



TECHNICAL UNIVERSITY OF LIBEREC  
Faculty of Mechanical Engineering ■

# Testing of FLM 3D Printer

## Master thesis

*Study programme:* N2301 – Mechanical Engineering  
*Study branch:* 2301T049 – Manufacturing Systems and Processes  
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## DIPLOMA THESIS ASSIGNMENT

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

Perform testing of the FLM 3D printer Rebel II for various materials (plastics) and, if necessary, propose adjustments of this printer configuration to obtain the highest quality of printing.

1. Become familiar with the existing 3D printer Rebel II in the lab.
2. Make research of existing materials for FLM technology and printing requirements for this materials.
3. Select at least three different materials and perform experimental 3D printing.
4. Propose adjustment of the printer and printing parameters for each material.
5. Assessment of the results and conclusion.

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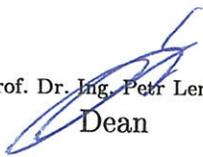
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- [1] REPRAP. RepRap Forums [online]. 2016 [cit. 2016-10-07].  
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[2] STRATASYS LTD. Professional 3D Printing. [online]. 2015 [cit. 2015-09-25].  
Available from: <http://www.stratasys.com/>  
[3] Gebhardt, A. Understanding Additive Manufacturing. GEBHARDT, Andreas. Understanding additive manufacturing: Rapid Prototyping - Rapid Tooling - Rapid Manufacturing. Munich: Hanser, 2011. ISBN 978-3-446-42552-1  
[4] Fused filament fabrication. In: Wikipedia: the free encyclopedia. Wikimedia Foundation, 2001 San Francisco (CA) [online]. 2001/2016 [cit. 2016-06-17].  
Available from <[https://en.wikipedia.org/wiki/Fused\\_filament\\_fabrication](https://en.wikipedia.org/wiki/Fused_filament_fabrication)>

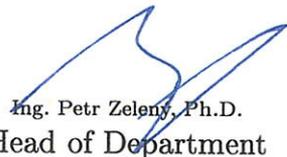
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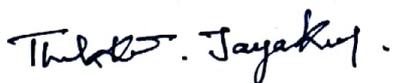
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**Abstract:-**

The work in the thesis deals with the testing of performance of the Rebel II 3D printer for various materials I.e., thermoplastics, to obtain the high quality of printing parts. To improve the quality of printing, some changes are done in the printer. Whereas the Rebel II 3D printer works with the FFF technology which is registered by the RepRap community. The main aim is to find the exact printing parameters of materials that can be printed in this printer, which includes printing temperature, print bed temperature, speed and in some case also the printing pattern in which the printer can produce the parts with high quality.

**Key words:**

FLM technology, 3D printing, Rebel II, RepRap community, thermoplastics, high quality of print

**Anotace:**

Diplomová práce se zabývá testováním nastavení 3D tiskárny REBEL II pro tisk z různých materiálů (termoplastů) s cílem získat co nejvyšší kvalitu vytisknutých součástí. Pro dosažení kvalitního tisku byly provedeny také konstrukční změny tiskárny. 3D tiskárna Rebel II pracuje s technologií FFF, která je registrována komunitou RepRap. Hlavním cílem je najít přesné tiskové parametry materiálů, které lze tisknout v této tiskárně, včetně teploty tiskové vrstvy při tisku, rychlosti a v některých případech i vzoru výplně vnitřku dílu, pro dosažení vysoké kvality výtisků.

**Klíčová slova:**

Technologie FLM, 3D tisk, Rebel II, komunita RepRap, termoplasty, vysoká kvalita tisku

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## List of Abbreviation

3D Printing, 3-Dimensional Printing

FLM, Fused Layer Manufacturing

FDM, Fused deposition Modeling

AM, Additive Manufacturing

CAD, Computer Aided Design

SLA/SLS, Sterolithography

MJP, Multijet Printing

CJP, Color Jet Printing

EBM, Electron Beam Melting

FLM, Fused Layer Manufacturing

SDL, Selective Deposition Lamination

LOM, Laminated Object Manufacturing

mm, millimeter

s, second

ABS, Acrylonitrile Butadiene Styrene

PLA, Polylactic Acid

PVA, Polyvinyl alcohol

HIPS, High Impact Polystyrene

PET, Polyethylene Terephthalate

USB, Universal Serial Bus

RAM, Random Access Memory

W, watts

°C, Celsius

MPa, Mega Pascal

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## 1. INTRODUCTION

Topic of the work is “**TESTING OF FLM 3D PRINTER**”. The work starts with the calibration of 3D printing machine in the Rebel II printer which works on the principle of Fused Layer Manufacturing, which is also known as the Fused Filament Fabrication (FFF). FLM is an additive manufacturing technology. It works same as the principle of FDM (Fused Deposition modelling), where FDM is developed by S. Scott Crum and the FLM has been developed by the members of **RepRap** to prove that FDM has only limited access in use. In this process, the material (plastics wire) is wounded on the top of the machine in a coil and it is feed through a heated moving head, the material is melted and extrudes it layer by layer in the desired shape.

The main work is focused on researching of existing materials for FLM technology and to obtain the higher quality of print with those materials. In this research we have chosen some materials and obtained their properties to print and the material is printed in the Rebel II. Printing parameters are identified by testing the material for each and every parameter and by analysing the result of the printed parts, the parameters for printing each material in identified. The printed parts are analyzed based on their dimensions and quality, to improve the dimensional standardization and the quality of print.

And the second of part the work will be making some necessary adjustment in the printer Rebel II, problem were identified in the printer for every material and the changes are done in both software and hardware if needed and the printing parameters for the materials are identified. In some cases the parts are updated in necessary conditions. The sample part is printed again and again by calibrating the printer until obtaining the high quality of results. Once it is done, the printing parameters is changed in the settings like change of thickness, change of speed, change of slicer is done and the part is printed and the necessary changes are done in the printer to obtain the good quality of printed part. The obtained results are compared with the previous results and the test is done.

### **Aim of the Work:**

Main aim of the work is to perform the test in FLM Rebel II 3D printer for various materials, and to identify the printing parameters of the each and every material to print it in the Rebel II printer and to obtain the good quality of print. Were the parameters plays the vital role in printing process. And the research of existing materials for the FLM technology is to be done and the best suitable material for the printing process is to be identified. If needs also to make

some necessary changes in the printer to obtain the good quality of print. The material should be printed in all parameters and in different kinds of speeds and in different patterns and the printed parts are relatively compared with each other. Considering the quality of the part, the best one is chosen and the printing parameters of it are taken to print the part with those materials.

## 2. METHODS AND METHODOLOGY

Additive manufacturing (AM) is defined as the process of joining the materials to make that a model is generated using a three dimensional Computer Aided Design. This can be fabricated directly without any planning. AM is the technology in which the complicated 3D design can be printed directly and easily. When compared to the other manufacturing process, they need to process carefully with geometry of the part, process to be followed, and tools to be used and so on. Where AM requires to know how machine works and what's the materials that can be used. In the additive manufacturing process the parts are made by just adding upon the materials in layers according to the CAD data. Each layer should be in fine thickness in order to surface finish, quality and dimensional stability. The change in thickness of the layer results in change of properties in the printed part. The Fig 1 shoes CAD image of the cup, how the part with the different layer thickness will look like. In which we can finely see the changes in the design [1][2].



**Figure 1 Cup printed with different layer thickness [1].**

## **2.1 Classification of Additive Manufacturing Systems:**

The good way to classify the AM systems is based on the initial type of the material is used in that systems. Based on the materials, it is divided into 3 types.

1. Liquid-based
2. Solid-based
- 3 .Powder-based

### **2.1.1 Liquid-based:**

In the liquid-based AM systems, the material which we are using is in the form of liquid state. The liquid state material is converted to the solid state. This type of process is also known as curing. The following AM systems fall into this type.

1. Stereolithography Apparatus (SLA)
2. Polyjet
3. Rapid freeze Prototyping

This type of AM systems builds parts in a vat of photo curable liquid resin, which solidifies under the effect of exposure of light, probably in the Ultraviolet range. The cures the resin near the surface and makes the layer harden. Once the previous layer is fully completed, the system allows the next layer of resin to be coated. This is continued till the part is completed [3]. Each technologies principles, advantages and disadvantages are explained below.

#### **2.1.1.1A Principle of SLA**

SLA process is based on the following principles;

- Parts are build from a photo curable liquid resin that cures when exposed to a laser beam (basically, undergoing the photo polymerization process) which scans across the surface of the resin.
- The building is done layer by layer, each layer being scanned by the optical scanning system and controlled by an elevation mechanism which lowers at the completions of each layer.

The first principle deals with the photo curable liquid resins, which are essentially photo polymers and the photo polymerization process.

The second principle deals mainly with the CAD data, laser, and the control of the optical scanning system as well as the elevation mechanism

### **2.1.1.1B Advantages of Stereolithography Apparatus (SLA)**

- Achieving Accuracy in industry.
- Capable of high detail and thin walls.
- Good surface finish.
- Market shares and industry presence.

### **2.1.1.1C Disadvantages of Stereolithography Apparatus (SLA)**

- Requires post curing.
- Limited materials (Photo polymers).
- Support structures always required, and the removal of support structure is difficult.
- Some shrinkage and curl due to change of phase [4].

### **2.1.1.2A Principle of Polyjet Printing**

As the normal inkjet printing method the required amount of material is released from the jetting head. The UV light which is integrated with the jetting head is used to cure the material when it is printed on the tray. Similar to polymerization process parts are built layer by layer from a liquid polymer. The movement of the jetting head (XY-axes) and each slice of the building process in the cross section of the parts are arranged in the software. The build tray is lowered for the next layer after completion of the cross section layer; this is done by levelling the height-Z. UV light is used to cure both part material and support material and water jet is used to remove the non toxic support material.

### **2.1.1.2B Advantages of Polyjet Printing**

- Safe and clean process.
- Smooth surface finish
- High quality.
- High accuracy.
- Fast process speed.

### **2.1.1.2C Disadvantages of Polyjet Printing:**

- Post process is quite difficult.

- There will be some material wastage [5].

