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Testing of Structural Materials for Additive Manufacturing by FLM Technology

Master thesis

Study programme: N2301 – Mechanical Engineering
Study branch: 2301T049 – Manufacturing Systems and Processes

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TECHNICKÁ UNIVERZITA V LIBERCI
Fakulta strojní

Testing of Structural Materials for Additive Manufacturing by FLM Technology

Diplomová práce

Studijní program: N2301 – Mechanical Engineering
Studijní obor: 2301T049 – Manufacturing Systems and Processes

Autor práce: **Sribalagi Rajaganesh**
Vedoucí práce: Ing. Petr Keller, Ph.D.

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DIPLOMA THESIS ASSIGNMENT

(PROJECT, ART WORK, ART PERFORMANCE)

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Topic name:	**Testing of Structural Materials for Additive Manufacturing by FLM Technology**
Assigning department:	**Department of Manufacturing Systems and Automation**

R u l e s   f o r   e l a b o r a t i o n :

Perform the testing of the FLM 3D printer for structural materials (plastics or composites such as Nylon, Iglidur, thermoplastics with graphite, etc.) and, if necessary, propose adjustments of this printer configuration to obtain the highest quality of printing.

Recommended methods of elaboration:
1. Become familiar with the existing 3D printer Rebel II in the lab.
2. Make research of existing structural materials for FLM technology and print requirements for these materials.
3. Design a suitable shape of the testing part(s), select at least three special materials and perform experimental 3D printing.
4. Propose adjustment of the printer and printing parameters for each material, resp. provide testing of printed parts mechanical properties.
5. Evaluate the results and conclusions.

Scope of graphic works: **according to need**

Scope of work report

(scope of dissertation): **approx. 55 pages**

Form of dissertation elaboration: **printed/electronical**

Language of dissertation elaboration: **English**
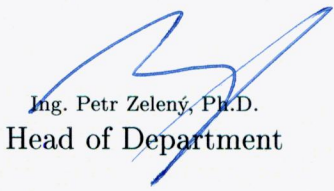
List of specialized literature:

[1] GEBHARDT, A. Understanding Additive Manufacturing: Rapid Prototyping - Rapid Tooling - Rapid Manufacturing. Munich: Hanser, 2011. ISBN 978-3-446-42552-1.
[2] Fused filament fabrication. In: Wikipedia: the free encyclopedia. Wikimedia Foundation, 2001 San Francisco (CA) [online]. 2001/2016 [cit. 2018-09-18]. Available from https://en.wikipedia.org/wiki/Fused_filament_fabrication.
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[4] STRATASYS LTD. Professional 3D Printing. [online]. 2015 [cit. 2018-09-18]. Available from: http://www.stratasys.com/.

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2. 5. 2019

Sribalagi Rajaganesh

Abstract

This thesis work is mainly focused on testing the performance for various materials in Rebel II 3D printer and to obtain high quality printing. Rebel II 3D printer is working with FLM technology. Some changes have to be made in this printer to obtain high quality parts. And the main aim is to obtain the printing parameters for the structural materials to get high quality of printed parts which includes: Bed temperature, Printing speed, Nozzle temperature and layer height.

Keywords

Rebel II 3D printer, RepRap community, FLM technology, high quality print.

Anotace

Tato práce je zaměřena především na testování kvality tisku z různých materiálů na tiskárně Rebel II 3D s cílem co nejvyšší kvality tisku. 3D tiskárna Rebel II pracuje na základě technologie FLM. Pro dosažení co nejlepší kvality tisku bylo třeba provést určité změny v její konstrukci. Hlavním cílem je nalézt tiskové parametry pro různé konstrukční materiály pro získání co nejkvalitnějších vytisknutých dílů. Parametry, které byly primárně měněny jsou: teplota podložky, rychlost tisku, teplota trysky a výška vrstvy.

Klíčová slova

3D tiskárna Rebel II, komunita RepRap, technologie FLM, vysoce kvalitní tisk.

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Last but not least, I would like to thank my family and loved ones for their continuous support, trust and help in the process study.

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List of Abbreviations

3D printing, 3-Dimentional printing

FLM, Fused Layer Manufacturing

FDM, Fused Deposition Modeling

AM, Additive Manufacturing

CAD, Computer Aided Design

SLA, Sterolithography apparatus

SLS, Selective Laser Sintering

EBM, Electron Beam Welding

SDL, Selective Deposition Lamination

LOM, Laminated Object Manufacturing

PETG, Polyethylene Terephthalate Glycol

HIPS, High Impact Polystyrene

PA, Polyamide

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1. INTRODUCTION

The topic of the work is "**Testing of Structural Materials for Additive Manufacturing by FLM Technology**". Rebel II 3D printer is used in this work. The principle behind this printer is Fused Layer Manufacturing and it is also known as Fused Filament Fabrication. FLM (Fused Layer Manufacturing) is a type of Additive Manufacturing technology and my work is based on the principle of Fused Deposition Modeling. Fused Deposition modeling is developed by S. Scott Crum. Fused Layer manufacturing is developed by the member of RepRap. It is the process where the plastic wire is placed in the top of the machine and then it is fed into the heated movable head and then the material is melted and extrudes it layer by layer and deposited as per the desired shape. The main work is focused on testing of structural material by FLM technology and to obtain higher quality of print with those materials. In this testing, some materials are chosen and their optimal properties are identified and printed with Rebel II 3D printer. Printing parameters are identified with the help of ABC analysis (used to find most important parameters) and by Taguchi method (used to find best combinations of parameter). And then the printed part is analyzed based on the quality and dimensions. And sometimes it is necessary to calibrate the printer if needed. So by using taguchi method, it is easy to find some good combinations of parameters and by using those parameters it is easy to do the experiment quickly and also to get the best results.

AIM OF THE WORK

Main aim of the work is to perform the test for various materials in FLM Rebel II 3D printer and to obtain the best printing parameters to get good quality printing parts. And some research has to be done for structural materials in FLM technology. If there is a need, it is also necessary to make some changes in printer to get best quality of printed part. Here parameter plays a major role. Some work has to be done on ABC analysis and Taguchi method to get combinations of parameters. With the help of these combinations of parameters, print has to be done. By considering good quality of printed parts, it is necessary to finalize those parameters as best parameters to print for those materials.

2. ADDITIVE MANUFACTURING

Additive manufacturing is the process of combining materials to make 3d model objects by depositing the materials layer by layer and fusing them together as putting an end to subtractive manufacturing methods. It involves the creation of complex structures in 3d modeling and components by the layering of materials to make the structure. Structures are created by the combination of thousands of minute layers which are combined together to make the complete product. It is done by the deposition of material through the printed end. The process involved in creating the structure is by the use of a computer and CAD software. The designed structure is sent as a message from CAD file to the printer. After receiving the information, the printer starts to print the required shape. In this technique of manufacturing, greater variety of shapes can be produced with many characteristics like product being stronger, no weak spots to compress or stress. Shapes with hollow centre can also be printed as a single piece without the need of attaching components or welding. One of the main advantages of additive manufacturing is being very quick and cost efficient[1]

designed model   fabricated object
(layer thickness 2*h*)   fabricated object
(layer thickness *h*)
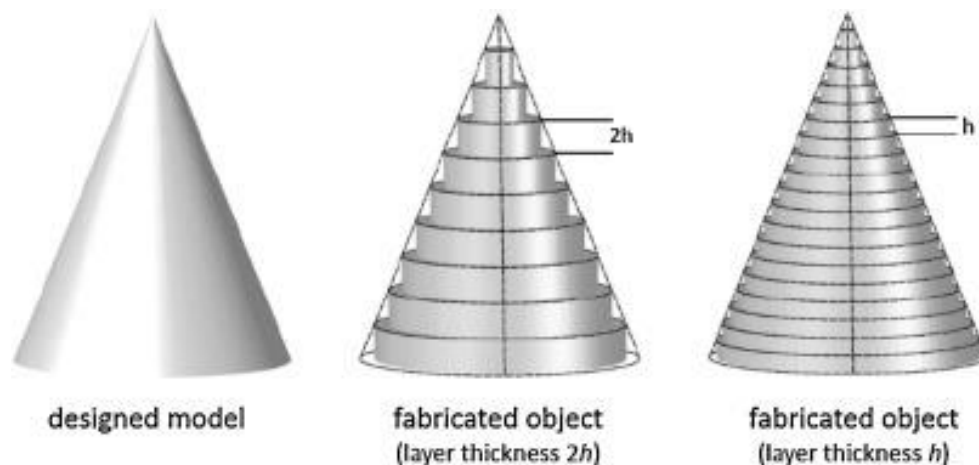
Figure 1 - Cone with different layer thickness[2]

Classifications of Additive manufacturing systems are

The best ways to classify Additive Manufacturing based on materials are

- Liquid-based
- Solid-base
- Powdered-base

2.1. LIQUID-BASED

In liquid-based additive manufacturing system, parts are built using the liquid resin (photo curable liquid resin) which is an organic resin which hardens when exposed to light, mainly under UV. The light rays first heal the resin near the surface, forming a thin hardened layer when exposed to it. After forming the complete layer of the part it is subjected to other process called elevation control system which allows the next layer of resin to be coated above the first layer. This will be continued until the entire part is completely done. The following are the few classifications of liquid based additive manufacturing systems.[3]
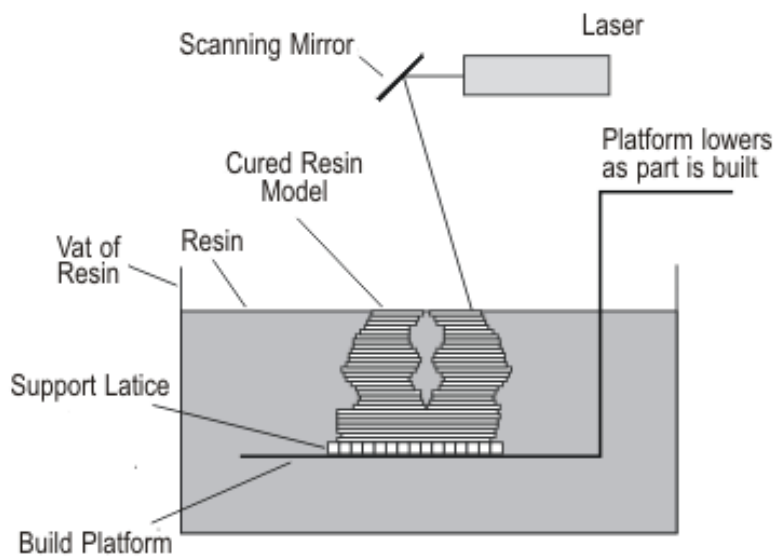
Figure 2 - Process diagram of Liquid- based[4]

Some of the classifications of Liquid-based additive manufacturing systems are shown below,

- Stereolithography apparatus(SLA)
- Poly-jet
- Rapid freeze prototype

2.1.1.Stereolithography apparatus (SLA)

Stereolithography is a 3d printing technology which is commonly used for making products or prototypes by depositing materials layer by layer using photo polymerization technique. The principle behind Stereolithography is the selective curing of photopolymer using a UV laser. A layer of liquid resin is prepared in the building space of the machine. The laser draws

a desired structure on the layer and starts printing the model's first layer. This process is followed until the model is printed completely. In this technique, the models are printed in two ways. One from bottom to top approach and another is top to bottom approach.
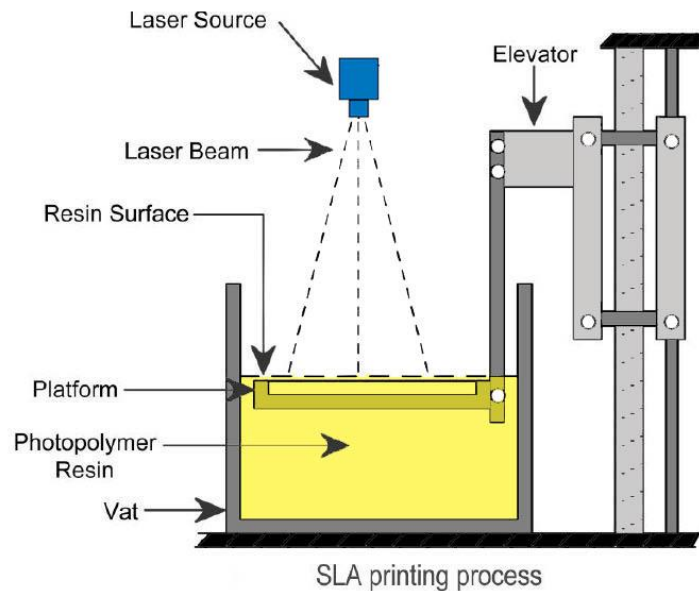
Figure 3 - SLA Printing Process[5]

a. Advantages

- One of the main advantages is precise and high-quality plastic prototypes can be fabricated by this technique.
- High accuracy and high smooth models can be created.
- We can obtain high resolution of small details clearly with quality surfaces.

