be inserted at various places of the operation like, at the starting of the printing process, end of the program, and before or after the layer change. These manual codes can be used to get the nozzle to stop to perform any actions like cleaning or cooling of the previous layer. Figure 12 shows the manual coding page of the Prusa Slicer printer configuration.

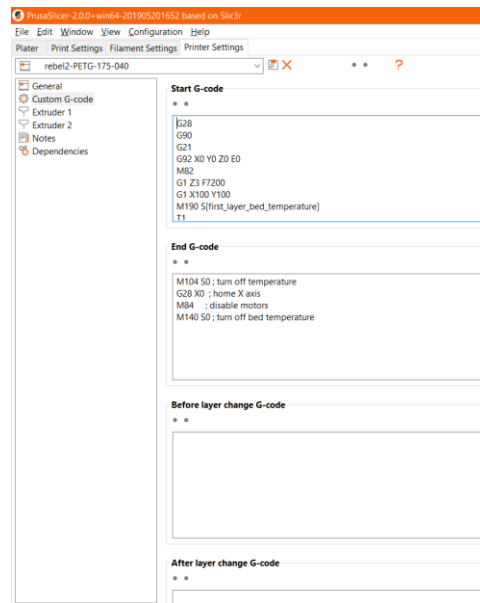


Figure 22 PrusaSlicer Configuration

Printer setting and print settings window of the prusa slicer is shown below which has various setting can be changed. The setting like layer height, vertical and horizontal shells and quality setting are available in print setting which most of them are set as defaults for the testing purpose. The settings like layer height limits, retraction settings and preview setting are available in printer setting window. Retraction of the inactive extruder was set to 10 mm which retracts or pulls the input wire in the inactive extruder back to the fixed length which helps in over heating of the material.

Multiple prints are tried with various settings as follows, some settings are maintained constant during printing such setting are as follows,

- Bed temperature = 90°C
- Layer Height = 0.25 mm
- Extruder 1 Temperature = 250°C
- Extruder 2 Temperature = 250°C

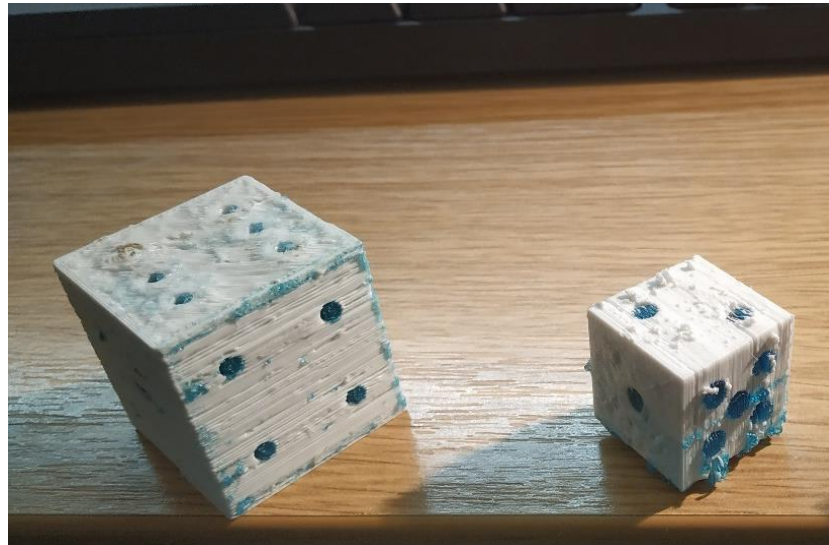


Figure 23 Print Sample 1(Right) & Sample 2(Left)

Above figure 23 shows the sample print 1 and 2. Sample 1 was print with printed with default setting of the printer and software. Feed rate was maintained between 55 to 70. The size of the print was fixed to 30*30 mm cube material consumption was high and in extruder 1 used 3868 mm and extruder 2 used 4599 mm of material each. Number of layers in sample 1 was 120 and time taken for printing was about 80 minutes.