### **2.1.1.3A Principle of Rapid freeze prototyping**

This Technology is based on the principle which is used to build icy cold prototype using a water freezing method where is environmentally friendly, the water solution which is easily recycled and before the building of frozen part. The system consists of three major hardware devices like a Positioning subsystem, a water ejecting subsystem and an electronic control device. Each equipment have major role during the building process. At first, In order to extract the water droplets from the nozzle, the XY table is placed in the freezer under a low temperature to freeze in short time. The nozzle is attached to the Z elevator and after every completed layer, it will move in an upward direction. For the first layer of the ice part, only water droplets are deposited. It forms the continuous water line because every water droplet does not solidify immediately during deposition. Through the cold environment, the water line will freeze by convection process and conduction from the previous frozen layer rapidly. During every process for building an Ice part, process parameter is needed to set for the water ejection system and electronic control device which is important as they affect the overall fabrication accuracy The important parameter are ambient build temperature, scan speed, and the water speed rate. The ratio of the material flow to XY movement speed is kept at the best value to avoid discontinuity in freezing strands. By adjusting the nozzle scanning speed and water speed rate, It is easy to determine the each layer thickness and smoothness rather than the mechanical mechanism.

### **2.1.1.3B Advantages of Rapid freeze prototyping**

- Low running cost
- Good accuracy
- Good building speed

### **2.1.1.3C Disadvantages of Rapid freeze prototyping**

- Requires a cold environment
- Need of additional processing
- Possibilities of errors in Repeatability [6].

### **2.1.2 Powder-based**

This type of AM systems is like a special group of solid-based additive manufacturing, where the initial materials is in the powder form. This type of AM systems works in the process of binding method. In this process laser technology is used print the part layer by layer, sometimes glue is used joining effect. The following AM systems fall into this category and their advantages and disadvantages are explained below

1. Selective Laser Sintering (SLS)
2. Electron Beam Melting (EBM)
3. EOSINT System

#### **2.1.2.1A Principle of SLS**

SLS process is based on the following principle:

- Parts are building by sintering when a CO2 laser beam hit a thin layer of powdered material. The interaction of the laser beam with the powder raises the temperature of the powder to the point of the melting, resulting in particle bonding, fusing the particles to themselves and the previous layer to form a solid. This is the basic principle of sintering bonding.
- The building of the part is done layer by layer. Each layer of the building process contains the cross section of one or many parts. The next layer is then build directly on the top of the sintered layer after an additional layer of powder is deposited via a roller mechanism.

#### **2.1.2.1B Advantage of SLS**

- No post curing required.
- Fast build times.
- Limited use of support structures.
- Mechanical properties of Nylon and polycarbonate parts.
- Variety of materials can be printed.

#### **2.1.2.1C Disadvantages of SLS**

- Post processing is required for finishing
- Poor surface finish

- Unit is very big
- Complex operation [7].

#### **2.1.2.2A Principle of Electron beam melting**

When an electron beam is fired at metal powder parts are built. As indicated by CAD model the computer controlled electron beam melts the layer of powder precisely in vacuum with the gain in electron kinetic energy. The parts are built layer by layer. Once a layer is melted the second layer is added. in this way, by melting thin metal slices the solid details are built up.

#### **2.1.2.2B Advantages of Electron beam melting**

- Excellent accuracy
- Excellent finishing
- Good build speed
- Superior material properties

#### **2.1.2.2C Disadvantages Electron beam melting**

- High power consumption
- Gamma rays are produced
- Need to maintain the vacuum chamber [8].

#### **2.1.2.3A Principle of EOSINT**

Similar to SLS technology this principle is based on the laser sintering principle and layer manufacturing principle. Performances and functionalities parameters of this system are properties of powder materials, the laser and the optical scanning system, the precision of the working platform and working temperature.

#### **2.1.2.3B Advantages EOSINT**

- Good part stability
- Wide range of processing material
- Support structures not required
- High performance plastic products can be produced

- Parts of various sizes can be built

### **2.1.2.3C Disadvantages of EOSINT**

- Complicated systems
- High power consumption
- Large physical size of the unit [9].

### **2.1.3 Solid-based**

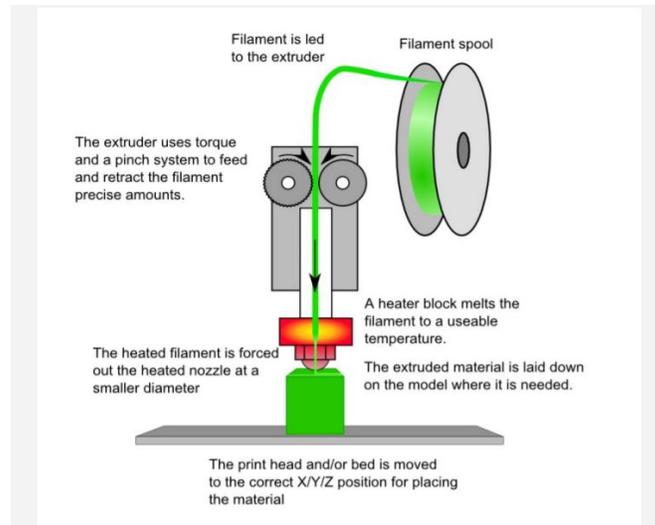
In this type of AM systems, the materials are in the solid state. Whereas the materials are in the form of wire and rolls. This type of process is totally different from liquid-based systems. In this type the materials are feeded into the heated nozzle; the melted material is printed in the form of layer by layer. The process continuous until the part is completed. The following AM systems fall into this category.

1. **Fused Layer Manufacturing (FLM)**
2. Selective Deposition Lamination (SDL)
3. Laminated Object Manufacturing (LOM)

#### **2.1.3.1 Fused Layer Manufacturing (FLM) Principle and Working**

##### **Principle of FLM:**

FLM is a Fused Layer Manufacturing commonly used for the modeling and prototyping, as I described before it is the trademark of RepRap community. It works in the principle by layering the material in the bed layer by layer. It is one of the solid-based additive manufacturing technologies. The product is build using the thermoplastic material, which is loaded on the top, where the thermoplastics are in the form of wire shaped. We use 2 types of materials to print the part, One is build material which is use to build the part, another is support material, Which is also called as Struts, The support material used for overhangs, where the hangs or extender part will fall during the printing, Unless they are support, In this cases, the support materials are used. Once the material extrudes from the hot printing head, the material gets harden. The principle of FFF is shown in this figure,



**Figure 2 Principle of Fused Filament Fabrication [10].**

### **Working:-**

The RepRap 3d printer falls under the category of Cartesian type. The name Cartesian named because of their dimensional co-ordinate system X axis, Y axis and Z axis. This axis shows the direction of movement of the printer.

In the type of printer, the printing bed moves in z-direction, the extruder are in the X axis and Y axis, where they can move in all four directions within their limit is fixed. Thus the printing is done with these technologies of printer.

#### **2.1.3.1A Advantage of FLM**

- No post curing
- Variety of materials can be printed
- Office friendly environment
- Machines are very less expensive
- Support material can be removed easily

#### **2.1.3.1B Disadvantages of FLM**

- Not suitable for small features and thin walls.
- Support required for some material.
- Weak in Z axis

### **2.1.3.2A Principle of Selective Deposition Lamination**

Its principle is based on the simple addition of sheets of paper. It is similar to Laminated Object Manufacturing (LOM). To form the final product various sheets of papers are accumulated with the adhesive and to cut every sheet at a time an adjustable tungsten carbide blade is used. By removing the waste we can produce the final product.

### **2.1.3.2B Advantages of Selective Deposition Lamination**

- Low cost
- High precision
- Safety
- Eco friendly
- High resolution in color printing

### **2.1.3.2C Disadvantages of Selective Deposition Lamination**

- Low strength
- Small build volume

### **2.1.3.3A Principle of Laminated Object Manufacturing**

In this parts are built layer-by-layer and the contour of the part of each layer is cut by a CO<sub>2</sub> laser. The elevation platform is activated by Z-control that lowers when each layer is completed. In this the excess material which is crosshatched for later removal acts as the support, therefore no additional support structure is required.

### **2.1.3.3B Advantages of Laminated Object Manufacturing**

- Fast build speed
- High precision
- Post-curing
- No need of support structure

### **2.1.3.3C Disadvantages of Laminated Object Manufacturing**

- Precise power adjustment
- Fabrication of thin walls
- Integrity of prototypes

- Removal of supports [10].

## **2.2 Process of Additive Manufacturing**

Printing of parts using AM systems undergoes the following steps to generate the useful physical part. Considering the common technologies the process chain is categorized in six following steps. These steps can be either grouped together or it can be spitted in some cases, it differs based upon the technology they use but the process chain remains same for all Additive Manufacturing process.

- Generation of CAD model
- Conversion of CAD model to .STL format
- File transfer to machine
- Machine setup
- Build
- Removal
- Post processing
- Application

### **2.2.1. CAD model**

Creating a CAD model is the very first step in Additive manufacturing process. The CAD models can create through different professional programs that are compatible for AM process. Reverse Engineering can also used to create the Digital model by 3D scanning technology. The digital model should fully describe about the geometry of the part.

### **2.2.2. Conversion to .STL format**

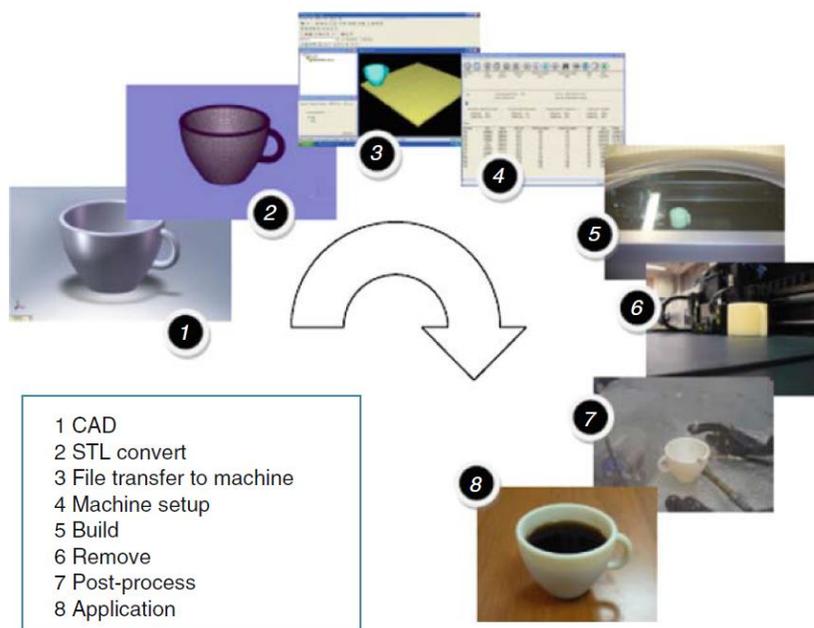
Almost all AM technology today uses Stereo Lithography (STL) file format. This has become de facto standard. STL uses triangle (Polygons) to describe the surface of an object. Every CAD program can give a output of STL file format. It shows about the closed surface of the CAD model and the basic calculation of slices.