b. Disadvantages

- The prototype will have a limited mechanical and thermal strength.
- Some complex structures cannot be printed so it will require some structures to support them.
- The support structure's surface quality of the area will be rough with scars.[3][6]

2.1.2.Poly-jet

Poly-jet is a 3d printing technology which produces accurate parts with smoothness, prototypes and tooling. It can produce thin walls and complex geometric structures with microscopic layer resolution more accurately using the greatest range of materials available.
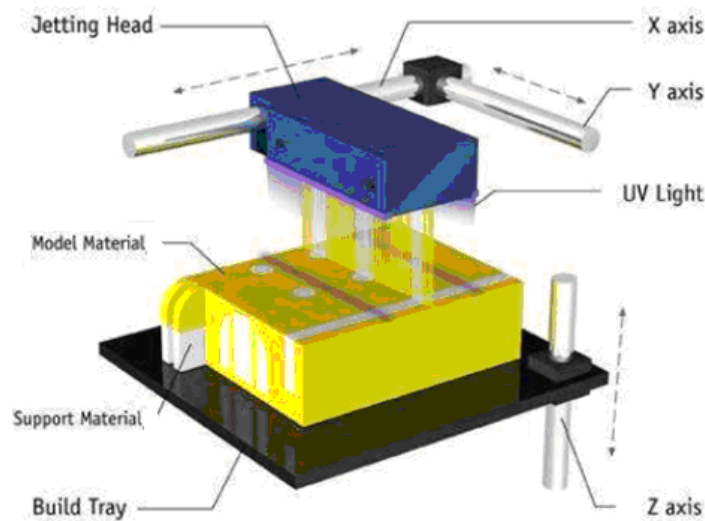
Figure 4– Poly-jet printing process[7]

a. Benefits of Poly-jet:
- By using poly-jet printing we can create smooth, detailed prototypes with fine features.
- It can produce accurate molds, jigs, fixtures and some other manufacturing tools.
- Complex shapes can be printed in a detailed manner.
- It has the unbeatable efficiency compared to others.[6]

2.2. POWDER BASED

Powder based additive manufacturing technique is one of the most practical and attractive form of manufacturing method. This type of technique is used to create parts which have more geometrical complexity with low cost and time effective. Selective laser sintering and electron beam melting are the two methods which are extensively used techniques. This technique provides a framework to understand about the materials and parameters to choose the characterization methods. Better quality parts are obtained than conventionally produced

parts. This technique is used in bio-medical industries, mechanical industries to fabricate the required prototype more accurately. Following are few types of powder based additive manufacturing method.[10]

Some categories of powdered based additive manufacturing are

- Selective Laser Sintering (SLS)
- Electron Beam Melting (EBM)
- Binder jet 3D printing

2.2.1.Selective laser sintering (SLS)

It is a sub- type of additive manufacturing technique which uses sinter powered material and laser as the power source. The powdered material like nylon and elastomers are used. The high power laser points (UV) is exposed to the material and binds it together to create a solid 3d structure. It fuses powered material by scanning the cross sections to obtain the information about the parts. It is a new technology which focuses on rapid prototyping. The complete part is obtained when the materials are deposited one layer above the other. The density of the part generally do not depend on the time of laser light subjected rather it depends on laser power. This technique is used worldwide because of its less manufacturing effect and complex geometric structures can be printed easily.

a. Advantages

- It has very good chemical resistance and has very good durability, strength and functionality.
- Complex geometric structures can be printed with high stiffness and with good chemical resistance.
- It has reliable mechanical properties and with high overhanging angles.
- High detailed parts with thin walls can be obtained.

b. Disadvantages

- Defective parts (i.e., porous parts) have to undergo post processing methods.
- Different parts with different intensity are obtained.
- Toxic gases are released while creating the parts.
- Smoothness of the surface will not good.[3][6]

2.2.2.Electron beam melting(EBM)

It is a type of additive manufacturing technique in which the material is placed under a vacuum and is fused together with the help of heated electron beam. The powdered metal is converted into solid metal when the heated electron beam is exposed to it. The beam melts the powder metal layer by layer as per the required geometrical structure. This method is done under the higher temperature to build up the parts.

a. Advantages

- No gas contamination because the whole process is done under the vacuum.
- We can obtain high productivity and this technique will be useful for very massive parts.
- It has very good thermal conductivity and mechanical properties.
- No internal stress is built with this technique.

b. Disadvantages

- The maintenance is very expensive in this type.
- It takes a very long time for completing the process especially cooling process.
- Only conductive parts are suitable for developing some parts under this technique.[11]

2.2.3.Binder jet 3d printing

It is also known as powder bed and inkjet head 3d printing which is a rapid prototyping additive manufacturing technique in which we can make three dimensional objects by data from the CAD file. The binder part is watery in nature to acquire the plaster form. Here, the part to be printed is build up by thin cross sectional areas where the printer head moves across it to print the required 3d object. The powered layer is spread across the section; the process is repeated until the whole part is printed with adhering to each previous layer. When the model is printed, it has to undergo a process called depowdering where the excess powder is removed. It is further subjected to other treatments to obtain desired properties in final product.

a. Advantages

- It is a fastest prototyping method in low metal cost.
- We can make fully colored parts through the integration of inks.

- There is no use of support structure.

b. Disadvantages

- Printed parts usually have unfinished and porous surface

- The parts should undergo further processing techniques like curing, sintering and additional finishing.

- The printed parts are weaker than parts printed with powder bed fusion process[12]

2.3. SOLID-BASED

To create a part or prototype, Solid-based additive manufacturing uses solids as a primary medium. The categories of solid- based additive manufacturing are[3]

- Fused layer manufacturing(FLM)

- Selective Deposition Lamination(SDL)

- Laminated Object Manufacturing(LOM)

2.3.1.Fused layer manufacturing(FLM)

It is one of the most commonly used additive manufacturing techniques which is more economical. It is widely used for creating prototypes and engineering parts. Because of its simple working nature, reliability and low cost this technique is quite quickly adopted and recognized. Here, layer by layer manufacturing fashion is used. Thermoplastic polymer filaments are heated and are deposited layer by layer and solidified to make the 3d object through the nozzle according to the digital CAD data. All the movements which subject to printing like movement of head and raw material supply are controlled with the computer. The printer platform is made of some metals and every layer which is printed is deposited on it. If one layer is printed, it is lowered and another layer is printed. The layer deposition in this technique is ultra thin and its complexity is high. On the other hand, the heat direction is also very critical. The parts or prototype printed by this technique will possess good mechanical properties and interconnectivity of pores will also be good with high porosity. The head of the nozzle with heated material moves in x-y plane and starts depositing the material as per the geometric structure required. The base material which is deposited below

is removed by exposing it to the ultrasonic vibrations and can also be removed by other process. The accuracy of the prototype obtained generally depends on the distance of the nozzle which moves vertically. This type of printing method gives a value for money and it finds applications in various fields like automotive industry, aerospace, medical, manufacturing industries etc.

a. **Advantages**

- It is safer and it does not emit any kind of toxic gases.
- It is less expensive and more economical.
- It has high durability and possess good strength.
- The prototype can be printed colorfully.

a. **Disadvantages**

- It lacks accuracy when comes to dimensional tolerance.
- Surface finish is not good and it needs further processing. [13]

2.3.2.Selective deposition lamination(SDL)

It is a printing technique where we do not use expensive polymers, plastic, powder or resin to print the prototype. Instead of those materials, we use paper to print the model. This technique is also called as paper based 3D printing process where using papers by cutting and bonding them together to create a 3D model. It simply uses glue to bond papers together. First few papers are glued to form a base layer and thicker layers are made to act as a supporting material. The sharp blade is used to cut the paper according to the data. After cutting, glue is applied before another layer of paper is fed into the printed. This process is repeated several times to make a complete model.

b. **Advantages**

- Material cost is low since no expensive materials are used.
- The model can be printed in various colors fully.

c. **Disadvantages**

- It consumes more time and the speed of printing is low.
- Material selection and properties sometimes be a limitation in this technique.[14]

3. MATERIAL USED

This chapter shows, what are all the materials which is used for testing to find their best printing properties in Rebel II 3D printer. And the materials which are used to test are HIPS, Polyamide, Polyamide with Carbon fiber and Iglidur.

3.1. HIPS

HIPS – High impact polystyrene. In this sub-chapter, some of their Advantage of HIPS, Disadvantage of HIPS, Properties of HIPS and their Technical information's are shown.

- High impact polystyrene is a type of thermoplastic which is low cost and can be easily fabricated because of its glassy and glass like texture.

- It is commonly used because of its general properties like tensile strength, durability, machinability, stability and impact strength

- Because of its bio-degradable nature, it widely used in packing applications like food packing, dairy packing and also in industrial packing.

- HIPS have small percentage of rubber in it so it is generally preferred for making parts which required high impact resistance.

- Since it has good surface finish, they have wide range of application in electronic and appliance.

- Because of its light weight nature, it can be combined with some other materials to improve its durability and increase its strength.[16]

a. Advantages

- HIPS have the ability to adapt to different types of activities or functions.

- HIPS can be hammered or pressed (molded) into different shapes without being cracked or broke which means it has good malleability and also it has good ability to resist breaking under stress.

- One more important advantage of HIPS is that it can be re-shaped many times and can be recycled.

- It is relatively light in weight, cheap and economical so it has extensive applications.

b. Disadvantages

- It is generally not water proof and has the absorption properties. In such a way, it can be easily affected by hydrocarbon solvents.

- The electrical properties of HIPS are naturally low and it cannot be used in all circumstances.[17]

c. Technical information

- Recommended printing temperature : 230-240˚C
- Recommended bed temperature : 90-110˚C
- Speed : As high as 70mm/s, but recommended Speeds are 40mm/s or less.
- Cooling : Cooling fan is not recommended, but can be used in low speed.
- Dissolves in : Limonene solvent [16]

d. Properties

- Lightweight
- Durable but flexible
- High impact resistant

e. Applications

- It can also be used on its own
- For ABS, it's a supporting material [17]

3.2. POLYAMIDES

In this sub chapter, some of the advantage of Polyamide, Disadvantage of Polyamide, Technical information, Properties and some of their variants are shown.

- Polyamide is a chemical compound with the combinations of amide bonds.
- Polyamide can be obtained both naturally and artificially comprising of many properties.
- There are available both in power form and plastic form (nylon).

- Naturally obtained polyamides are from plants, animals, bugs etc., two best example of this is silk and proteins.
- Artificially obtained polyamides are made by polymerization method.
- Artificially made polyamides have extensive application in textile industries, automotive industries, transport manufacturing industries because of their durability and strength properties.[18]

a. Advantages

- Polyamides have the ability to withstand the shock or force applied on it which technically means impact resistance
- It can be melted and remolded into different shapes because it is silky and synthetic in nature.
- Polyamides can be used under high temperature environment because they are resistant to high temperature.
- Generally it is strong and it is long lasting because of some properties like abrasion resistant and low coefficient of friction. Their mechanical properties are not changed even in high temperature.
- Polyamides are used widely in industrial and engineering applications.

b. Disadvantages

- They react with acid and oxidizing agent which is a big disadvantage.
- The presence of moisture content can affect the electrical and mechanical properties of polyamides.
- It also has some dimensional instability.
- If a part is overfilled while using polyamides it can cause a mess with strings everywhere.[19]

c. Technical information:

- Recommended printing temperature : 260-280°C
- Recommended bed temperature : 75°C
- Printing speed : 30mm/s to 60mm/s
- Adhesion : Buildtak adhesion sheet or Elmer's
- Cooling : Cooling fan is no needed, Print in a room without any cooling or no draft is possible.

d. Properties

- Coefficient of friction is low

- Easy to color or dye

- Layer adhesion is good

- Extremely durable

- High Chemical resistant than PLA and ABS

- Abrasions resistant

e. Variants of Nylon

- Nylon 618   :   It is very popular and has white color naturally.

- Nylon 645   :   It is difficult to work but it is bright enough.

- Nylon FX256   :   It is stronger than ABS and PLA but is less brittle.

3.3. POLYAMIDES WITH CARBON FIBER

In this sub chapter, some advantage of polyamide with carbon fiber, some disadvantages of polyamides with carbon fiber are shown.

- It is light fiber and very strong which contains carbon fibers.

- The material contains subset of high modulus polyethylene. It can be recycled, molded in any shape and can be polished and waxed.

- It has extensively wide applications in aerospace engineering, automotive engineering etc.

- Parts made with this are corrosion resistant and stiff and has greater magnitude, toughness, elasticity and tensile strength.

- High toughness at tensile load and bending load and is resistant to radiation shock.

a. Advantages

- They are more resistant to shock, heat and corrosive liquids.

- Their density and thermal expansion factor is low.

- They can withstand wide range of temperature.

- They have high dimensional stability when products are molded.

- They have high toughness, tensile modules and bending load.

b. Disadvantages

- Even if it contains small air bubbles in the material it will reduce its strength
- It has a high initial cost because of the materials[21]

3.4. IGLIDUR

In this sub chapter, some information about the variants of Iglidur and some of the technical information for Iglidur are shown.