Sample 2 was resized to 20*20mm cube to make printing process faster and also to reduce material consumption. During this print manual cleaning of nozzle is followed. Custom G-code was used before tool change command to move the nozzle head to a particular point where the nozzle head is stopped and cleaned before next layer. Custom G-Code is given below,

G₁ X200

G₁ Z50

G₉₂ E0

G₁ E10

G₄ S10

G₁ Z[Layer_z]

Feed rate was maintained between 50-55. Number of layers in the print was reduced to 80 layers. The material consumption was reduced to 1535 mm for extruder 1 and 1249mm for extruder 2. The print quality was slightly improved

because of the cleaning of nozzle as no material in the previous layer is disturbed by the nozzle.

Sample 3 was a 20*20 mm cube; this sample was printed with the option of ooze prevention. Ooze prevention is an option used where the temperature of the inactive extruder is reducing to a certain value where melting is stopped. This avoids the oozing of extra material from the inactive nozzle. As this required a certain specific setting which was unable to be used ooze prevention was not working as expected and the print had the same finish as of the sample 2.



Figure 24 Print Sample 3

Sample 4 was also a 20*20 mm cube, which is printed with the ooze prevention. This time ooze prevention worked perfectly and the temperature of the inactive nozzle is reduced to 235°C ($\Delta-15^{\circ}\text{C}$)

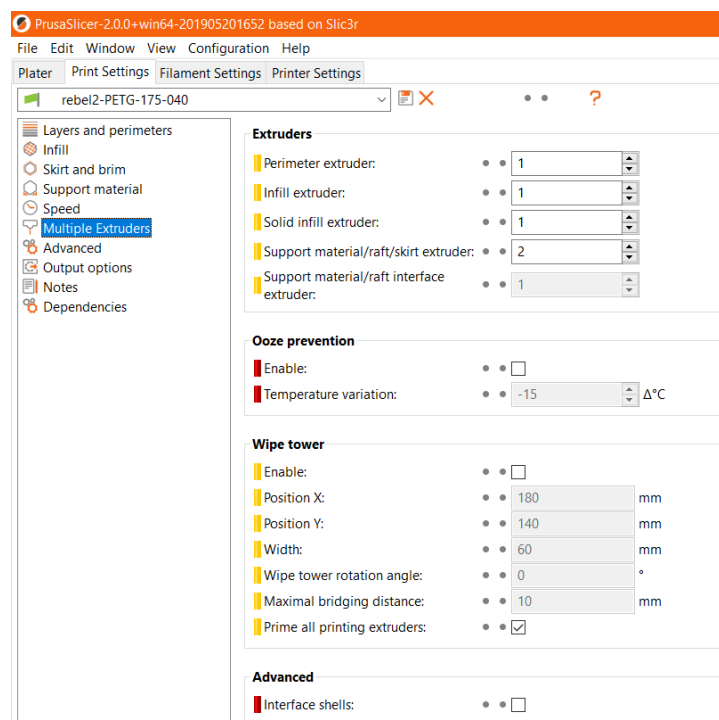


Figure 25 Ooze Prevention Settings

Figure 25 Show the enabled ooze prevention and the temperature set to be reduced to 15°C from the default nozzle temperature which is 235°C here in the printer. The total time taken for the print was 40 minute and 23 seconds. Material consumption of extruder 1 was 1869 mm and extruder 2 was 7598 mm. Manual cleaning was also performed in this process as it was the impacting the quality of the print.



Figure 26 Print Sample 4

	Sample 1	Sample 2	Sample 3	Sample 4
Extruder Temperature	250°C	250°C	250°C	250°C
Bed Temperature	90°C	90°C	90°C	90°C
Material Consumption (Extruder 1+ Extruder 2)mm	3868+4599	1535+1249	2089+1828	1869+1598
Feed Rate	55-65	50-55	50	80
Number of layers	120	80	80	80
Special Settings	No Special Settings	Manual Cleaning	Ooze Prevention(not Working)	Ooze Prevention

Table 2 Sample and Printer settings

3.2.1) Procedure

- CAD Design of the sample or prototype.
- Conversion of CAD files to Machine Understandable format (.STL).
- Connecting the printer to a computer. Printer is connected with cable or the files or input using a SD card.
- Printer setup and calibration.
- Configuration of printer is done as required.
- Samples are imported to the software.
- Slicing process is done.