### 2.2.3. File Transfer to machine

Once the file is converted into STL format, it is transferred to the machine. The file is imported to the slicer program. The program makes the STL is converted to G codes, which is the basic language used in Computer Aided Manufacturing. The program allows the user to customize the build parameters includes support, layer height, position and the orientation of part.

### 2.2.4. Machine setup

The machine is prepared before the printing process according the materials in which the part to be printed and where the part could be placed heating the bed and the extruder to the required temperature, Loading the required and sufficient material which is required to print the part. Setup the setting like material constrains, speed, timings and energy source, etc



**Figure 3 Additive Manufacturing Process [11].**

### 2.2.5. Build or Print

In the 3D printing machines, the raw materials are loaded and once the machine is started is started to print, the machine does not required any monitoring since it is fully an automated

process. The error occurs only when the machine run out of material or some error is software or due to power failures.

#### **2.2.6. Removal of Print**

Once the AM machine finished printing the part, the part should be removed carefully from the printing bed; in some printers it is very easy to remove the part from the bed, but for industrial 3D printers its highly complicated process to remove the part from the bed very precisely. This process is little complicated and need to be done carefully with the skilled workers with some safety equipments and it should be done in a controlled environment.

#### **2.2.7. Post Processing**

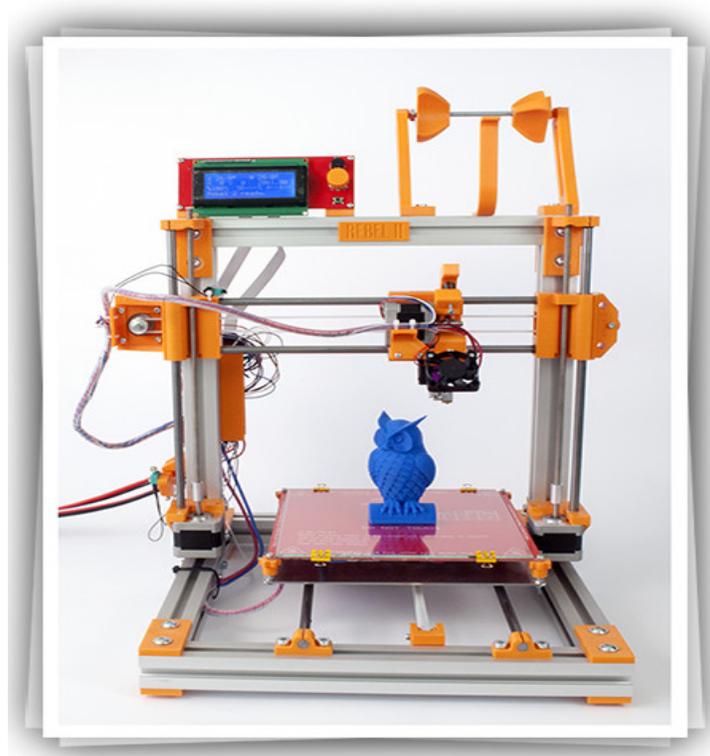
This process varies for each technology, once the part is removed from the printer, parts may required additional cleaning to use that parts. The support material used for the printing process is also removed during this process. The post processing process also includes coloring, high pressure air cleaning, and polishing.

#### **2.2.8. Application**

The parts can be ready to use now, but they may required some more treatment to be done before they are accepted to use likely painting and priming for the good aesthetic and finish [11] [12].

### **3. ABOUT REBEL II PRINTER**

It is one of the very famous printers in Czech Republic, by the RepRap comity. It is very cheaper and easily available with robust and proven mechanical design. The image of the constructed Rebel II 3D printer is shown in the figure. And the specifications of the printer are described [13].



**Figure 4 Rebel II 3D Printer [9].**

### **3.1 Technical Specification of Rebel II 3D printer**

#### ***a. Printing***

Printing Technology – Fused Filament Fabrication (FFF), the plastics in the form of wire is pushed into the heated nozzle and it is printed on the bed in a thin layer.

Layer height – It depends upon the type of the nozzle, minimum of 0.05mm

Presser foot – Heated pad 200\*200 mm

Print size – 200\*200\*180 mm

Print speed – 30 mm / s to 120 mm / s

Cross speed – 30 mm / s to 200 mm/ s

Printing surface – 3 mm thickness of removable glass

Plastic diameter – 1.75 mm (any plastics can be used)

Type of plastics – ABS, PLA, TPE, PC, PA, PET, HIPS, PVA, ASA, and others.

Nozzle diameter – mainly 0.3 mm, 0.4 mm, 0.5 mm (possibilities of 0.2 mm, 0.6 mm)

Maximum nozzle temperature - 290° C

### ***b. Software***

Firmware: Open Source Marlin with customization options and Repetier firmware

Software: Repetier-Host, Slic3r, CureEngine (RepRap compatible)

### ***c. Hardware***

Dimensions: 420 mm \* 420 mm \* 600 mm including coil.

Higher size dimensions: 420 mm \* 420mm \* 650 mm including coil.

Frame: Anodised aluminium profiles 30 \* 30 mm

Plastic parts: ABS parts

### ***d. Electronics***

Communication: USB, optional SD card in LCD module.

Control board: Arduino Mega 2560 and RAMS 1.4.

Power supply: industrial switching power supply 12V 240W [14].

## **4. MATERIALS USED**

Selecting the correct material to print the object is a very difficult job, whereas in FLM 3D printing technology, PLA and ABS are the main polymers playing an vital role but currently there are lot of dominance form the other polymers to play a key role in the FLM technology. In this study we focus on some polymers and composites that exist in the today's market. The case study and the properties are listed below, were it can make the users to make decision about the materials for their products. The materials are:

- **PLA (Polylactic Acid)**

Extrude temperature: 190°C to 250°C

- **ABS (Acrylonitrile Butadiene Styrene)**

Extrude temperature: 230°C to 250°C

- **PVA (Polyvinyl alcohol)**

Extrude temperature: 170°C to 190°C

- **PET - (Polyethylene Terephthalate)**

Extrude temperature: 207°C to 235°C

- **HIPS (High Impact Polystyrene)**

Extrude temperature: 230°C to 235°C

- **Nylon 12**

Extrude temperature: 175°C to 180°C

#### 4.1 Polylactic Acid (PLA)

Polyactic or Polylactide is a biodegradable thermoplastic which is derived from renewable resources; PLA is the second highest consumed volume of bio-plastics in the world, where polyhydroxyalkanoates (PHAs) is the highly consumed bio-plastics in the world

**Table 1 Properties of Polylactic Acid (PLA)**

PROPERTY	VALUE
Technical Name	Polylactic Acid (PLA)
Chemical Formula	(C <sub>3</sub> H <sub>4</sub> O <sub>2</sub> ) <sub>n</sub>
Melt Temperature	157 °C - 170 °C
Typical injection molding Temperature	178 °C - 240 °C
Heat Deflection Temperature (HDT)	49 - 52°C at 0.46 MPa
Tensile Strength	61 - 66 MPa
Flexural Strength	48 - 110 MPa
Specific Gravity	1.24
Shrink Rate	0.37 – 0.41%

[15]

#### 4.1A Advantages of Polylactic Acid (PLA)

- Can print on the cold surface.
- More eco-friendly.
- Smooth and shiner appearance.
- No harmful fumes during printing.
- Higher 3d printing speed.

#### 4.1B Disadvantages of Polylactic Acid (PLA)

- Can deform due to heat.
- Less strength compared to ABS. [16]

#### 4.2 Acrylonitrile butadiene styrene (ABS)

It is a common thermoplastic polymer, which is made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. It is one of the low cost engineering plastic which is easy to machine and fabricate. This type of material is mostly used for making prototypes which has good dimensional stability.

**Table 2 Properties of Acrylonitrile butadiene styrene (ABS)**

Property	Value
Technical Name	Acrylonitrile butadiene styrene
Chemical formula	$(C_8H_8)_x \cdot (C_4H_6)_y \cdot (C_3H_3N)_z$
Glass Transition	105 °C
Melt Temperature	230°C - 250°C
Heat Deflection Temperature	98 °C at 0.46 MPa
UL RTI	60 °C
Tensile strength	46MPa
Flexural Strength	74MPa
Specific Gravity	1.06
Shrink Rate	0.5 – 00.7 %

[17]

#### 4.2A Advantages of Acrylonitrile butadiene styrene (ABS )

- Very strong and hard.
- High melting point.
- Longer life span.
- Excellent impact resistance.
- Easy to paint and glue.
- Good aesthetic quality.

- Excellent machinability.

#### 4.2B Disadvantages of Acrylonitrile butadiene styrene (ABS)

- Deforms when it's not printed on the heated surface.
- Hot plastic fumes are produced during printing.
- Need of ventilation.
- Made of oil, which can affect environment [17].

#### 4.3 Polyvinyl alcohol (PVA)

It is a type of synthetic polymer which soluble in water. It is colorless and odorless and sometimes it is also used as solutions in water

**Table 3** *Properties of Polyvinyl alcohol (PVA)*

Property	Value
Technical Name	Polyvinyl alcohol
Chemical formula	$[\text{CH}_2\text{CH}(\text{OH})]_n$
Melt Temperature	190 °C
Boiling point	228 °C
Specific gravity	1.19 – 1.31

[18]

#### 4.3A Advantages of Polyvinyl alcohol (PVA)

- It costs lesser than some adhesive.
- It can be cleaned with water, no chemicals required.
- Do not produce any fumes during printing.
- Used in paper making, textiles and for some coatings.

#### 4.3B Disadvantages of Polyvinyl alcohol (PVA)

- Curing time takes up to 1 day.
- Could bond it together with some materials like wood.

- Higher price.
- Should be stored in sealed box or in a container. [18]

#### 4.4 Polyethylene Terephthalate (PET)

It is one of the most commonly used thermoplastics in worldwide for manufacturing containers. PET is a good water resistant material and this type of material is commonly recycled.

**Table 4 Properties of Polyethylene Terephthalate (PET)**

Property	Value
Technical Name	Polyethylene Terephthalate
Chemical formula	$(C_{10}H_8O_4)_n$
Melt temperature	Lesser than 250 °C
Tensile strength	55MPa – 75MPa
Glass Transition temperature	67 °C - 81 °C

[19]

#### 4.4A Advantages of Polyethylene Terephthalate (PET)

- Commonly used in the packing industry.
- High strength to weight ratio.
- (PET) is very high resistant to moisture.
- Easily recycled.