- This type of material is generally used in long-life applications and also with soft shaft.
- They have excellent vibration dampening.
- It is also water proof and versatile material.
- It is generally strong and low cost material used in high-quantity production.

a. Variants of Iglidur

- Iglidur ®|150   :   It is easy for beginners. Without heated build plate we can Processed (but Igus Adhesion foil is needed).
- Iglidur ®|180   :   It is for advanced users. Because many conditions needed to Be known (like switching off fans, enclosed printer).
- Iglidur ®|170   :   It is for experts. Because, it is hard to process.
- Iglidur ®|J260   :   It is for experts. Because, it is hard to process.
- Iglidur ®|C210 :   It is for experts. Because, it is hard to process.

b. Technical information:

- Nozzle temperature :   250-260˚C
- Bed temperature   :   80-100˚C
- Print speed   :   ~50mm/s [20]

4. ABOUT PRINTER

In this chapter, some of the Technical information of Rebel II 3D, software used, Hardware used and electronics which are used in Rebel II 3D printer are shown.

Technical information

- Printing technology : FFF (Fused Filament Fabrication) -Plastic in The form of wire is passed through the nozzle (Heated nozzle) and then applied to the print pad in thin layers.
- Layer height : depending on the nozzle type, minimum 0.05 mm.
- Print Pad : Heated Pad 200 x 200 mm.
- Print size : 200 x 200 x 200 mm.
- Print speed : up to 120 mm / s.
- Drive speed : 200 mm / s
- Print pad surface : removable glass 2 or 3 mm, aluminum plate
- Plastic diameter : 1.75 mm (any plastic on the reel can be used).
- Type of plastic : ABS, PLA, TPE, PC, PA, PET, HIPS, PVA, ASA, WOOD and others.
- Nozzle diameter : 0.2 to 0.6 mm.
- Maximum nozzle temperature : up to 290 ° C, depending on the extruder used.[22]

Software

- Firmware : Open Source Repetier or Marlin with customization options.
- Software : Repetier-Host , Slic3r , CuraEngine (compatible with RepRap) or commercial Simplify 3D[22]

Hardware

- Dimensions : 420mm x 420mm x 650mm including spool.
- Frame : Anodized aluminum profiles 30 x 30 mm.
- Plastic parts : printed PET-G or ABS parts[22]

Electronics

- Communication :   USB, SD card in LCD module.
- Control board :   Arduino Mega 2560 and modified RAMPS 1.4.
- Power supply   :   industrial switching power supply 12V 240W or ATX power Supply from PC[22]

Figure 5 - Rebel II 3D printer

5. METHODS

Before starting testing of parts, it is must to find some methods because it not only important to find the best quality by printing with random parameters, it's needed to save time and money so that some methods are found to solve this problem. First it's important to find which parameters are most affecting the parts and then it is necessary to find best combinations of parameters.

To determine the optimal parameters some methods are used and the methods are,

1. ABC Analysis
2. Taguchi Method

5.1. ABC ANALYSIS

It is a method to find out or separate the subject into three categories like A, B, C so here A is most important, B is average and C is least important.

Why ABC

There are more than 20 parameters like (Nozzle Temperature, print speed, Bed temperature, Infill rate, Shape of infill, height of layer, shape of top layer and so on) so it is not possible to work with all of these parameters, instead we can find most optimal or important parameters (important parameters which are more affecting the part) with help of ABC analysis.

So to find ABC we need some weightage for each parameter. With the help of DOE (Design of Experiment), weightage for each parameter can be obtained.

There is a need to finalize the major problems during printing. So for these problems it is necessary to give weightage for each parameters (which cause or which parameter is more important to that problem) given in the table.

So with the help of this technique, it's easy to get weightage for each parameter which is shown in Table 1 and then with the help of these weightage, it is easy to separate or find most important parameters/Medium important parameters and least important parameters from ABC analysis which is shown below in Table 2.

Table 1 - Weightage Method

Problems/Parameters	Weigh-tage	Bed temp.	First layer temp.	Speed of retr-action	Nozzle temp.	First Layer height	Width of extruder line	No. of walls	Length of retr-action	Top layer thick-ness	Shape of top layer filler	% of fill	Shape of filling	Print speed	Print Thick-ness
Problems with sticking of first layer	**4**	5	3	0	4	2	1	0	0	0	0	1	2	3	1
Problem with sticking of filament with previous layer	**5**	1	0	0	4	0	1	1	1	1	0	1	3	3	3
Cooling problem	**4**	1	0	0	4	0	0	0	0	1	0	1	4	4	3
Low quality	**3**	1	0	1	2	0	0	0	0	1	1	0	3	2	2
Bad finishing	**3**	1	0	1	2	0	0	0	0	0	2	0	1	2	4
Rough surface	**2**	1	0	0	2	0	0	0	0	0	1	0	1	2	4
WEIGHTAGE TOTAL		**37**	**12**	**6**	**68**	**8**	**9**	**5**	**5**	**12**	**11**	**13**	**53**	**59**	**57**

Table 2 - ABC Analysis

Parameters	Weight	AVG		
Nozzle temperature	68	19.15%		
Print speed	59	16.62%		
Print Thickness	57	16.06%	**77.18%**	**A(Most important)**
Shape of filling	53	14.93%		
Bed Temperature	37	10.42%		
Percentage of fill	13	3.66%		
First layer temperature	12	3.38%		
Top layer thickness	12	3.38%	**13.52%**	**B(Medium)**
Shape of top layer filler	11	3.10%		
Width of extruder line	9	2.54%		
First Layer	8	2.25%		
Speed of retraction	6	1.69%	**9.30%**	**C(Least important)**
Number of walls	5	1.41%		
Length of retraction	5	1.41%		
	355	**100.00%**		

Here three different categories of parameters like most important, average and least important is obtained. So with the help of ABC analysis, finalizing the Nozzle temperature,

Print speed, Print thickness, Shape of fill and Bed temperature as most important parameters. So it is easy to finalize that, these parameters are affecting more in the printing part. So these parameters can be next method (Taguchi method) to find the combinations of parameters which is used to print.

5.2. TAGUCHI METHOD

Taguchi method helps to obtain the best possible combination of parameters. A set of experiment is conducted by using an orthogonal Array. Here MINITAB software is used to find the combination of parameters from taguchi method. For this the number of factors and the level of design is needed.

- Here number of factors are 3
- And level of design is 3

So 9 different combinations of parameters are obtained. In Taguchi, it's important to use the parameters which are shown as most important parameters in ABC analysis.

Table 3 - Orthogonal Array L9[24]

A	B	C
1	1	1
1	2	2
1	3	3
2	1	2
2	2	3
2	3	1
3	1	3
3	2	1
3	3	2

Why Taguchi

Without Taguchi, it is very hard to find the good combination of parameters because in ABC analysis there are 5 parameters which are showed as important. When doing manually with those 5 parameters, experiment for more than 50 combinations has to be done but with the help of Taguchi, it's enough to do only 9 experiment.

So to find some value range (parameters which we are going to use) for material which are going to be printed? So next step is to upload the values in Minitab software and then automatically it will give the 9 different combinations of parameters. Then with the help of these combined values it's easy to get best results at the end of the experiments. If best results are not obtained, there will be one solution to find good range of value. So for that, it is necessary to find some good quality parts from those 9 experiments so it means best values are somewhere around there. So now it is easy to change or adjust the parameters in Taguchi and print has to be done again to get best results.

These are the main reasons to use Taguchi to find the best results. If working without Taguchi, it will take a lot of time to find the best results so that a lot of materials and time will be wasted.

6. PREPARATION OF THE PRINTER TO PRINT

Before starting printing, it's important to know how to work with this printer and also its need to finalize the structure of design which is going to be work further.

6.1. HOW TO PRINT

This sub chapter shows the step by step process about how to print a part in Rebel II 3D printer.

a. Object placement

Import a 3D model and place it in Repetier-host software's bed and duplicate them on your virtual bed. Design which is used to print is shown below. And the details of finalizing this design to print are shown below.
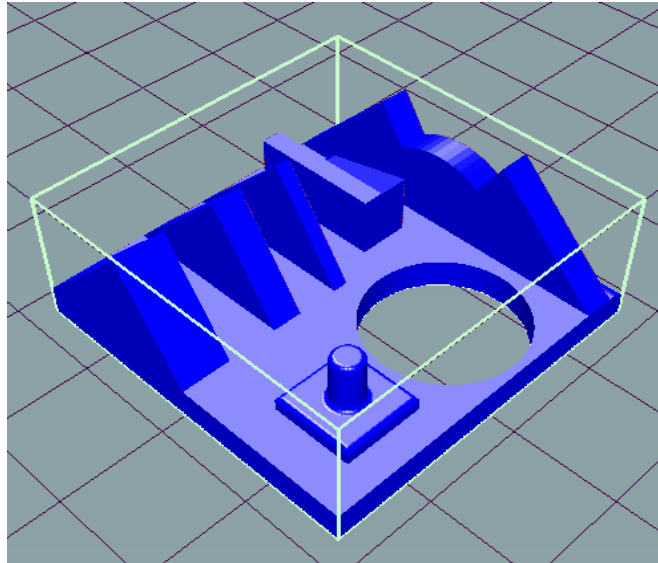
Figure 6- Design of Testing part

b. Slice

Next step is to slice with Slic3r Prusa Edition, after entering the required settings. It is possible to change the values of each parameter manually in slic3r Prusa Edition software.

c. Preview

It is possible to check the results completely layer by layer before printing itself and also estimated time of printing will be displayed in Repetier-host software. It is also available that, the number of layers to be printed to get a complete part.

d. Print

It is possible to print from Repetier-host server and also from SD card.

Figure 7 - Step by step process[25]

6.2. FINALIZING THE DESIGN

PETG

Polyethylene Terephthalate (PETG), where G stands for "Glycol-modified". During Polymerization, "Glycol-modified" is added to material composition. It is more durable, stronger and can be handled with strong impact.

Before starting the experiment, it is necessary to calibrate the printer. For testing, Polyethylene Terephthalate (PETG) with optimized values of parameter is used.
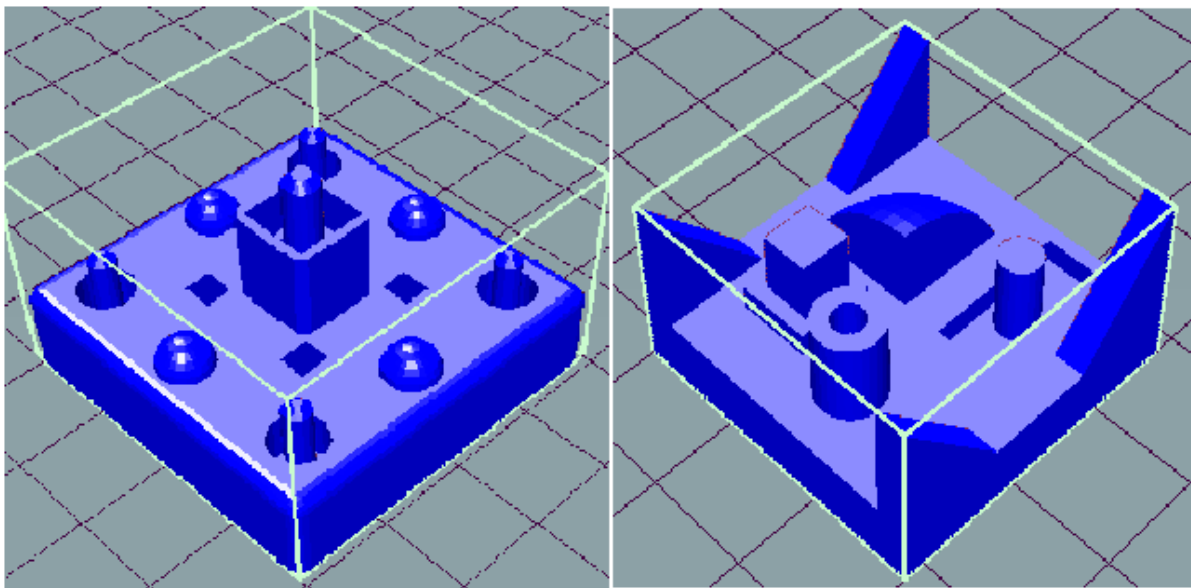
Figure 8 - Defects in Printed part PETG

This is the first part, which is printed in REBEL II printer. And here a lot of defects are seen in the shape. So it's necessary to calibrate the printer. First, it's important to clean the nozzle because the material will get struck into the nozzle and then it's needed to clean the servo driven gear because the material will be covered on servo driven gear. And then, measure the filament outlet by marking the filament for about 10 mm using measuring scale and then make the filament to come out manually by using manual control section in Repetier-host software so it is easy to check.
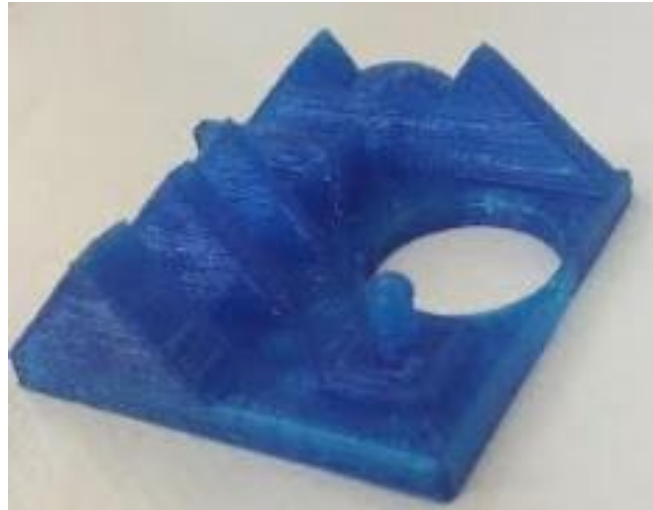
Figure 9 - Final design to do Experiment

So after calibration of the printer, the part without any defect is obtained and then this design is finalized to continue to do the experiment with other materials. Because this design contains many sharp edges and some arc shape, so it helps to find quality of product while working with other materials.