- Temperature is set and extrude is heated.
- Printing is started. Printing consumes time depending on the
- Once printing is done print is let to cool down and print is removed.

3.3) Holder and Brush

After getting to know how the printer and since cleaning the nozzle in between the layer change improves the print quality. Thus a brush holder is designed and attached to the printer itself. Below figure shows the design of brush holder.

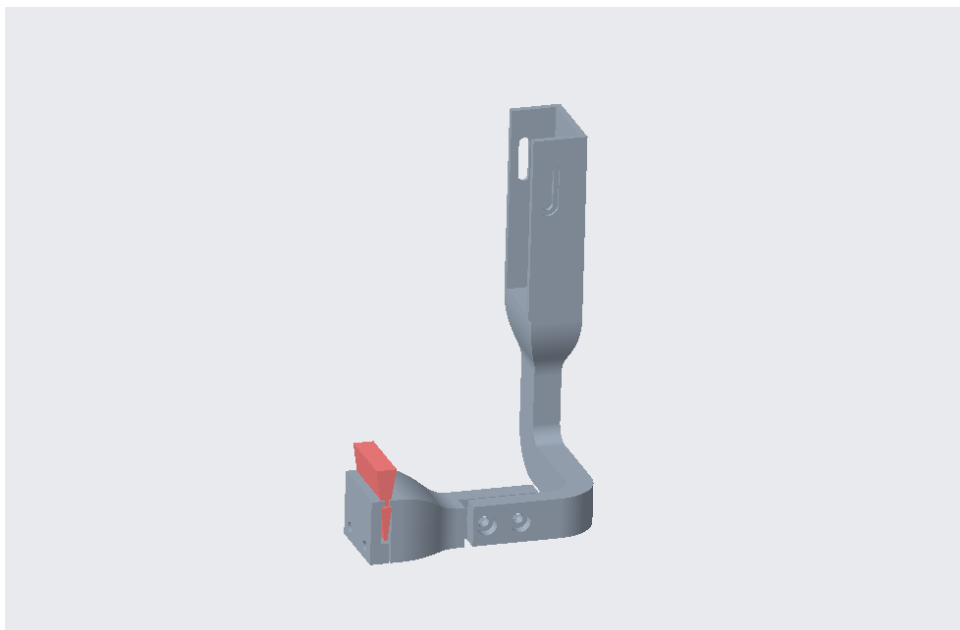


Figure 27 3D model of Brush & Holder

Holder is designed as it can be adjusted and fixed with a tolerance. The holder was fixed to the right side guider which moves up and down guided by the right side guiding rod. The belt which controls the horizontal movement of the extruder is also fixed to the guider.

While fixing the working are being reduced from 200mm to 195mm. to resolve this problem the existing right hand side guider was analysed and resized where the horizontal dimension was reduced and replaced with the old one.

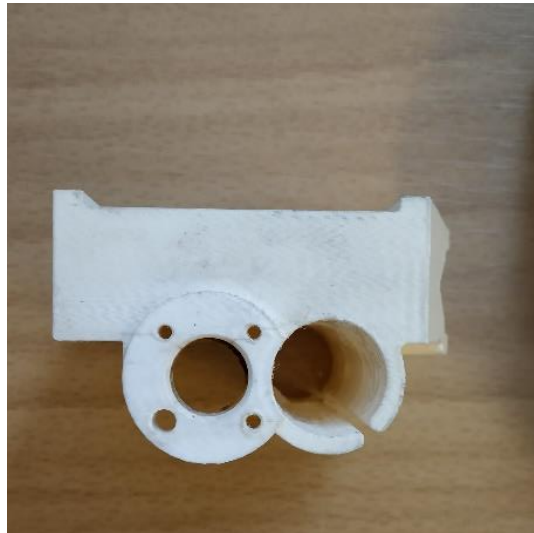


Figure 28 Old Right Side Guider



Figure 29 New Right Side Guider

The above images show the new and old part. The black one is new part which is 5mm lesser than older design. This helps to restore the workspace to 200mm.