#### 4.4B Disadvantages of Polyethylene Terephthalate (PET)

- It is somewhat susceptible to oxidation.
- It is not biodegradable [19].

#### 4.5 High impact polystyrene (HIPS)

It is an type of aromatic polymer, which is in solid form. It is clear, hard and colourless material which is easy to thermoform and fabricate.

**Table 5 Properties of High Impact Polystyrene**

Property	Value
Technical Name	High impact polystyrene
Chemical formula	$(C_8H_8)_n$
Melting point	Less than 240 °C
Solubility	Very soluble in acetone
Tensile strength	46MPa – 60MPa
Glass Transition temperature	100 °C

[20].

#### **4.5A Advantages of HIPS (High Impact Polystyrene)**

1. It is easy to machine and fabricate.
2. It is a good insulator.
3. It is FDA complaint.
4. It is easy to paint and glue.
5. It has a relatively low cost.

#### **4.5B Disadvantages of HIPS (High Impact Polystyrene)**

1. Older types of expanded polystyrene contain CFCs.
2. Highly Flammable, especially if oil painted.
3. It takes long time to decompose and is regarded as a pollutant [20].

#### **4.6 Nylon 12**

The word Nylon would be new to the additive manufacturing industry, but it's becoming more popular by its physical properties after it printed. It is available in cheap because of the usage of it in the other industries. It has very high tensile strength and it has good chemical resistance

**Table 6 Properties of Nylon 12**

Property	Value
Technical Name	Nylon 12
Chemical formula	$(C_{12}H_{21}NO_2)_n$
Melt temperature	175°C to 180°C
Heat deflection temperature	97°C
Tensile Strength	77.7MPa Grade count 330

[21] [22].

#### **4.6A Advantages of nylon12**

1. High elongation.
2. Good finish in the products (smooth and sliky).
3. Good Chemical resistance.
4. Incredible tensile strength.
5. Very low friction coefficient.
6. Can be pre-cooled or dyed in a wide range of colours.

#### **4.6B Disadvantages of nylon12**

1. High shrinkage in moulded sections.
2. High moisture absorptivity reduces electrical and mechanical properties.
3. Attacked by oxidizing agent
4. Low humidity resistance [21] [22].

## **5. PREPARATION OF PRINTER TO PRINT**

The preparation of the printer starts with the design of the part, once the part is designed; it is connected into .STL format by the printer.

The printer is connected to the computer, it is connected to the electricity and the printer is switched on.

The special software for the Rebel II printer is Repetier host; the software is installed in the computer in which we use.

The reference point is the printer is checked, If not the reference is to be set in the printer.

The design in the .stl format is loaded in the Repetier Software and the object is aligned in the bed, where to be printed and it needed, the scale of the object can be changed.

The quality of the material, printing speed should be changed as per the requirement of the finished product quality.

The design is sliced using the slice, the design is sliced as per the requirement of the product quality, and the nozzle diameter should rechecked before we set the quality.

Before we start printing, it is advisable to notice, that the material to print is loaded and its quantity is enough to print both filler and support material.

The glue should be applied on the bed to ensure the material stick to it and it is easy to remove after printing.

The bed temperature and the extruder temperature are set manually according to the material we use.

Once above things are done, the printer is ready to print, where we can start printing.

## **6. PROBLEM IDENTIFICATION ON REBEL II PRINTER**

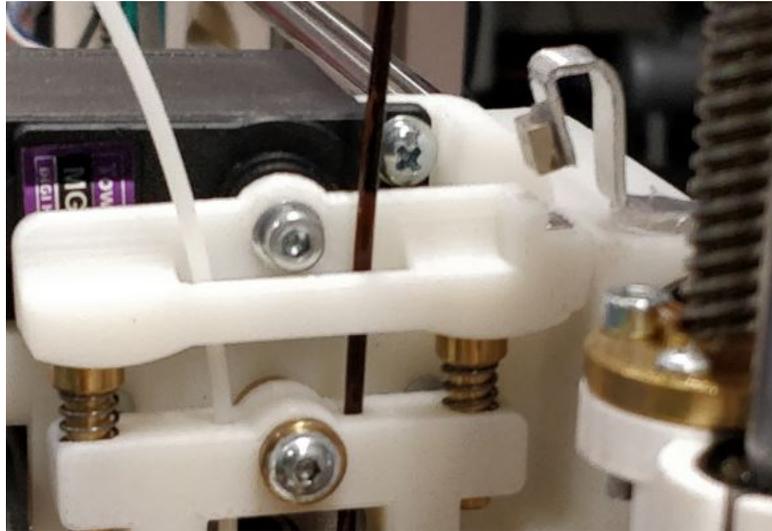
In the REBEL II printer, during the continuous printing process it is identified that servomotor is heated up to 70°C-80°C, which is abnormal temperature for the printer. But the same technology of the printer can be used for printing the small parts which is less complex in design. But during the printing of bigger parts, the problem is identified. And the second problem was, during the printing of parts with the support materials it clear that the support material from the second extruder is not extruding from the extruder head in a good way, even after doing the necessary changes in the software and hardware. So it decided to makes some changes in the printing head to make the second extruder to work properly.

### **6.1 Possible Solution**

#### **6.1a Printing heads with magnets**

To improve the printing quality of the printer and to improve the performance of the servo-drive, we have planned to fix the extruder with less movement which may reduce the heating of the servo drive. So the magnet is placed on the head and if the movement of the

extruder is about to control with the magnetic force. The photo of the magnetic holder is shown in the photo.



**Figure 5 Magnetic Holder**

The print was started, and the magnetic extruder was about to set perfectly. But due to the excessive force from the spring, which is under the extrusion control lever, the magnetic force couldn't withstand at the same position, where the extruder should be fixed. Due to this, the extruder was controlled with the power of servomotor. So this idea was not successful to improve it.

### **6.1b Change of Servo Motor**

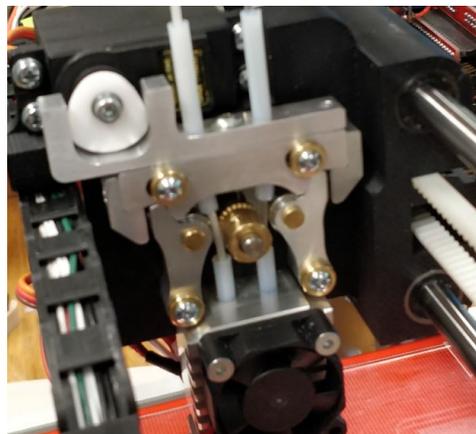
We have planned to change the servo drive as a necessary step, and we have found a new servo drive with the same specifications but slightly advanced than the previous one, where the new servo has more power than the previous, which will be good in feeding the material in to the nozzle with more power. The old servo was MG996, and it is replaced by my new servo MG995. And the testing is planned to go with this setup to know how far the printer is good with this setup and to find the optimum solution of the printer with this setup and the testing is carryout.



**Figure 6 New Servo motor**

### **6.1c Implementation of new printing head**

For improving the printer, we have done many changes in the printer, in this, we have planned to change the printer head, the design of the printing head is chosen from the advanced FLM 3d printer with new technology. In this moment to change the extruder is very less and it is very quick, when compared to the previous design .The design of the new printing head is taken and the dimensions are changed according to the constraints of the REBEL II printer. The new printing head is machined and assembled and it is fixed to the printer. The photo of it is shown in the figure.



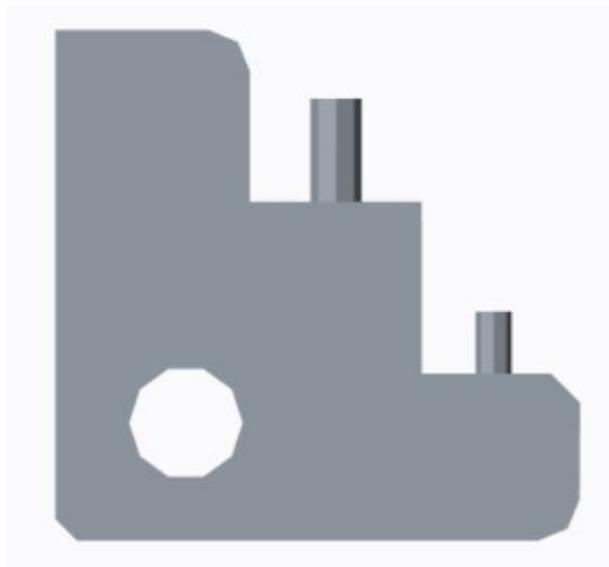
**Figure 7 Design of New Printing Head**

With this, new printing head, it is planned to test all the materials. Before testing material the material, the reference point is checked and the extrusion of the material from the nozzle is checked and then printer us about to proceed with the testing.

## 6.2 Testing of Materials

### 6.2.1A Testing of ABS

The testing of ABS (Acrylonitrile Butadiene Styrene) Starts with the preparation and the design to be printed, the part is designed and it's converted into .stl format. The design is common for testing all the materials which will be described below. The design is shown in the figure. And the dimensions of it in X, Y and Z axis are 20\*25\*25 mm



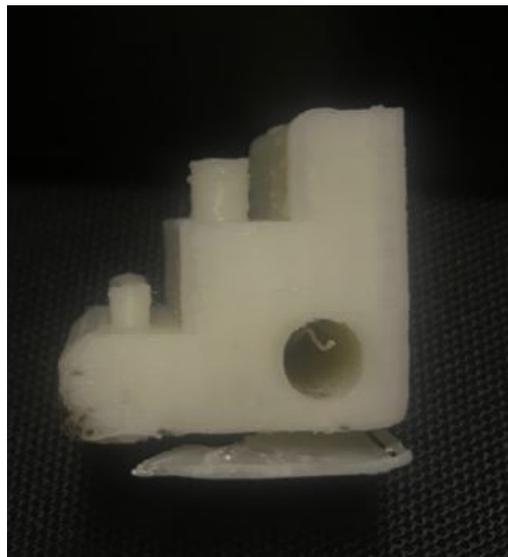
**Figure 8 Design of testing part**

And the printer is corrected to the computer with the replier host software installed in it. The rebel 3D printer is connected to the computer. The setup file for the respective material is loaded to the software.