6.3. ADDING COOLING SYSTEM

In this printer there is missing of cooling system. Cooling system for materials is very much important because some material needs cooling and some may not. So it is important to add a new fan to cool the material whenever it is needed. So with the help of cooling system, the material will cool quickly and we can avoid the problem of sticking with the next layer and also good quality of top layer without any defects can be obtained. And the picture of fan is shown below.
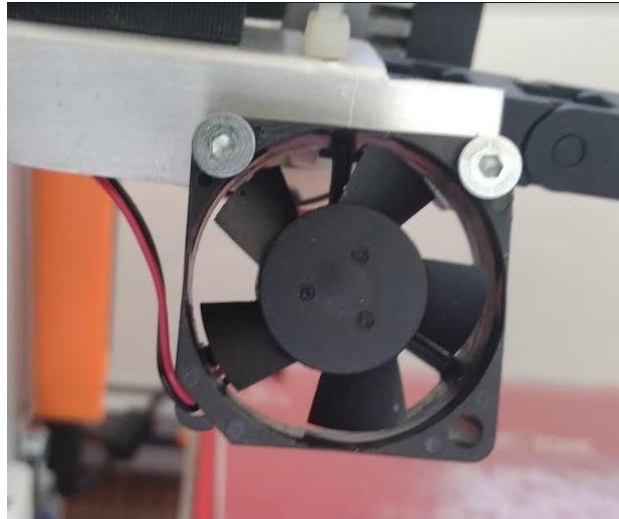
Figure 10 - New fan

7. EXPERIMENTS

7.1. HIPS

High impact polystyrene (HIPS) is the first material to start the experiment by using Taguchi method combinations. Here, 3 major parameters are used from Taguchi results; they are Nozzle temperature, Print speed and layer height as per ABC analysis. The best combination of these three parameters from Taguchi method is obtained. And here Bed temperature is fixed as 90°. So the combination of parameters from Taguchi is shown below

Table 4 - Combinations of parameter for HIPS by Taguchi.

Nozzle Temp.	Print Speed	Layer height
220	30	0.2
220	40	0.25
220	50	0.3
230	30	0.25
230	40	0.3
230	50	0.2
240	30	0.3
240	40	0.2
240	50	0.25

Let's go step by step, first upload the .stl file in Repetier host software and before slicing it is needed to update the parameters with the help of Taguchi. After that, slice with slic3r purusa edition and after checking the estimation time and the number of layers, it's the time to start printing. Make sure that the glue is applied on heating bed. Now, it's time to wait for nozzle and heat bed to get heated. First, test is with the combination of 240's in Taguchi's table. So there are 3 different combinations for 240, that is 240-30-0.3, 240-40-0.2 and the final one is 240-50-0.25. These are all in the order of Nozzle temperature – print speed – layer height respectively.

First part in figure 13 is the combination of 240-30-0.3, so here a lot of defects are seen but 70% of the part shape is obtained but shape does not look good and the quality is too bad. And it is possible to see a lot of unwanted extra materials in the surface of the part. With the help of this one part, it is not good to conclude this temperature which bad for this material because good shape and quality not only depends on the temperature but also depends on speed and layer height. So it is important to wait for remaining two combinations of 240(Nozzle temperature).

Figure 11 - Defects in printed part - HIPS

Second part in figure 14 is the combination of 240-40-0.2, here only 40% of the shape with poor quality is obtained and due to the over heat of the material, print is collapsed with over leakage or some clot of material in the printed part. And also it is possible to see a lot of unwanted materials sticking between two shapes. So due to the bad surface and some clot of materials in the part, it is impossible to work with this combination anymore.

Figure 12 - Defects in part

Third part in figure 15 is the combination of 240-50-0.25; here only 20% of the shape is obtained because of high printing speed. And also it is possible to see a huge amount of material stored in the same place; it's mainly because of high temperature. In last two parts the material is over melted. So it is easy and important to finalize that 240 is somewhat higher temperature for this material. So Printing of full part with nozzle temperature 240 combinations is impossible. So that nozzle temperature 240 is high for this material.

Figure 13 - Defects in printed part

While printing HIPS, there is another problem. Here some curve shape at the edges can be seen in the above picture. Reason for this problem is cooling. As mentioned above, fan is added to this printer for cooling purpose. But for HIPS, cooling is needed but not for bottom layers. Due to this cooling only temperature of heating pad get deflected and make the object to unstuck from the heating pad. But cooling is mainly needed for top layers because due to less printing area in top layers. It is needed to mention that, this is not the problem related to

sticking of first layer because while starting printing, print is going good for first 15-20 layers and then after first 20 layers, one or two edges it turns into curve shape as you see in figure so after sometime whole part is getting out from the heating bed.

Figure 14 - curved edges

230° combinations

This part is the combination of 230-30-0.25. While printing this parameter there is some problem – sticking of the part with heating bed. This is mainly due to the high cooling speed of the fan which is placed in printer. A lot of material is wasted due to this problem because while starting its looks good so waiting for the full part but after 15-20 layers, the part coming out of the heating bed. You can see the pictures of waste parts below
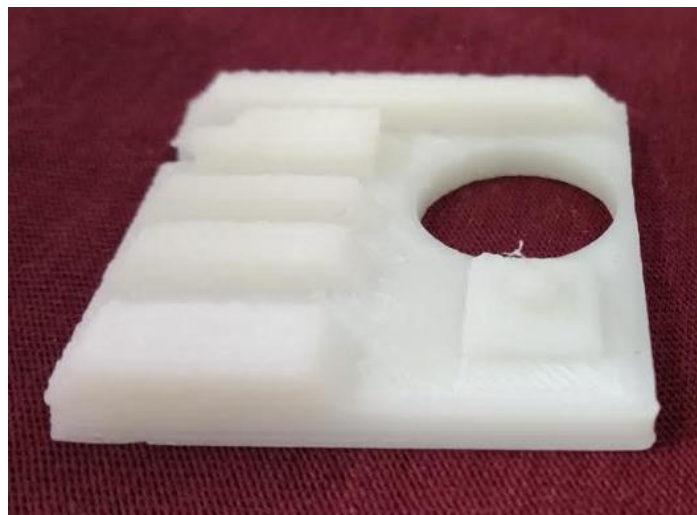

Figure 15 - Wasted printing part

So to avoid this problem, fan is switched off for first 10-15 layers and again switched on only for top layers (last 15-20 layers). So it is possible to reduce the unstuck problem of part from

heating bed. And why switching on the fan for top layer because it is important to cool the material quickly on top layers or else material will get collapsed while printing due to semi solid material state. The main reason for the material to be semi solid is less printing area on the top layers. It is needed to cool that quickly so that using fan for top layers.

This part is the combination of 230-30-0.25; here it is possible to see many defects like rough surface, unwanted sticking materials in the side walls. But when compared to 240° C combination, this combination is better and also we got 80% of the shape. As mentioned before, the fan is switched off for first few layers and then switched on for top few layers. This part is looking somewhat good when compared to next two parts because it's mainly due to the low printing speed and due to 0.25 layer height. For this temperature 230˚C, the combination of 0.25(layer height) and 30(print speed) is best when compared to other two following combinations of 230˚C.

Figure 16 - defects in Printed part

This part is the combination of 230-40-0.3(Nozzle temperature, Print speed, Layer height). Here bottom layers are looking good. Good quality, good surface and very good first layer but here the problem is in the top layers. A lot of defects (in top layers) and incomplete shape (only in top)- missing of only 15-20% of shape. Remaining 80-85% of shape looks good. So by compared to combination of 240˚C Nozzle temperature, 230˚C combination looks fine. And by using fan for top layers only we can't get full shape with proper dimensions. So this may be a problem with wrong combination of parameters so we have to wait for remaining experiments which are mentioned in Taguchi.

Figure 17 - Printed part HIPS

This part is the combination of 230-50-0.2(Nozzle Temperature, Print speed, Layer height). By using this combination, the printed parts looks like- rough surface, bad quality and incomplete shapes. This is mainly because of high printing speed. It is not good to conclude that high printing speed is bad for this material because bad shape can also be due to wrong combination of parameters. So maybe this high speed needs some other nozzle temperature and layer height. So it is important to finalize that, this temperature is not suitable for this HIPS material. Going further with other parameters is shown in taguchi for getting better results.

220˚C combinations

This part is the combination of 220-30-0.2(Nozzle Temperature, Print speed, Layer height). While printing this combination, printer is going well and also printing part really looks nice – without any defect and also good surface and quality. But for top few layers, this combination is not working properly. By seeing this quality and surface of the material, it is easy to conclude that – this temperature is best for this HIPS material but for top few layers it needs some different combination of layer height and printing speed. 90% of the part is obtained and remaining 10% of the part is not looking well with bad quality. Even though cooling is on, last few layers are bad.
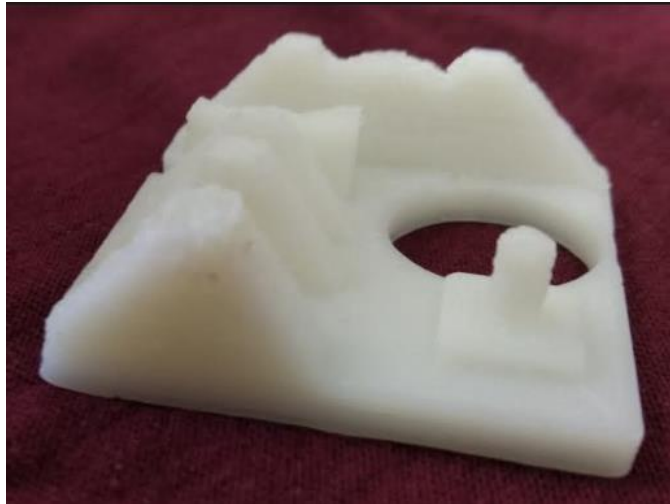
Figure 18 - Printed part Hips

This part is the combination of 220-40-0.25(Nozzle Temperature, Print speed, Layer height). There is no problem faced during printing this part. From first layer to last layer – no defects are found. This may be because of best combination of parameters for this material. Surface is looking good and quality is also fine and also got 100% of the shape. While printing this part fan is switched on only for top layers. So finalizing that, this combination of parameters is good for this material.

This part is the combination of 220-50-0.3(Nozzle Temperature, Print speed, Layer height). This is also same like previous combination of parameters because the printed part is looking very nice with good surface, good quality and got full shape of the part without any defect. While printing this part, fan is switched on for only top layers. Sharp edges are obtained without any quality defect. Here, printing speed is also high when compared to all other combinations so it will take just around 20–25 minutes to print this material with good quality so we can finalize that this combination of parameters is best for this HIPS material.

Figure 19 - Printed part with HIPS

7.2. POLYAMIDES

Polyamides are the second material to start the experiment with using Taguchi method combinations. Here, 3 major parameters are used from Taguchi results; they are Nozzle temperature, Print speed and layer height as per ABC analysis. The best combination of these three parameters from Taguchi method is obtained. This material has the problem of sticking of first layer with bed if bed temperature is low. So bed temperature is fixed as 100°C. So combination of parameters from Taguchi is shown below.

Table 5 - parameter combination for PA by taguchi.

Nozzle Temp.	Print Speed	Layer height
230	20	0.2
230	25	0.25
230	30	0.3
240	20	0.25
240	25	0.3
240	30	0.2
250	20	0.3
250	25	0.2
250	30	0.25

Let's go step by step, first upload the .stl file in Repetier host software and before slicing it is needed to update the parameters with the help of Taguchi. After that, slice with slic3r purusa edition and after checking the estimation time and number of layers, it's time to start the print. Make sure the glue is applied in heating bed. Now it's time to wait for nozzle and heat bed to get heated. First test is with Combination of 230's in Taguchi table. So there are 3 different combinations for 230 that are 230-20-0.2, 230,25,0.25 and the final one is 230-30-0.3. These are all in the order of Nozzle temperature – print speed – layer height respectively.