Right hand side guider is also resized in order to make workspace extended in right side. The switch used to stop the nozzle is also replaced with a new one which is smaller in size and is place in the new right guider.



Figure 30 New Left Guider

The holder is designed and printed in Stratasys Dimension SST 768 3D printer using ABS (Acrylonitrile Butadiene Styrene). Acetone is used to fix the new parts in their place, as acetone works as a paste when applied on the acetone. This happens because acetone dissolves the ABS but it reconstitutes once acetone is evaporated.



Figure 31 Printed Holder and support material-1



Figure 32 Printed Holder and support material-2

Above figures 31 and figure 32 shows the printed holder in the print plate with the support material. Holder is designed in various parts which enables repositioning of the brush as needed. Part 1 of the holder is the main part which is attached to the printer itself through the guider.



Figure 33 Holder Part 1 Side view



Figure 34 Holder Part 1 Front View

Above figure 33 and figure 34 shows the Part 1 of the holder. The part is fixed using the nut and bolt with the groove which can be view in Figure 35. The second part is attached to the first part with the holes provide in the end. This section is designed to make the holder adjust the horizontal distance of the brush.



Figure 35 Holder Part 2 Top View

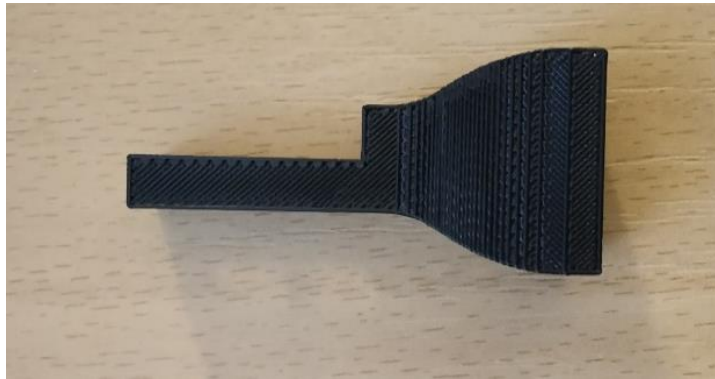


Figure 36 Holder Part 2 front view

The third part is the holder which is locked with the brush in place. The whole holder setup is fixed and set to undergo the process of cleaning the nozzle during each layer change as it is done in manual cleaning process.

