# INVESTIGATING THE EFFECT OF VAPOR SMOOTHING PROCESS ON VARIOUS PROPERTIES OF FDM BASED ABS REPLICAS

**DISSERTATION-II**

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**BY**

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## Abstract

In this research work, an effort has been made to study the influence of fused deposition modelling (FDM) and chemical vapour smoothing (CVS) process parameters. FDM (fused deposition modelling) is a RP (rapid prototyping) technique used to manufacture prototypes on additive manufacturing technology. It is the method of fabricating 3-D object directly from the CAD file by converting CAD to STL and the feeding to FDM machine set up. The material in FDM is withdraw from string of spool of material as well as support material which then passes through heating coil that are attached to a nozzle and material get deposited layer by layer. FDM draws attention of the customers towards itself due to its excellent results. The material used is ABS (acronitirile butadiene styrene) plastic. In this particular research there are certain things are highlighted they are surface roughness, dimensional deviation 1 & 2 by considering the effect of two process parameters such as orientation and speed. The CVS process reduces both the dimensions slightly due to reflow of the material. In the calculation part we have applied two methods i.e. Taguchi $\boldsymbol{L_9}$ orthogonal array and also the ANOVA. With this we have analysed the results. Perhaps CVS process dramatically improve the surface finish and also the quality of parts due to reflow of the ABS material, but some minor deviations in the dimensions of the component has been observed after the smoothing operations. SEM images confirms the reflow of the material which ultimately enhances the surface finishes of the fabricated parts. Similar to surface roughness, dimensional deviation was found to be highly influenced by the variation in orientation angle and smoothing time**.**

**ACKNOWLEDGEMENT**

I would like to express my deep sense of respect and gratitude towards my supervisor **MR.JASPREET SINGH,** who not only guided the dissertation work but also stood as a teacher and philosopher in realizing the imagination in pragmatic way; I want to thank him for introducing me for the field of optimization and giving the opportunity to work under him. His preserve and optimism have provided an invaluable influence on my career and outlook for the future. I consider it my good fortune to have got an opportunity to work with such a wonderful person. I am especially in debuted to my parents for their love, sacrifices and support. They are my teachers after I came to this world and have set great example for me about how to live, study and work. Last but not the least I would again like to express my sincere thanks to all the people who are supporting me by various ways.

**PRASENJEET SINGH**

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# CERTIFICATE

I hereby certify that the work being presented in the dissertation entitled "Investigating the effect of vapor smoothing process on various properties of FDM based ABS replicas" in partial fulfillment of the requirement of the award of the Degree of Master of Technology and submitted to the department of Mechanical Engineering of LPU, Phagwara is an authentic record of my own work carried out under the supervision of **Mr. JASPREET SINGH,** assistant professor department of mechanical engineering ,LPU. The matter embodied in this dissertation has not been submitted in part or full to any other university or institute for the award of any degree.

**DATE:** **PRASENJEET SINGH**

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**This is to certify that the above statement made by the candidate is correct to the best of my knowledge.**

**DATE:** **Jaspreet Singh**

**Jainderpreet Singh**

**(COD-MEC)**

**The external viva-voice examination of the student was held on successfully..............................**

**SIGNATURE OF EXAMINER**

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## NOMENCLATURE

- **RP-** Rapid Prototyping
- **STL-**Stereo-Lithography
- **FDM-** Fused deposition modelling
- **ABS-** Acrylonitrile butadiene styrene
- **CCD-** Central composite design
- **ANOVA-** Analysis of Variance
- **SLS-**Selective laser sintering
- **LOM-**Laminated Object Manufacturing
- **CVS-** Chemical vapors smoothing
- **CAD-**Computed aided design.
- **PP-**Polypropylene
- **PC-** Polycarbonate
- **STL-**Standard tessellation language.
- **SGC-** Solid ground curing.
- **CNC-** Computer numeric control
- **CAM-**Computer aided manufacturing
- **CSG-** Constructive solid geometry
- **DMLS-** Direct metal laser sintering