This part is the combination of 230-20-0.2(Nozzle Temperature, Print speed, Layer height). While starting printing itself it is easy to find that, this temperature is not suitable for this material. Nozzle temperature 230℃ is not sufficient enough for the material to get melt properly. So the material is not coming out from the nozzle properly and it is impossible to continue printing with this combination of parameter because material gets stick inside nozzle because of the low temperature. There is same problem for remaining two combination of 230˚C nozzle temperature. The picture of that combination of 230˚C is shown above. Here finalizing that, this combination of parameters is not recommended for this material. So the combinations of 230-20-0.2, 230-25-0.25 and 230-30-0.3 are not recommended for this material.
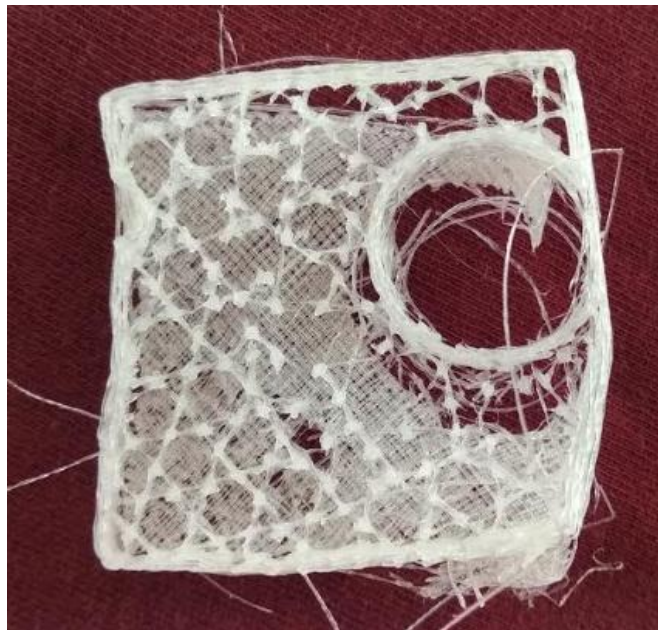
Figure 20 - Defects in printed part PA

This part is the combination of 240-20-0.25(Nozzle Temperature, Print speed, Layer height). As mentioned before, this material needs some high temperature to melt. So while working with nozzle temperature 240˚C, by seeing the part it is easy to realize that, this temperature is also not suitable for this material. Because even though full part is obtained, there are many defects in the printed part. 240˚C is not enough to melt that material so in many places it is possible to see missing of materials. Speed of printer is very much important for this material. It needs some slow speed to give good quality of printed parts. Fan (Cooling system) is not required for this material. But when compared to 230˚C nozzle temperature, this combination is better than that. So because of low nozzle temperature, it is possible to see a lot of gaps between layers, bottom layer is too bad, quality is very poor and very rough surface. So here finalizing that, the combination of 240-20-0.25, 240-25-0.3 and 240-30-0.2 (Nozzle Temperature, Print speed, Layer height) is not suitable for this kind of material. This material needs some high nozzle temperature.
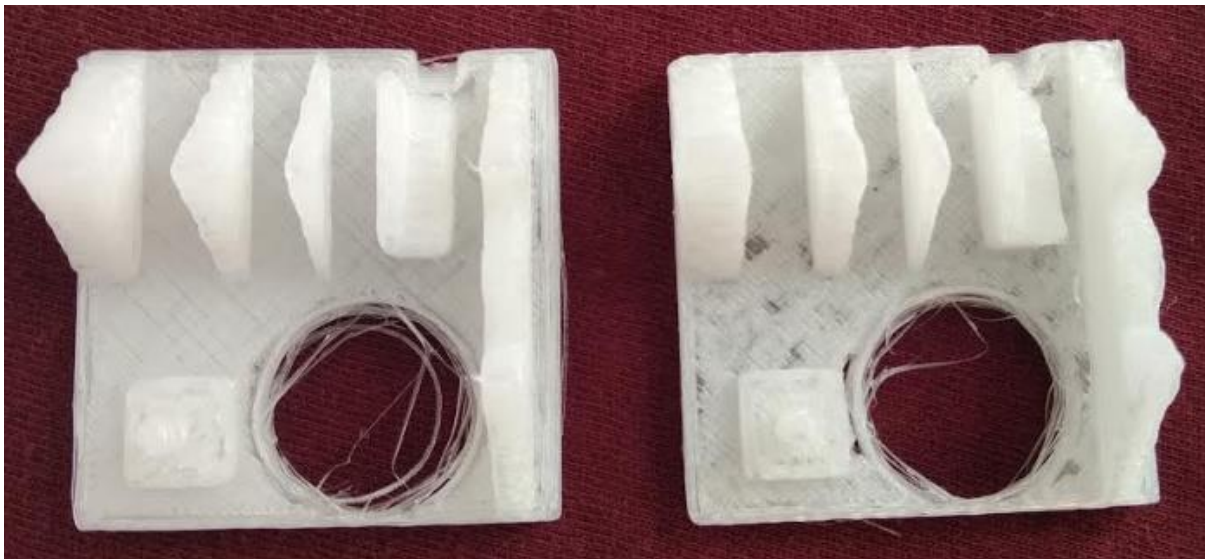
Figure 21 - Defects in printed part (PA)

This part is the combination of 250-20-0.3(Nozzle Temperature, Print speed, Layer height). Finally, full shape with perfect dimensional part is obtained. This is mainly because of good nozzle temperature and printing speed because this material is very much sensitive for printing speed. This material definitely needs some lower printing speed. Good quality, good surface finish and full shape is obtained but there are some unwanted thread like structure visible inside the circle shape, this is may be because of layer height. So it is important to

wait for other two combinations of taguchi. So here it is needed to finalize that, 250 nozzle temperatures, 20m/s printing speed is good for this material.

This part is the combination of 250-25-0.2(Nozzle Temperature, Print speed, Layer height). Best printing part from this material is obtained. This part is very much better than the previous part. Very good surface, very good quality, very good shapes, sharp edges and there is not even a single thread like structure in the printed part. This is mainly because of good printing speed and also good layer height. So this material is not only sensitive for nozzle temperature but also very much sensitive for printing speed. So 250-25-0.2(Nozzle Temperature, Print speed, Layer height) is recommended as best the combination of parameters for this material.
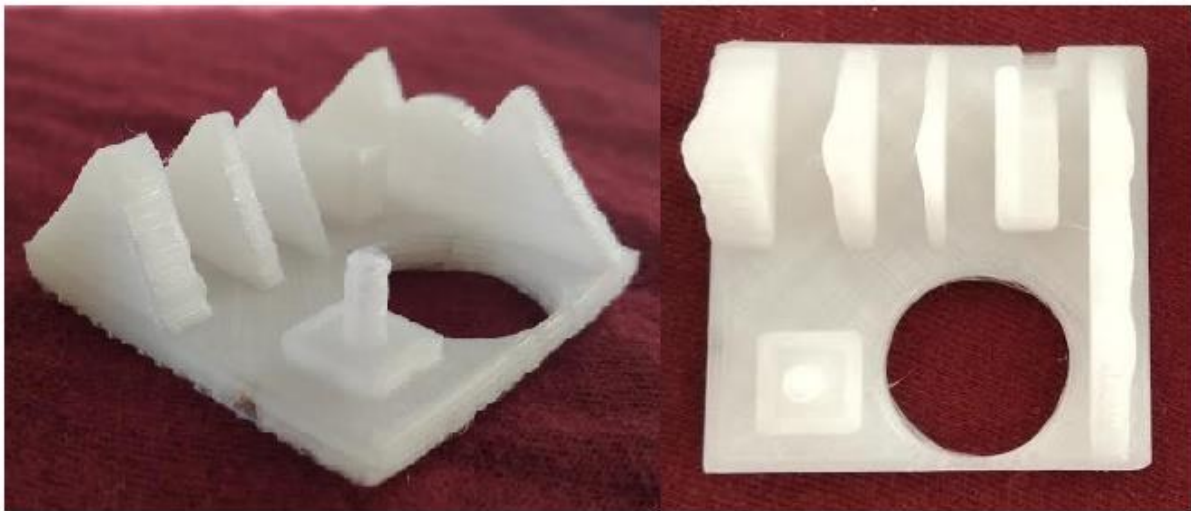

Figure 22 - Printed part with PA

This part is the combination of 250-30-0.25(Nozzle Temperature, Print speed, Layer height). Here temperature is fine and also layer height is also fine but the problem is with printing speed. As mentioned before, high printing speed is not recommended for this material but here in this combination, it is printed in high speed. So it is easy to see a lot of unwanted material sticked on the surface of the printed part, this is mainly because of high speed movement of nozzle. Here 100% of the shape is obtained but due to high printing speed, there are some mistakes. But this layer height is looking fine for this material. So it is recommended to use 250°C nozzle temperature but not high printing speed.
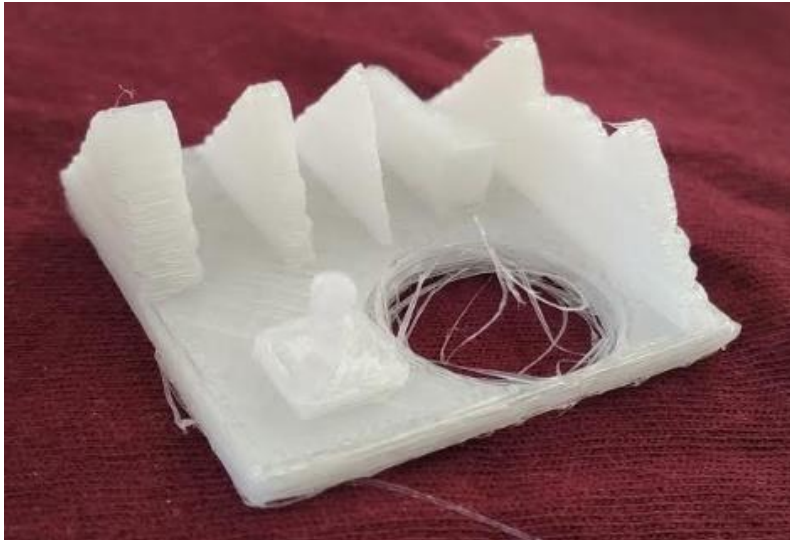
Figure 23 - Defects in printed part (PA)

7.3. POLYAMIDE WITH CARBON

Polyamides with carbon are the next material to start the experiment by using Taguchi method combinations. Here 3 major parameters are used from Taguchi results; they are Nozzle temperature, Print speed and layer height as per ABC analysis. The best combination of these three parameters from Taguchi method is obtained. This material has the problem of sticking (first layer) with bed if the bed temperature is low. So bed temperature is fixed as 100℃. So combination of parameters from Taguchi is shown below

Table 6 - Parameters combination

Nozzle Temp.	Print Speed	Layer height
240	30	0.2
240	40	0.25
240	50	0.3
250	30	0.25
250	40	0.3
250	50	0.2
260	30	0.3
260	40	0.2
260	50	0.25

Let's go step by step, first upload the .stl file in Repetier host software and before slicing it is needed to update the parameters with the help of Taguchi. After that, slice with slic3r purusa edition and after checking the estimation time and number of layers, it's time to start the print. Make sure the glue is applied in heating bed. Now it's time to wait for nozzle and heat bed to get heated. First test is with Combination of 240's in Taguchi table. So there are 3 different combinations for 240, that is 240-30-0.2, 240-40-0.25 and the final one is 240-50-0.3. These are all in the order of Nozzle temperature – print speed – layer height respectively.

Before starting printing, it is very much important to change the nozzle because in this material there will be some carbon content so definitely it will cause damage to the brass nozzle. So it is highly recommended to change the nozzle to stainless steel nozzle.

Figure 24 - Stainless steel nozzle [26]

Now, the combination of 240-30-0.2(Nozzle Temperature, Print speed, Layer height) is yet to start the printing with new nozzle. This material is very much sensible to temperature because it needs very accurate temperature or else it is very much difficult to print with this material. Main problem in this material is, layers will not stick together properly if there is less nozzle temperature. So while printing, it is finalized that nozzle temperature 240˚ is not good for this material because while printing, middle layers will be coming out and there will be problem regarding sticking of layers to one another. And quality is very bad; it is easy to break with hands. Not only this, the combination of 240˚C nozzle temperature has the same problem of sticking to layer with previous layer. So it is highly recommended not to use this nozzle temperature for this material. The picture of this combination is shown below.