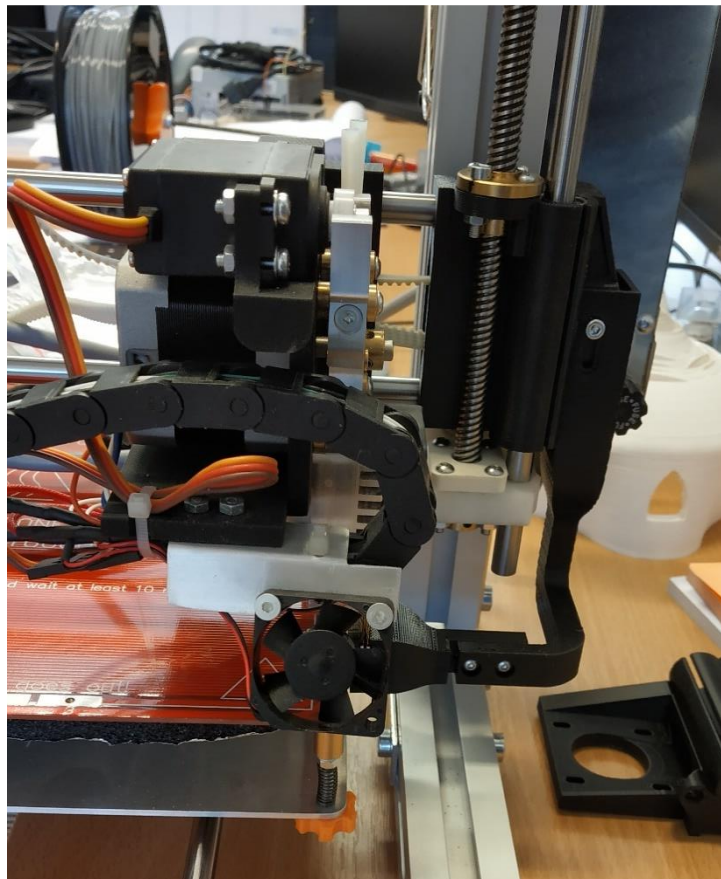


Figure 37 Rebel II with new Holder and guider

Above figure 37 shows the holder and the new resized right guider has been replaced and fixed. Bed was calibrated once the new parts are replaced. Calibration

of the bed is considered most important for quality of print as the position of bed affects the printing process.

During this process the bed was removed for the convenience of work and is fixed and calibrated. Step limit in x direction was increased to 212.00 mm. maximum bed length is also now higher than the old one.

Once the new holder and brush is fixed sample 5 was printed with previous settings and the print was slightly downgraded. The problem faced here was the material in the brush tends to stick to the nozzle during next cycle which disturbs the layers. The sample was a cube of 20*20*20 mm and ooze prevention was functional. Material consumed by extruder 1 was 1247 and extruder 2 was 923 mm. the feed rate was maintained at 60 mm/second. The number of layers was 80 and Estimated time for printing was 44 minute and 17secs.



Figure 38 Print Sample After attachments

Above figure 38 shows the samples print after the attaching the holder and brush in the printer. The first sample towards the left is the sample 5 whose details are mentioned above. The problem of material sticking to the nozzle back while cleaning was reduced by reducing the cleaning speed to F1500 which is fixed at F7200. The result was obvious and could be seen in the figure in sample 6 (middle). The last sample in the right is sample 7 which is print with the skirt around the cube

in the same height as the cube. The quality of the print almost perfect. All other setting of the extruder and printer were maintained the same throughout except the cleaning speed in all three prints. The quality of the print is improved but still faces a problem of the material being shifted in a particular direction. This is caused by the placement of the nozzles. The nozzle is designed to be a particular place which is not exactly achievable due to the restriction in the area to be accessed or worked by bare hands.

4) COMPENSATION OF NOZZLE

Due to the slight difference in the position of the nozzle the quality of the print is affected. The position of the nozzle cannot be fixed exactly due to technical difficulties like the size and the space available. The nozzle size is too small to identify the exact position through naked eyes. Also the space available stays as a restriction to work with tools or bare hands. This leads to a slight variation in the distance between the nozzles.

The theoretical or fixed distance between the nozzles should be 10mm from the centre of the nozzle 1 to centre of the nozzle 2. The actual distance between the nozzle is not as mentioned above.

The effect of this condition can be noted in all the above samples or the figure 39 below,



Figure 39 Nozzle Compensation Error

In above image the problem faced by the improper compensation of nozzle can be noted. The White outer material is printed from nozzle 1 and the blue inner is printed by nozzle 2. As mentioned above the distance between the nozzles are considered to be 10mm and the Arduino is coded accordingly. Due to the misalignment of the nozzle the print quality is affected. The blue inner material which is printed by nozzle 2 is slightly moved from its position.

The changed position is calculated by testing what the distance between the nozzle. For this test a small test was undertaken. Two squares of dimension 20*20 mm and 22*22 mm was printed and the dimensional changes can be note below images shows the error in the printing clearly.