The setup file consist of the printing parameter for that particular material i.e., speed, temperature, melting point, thickness etc.,

Then the part is sliced according to the quality we required. In our case, the quality of the material is chosen as 0.25mm and the density for all is 20% and the infill pattern and the solid

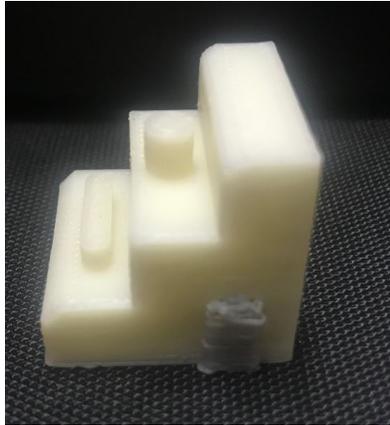
infill pattern is chosen as rectilinear and the design is sliced using slicer and the design is sliced. The temperature for the printing is settled as 250°C for both fill and support and the bed temperature as 90°C the part is printed. During the printing, the more problems well face. The main problem was the part did not stick with the bed and the filament did not stick with the previous layer due to the temperature is not up to the limit, which is required and the surface is getting rough and unfinished. The major problem was the support material is not extruding in a good form and some timer, the support material is stop extruding due to very less temperature of the extruding filament, The printed part is shown below in the figure.



**Figure 9 Defect in Printed part in ABS**

With this result, it is clear that the first layer does not stick to the bed properly and the rough surface on the top results in lack of temperature during printing.

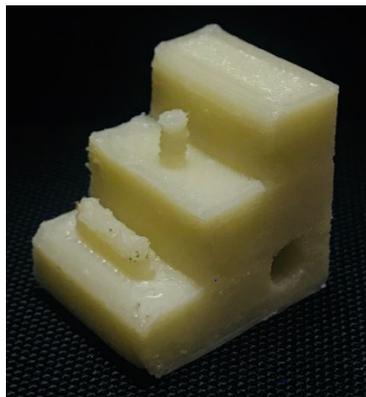
The changes are done by increasing the melt temperature of fill material as 260 degree Celsius and the support material as 265 degree Celsius, the bed temperature is increased as 100 degree Celsius and the printing bed is glued to make the print top stick properly also the speed is reduced to 80% of the original speed and the part is printed again with the same parameter except these changes. The part is printed successfully; the printed part is shown in the figure.



**Figure 10 Printed part with 0.25mm thickness in ABS**

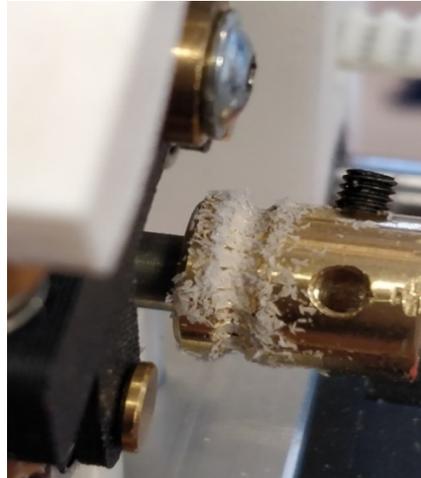
The part has good surface finish and dimensional stability during the printing process, At the time of printing, the support material we face the problem which we faced earlier during the precious printing. The support material does not extrude properly from the extruder. It needs external push for the material to be extruded.

The printer is about to check for the different parameter with the same design. So the thickness of the layer is changed to 0.3mm, and the infill pattern and the solid infill pattern is changed to line and the speed is reduced to 70% to obtain more quality and the part is produced. The result of the part was very good when compared to the previous one with very good surface finish but the same problem occurred in the extrusion of the support material. The result of the part is shown in the figure.



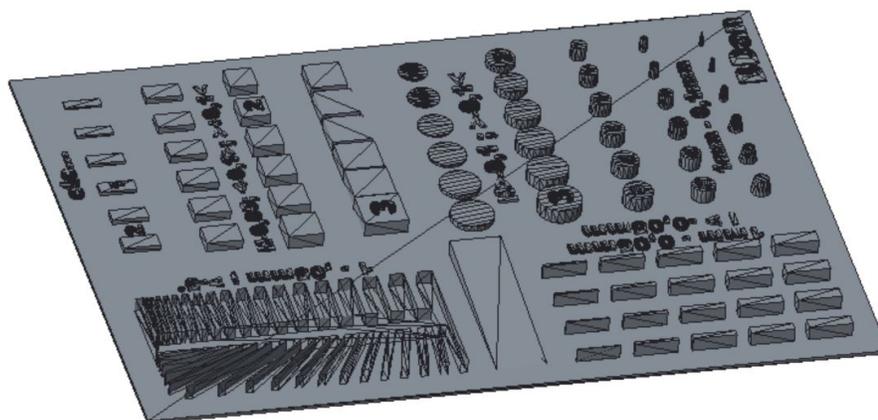
**Figure 11 Printed part with 0.03mm thickness in ABS**

During this process, It is found that the servo driven gear is fully covered with the fill material. Due to the extrusion of the material force is reduced. It occurs due to the excessive speed and the excessive force by the servo drive. The photo of the servo gear is shown in the figure.



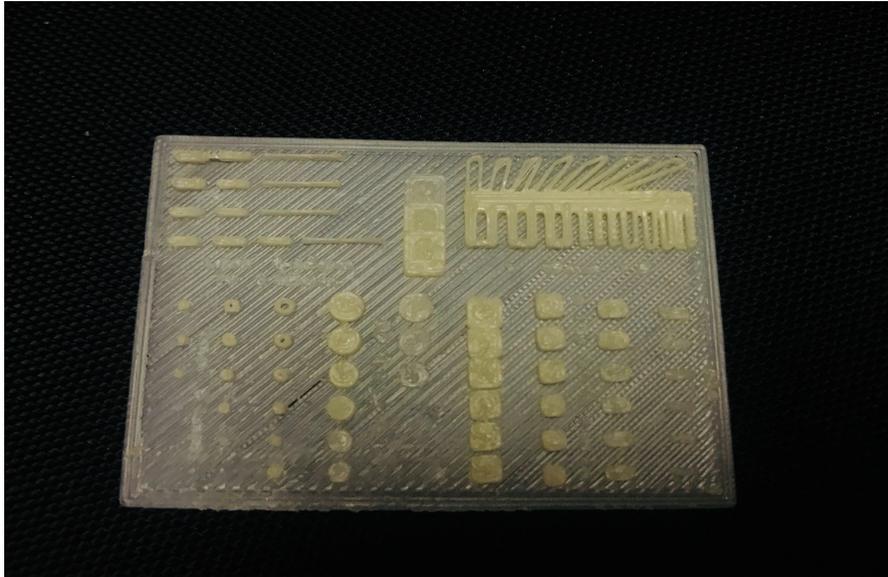
**Figure 12 Servo Driven Gear covered by material**

The servo driven gear is removed and cleaned and it is carefully assembled to its original position. To test the minimum thickness of the printer. The design of caliper plate with the thickness of 1mm is chosen and the plate consists of many dimensional constrain design. The image of it is shown in the figure. And its dimensions are 50\*38\*1.5mm



**Figure 13 Design of Caliper plate**

The part is print with the same parameters and the part is printed without and defects, the printed part is shown in figure.'



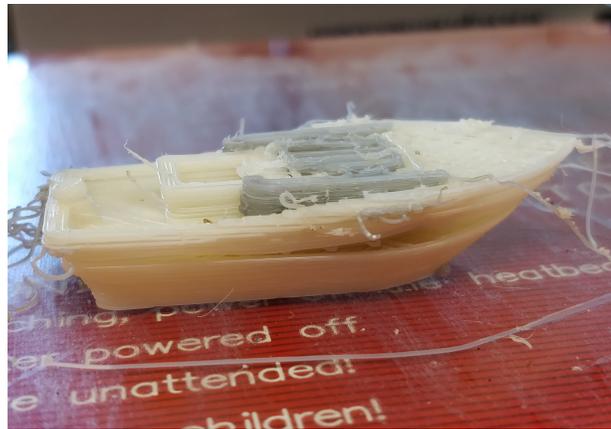
**Figure 14 Printed part of Calibration Plate in ABS**

Finally to test the printer for long run, the ship design is chosen and it's about to print, the design is shown in the figure. And the dimensions of it are 60\*30\*50 mm



**Figure 15 Design of Ship**

When it is sliced, the estimated time of print is about shown and 45 minutes and the print was started. We face the same problem as before, with support material though we continued to print future, during the printing process, the speed was rapidly changed to check the printer capacity. The printer speed was changed from 50% to 120% of the normal speed due to the change of speed rapidly, the part does not print properly and the filament does not stick to the previous layer in properly. The print was killed the photo of the printed part is shown in the figure.



**Figure 16 Defects in Printed Parts in ABS**

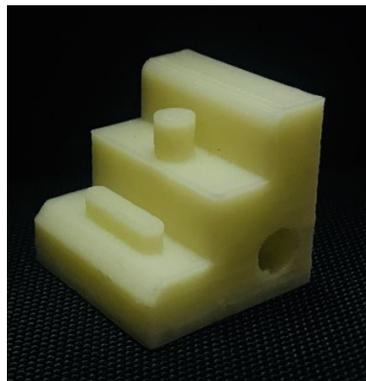
The same design is printed again without support and in a constant speed of 75%. The printing was good with the fine finish. The print was running for 1.5 hours after that due to time constraints. The print is killed and the printed part is shown in figure and the printer was running well without any problem.



**Figure 17 printed part of Ship in ABS**

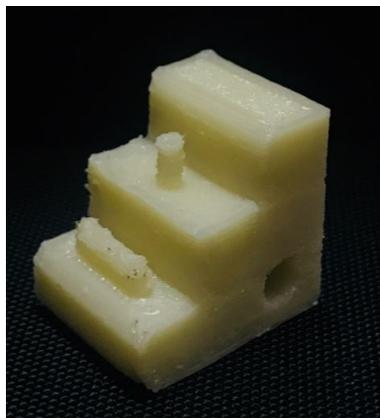
### 6.2.1B Testing ABS with new head

In this, we have already discussed about the setting of parameters and the suitable temperature for this material for printing it. The test of the ABS starts with the printing of part, which is designed as shown in the figure 7. For this, the temperature is set as 250 °C and for the support material it is set as 232 °C and the part is about to print with the thickness of 0.25mm. The printing pattern is chosen as linear and the printing speed is set about 80%. The printing is started, in the printing head, the extrusion of the support material is very good. And the print was good finish. The printed part is shown in the figure 8.