# CHAPTER 1: INTRODUCTION

In this fast moving era the ever-growing technology has opened the doors to the customization of the products. The rapid change in the technology has also made the customers inpatient as every now and then the new technology is far better than its former and making the manufacturing design and customization easy and in a quick time frame. The ancient times were dependent on the seller's will or capability, where due to the lack of technology only standard products were at sales. The hand tools lacked finishing accuracy and took greater time to finish all the processes to manufacturer the end product. But nowadays due to the competition sellers need to be diverse in their product offerings and in the delivery much faster than the other present in the market. The complexity in the design of the product has made the old trends extent from the industries as they lack the surface finish, reluctant to the change in the standard measures and took more time to fulfil the targeted orders. The processes could not supposedly handle even the minute changes in the design of the products and required a hectic iterations of the redesigning, analysing production and assembly before the due dates. For instance, a basic casting process which consume more time as we firstly needed to make the patterns then to wait for the casting to be completed and at last to examine the performance of the processes. The human hands were only tools available which requires the ample amount of time to process all the manufacturing activities. So all these represents an era with many demerits and which was not efficient to pull over the basic necessity with the rate at which it was required. The 21$^{st}$ century introduced a technology named as product prototyping to cope up with the fast changing manufacturing parameters and the demerits of the former technologies. Product definition simply means ‘‘figuring out what to make before making it”. A product definition is a layout of what the purpose of the product is, whom it is targeted toward, and how it will be built and manufactured. By reaching a definition for a product, not only has there been considerable customer interaction regarding the product, but many prototypes have already been completed to get the best possible design. Basically can be defined as the customization process which is highly effective in the customization and has revolutionized the global manufacturing to a greater extent because of the feasibility of complexity that offers. It basically comes under engineering design process which describe the process of manufacturing the parts by design. Likely by transferring the details or needs given by the customers in some of the design data to evaluate the parts. In the product prototyping the manufacturing of the parts need to know some useful points which is to be kept in mind while manufacturing the parts like:

1. Needs of Part.

2. Definition

3. Cost.

4. What affects does it make in the market?

5. Market demands.

6. Time to fabricate it.

Product prototyping was a very interesting method that explain the concept of concurrent engineering which says that before making a part just let's discuss about it. Then all the departmental engineers gather and give their views about the part which is to be manufactured. Will there be any problem in designing, feasibility and at last manufacturing of that? Most of the time was consumed in defining the product that how it will manufacture. What response it will have from the market, can be controlled by the market survey. There can also be technological issue like the industry using the old techniques or they are not using the skilled workers. Then came the cost factor, how much a new concept part will cost so for this.

## 1.1 Factors affecting RP

### 1.1.1. For Market Survey

(a) Go to customers and ask about their demands;

(b) Convert their demands to some useful data;

### 1.1.2 For Cost Factor

(a) Take cost from previously made parts; (b) Discuss with experts;

(c) Adding all small component's cost;

### 1.1.3 For Technological problem

(a) Check quality at specific time interval;

(b) Replace the outdated machinery;

(c) Hire the skilled workers.

But there were also a several problems like it can be manufactured for sure or we can say just for the sake of feasibility. [3] To overcome with these problems a scientist name as Joseph Condon developed a program with the name of Unix Circuit Design system in early 1970s to make the circuits more reluctant. This technology got advanced in 1980s.So this technology was later be named as Rapid prototyping (RP) which means to manufacture the products rapidly or within time. It is one of the helpful and profitable techniques for the coming generations for design and manufacturing. The concept of Rapid Prototyping is similar to the topographical views of a scientist named Joseph E Blanther in 1892 who mentioned about manufacturing process that can built a product or a mould layer by layer. And, with the advancements in the manufacturing technology has made this possible. Nowadays the global manufacturing industries are vastly utilizing RP and its variant techniques.