Figure 25- Defects in printed part

This part is the combination of 250-30-0.25(Nozzle Temperature, Print speed, Layer height). As mentioned before, this material is very much sensitive with nozzle temperature than printing speed. So we find the same problem here as before like sticking of layers to previous layer. But here, full shape is obtained but the problem is sticking of layers to next layer. Somewhere in middle, layers are coming out and make the printer to stop. Nice surface, proper dimensional shapes and 100% shape is obtained but it is not possible to get good quality and also not possible to get a part without layer problem with these combinations of parameters. Due to the problem of sticking of layer with previous layer, print is getting interrupted and lot of materials is getting wasted. Not only this combination, all combination of parameters with nozzle temperature 250̊ C faces the same problem. So it is highly recommended that the combination of 250-30-0.25, 250-40-0.3 and 250-50-0.2(Nozzle Temperature, Print speed, Layer height) is not good for this material. The picture is shown below.
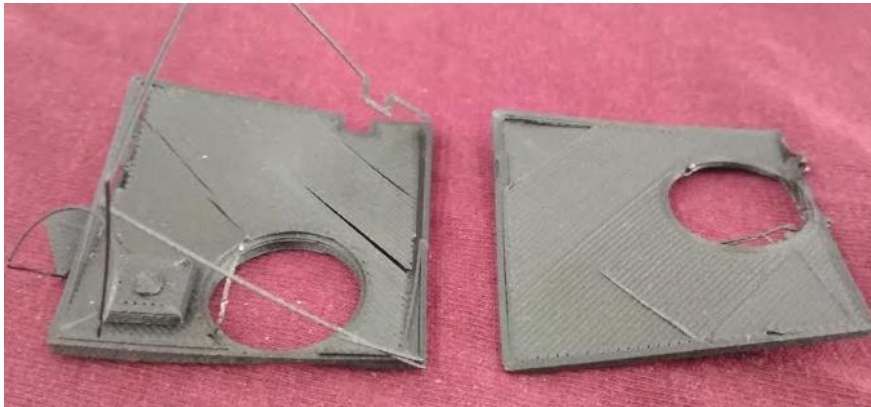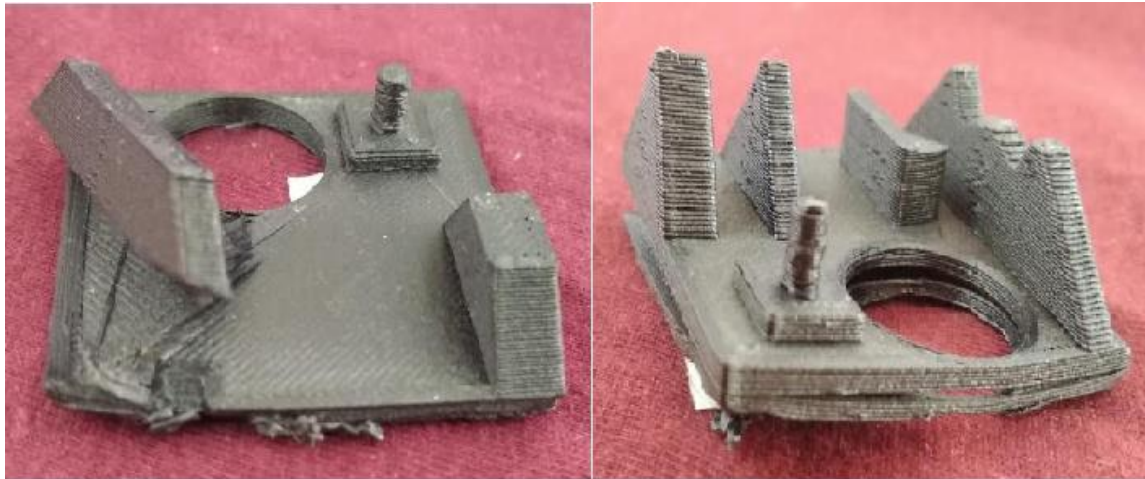
Figure 26 - Defects in printed part

This part is the combination of 260-30-0.3 (Nozzle Temperature, Print speed, Layer height). While printing it is easy to find that, this temperature is best for this material because while printing there is no problem of sticking layers with previous layer. No cooling system is required for this material. Quality of the part is very strong and perfect dimensional part is obtained. Very sharp edges, nice surface and good printed part without any defects are obtained. 260°C nozzle temperatures is best for this material. There is no problem with printing speed because printed part is looking good for both high printing speed and also for low printing speed, and also same for layer height. Quality of the shapes is very weak in those 250 and 260°C combinations of nozzle temperature but here in 260°C the quality of shapes are looking very strong than other two combinations. So there is same situation is for all other combinations in 260°C. So here it is important to finalize that the combinations of 260-30-0.3, 260-40-0.2 and 260-50-0.25(Nozzle Temperature, Print speed, Layer height) is best for this material.

Figure 27 - Printed part- Polyamide with carbon

7.4. IGLIDUR

Iglidur is the next material to start the experiment with Taguchi method combinations. Here 3 major parameters are used from Taguchi results; they are Nozzle temperature, Print speed and layer height as per ABC analysis. The best combination of these three parameters from Taguchi method is obtained. And here Bed temperature is fixed as $60°$ because this material has a good quality to stick with heating bed. So combination of parameters from Taguchi are shown below

Table 7 - Combination of parameters for IGLIDUR

Nozzle Temp.	Print Speed	Layer height
250	30	0.2
250	40	0.25
250	50	0.3
255	30	0.25
255	40	0.3
255	50	0.2
260	30	0.3
260	40	0.2
260	50	0.25

It is important to go step by step, first upload the .stl file in Repetier host software and before slicing it is needed to update the parameters with the help of Taguchi. After that, slice with slic3r purusa edition and after checking the estimation time and number of layers, it's time to start the printing process. Make sure that the glue is applied on the heating bed. Now it's time to wait for nozzle and heat bed to get heated. First test is with the combination of 250's in Taguchi table. So there are 3 different combinations for 250, that is 250-30-0.2, 250-40-0.25 and the final one is 250-50-0.3. These are all in the order of Nozzle temperature – print speed – layer height respectively.

It is the combination of 250-30-0.2(Nozzle Temperature, Print speed, Layer height). This material has very good quality of sticking with heating bed so there is no need of cooling system here. Fan is not needed for top layers also. This material is not that much sensitive like polyamides. While printing this part it is easy to find out that, nozzle temperature is

somewhere around 250 because the printed part is looking nice and also got full shape. But here the problem is surface quality and some mistakes on shapes. This may be because of wrong combination of printing speed and layer height. The same problem occurs while printing with other combinations of 250˚C. Obtained full shape but some problem with surface quality and also with shapes (not obtained shapes with proper dimensions). This material also has problem with high printing speed but it doesn't means it is not curable because it is also possible with printing parts with high speed but with proper combinations of nozzle temperature and layer height. So by here, finalizing that nozzle temperature 250 is good for this material but it is not 100% best for this material. Picture is shown below.

Figure 28 - Printed part with IGLIDUR

This part is the combination of 255-30-0.25(Nozzle Temperature, Print speed, Layer height). While printing this part, it is easy to recognize that this is very best combination for this material. Because there are no defects in the part, very good quality, very nice surface, sharp edges and obtained with proper dimension. Not only for this combination but also for other two combination of nozzle temperature 255˚C because all three parts are looking same with good quality and surface without any defects. While printing with 255-50-0.2(Nozzle Temperature, Print speed, Layer height) also there is no defect why it is important to mention this because this combination is with high printing speed but also there are no defects in the printing and proper dimensional shape without any mistake is obtained. Fan is switched off while printing this material, as mentioned before cooling system is not needed for this material and if cooling system is switched on means there may be problem with sticking of first layer with heating bed so it is highly recommended that the combination of 255-30-0.25,

255-50-0.2, 255-40-0.3 (Nozzle Temperature, Print speed, Layer height) is best combination for this material.

Figure 29 - Printed part with IGLIDUR

While continuing with next set of parameters, there will be problems occurring. Material will not come out from the nozzle. This may be because of five problems that are over lapping filament, wrong extruder selection, not working of servo motor, unwanted materials sticking in feeder and less nozzle temperature. So here there is no chance for problem in nozzle temperature because good temperature is already obtained so it is important to check other four problems. So finally a problem is found that got unwanted material stick into feeder. So it is highly recommended that to clean the feeder and remove the unwanted material which is stick into the feeder.

Figure 30 - Materials stick in feeder

This part is the combination of 260-30-0.3(Nozzle Temperature, Print speed, Layer height). Before completing all the experiments, it is not a good idea to conclude the best results because there are possibilities to get more accurate printed parts so while trying with this

combination it happens. Nozzle temperature 260˚C is also very good temperature for this material. The combination of 260-30-0.3 is looking good for this material with very good surface finish, good quality and also with proper dimension.

Figure 31 - Printed part with bad surface

But the problem is the combination of those three parameters. High printing speed is not suitable for this 260˚C because the printed part does not look well, especially in the top layers, very bad surface and bad quality is obtained. This problem happens in the combination of 260-40-0.2 and 260-50-0.25(Nozzle Temperature, Print speed, Layer height). In those parameters combinations – printing speed is quite high so there are many problems while printing. So it is highly recommended to use low printing speed for nozzle temperature 260˚C.
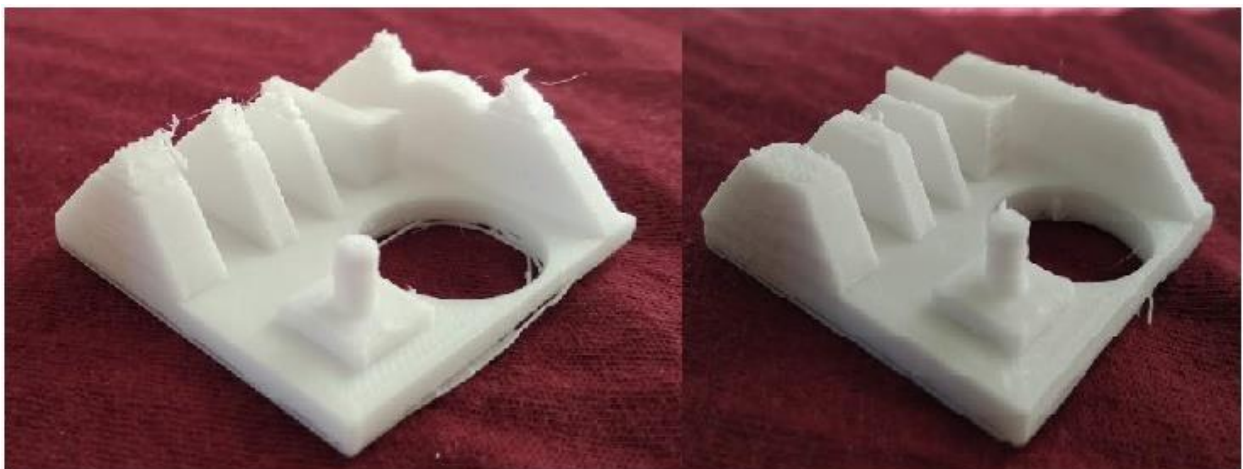
Figure 32 - Defects in printed part

8. CONCLUSION

Main aim of this work is to perform the test for various materials in FLM Rebel II 3D printer and to obtain best printing parameters to get good quality printing parts. If there is a need, it is also necessary to make some changes in printer to get best quality of printed part. Here parameter plays a major role. Some work has to be done on ABC analysis and Taguchi method to get combinations of parameters.

This thesis work presents the work of obtaining the high quality parts from finding the exact printing parameters which is used to print in Rebel II 3D printer using Fused Layer manufacturing. In this research, most important parameters are obtained by using ABC analysis and combination of parameter (which is used to print) is found by using taguchi method. And then with the help of these parameters, print is done and results are finalized. While printing, some problem occurs. First, the cooling system, this printer misses the cooling system (fan). So after some discussion, the fan is fixed to cool the material. And then another problem is with the filament which does not come out of extruder properly. So to solve this problem, calibration is done for this printer. After this, printing process is started according to ABC analysis and Taguchi, so with the help of this, best printing parameters for materials which are used print are found and they are listed below.

Materials/parameters	HIPS	POLYAMIDE	POLYAMIDE WITH CARBON	IGLIDUR
EXTRUDER TEMPERATURE	220°C	250°C	260°C	255°C
BED TEMPERATURE	90°C	100°C	100°C	60°C
PRINT SPEED	50	25	30-50	30-50
COOLING SYSTEM	Yes	No	No	No
LAYER HEIGHT	0.3	0.2	0.25	0.2,0.3

RECOMMENDATION

HIPS: Due to the characteristics like low cost and strong plastics, it can be used for Models, Prototypes, toys and also in many home appliances.

POLYAMIDE: Due to high strength and abrasion resistant it can be used for making car bumpers, mirror housing, fishing nets and so on.

POLYAMIDE WITH CARBON FIBER: Due to light weight and high toughness, this material can be used in inner body parts of car.

IGLIDUR: Due to low coefficient of friction, it can be used as sliding guides.