**Figure 18 Newly printed part with thickness of 0.25mm in ABS**

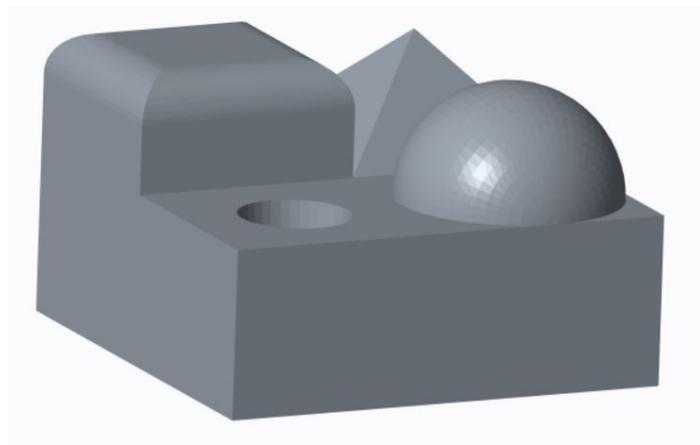
The same part is about to print with different parameters, the thickness was changed to 0.3mm and the printing pattern was chosen as concentric and the material infill percentage was chosen as 80% and the printing is done, the printing was done in the speed of 120%, The print was okay, because it was printed in a very high speed. The photo of the printed part is shown in the figure.



**Figure 19 Newly printed part with thickness of 0.3mm in ABS**

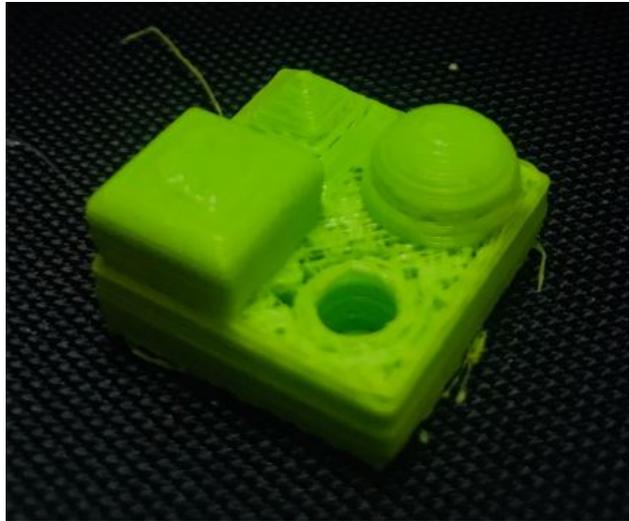
### 6.2.2A Testing of PLA:

The testing of PLA starts with the checking of parameters in the printers. Once the material is loaded in the printer, the extruder is heated up to 205°C-215°C to check the extrusion of the material. The amount of material to be extruded is measured and marked on the filament. The exact measured value is extruded manually and checked whether the exact value of the measured filament is extruding or not. The exact value of the filament is extruded, and then the printer is in correct condition. If not the non-extruded material is measured and the steps are calculated and the value is changed in the settings. The process is continued until we get the exact measured value. Then the set up of the particular material are uploaded in the software. And the temperature is set about 215°C and the bed temperature is set about 50°C. The part to be printed is designed and is converted into .stl format. The design of the part is shown in the figure. And the dimensions of it are 20\*20\*12 mm



**Figure 20 Design of Test Block**

And the part is printed with a thickness of 0.25mm, and the infill and the solid infill material is set as line, where the printing layer will be printed as lines. The printing was started. During the first few layers of print the speed is identified. If the speed of printing is very high then it is controlled to 70% of the setup speed. In between this the first layers are damaged. After controlling the speed, the part is perfectly printed and the printed part is shown below in the figure.



**Figure 21 Printed Part of Test block on PLA**

Then the base layer of the part is perfectly printed as per the dimensional qualities. With this the print is about to continue with the next part and also with a new design. The print is about to test with the bigger parts. So we are about to test the design which is shown on the figure13. The model of the ship, which is tested for ABS material. The design is about to print with PLA with a thickness of 0.3mm and the speed and the infill pattern and the solid infill pattern were chosen as rectilinear, and the printing is started.

At the starting of the print, due to higher thickness, the material flow from the extruder is very less when compared to the normal flow. So the temperature is increased from 215°C to 225 °C. and in-between, due to the complex design of the part, the printing was not good due to high speed, so the speed is reduced to 55% of the setup speed. The estimated time of the print was about 3hours and 45minutes and the print was successfully completed. During the printing process, the printer was thoroughly checked, if the printer attains any problem. But the printer condition was very good and the part was good from the starting till the end. The printed part is shown in the figure 15.



**Figure 22 Printed Part of Ship in PLA**

In the figure, we can identify the defect in the base layer, which is due to high speed of the print with more thickness. And by controlling the speed the problems were rectified in the material and the printed part has good surface finish and good dimensional stability.

#### **6.2.2B Testing of PLA with new head**

This type of material is very easy to test because we have the exact setup for this material. The material is to be tested for the design as shown in the figure 8. The temperature is set about 215°C and the bed temperature as 60°C and the thickness about 0.25mm, the pattern is chosen as Rectilinear and the speed was about 80%. The result of the printed part was good as expected. The photo of the printed part is shown in the figure.



**Figure 23 Newly printed part with thickness of 0.25mm in PLA**

For the same design, the printer is about to test with different parameters, the thickness is changed to 0.3mm. And the pattern is chosen as hilbertcurve and the material infill percentage as 30%, previously it was about 20% and the print was started. It was printed at a speed of 100% and the printing was successfully finished. The printed part is shown in the figure. When compared this part to the previous one, the surface finish of this part was good as previous one and a slight deformation is occurred in the top. It is because of the printing. But the remaining portions are good as expected.



**Figure 24 Newly printed part with thickness of 0.3 mm in PLA**

### 6.2.3A Testing of PVA

The testing of PVA starts with the loading of material in the machine. Since we don't have a setup for this material, it is going to be tested, in this setup the PLA can be printed successfully. The material is loaded in the printer, with the filament diameter of 1.75mm. We know that, the melt temperature for PVA is between 195°C-225°C with bed temperature of 70°C. First the print is started to test with the PLA setup. The part was started to print as shown in the figure 8, with the parameters of 205°C in the speed of 80% of the setup speed and the line type pattern is chose with the thickness of 0.25mm. But the printing results were not good. So, change of temperatures and change of pattern has been done and once we start printing the part the part was not good. The results of the printed parts are shown in the figure.



**Figure 25 Defects in Printed part in PVA**

The setup was changed from PLA to the ABS settings and the printing process is started for the same design. The extrusion temperature and the temperature of the bed are changed by editing the G-codes. As same as the previous testing, the parameters are same and the printing is started. The print was very good. But in this print the support is not enabled. And the end of the printing the part, the print wasn't good. It is due to speed printing of layers and the lack of cooling due to the printing process. The result is shown in the figure.



**Figure 26 Printed with 0.25mm thickness in PVA**

To improve the cooling process during the printing, the pattern type was changed, from line to the others one by one. The pattern type is changed to rectilinear and the thickness is changed to 0.3mm. The part is designed as shown in the figure and the printing is started. During the printing it is found that, in few places the material was filled in a flow, so to improve that the extrusion temperature is increased to 230°C and the speed is also reduced to 70% and the print was in OK. It was not good as expected. It is shown in the figure.



**Figure 27 Printed Part with 0.3mm thickness in PVA**

So with this same parameters, the infill pattern is alone change to concentric, with the same thickness. And the part to be printed is designed as shown in the figure 20 and the part is printed

without any problem. The result of the printed part was very good as expected. The result of the printed part is shown in the figure.



**Figure 28 Printed Part of Test block in PVA**

To check the printing, with the PVA material, for long run, it is planned to print the part as the design is shown in the figure 15. And the printing was started with the default settings. The temperature of the bed and the extruder is changed in the G-codes manually. The infill pattern was concentric and the printing is started. But after few minutes, the print started to collapse. And the layer was messing one and another. The print is killed and the pattern is changed to honeycomb structure and the print is collapsed with the layer after a particular period of time. The results of the prints are shown in the figure.



**Figure 29 Defects in the Printed parts in PVA**

It is identified that, it is due to improper cooling during the printing. To improve this, the cooling setup must be made on the printer and the process of printing should be slow. It cannot be controlled manually because, it is everything in the setup of printing, and we don't have any

setup for this material. Finally the thickness was changed to 0.25mm, and the speed was set about 75% of the setup speed, bed temperature about 75°C and the pattern was set as Hilbert curve. And the infill densities were given as 50%. Previously it was 20%. The Hilbert curve was chosen because, the shape is very complex, where the printer takes more time to print the layers compared to the line pattern. The printer was printing well, suddenly the printer stop extruding the material. The print is paused, during the checking, it is identified that, the material is stuck into the nozzle. The image of the printed part is shown in the figure.



**Figure 30 Printed part of Ship in PVA**

When we extrude the material, after the part is paused, the material doesn't extrude. So, the printing head is dismantled and the extruder nozzle is removed and inspected, it is identified that the material is expanded and got stuck in to the nozzle. The print is killed and the part is removed from the bed. The part was printed good as expected. The block in the nozzle is tried to removed by, we couldn't, since PVA is soluble in water. The nozzle is submerged into the water, to make the PVA dissolve. After a period of time, the block is cleaned and the nozzle is set back to its original position. The removal of material is shown in the figure.



**Figure 31 Material elongation of PVA in the printer**

This figure shows the difference between the material and problem occurred in the material. It is occurred due to excess of force is applied continuously on it.

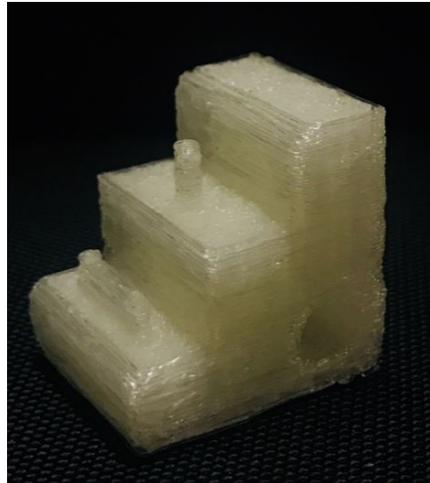
### **6.2.3B Testing of PVA with new head**

The PVA is a support material, which is very known that it is soluble in water. Now the PVA is going to be tested by printing the part fully with the material. The part is designed as shown in the figure. The parameters are settled for the printer to print the part, temperature of 230°C and the speed of 80% of setup speed. The printing pattern is chosen as line and the printing is done. The print was successful, But we have very small problems during the printing because printing of PVA requires cooling unfortunately we don't have cooling fan in our printer, so during the material was very hot and it's not enough to be cooled naturally. Some dark brown spots can be seen in the printed part. The photo of the printed part is shown in the figure.