### 1.2 Rapid Prototyping

Rapid prototyping is the process of fabricating the parts using layered manufacturing techniques direct from CAD models by converting them to the “STL” format file (i.e. Standard Tessellation Language). It is the best technique used as compared to the conventional methods of manufacturing. In the past time the tools or the workpiece were made by hands. There were problems like time, accuracy and finish as well. Then the evaluation comes literally about making the product with die machines etc. But those products were also having some problems like surface finish, timing etc. Then come to the designing evaluation. People starts thinking about the product, they started brain storming. Then they start analysing the product before manufacturing it. As we can take the example of CNC machine which is the latest technology used to manufacture the workpiece. CNC is subtractive process in which the workpiece is to be machined under different processes. Firstly, it came with NC (i.e. Numerical Control introduces in 1949 by John Parsons [4].In which you will be controlling your tool with some numerical data which was then followed with CNC which means to control the numerical data with linking it to the computer. Then in 1959, there comes the concept of Xerox machine that is 2D printing which was based on the problem that needs to copy something, so there must be something which can save time as well as the work. After that the concept of photocopy in which the page is being scanned with laser which printed in a blank page. The first photocopier machine was made in 1938 by using static electricity, handkerchief, light and dry powder but hasn’t come to market till 1959 around 20 years later. Rapid prototyping is the combination of machining techniques to make model of a part or any assembly with the help of three dimensional computer aided designing (i.e. CAD). The company was found in 1986. It is also Named as layered manufacturing or solid manufacturing from design or computer aided manufacturing. [5] These models can be used for analysing as it is a visualizing machine for model that it will be worth to demand. Sometimes, it is used as main models for tools like investment castings. And sometimes for making the final parts which is use perhaps we don't use it as final product due to the poor accuracy. If the material is suitable for highly untwisted parts which can be made with the help of Rapid Prototyping technique. This is due to the nature of Rapid Prototyping. Rapid Prototyping is also known as tailored manufacturing process. Rapid Prototyping technique decreases the production time and allows to modify any changes in the design before the modelling of the final product.

### 1.3 Geometric Modelling and its various techniques

Geometric modelling is the technique to study two or three dimensional shapes with respect to their mathematical computations within a finite set of dimensions. It takes directly the input from CAD/CAM models and have the ability to explore the various aspects such as dimensions, of the models or shapes. This method categories the procedural and object oriented models and runs on an opaque algorithm which can exhibit the implicit sight of the model. The introduction of computer-controlled fabrication systems, especially that of Numerical Controlled machine tools some 40 years ago, created the need for electronic representation of product data. The first generation of computer-aided design tools were 2D drafting systems that electronically mirror the processes traditionally conducted by draftsmen in the drawing office. 2D geometrical models consist of graphical primitives such as lines, arcs, text, symbols, and other notations required to represent engineering drawings in an electronic format.

#### 1.3.1 Types of Geometric Modelling Techniques

#### (i) Wireframe Modelling

The word "wireframe" is related to the fact that one may imagine a wire that is bent to follow the object edges to generate a model. Model consists entirely of points, lines, arcs and circles, conics, and curves. Analogous to 2D geometrical models, wireframe models consist of graphical primitives defined in three-dimensional space. These models represent 3D design objects only with edges and vertices. Edges can be lines or curves. The construction of wireframe techniques is considered to be a lengthy and difficult process because of the amount of input data and command sequences needed to create can them. However, wire frame models be easily stored in engineering databases as only a small amount of computer memory is required and the data can be retrieved, edited or updated quickly. The main purpose of wire frame models is to support the creation of engineering documentation and also in some cases to serve as input data for finite element analysis. Using these models, various projections of the 3D object can be created by applying geometrical transformations to the graphical primitives. Wireframe models do not contain surface and volume data, which makes them unsuitable for RP purposes. In general, wire frame modelling techniques are considered natural extensions of traditional drafting methods**.**