9. REFERENCES

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10.   ATTACHMENTS

Setup for Printing HIPS

 # generated by Slic3r Prusa Edition 1.40.1+win64 on 2018-12-12 at 12:39:51

avoid_crossing_perimeters = 0

bed_shape = 0x0,200x0,200x200,0x200

bed_temperature = 90,90

bottom_solid_layers = 4

bridge_acceleration = 0

bridge_angle = 0

bridge_fan_speed = 100,100

bridge_flow_ratio = 1

bridge_speed = 40

brim_width = 0

clip_multipart_objects = 0

complete_objects = 0

cooling = 0,0

cooling_tube_length = 5

cooling_tube_retraction = 91.5

default_acceleration = 0

deretract_speed = 0,0

disable_fan_first_layers = 1,1

dont_support_bridges = 1

duplicate_distance = 6

elefant_foot_compensation = 0

end_filament_gcode = "; Filament-specific end gcode \n;ENDgcode for filament\n";";
Filament-specific end gcode \n;ENDgcode for filament\n"

end_gcode = M104 S0 ; turn off temperature\nG28 X0 ; home X axis\nM84   ;
disable motors\nM140 S0 ; turn off bed temperature\n

ensure_vertical_shell_thickness = 0

external_fill_pattern = rectilinear

external_perimeter_extrusion_width = 0

external_perimeter_speed = 30

external_perimeters_first = 0

extra_perimeters = 1

extruder_clearance_height = 20

extruder_clearance_radius = 20

extruder_colour = #0000FF;

extruder_offset = 0x0,0x0

extrusion_axis = E

extrusion_multiplier = 1,1

extrusion_width = 0

fan_always_on = 0,0

fan_below_layer_time = 60,60

filament_colour = #FFFFFF;#FFFFFF

filament_cost = 0,0

filament_density = 0,0

filament_diameter = 1.75,1.75

filament_loading_speed = 28,28

filament_max_volumetric_speed = 0,0

filament_notes= ;

filament_ramming_parameters = "120 100 6.6 6.8 7.2 7.6 7.9 8.2 8.7 9.4 9.9 10.0|
0.05 6.6 0.45 6.8 0.95 7.8 1.45 8.3 1.95 9.7 2.45 10 2.95 7.6 3.45 7.6 3.95 7.6 4.45 7.6
4.95 7.6";"120 100 6.6 6.8 7.2 7.6 7.9 8.2 8.7 9.4 9.9 10.0| 0.05 6.6 0.45 6.8 0.95 7.8
1.45 8.3 1.95 9.7 2.45 10 2.95 7.6 3.45 7.6 3.95 7.6 4.45 7.6 4.95 7.6"

filament_settings_id= ;

filament_soluble = 0,0

filament_toolchange_delay = 0,0

filament_type = PET;PET

filament_unloading_speed = 90,90

fill_angle = 45

fill_density = 25%

fill_pattern = stars

first_layer_acceleration = 0

first_layer_bed_temperature = 90,90

first_layer_extrusion_width = 200%

first_layer_height = 0.25

first_layer_speed = 15

first_layer_temperature = 250,250

gap_fill_speed = 50

gcode_comments = 0

gcode_flavor = reprap

infill_acceleration = 0

infill_every_layers = 1

infill_extruder = 1

infill_extrusion_width = 0

infill_first = 0

infill_only_where_needed = 0

infill_overlap = 15%

infill_speed = 50

interface_shells = 0

layer_height = 0.3

max_fan_speed = 100,100

max_layer_height = 0.3,0.3

max_print_height = 200

max_print_speed = 50

max_volumetric_extrusion_rate_slope_negative = 0

max_volumetric_extrusion_rate_slope_positive = 0

max_volumetric_speed = 0

min_fan_speed = 35,35

min_layer_height = 0.15,0.15

min_print_speed = 10,10

min_skirt_length = 0

notes = Konfiguracnisoubor pro PETG, celokovovyhotend 1,75 mm, tryska 0,35 mm

nozzle_diameter = 0.35,0.35

only_retract_when_crossing_perimeters = 1

ooze_prevention = 0

output_filename_format = [input_filename_base].gcode

overhangs = 1

parking_pos_retraction = 92

perimeter_acceleration = 0

perimeter_extruder = 1

perimeter_extrusion_width = 0

perimeter_speed = 40

perimeters = 3

raft_layers = 0

resolution = 0

retract_before_travel = 2,2

retract_before_wipe = 0%,0%

retract_layer_change = 1,1

retract_length = 1,1

retract_length_toolchange = 10,10

retract_lift = 0,0

retract_lift_above = 0,0

retract_lift_below = 0,0

retract_restart_extra = 0,0

retract_restart_extra_toolchange = 0,0

retract_speed = 40,45

seam_position = random

serial_speed = 250000

single_extruder_multi_material = 0

skirt_distance = 5

skirt_height = 1

skirts = 3

slowdown_below_layer_time = 30,30

small_perimeter_speed = 30

solid_infill_below_area = 70

solid_infill_every_layers = 0

solid_infill_extruder = 1

solid_infill_extrusion_width = 0

solid_infill_speed = 30

spiral_vase = 0

standby_temperature_delta = -5

start_filament_gcode = "; Filament gcode\n";"; Filament gcode\n"

start_gcode = G21\nM190 S[first_layer_bed_temperature]\nG28\nG90\nG21\nG92 E0\nM82\nT1\nM104 S[first_layer_temperature]\nG92 E0\nT0\nM109 S[first_layer_temperature]\nG92 E0\n

support_material = 0

support_material_angle = 0

support_material_buildplate_only = 0

support_material_contact_distance = 0.2

support_material_enforce_layers = 0

support_material_extruder = 2

support_material_extrusion_width = 0

support_material_interface_contact_loops = 0

support_material_interface_extruder = 1

support_material_interface_layers = 0

support_material_interface_spacing = 0

support_material_interface_speed = 100%

support_material_pattern = rectilinear

support_material_spacing = 2.5

support_material_speed = 40

support_material_synchronize_layers = 0

support_material_threshold = 46

support_material_with_sheath = 1

support_material_xy_spacing = 50%

temperature = 250,250

thin_walls = 1

threads = 8

top_infill_extrusion_width = 0

top_solid_infill_speed = 20

top_solid_layers = 4

travel_speed = 120

use_firmware_retraction = 0

use_relative_e_distances = 0

use_volumetric_e = 0

variable_layer_height = 1

wipe = 0,0

wipe_tower = 0

wipe_tower_bridging = 10

wipe_tower_rotation_angle = 0

wipe_tower_width = 60

wipe_tower_x = 180

wipe_tower_y = 140

wiping_volumes_extruders = 70,70,70,70

wiping_volumes_matrix = 0,140,140,0

xy_size_compensation = 0

z_offset = 0.

SETUP FOR PRINTING POLYAMIDES

 # generated by Slic3r Prusa Edition 1.40.1+win64 on 2019-04-22 at 03:45:52

avoid_crossing_perimeters = 0

bed_shape = 0x0,200x0,200x200,0x200

bed_temperature = 100,100

bottom_solid_layers = 4

bridge_acceleration = 0

bridge_angle = 0

bridge_fan_speed = 100,100

bridge_flow_ratio = 1

bridge_speed = 30

brim_width = 0

clip_multipart_objects = 0

complete_objects = 0

cooling = 0,0

cooling_tube_length = 5

cooling_tube_retraction = 91.5

default_acceleration = 0

deretract_speed = 0,0

disable_fan_first_layers = 40,40

dont_support_bridges = 1

duplicate_distance = 6

elefant_foot_compensation = 0

end_filament_gcode = "; Filament-specific end gcode \n;ENDgcode for filament\n";";
Filament-specific end gcode \n;ENDgcode for filament\n"

end_gcode = M104 S0 ; turn off temperature\nG28 X0 ; home X axis\nM84   ;
disable motors\nM140 S0 ; turn off bed temperature\n

ensure_vertical_shell_thickness = 0

external_fill_pattern = rectilinear

external_perimeter_extrusion_width = 0

external_perimeter_speed = 30

external_perimeters_first = 0

extra_perimeters = 1

extruder_clearance_height = 20

extruder_clearance_radius = 20

extruder_colour = #0000FF;

extruder_offset = 0x0,0x0

extrusion_axis = E

extrusion_multiplier = 1,1

extrusion_width = 0

fan_always_on = 0,0

fan_below_layer_time = 60,60

filament_colour = #FFFFFF;#FFFFFF

filament_cost = 0,0

filament_density = 0,0

filament_diameter = 1.75,1.75

filament_loading_speed = 28,28

filament_max_volumetric_speed = 0,0

filament_notes= ;

filament_ramming_parameters = "120 100 6.6 6.8 7.2 7.6 7.9 8.2 8.7 9.4 9.9 10.0|
0.05 6.6 0.45 6.8 0.95 7.8 1.45 8.3 1.95 9.7 2.45 10 2.95 7.6 3.45 7.6 3.95 7.6 4.45 7.6
4.95 7.6";"120 100 6.6 6.8 7.2 7.6 7.9 8.2 8.7 9.4 9.9 10.0| 0.05 6.6 0.45 6.8 0.95 7.8
1.45 8.3 1.95 9.7 2.45 10 2.95 7.6 3.45 7.6 3.95 7.6 4.45 7.6 4.95 7.6"

filament_settings_id= ;

filament_soluble = 0,0

filament_toolchange_delay = 0,0

filament_type = PET;PET

filament_unloading_speed = 90,90

fill_angle = 45

fill_density = 25%

fill_pattern = stars

first_layer_acceleration = 0

first_layer_bed_temperature = 100,100

first_layer_extrusion_width = 200%

first_layer_height = 0.3

first_layer_speed = 15

first_layer_temperature = 240,240

gap_fill_speed = 30

gcode_comments = 0

gcode_flavor = reprap

infill_acceleration = 0

infill_every_layers = 1

infill_extruder = 1

infill_extrusion_width = 0

infill_first = 0

infill_only_where_needed = 0

infill_overlap = 15%

infill_speed = 30

interface_shells = 0

layer_height = 0.3

max_fan_speed = 100,100

max_layer_height = 0.3,0.3

max_print_height = 200

max_print_speed = 50

max_volumetric_extrusion_rate_slope_negative = 0

max_volumetric_extrusion_rate_slope_positive = 0

max_volumetric_speed = 0

min_fan_speed = 35,35

min_layer_height = 0.15,0.15

min_print_speed = 10,10

min_skirt_length = 0

notes = Konfiguracnisoubor pro PETG, celokovovyhotend 1,75 mm, tryska 0,35 mm

nozzle_diameter = 0.35,0.35

only_retract_when_crossing_perimeters = 1

ooze_prevention = 0

output_filename_format = [input_filename_base].gcode

overhangs = 1

parking_pos_retraction = 92

perimeter_acceleration = 0

perimeter_extruder = 1

perimeter_extrusion_width = 0

perimeter_speed = 30

perimeters = 3

raft_layers = 0

resolution = 0

retract_before_travel = 2,2

retract_before_wipe = 0%,0%

retract_layer_change = 1,1

retract_length = 1,1

retract_length_toolchange = 10,10

retract_lift = 0,0

retract_lift_above = 0,0

retract_lift_below = 0,0

retract_restart_extra = 0,0

retract_restart_extra_toolchange = 0,0

retract_speed = 40,45

seam_position = random

serial_speed = 250000

single_extruder_multi_material = 0

skirt_distance = 5

skirt_height = 1

skirts = 3

slowdown_below_layer_time = 30,30

small_perimeter_speed = 30

solid_infill_below_area = 70

solid_infill_every_layers = 0

solid_infill_extruder = 1

solid_infill_extrusion_width = 0

solid_infill_speed = 30

spiral_vase = 0

standby_temperature_delta = -5

start_filament_gcode = "; Filament gcode\n";"; Filament gcode\n"

start_gcode = G21\nM190 S[first_layer_bed_temperature]\nG28\nG90\nG21\nG92 E0\nM82\nT1\nM104 S[first_layer_temperature]\nG92 E0\nT0\nM109 S[first_layer_temperature]\nG92 E0\n