**Figure 32 Newly printed part with thickness of 0.25mm in PVA**

The same design is tested with the different parameters, the thickness of 0.3mm and the pattern is changed to concentric and the material infill percentage is 20%. The part is printed with the speed of 100%. The part was printed successfully without any problems but the same problem is occurred due to lack of cooling during the printing process. The photo of the printed part is shown in the figure, but though we don't need to worry about cooling fans because the PVA is only used as a support material, where support won't be printed for long time.



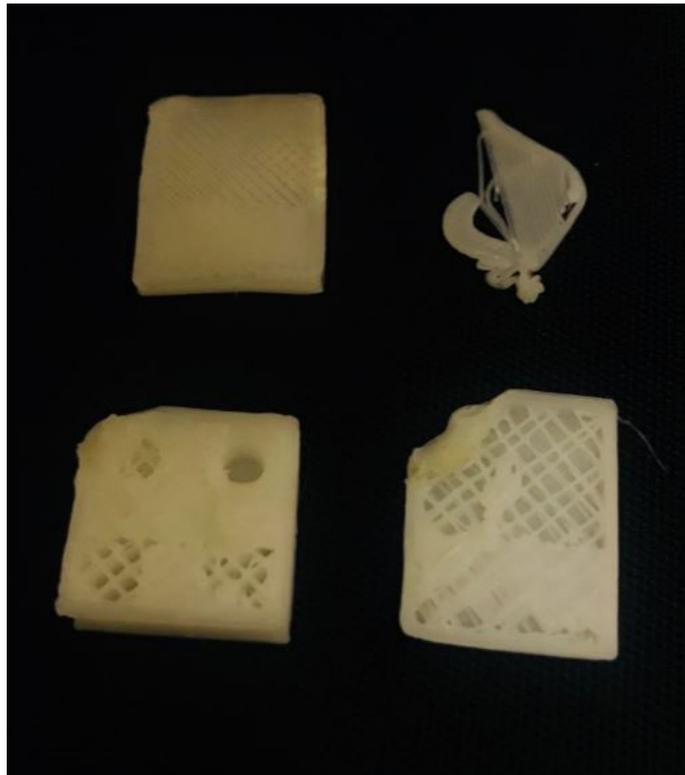
**Figure 33 Newly printed part with thickness of 0.3 mm in PVA**

#### **6.2.4A Testing of HIPS**

HIPS are same as the ABS material, where they have almost same properties. But the only thing, the HIPS require more temperature to melt. We know the properties of HIPS, so the print is prepared for printing the HIPS. The ABS print setup is planned to use for printing the material. The print is started to test the design as shown in the figure7.

The temperature is set as 240<sup>o</sup>c and the bed temperature is set as 90<sup>o</sup>c and the design is about to print with the thickness of 0.25mm. The slicing is done and the print is started. In this, the print was good, the side walls get curled. And the main drawback was, the base doesn't stick to the bed properly and wrapping is occurred, on the joining of two corners in the print. It is identified, the edges and corners are wrapping due to the sudden loading on the printed material. The surrounding temperature must be controlled during the printing process. The parameters are changed to make the printing process good. The bed temperature is changed to 110<sup>o</sup>c and the

glue is applied on the bed to make the part to stick on the bed perfectly and the material infill percentage was set as 30%. And the speed is about 80% and the print is started, the print was not good. And the layer doesn't stick to the base and the corner is curled. The print started is tested with all the patterns. The results of the failures parts are shown in the figure.



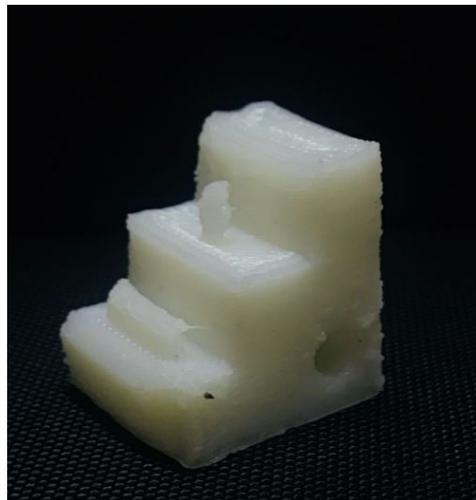
**Figure 34 Defects in Printed parts in HIPS**

To improve the quality of the print, the parameters are changed to fix the part to the bed. The thickness of the first layer of the part to be printed is changed to 0.35mm, the concentric pattern is used to print and the initial position of the printing head is increased slightly in the Z-axis. Due to the printing of increased first layer thickness, the change is done on the orientation of the head. And the printing is started. And the part is printed successfully but in some corners the wrapping can be seen. The photo of the printed part is shown in the figure.



**Figure 35 Printed part with thickness 0.25 in HIPS**

To check the printer with different parameters, the same design is planned to print with different speed. With the increased layer thickness of 0.3mm and with the speed of 100%, the printing pattern was chosen as Rectilinear, and the temperature was about 240°C and the bed temperature as 115°C, the printing is done. The print was good without any curling. But the surface finish was little poor due to printing in high speed. The results of the print are shown in the figure.



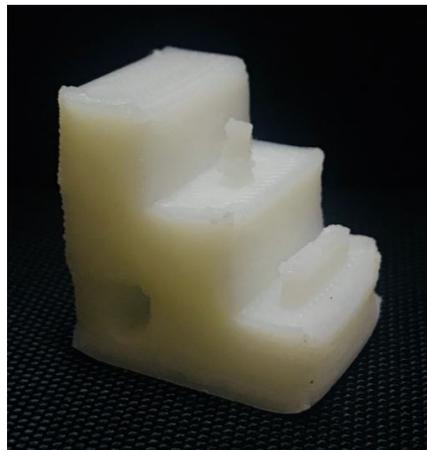
**Figure 36 Printed Part with thickness of 0.3mm in HIPS**

#### **6.2.4B Testing of HIPS with new head**

This material is also mainly used as a support material, where HIPS is soluble in lemon extract. For printing this material we are using the previous setting, which we used in the previous

version. The setup of ABS is used to print this material. And the material is planned to test with the design as shown in the figure 8.

The temperature is set about 215°C and the bed temperature as 115°C, the pattern is chosen as line and concentric. The thickness was set about 0.25mm and the print is printed at a speed of 50% of the setup speed. And the first layer thickness was changed to 0.35mm, to make the base to fix properly in the bed. The printing was finished successfully and the printed part is checked for the defects. The result of the printed part was very good as expected. But the only problem was the corners get curled because of sudden cooling of the material. It is because of the atmospheric temperature/room temperature. The printed part is shown in the figure.



**Figure 37 Newly printed part with thickness of 0.25 mm in HIPS**

To obtain more accurate result from the printer, the parameters are changed and the printing is started. The thickness is changed to 0.3mm and the pattern is changed to Rectilinear and the material infill percentage is changed to 30%. And the printing was going good, but this time the printing speed is set about 130% of the setup speed. Due to this, the deformation is slightly occurred in the side walls of the printing part. It is due to sudden cooling. To rectify this problem the printing speed should be high, to ensure that the other layer is printed fast before the previous layer get cooled or the room temperature in the room should be controlled. The photo of the printed part is shown in the figure.



**Figure 38 Newly printed part with thickness of 0.3 mm in HIPS**

## **7. IMPLEMENT OF FINAL SOLUTION**

From the possible solution, we got a more idea about the printing parameter of the materials in Rebel II printer. In each solution, some changes are done in printer and the materials are printed and the results are obtained. The materials are tested for the same design, so that it will be easy for the comparison of results. By comparing the printing parameters of the material and the quality and surface finish of the printed part and also by considering the life of the printer in future, the solution with new head in the printer is finalized to implement it to the printer for future printing process.

It is mainly chosen by comparing the quality of the printed part, which is a very important factor doing this project. This new printing head is finalized because, The old one was not able to print in the second extruder and the switching of extruder takes a long time than the new one and the material flow was not good enough due to push in the material was not with good force. For some material as they need an external force to extrude the material in a flow to print the print .But the new printing head was good in printing the parts without any problem and the result, the printing was good as expected.

## Conclusion:

**Aim of the Work:** Main aim of the work is to identify the printing parameters of the each and every material to print it in the Rebel II printer and to obtain the good quality of print. Were the parameters plays the vital role in printing process. If need also to make some necessary changes in the printer to obtain the good quality of print.

This thesis work presents the work of finding the exact printing parameters for the materials which is used to print in Rebel II printer using the Fused Layer manufacturing technology for obtaining the high quality of results. In research we identified the basic properties of the materials which we are using. Then we have decided to print the materials and check the quality of print, by printing the each material one by one with different parameters and checking the results. During the printing process initially we face some problems in the printer with the servo motor and the printing head. After considering all possible solutions, the better solution is implemented by changing the servomotor from MG996 to MG995. Though we change the servo we have some problem with the printing head, so the printing head is changed after considering all possible solutions. The materials are tested in the new head, by comparing the results of newly printed parts and the printed parts from the old one, by considering the quality of printed parts. We decided to implement the new printing head in the printer and the printing parameters are identified for the materials from which we can obtain a good and high quality of print. The printing parameters of the materials for obtaining the high quality of print are listed and tabulated below.