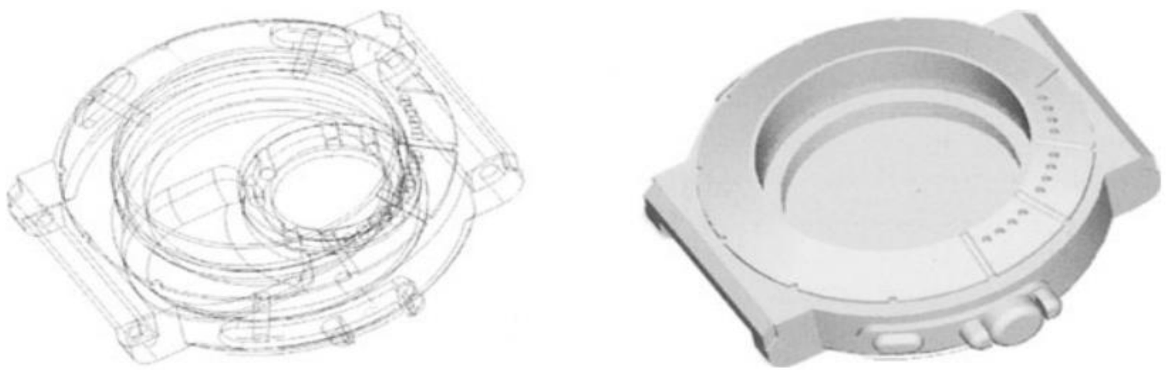

**Fig. 1.1** Wire Frame and Solid Models of a Watch **[6]**

**(ii)Surface Modelling**

**Surface models are more complete and less ambiguous representations than their wire frame counterparts. Their geometrical databases are richer and provide information on surfaces connecting model edges. This data is sufficient for generating cutter paths for NC machining and therefore most CAM systems are based on this representation technique. Unfortunately, surface models define only the geometry of objects, do not store any information about their topology and can only be regarded as a set of surfaces belonging to one object. Thus, if one edge is common to two surfaces this information is not stored in the model. This leads to the existence of gaps between the surfaces which means that surface models cannot define closed volumes. To use surface models for RP purposes, these gaps must be removed, which can be very difficult or even impossible. A surface model is a set of faces. A surface model consist of wireframe entities that form the basis to create surface entities.**