The inner square is a 20*20 blue square is shifted towards left in very small value and shifted a lot in upwards. In x axis it is shifted in $-X$ direction and y axis it is shifted in $+Y$ direction. The deviation can be seen in figure 41

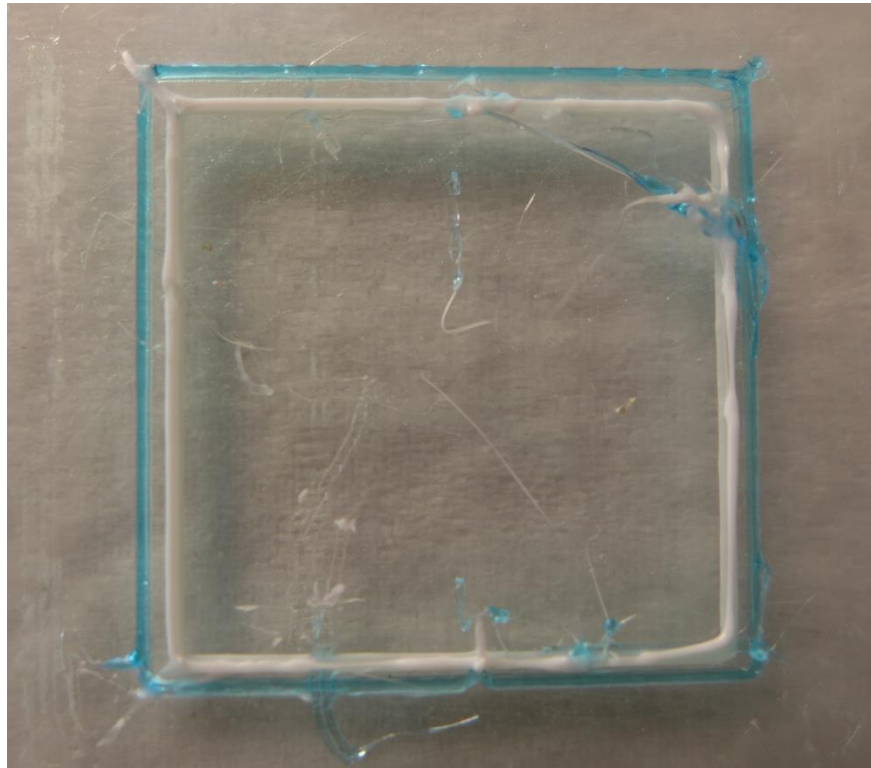


Figure 40 Calibration Test

4.1) Calibration Tests

The deviation can only have altered by changing the input in EEPROM Arduino thus the g codes remain the same as used in previous prints. Various values are assumed and printed and calibration test is performed. Each layer in the test is printed with both the nozzle due to the difference in the nozzle position the determined print is not achieved. The value is corrected and multiple print is done to verify the distance error in the nozzles



Figure 41 Calibration Test 1 (x-0.1_y-0.5)



Figure 42 Calibration Test (x0.1_y-0.25)



Figure 43 Calibration Test (x0.05_y-0.2)

Various tests are performed to find the deviation and above figures show the deviation test for x axis in -0.1, +0.1 and 0.05 and in y direction as -0.5, -0.25 and -0.2. From the above test the last test in figure 43 with the dimension as 0.05 in x and y as -0.2 looks closer to in defined position.

5) CONCLUSION

Rebel II is a commercial 3D printer capable of printing a filament form material. It is designed generally with a single nozzle. Extra nozzle is added in order to print with multiple materials. The quality of print is affected by certain issue like improper compensation of nozzles. This issue reduced quality is focused here, the main aim of this thesis is to improve the quality of the print.

A dice is designed and printed to check the quality of the print, it was designed as two parts to be able to print by multiple nozzles the defects in the print are identified.

The quality of the print is improved by focusing on multiple possibilities. One such action is designing and attaching a brush holder to clean the nozzles frequently during the printing process. Also the thesis focused on trying various printer and extruder setting based on the setup

The difference in the nozzle alignment is measured and corrected in Arduino and the nozzle is compensated to increase the quality of the print. With cleaning the brush and compensated nozzle the quality of the print was increased when compared with the usual multiple nozzle print.

Multiple material like ABS, Iglidur is also used to print, samples are unable to print due the pandemic situation of Covid-19.

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