<b>Material</b>	<b>ABS</b>	<b>PLA</b>	<b>PVA</b>	<b>HIPS</b>
<b>Extrusion Temperature</b>	250	215	230	240
<b>Bed Temperature</b>	90	60	70	115
<b>Speed of the printing</b>	80	100	60 - 80	130 - 150

<b>Print Pattern</b>	Any(Line/ Rectlinear recommended)	Any	Hilbertcurve	line
<b>Print Thickness</b>	0.25mm	0.25mm	0.3mm	1 <sup>st</sup> layer 0.35mm  From 2 <sup>nd</sup> layer 0.3mm
<b>Material Setup</b>	ABS	PLA	ABS	ABS
<b>Cooling systems</b>	Not required	Not required	Required	Not required

## Reference

1. *Stratasys* [online]. [feeling. 2018-05-08]. Available from: <http://www.stratasys.com/legal/legal-information>
2. I, Gibson, Rosen DW, and Stucker B. *Additive Manufacturing Technologies* [online]. 2010 [cit. 2018-05-08]. ISBN 10.1007 / 978-1-4419-1120-9\_1.
3. D, Kochan. *Solid Free Manufacturing: Possibilities and Restrictions, Computer in Industries* [online]. 1992, 133-140 [cit. 2018-05-08].
4. PF, Jacobs. Stereolithography and other RP & M Technologies. : *Society of Manufacturing Engineer*[online]. pp. 29-35 [cit. 2018-05-08].
5. M., Durham. *Rapid Prototyping - (Stereolithography), Selective Laser Sintering, & Polyjet, Advanced Material and Processes* [online]. Vol. 161, 2003, 40-42 [cit. 2018-05-13].
6. MC, Leu, Zhang, and SUI. An Experimental Analytical Study of Part Fabrication with Rapid Freeze Prototyping. *An Experimental Analytical Study of Ice Part Fabrication with Rapid Freeze Prototyping*[online]. Vol 49. 147-150 [cit. 2018-05-13].
7. WF, Hug and Jacobs PF *Laser Technology Assessment for stereolithographic systems. In the second International Conference on Rapid Prototyping*, [online]. 1991, 23-26, 29-38. [ 2018-05-08].
8. <https://web.archive.org/web/20140203071900/https://thre3d.com/how-it-works/powder-bed-fusion/electron-beam-melting-ebm> [online]. 2014February [cit. 2018-05-13].
9. JC, Serbin, Pretsch W and Shellabear M. Stereos and Eosint. *New Development and State of Art* [online]. 1995 [cit. 2018-05-13]. Zbytečný citronový dort.
10. REPRAP. RepRap Forums [online]. 2016 [cit. 2018-05-08]. Available from: <http://forums.reprap.org/index.php>
11. TT, Wohlers. *Rapid Prototyping & Tooling State of Industry: Annual Global Progress Report. Wohlers Associates*, [online]. Detroit, M, 2009 [cit. 2018-05-08].
12. *Additive Manufacturing Process* [online]. [feeling. 2018-05-08]. Available from: <https://www.3dhubs.com/knowledge-base/additive-manufacturing-process#author>.
13. *Computer Laboratory* [online]. [2018-05-08]. Available from: <https://www.clexpert.com/default>.

14. *Computer Laboratory* [online]. [2018-05-08]. Available from: <https://www.clexpert.cz/3dtisk/rebel2/technicke-parametry.15>.
15. *Creative Mechanism* [online]. [2018-05-08]. Available from: <https://www.creativemechanisms.com/blog/learn-about-polylactic-acid-pla-prototypes>.
16. *3 D-Insider* [online]. [2018-05-08]. Available from: <http://3dinsider.com/pla-vs-abs-plastic-pros-cons/>.
17. *Creative Mechanism* [online]. [feeling. 2018-05-08]. Available from: <https://www.creativemechanisms.com/blog/everything-you-need-to-know-about-abs-plastic>.
18. J, Fomageau, Brusseau E, Vray D, Gimenez G, and Delachartre P ., *Characterization of PVA cryogel for Intervascular Ultrasound elasticity imaging*, [online]. 2003, 1318-1324 [cit. 2018-05-08].
19. AK, Van der Vegt and Govaert LE *Polymeren, van keten tot kunstof* [online]. 2005 [cit. 2018-05-08]. ISBN 9071301486.
20. L., Michael and Berins. *SPI Plastics Engineering Handbook of the Society of Plastics Industry* [online]. 5th. 2000 [cit. 2018-05-08].
21. Wolfgang. Griehl and Djavid. Rue. " *Nylon 12-Preparation, Properties and Applications* " [online]. Vol 22, 1970, 16-22 [cit. 2018-05-08].
22. Mark and James E. *Polymer Data Handbook* [online]. Oxford University Press, 1999 [cit. 2018-05-08]. ISBN 978-0195181012.

## Attachments

### Setup for Printing ABS

```
# generated by Slic3r
avoid_crossing_perimeters = 0
bed_shape = 0x0,200x0,200x200,0x200
bed_temperature = 100
before_layer_gcode =
bottom_solid_layers = 4
bridge_acceleration = 0
bridge_fan_speed = 100
bridge_flow_ratio = 1
bridge_speed = 60
brim_width = 0
complete_objects = 0
cooling = 0
default_acceleration = 0
disable_fan_first_layers = 1
dont_support_bridges = 1
duplicate_distance = 6
end_gcode = M104 S0 ; turn off temperature\nG28 X0 ; home X axis\nM84 ; disable
motors\nM140 S0 ; turn off bed temperature\n
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_offset = 0x0
extrusion_axis = E
extrusion_multiplier = 1
extrusion_width = 0
fan_always_on = 0
fan_below_layer_time = 60
filament_colour = #FFFFFF
filament_diameter = 1.75
fill_angle = 45
fill_density = 25%
fill_pattern = line
first_layer_acceleration = 0
first_layer_bed_temperature = 100
first_layer_extrusion_width = 200%
first_layer_height = 0.2
first_layer_speed = 20
```

```
first_layer_temperature = 230
gap_fill_speed = 60
gcode_arcs = 0
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 = 60
interface_shells = 0
layer_gcode =
layer_height = 0.2
max_fan_speed = 100
max_print_speed = 60
max_volumetric_speed = 0
min_fan_speed = 35
min_print_speed = 10
min_skirt_length = 0
notes = Konfiguracni soubor pro ABS, celokovovy hotend 1,75 mm, tryska 0,3 mm
nozzle_diameter = 0.3
octoprint_apikey =
octoprint_host =
only_retract_when_crossing_perimeters = 1
ooze_prevention = 0
output_filename_format = [input_filename_base].gcode
overhangs = 1
perimeter_acceleration = 0
perimeter_extruder = 1
perimeter_extrusion_width = 0
perimeter_speed = 60
perimeters = 3
post_process =
pressure_advance = 0
raft_layers = 0
resolution = 0
retract_before_travel = 2
retract_layer_change = 1
retract_length = 1
retract_length_toolchange = 10
retract_lift = 0
retract_restart_extra = 0
retract_restart_extra_toolchange = 0
retract_speed = 65
```

```

seam_position = random
skirt_distance = 5
skirt_height = 1
skirts = 3
slowdown_below_layer_time = 30
small_perimeter_speed = 50
solid_infill_below_area = 70
solid_infill_every_layers = 0
solid_infill_extruder = 1
solid_infill_extrusion_width = 0
solid_infill_speed = 50
spiral_vase = 0
standby_temperature_delta = -5
start_gcode = G21\nM190 S[first_layer_bed_temperature]\nG28\nG90\nG21\nG92
E0\nM82\nM109 S[first_layer_temperature]\nG92 E0\n
support_material = 0
support_material_angle = 0
support_material_contact_distance = 0.2
support_material_enforce_layers = 0
support_material_extruder = 1
support_material_extrusion_width = 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 = 60
support_material_threshold = 46
temperature = 230
thin_walls = 1
threads = 6
toolchange_gcode =
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
vibration_limit = 0
wipe = 0
xy_size_compensation = 0
z_offset = 0

```

## Setup for Printing PLA

```
# generated by Slic3r
avoid_crossing_perimeters = 0
bed_shape = 0x0,200x0,200x200,0x200
bed_temperature = 50
before_layer_gcode =
bottom_solid_layers = 3
bridge_acceleration = 0
bridge_fan_speed = 100
bridge_flow_ratio = 1
bridge_speed = 50
brim_width = 0
complete_objects = 0
cooling = 1
default_acceleration = 0
disable_fan_first_layers = 1
dont_support_bridges = 1
duplicate_distance = 6
end_gcode = M104 S0 ; turn off temperature\nG28 X0 ; home X axis\nM84 ; disable
motors\nM140 S0 ; turn off bed temperature\n
external_fill_pattern = rectilinear
external_perimeter_extrusion_width = 0
external_perimeter_speed = 40
external_perimeters_first = 0
extra_perimeters = 1
extruder_clearance_height = 20
extruder_clearance_radius = 20
extruder_offset = 0x0
extrusion_axis = E
extrusion_multiplier = 1
extrusion_width = 0
fan_always_on = 0
fan_below_layer_time = 60
filament_colour = #FFFFFF
filament_diameter = 1.75
fill_angle = 45
fill_density = 25%
fill_pattern = line
first_layer_acceleration = 0
first_layer_bed_temperature = 50
first_layer_extrusion_width = 200%
first_layer_height = 0.2
first_layer_speed = 20
first_layer_temperature = 200
gap_fill_speed = 50
gcode_arcs = 0
```

```
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_gcode =
layer_height = 0.2
max_fan_speed = 100
max_print_speed = 60
max_volumetric_speed = 0
min_fan_speed = 35
min_print_speed = 10
min_skirt_length = 0
notes = Vzorovy konfigurační soubor pro PLA, celokovovy hotend 1,75 mm, tryska 0,3
mm\n\nZahradnik se bavi Rebel 2\nhttp://www.zahradniksebavi.cz\n\nPetr
Zahradnik\nclexpert@clexpert.cz
nozzle_diameter = 0.3
octoprint_apikey =
octoprint_host =
only_retract_when_crossing_perimeters = 1
ooze_prevention = 0
output_filename_format = [input_filename_base].gcode
overhangs = 1
perimeter_acceleration = 0
perimeter_extruder = 1
perimeter_extrusion_width = 0
perimeter_speed = 50
perimeters = 3
post_process =
pressure_advance = 0
raft_layers = 0
resolution = 0
retract_before_travel = 2
retract_layer_change = 1
retract_length = 1
retract_length_toolchange = 10
retract_lift = 0
retract_restart_extra = 0
retract_restart_extra_toolchange = 0
retract_speed = 65
seam_position = random
```

```

skirt_distance = 5
skirt_height = 1
skirts = 3
slowdown_below_layer_time = 30
small_perimeter_speed = 40
solid_infill_below_area = 70
solid_infill_every_layers = 0
solid_infill_extruder = 1
solid_infill_extrusion_width = 0
solid_infill_speed = 40
spiral_vase = 0
standby_temperature_delta = -5
start_gcode      =      G21\nM190      S50\nG28\nG90\nG21\nG92      E0\nM82\nM109
S[first_layer_temperature]\nG92 E0\n
support_material = 0
support_material_angle = 0
support_material_contact_distance = 0.2
support_material_enforce_layers = 0
support_material_extruder = 1
support_material_extrusion_width = 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_threshold = 46
temperature = 200
thin_walls = 1
threads = 6
toolchange_gcode =
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
vibration_limit = 0
wipe = 0
xy_size_compensation = 0
z_offset = 0

```