support_material = 0

support_material_angle = 0

support_material_buildplate_only = 0

support_material_contact_distance = 0.2

support_material_enforce_layers = 0

support_material_extruder = 2

support_material_extrusion_width = 0

support_material_interface_contact_loops = 0

support_material_interface_extruder = 1

support_material_interface_layers = 0

support_material_interface_spacing = 0

support_material_interface_speed = 100%

support_material_pattern = rectilinear

support_material_spacing = 2.5

support_material_speed = 30

support_material_synchronize_layers = 0

support_material_threshold = 46

support_material_with_sheath = 1

support_material_xy_spacing = 50%

temperature = 240,240

thin_walls = 1

threads = 4

top_infill_extrusion_width = 0

top_solid_infill_speed = 30

top_solid_layers = 4

travel_speed = 120

use_firmware_retraction = 0

use_relative_e_distances = 0

use_volumetric_e = 0

variable_layer_height = 1

wipe = 0,0

wipe_tower = 0

wipe_tower_bridging = 10

wipe_tower_rotation_angle = 0

wipe_tower_width = 60

wipe_tower_x = 180

wipe_tower_y = 140

wiping_volumes_extruders = 70,70,70,70

wiping_volumes_matrix = 0,140,140,0

xy_size_compensation = 0

z_offset = 0

SETUP OF POLYAMIDES WITH CARBON

 # generated by Slic3r Prusa Edition 1.40.1+win64 on 2019-04-23 at 00:19:31

avoid_crossing_perimeters = 0

bed_shape = 0x0,200x0,200x200,0x200

bed_temperature = 100,100

bottom_solid_layers = 4

bridge_acceleration = 0

bridge_angle = 0

bridge_fan_speed = 100,100

bridge_flow_ratio = 1

bridge_speed = 30

brim_width = 0

clip_multipart_objects = 0

complete_objects = 0

cooling = 0,0

cooling_tube_length = 5

cooling_tube_retraction = 91.5

default_acceleration = 0

deretract_speed = 0,0

disable_fan_first_layers = 40,40

dont_support_bridges = 1

duplicate_distance = 6

elefant_foot_compensation = 0

end_filament_gcode = "; Filament-specific end gcode \n;ENDgcode for filament\n";"; Filament-specific end gcode \n;ENDgcode for filament\n"

end_gcode = M104 S0 ; turn off temperature\nG28 X0 ; home X axis\nM84   ; disable motors\nM140 S0 ; turn off bed temperature\n

ensure_vertical_shell_thickness = 0

external_fill_pattern = rectilinear

external_perimeter_extrusion_width = 0

external_perimeter_speed = 30

external_perimeters_first = 0

extra_perimeters = 1

extruder_clearance_height = 20

extruder_clearance_radius = 20

extruder_colour = #0000FF;

extruder_offset = 0x0,0x0

extrusion_axis = E

extrusion_multiplier = 1,1

extrusion_width = 0

fan_always_on = 0,0

fan_below_layer_time = 60,60

filament_colour = #FFFFFF;#FFFFFF

filament_cost = 0,0

filament_density = 0,0

filament_diameter = 1.75,1.75

filament_loading_speed = 28,28

filament_max_volumetric_speed = 0,0

filament_notes= ;

filament_ramming_parameters = "120 100 6.6 6.8 7.2 7.6 7.9 8.2 8.7 9.4 9.9 10.0| 0.05 6.6 0.45 6.8 0.95 7.8 1.45 8.3 1.95 9.7 2.45 10 2.95 7.6 3.45 7.6 3.95 7.6 4.45 7.6 4.95 7.6";"120 100 6.6 6.8 7.2 7.6 7.9 8.2 8.7 9.4 9.9 10.0| 0.05 6.6 0.45 6.8 0.95 7.8 1.45 8.3 1.95 9.7 2.45 10 2.95 7.6 3.45 7.6 3.95 7.6 4.45 7.6 4.95 7.6"

filament_settings_id= ;

filament_soluble = 0,0

filament_toolchange_delay = 0,0

filament_type = PET;PET

filament_unloading_speed = 90,90

fill_angle = 45

fill_density = 25%

fill_pattern = stars

first_layer_acceleration = 0

first_layer_bed_temperature = 100,100

first_layer_extrusion_width = 200%

first_layer_height = 0.3

first_layer_speed = 15

first_layer_temperature = 260,260

gap_fill_speed = 30

gcode_comments = 0

gcode_flavor = reprap

infill_acceleration = 0

infill_every_layers = 1

infill_extruder = 1

infill_extrusion_width = 0

infill_first = 0

infill_only_where_needed = 0

infill_overlap = 15%

infill_speed = 30

interface_shells = 0

layer_height = 0.3

max_fan_speed = 100,100

max_layer_height = 0.3,0.3

max_print_height = 200

max_print_speed = 50

max_volumetric_extrusion_rate_slope_negative = 0

max_volumetric_extrusion_rate_slope_positive = 0

max_volumetric_speed = 0

min_fan_speed = 35,35

min_layer_height = 0.15,0.15

min_print_speed = 10,10

min_skirt_length = 0

notes = Konfiguracnisoubor pro PETG, celokovovyhotend 1,75 mm, tryska 0,35 mm

nozzle_diameter = 0.35,0.35

only_retract_when_crossing_perimeters = 1

ooze_prevention = 0

output_filename_format = [input_filename_base].gcode

overhangs = 1

parking_pos_retraction = 92

perimeter_acceleration = 0

perimeter_extruder = 1

perimeter_extrusion_width = 0

perimeter_speed = 30

perimeters = 3

raft_layers = 0

resolution = 0

retract_before_travel = 2,2

retract_before_wipe = 0%,0%

retract_layer_change = 1,1

retract_length = 1,1

retract_length_toolchange = 10,10

retract_lift = 0,0

retract_lift_above = 0,0

retract_lift_below = 0,0

retract_restart_extra = 0,0

retract_restart_extra_toolchange = 0,0

retract_speed = 40,45

seam_position = random

serial_speed = 250000

single_extruder_multi_material = 0

skirt_distance = 5

skirt_height = 1

skirts = 3

slowdown_below_layer_time = 30,30

small_perimeter_speed = 30

solid_infill_below_area = 70

solid_infill_every_layers = 0

solid_infill_extruder = 1

solid_infill_extrusion_width = 0

solid_infill_speed = 30

spiral_vase = 0

standby_temperature_delta = -5

start_filament_gcode = "; Filament gcode\n";"; Filament gcode\n"

start_gcode = G21\nM190 S[first_layer_bed_temperature]\nG28\nG90\nG21\nG92 E0\nM82\nT1\nM104 S[first_layer_temperature]\nG92 E0\nT0\nM109 S[first_layer_temperature]\nG92 E0\n

support_material = 0

support_material_angle = 0

support_material_buildplate_only = 0

support_material_contact_distance = 0.2

support_material_enforce_layers = 0

support_material_extruder = 2

support_material_extrusion_width = 0

support_material_interface_contact_loops = 0

support_material_interface_extruder = 1

support_material_interface_layers = 0

support_material_interface_spacing = 0

support_material_interface_speed = 100%

support_material_pattern = rectilinear

support_material_spacing = 2.5

support_material_speed = 30

support_material_synchronize_layers = 0

support_material_threshold = 46

support_material_with_sheath = 1

support_material_xy_spacing = 50%

temperature = 260,260

thin_walls = 1

threads = 4

top_infill_extrusion_width = 0

top_solid_infill_speed = 30

top_solid_layers = 4

travel_speed = 120

use_firmware_retraction = 0

use_relative_e_distances = 0

use_volumetric_e = 0

variable_layer_height = 1

wipe = 0,0

wipe_tower = 0

wipe_tower_bridging = 10

wipe_tower_rotation_angle = 0

wipe_tower_width = 60

wipe_tower_x = 180

wipe_tower_y = 140

wiping_volumes_extruders = 70,70,70,70

wiping_volumes_matrix = 0,140,140,0

xy_size_compensation = 0

z_offset = 0

SETUP FOR IGLIDUR

 # generated by Slic3r Prusa Edition 1.40.1+win64 on 2019-04-22 at 23:00:42

avoid_crossing_perimeters = 0

bed_shape = 0x0,200x0,200x200,0x200

bed_temperature = 100,100

bottom_solid_layers = 4

bridge_acceleration = 0

bridge_angle = 0

bridge_fan_speed = 100,100

bridge_flow_ratio = 1

bridge_speed = 50

brim_width = 0

clip_multipart_objects = 0

complete_objects = 0

cooling = 0,0

cooling_tube_length = 5

cooling_tube_retraction = 91.5

default_acceleration = 0

deretract_speed = 0,0

disable_fan_first_layers = 40,40

dont_support_bridges = 1

duplicate_distance = 6

elefant_foot_compensation = 0

end_filament_gcode = "; Filament-specific end gcode \n;ENDgcode for filament\n";"; Filament-specific end gcode \n;ENDgcode for filament\n"

end_gcode = M104 S0 ; turn off temperature\nG28 X0 ; home X axis\nM84   ; disable motors\nM140 S0 ; turn off bed temperature\n

ensure_vertical_shell_thickness = 0

external_fill_pattern = rectilinear

external_perimeter_extrusion_width = 0

external_perimeter_speed = 50

external_perimeters_first = 0

extra_perimeters = 1

extruder_clearance_height = 20

extruder_clearance_radius = 20

extruder_colour = #0000FF;

extruder_offset = 0x0,0x0

extrusion_axis = E

extrusion_multiplier = 1,1

extrusion_width = 0

fan_always_on = 0,0

fan_below_layer_time = 60,60

filament_colour = #FFFFFF;#FFFFFF

filament_cost = 0,0

filament_density = 0,0

filament_diameter = 1.75,1.75

filament_loading_speed = 28,28

filament_max_volumetric_speed = 0,0

filament_notes= ;

*filament_ramming_parameters = "120 100 6.6 6.8 7.2 7.6 7.9 8.2 8.7 9.4 9.9 10.0|
0.05 6.6 0.45 6.8 0.95 7.8 1.45 8.3 1.95 9.7 2.45 10 2.95 7.6 3.45 7.6 3.95 7.6 4.45 7.6
4.95 7.6";"120 100 6.6 6.8 7.2 7.6 7.9 8.2 8.7 9.4 9.9 10.0| 0.05 6.6 0.45 6.8 0.95 7.8
1.45 8.3 1.95 9.7 2.45 10 2.95 7.6 3.45 7.6 3.95 7.6 4.45 7.6 4.95 7.6"*

filament_settings_id= ;

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filament_toolchange_delay = 0,0

filament_type = PET;PET

filament_unloading_speed = 90,90

fill_angle = 45

fill_density = 25%

fill_pattern = stars

first_layer_acceleration = 0

first_layer_bed_temperature = 100,100

first_layer_extrusion_width = 200%

first_layer_height = 0.3

first_layer_speed = 15

first_layer_temperature = 240,240

gap_fill_speed = 50

gcode_comments = 0

gcode_flavor = reprap

infill_acceleration = 0

infill_every_layers = 1

infill_extruder = 1

infill_extrusion_width = 0

infill_first = 0

infill_only_where_needed = 0

infill_overlap = 15%

infill_speed = 50

interface_shells = 0

layer_height = 0.3

max_fan_speed = 100,100

max_layer_height = 0.3,0.3

max_print_height = 200

max_print_speed = 50

max_volumetric_extrusion_rate_slope_negative = 0

max_volumetric_extrusion_rate_slope_positive = 0

max_volumetric_speed = 0

min_fan_speed = 35,35

min_layer_height = 0.15,0.15

min_print_speed = 10,10

min_skirt_length = 0

notes = Konfiguracnisoubor pro PETG, celokovovyhotend 1,75 mm, tryska 0,35 mm

nozzle_diameter = 0.35,0.35

only_retract_when_crossing_perimeters = 1

ooze_prevention = 0

output_filename_format = [input_filename_base].gcode

overhangs = 1

parking_pos_retraction = 92

perimeter_acceleration = 0

perimeter_extruder = 1

perimeter_extrusion_width = 0

perimeter_speed = 50

perimeters = 3

raft_layers = 0

resolution = 0

retract_before_travel = 2,2

retract_before_wipe = 0%,0%

retract_layer_change = 1,1

retract_length = 1,1

retract_length_toolchange = 10,10

retract_lift = 0,0

retract_lift_above = 0,0

retract_lift_below = 0,0

retract_restart_extra = 0,0

retract_restart_extra_toolchange = 0,0

retract_speed = 40,45

seam_position = random

serial_speed = 250000

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solid_infill_every_layers = 0

solid_infill_extruder = 1

solid_infill_extrusion_width = 0

solid_infill_speed = 50

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standby_temperature_delta = -5

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support_material_angle = 0

support_material_buildplate_only = 0

support_material_contact_distance = 0.2

support_material_enforce_layers = 0

support_material_extruder = 2

support_material_extrusion_width = 0

support_material_interface_contact_loops = 0

support_material_interface_extruder = 1

support_material_interface_layers = 0

support_material_interface_spacing = 0

support_material_interface_speed = 100%

support_material_pattern = rectilinear

support_material_spacing = 2.5

support_material_speed = 50

support_material_synchronize_layers = 0

support_material_threshold = 46

support_material_with_sheath = 1

support_material_xy_spacing = 50%

temperature = 240,240

thin_walls = 1

threads = 4

top_infill_extrusion_width = 0

top_solid_infill_speed = 50

top_solid_layers = 4

travel_speed = 120

use_firmware_retraction = 0

use_relative_e_distances = 0

use_volumetric_e = 0

variable_layer_height = 1

wipe = 0,0

wipe_tower = 0

wipe_tower_bridging = 10

wipe_tower_rotation_angle = 0

wipe_tower_width = 60

wipe_tower_x = 180

wipe_tower_y = 140

wiping_volumes_extruders = 70,70,70,70

wiping_volumes_matrix = 0,140,140,0

xy_size_compensation = 0

z_offset = 0