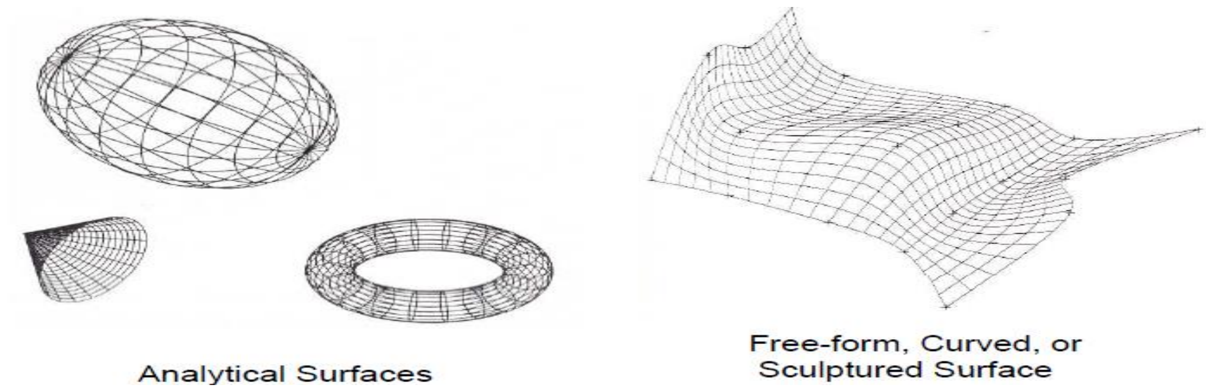


**Fig 1.2** Depiction of Surface Modelling Technique**.[6]**

(iii) Solid Modelling

The definition of models in solid modelling is easier than with the other two modelling techniques. Minimal input data is required and command sequences are much simpler. Solid modelling stores many details of the model and hence needs more space to store the data. However today computer are fast and with large memory, thus solid modelling is extensively used. The benefits of solid modelling include better visualization with greater detail, ability to perform engineering analysis and computer simulation, and effective transfer of data between different software's. Most Solid Modelling packages support a Constructive Solid Geometry (CSG) user input. This user interface allows complex objects to be built from a set of predefined 3D primitives. These primitives can be either simple basic shapes such as planes, cylinders, cones, spheres, etc. or more complex solid objects created by sweeping 2D sections of wire frame entities. To define a solid model, such primitives are combined using the Boolean operations of union, intersection and difference. Solid models provide a complete and unambiguous representation of objects. The completeness and unambiguity of these models are due to the information stored in their databases. After a part is constructed, the solid modeler converts the input into a data structure which maintains the geometry and topology of the object. In contrast to both wire frame and surface models that store only geometrical data, solid modelling databases are complete and the models are very easy to verify. It is widespread use was made possible by the large increase in computing power to cost ratio over the last 10 years. Solid modelling is now considered the most reliable way of creating 3D models for RP purposes.

### 1.4 Classification of Rapid Prototyping Processes

Rapid prototyping is the 3D modelling process with a capability to generate and extract the appearance of the model using the mathematical coordinates in the drawing space. Physical models of parts produced from CAD data files can be manufactured in a matter of hours and allow the rapid evaluation of manufacturability and design effectiveness. In this way, rapid prototyping serves as an important tool for visualization and concept verification. Now, there are various kinds of processes through which the prototypes can be generated which are described in the below sub-sections.

#### 1.4.1. Subtractive Prototyping

Making a prototype traditionally has involved a series of processes using a variety of tooling and machines. This approaches requires skilled operators using material removal by machining and finishing operators until the prototype is completed. To speed up the process ,subtractive processes increasingly used computer based technologies such as computer based drafting, manufacturing software for planning operations to produce the desired shapes, and computer numerical control machinery . For the purpose of the shape verifications a soft polymer or wax is used in order to reduced or avoid any machining difficulties.

#### 1.4.2 Additive Prototyping

Additive rapid- prototyping operations all build parts in layers. All of the processes to be described build parts slice by slice. The main difference between the various additive processes lies in the method of producing the individual slices, which are typically 0.1 to .5mm thick and can be thicker for some systems. All additive operations require elaborate (complicated) software. The first step is to obtain a CAD file description of the part. The computer then constructs slices of the 3D part. Each slice is analysed separately and a set of instructions is compiled in order to provide the RP machine with detailed information regarding the manufacture of the part.

**<u>Additive Processes: RP technologies</u>**

| <u>Prototyping technologies</u> | <u>Base materials</u> |
|---|---|
| Selective laser sintering (SLS) | Thermoplastics, metals powder. |
| Direct metal laser sintering (DMLS) | almost any alloy metals. |

| | |
|---|---|
| Fused deposition modelling (FDM) | Thermoplastics, eutectic metals |
| Stereo lithography (SLA) | Photopolymer |
| Laminated object manufacturing (LOM) | papers |
| Electron beam melting (EBM) | Titanium, alloys |
| 3D printing (3DP) | various materials. |

### 1.4.3 Virtual Prototyping

In this type, of RP process it uses visualization technologies which is based on advance computer techniques.

## 1.5 Rapid Prototyping are classified as different categories

(a) Liquid Based rapid prototyping

In this RP process we will initiative the liquid in mostly all the process which can cure easily and quickly. This particular process mainly contains the liquid which is heat at the desired temperature then we use the liquid and then convert into the solid part which is then further proceed for the post processing. The example of this method are SLA.

(b) Solid based rapid prototyping

In this particular RP process, the material state should be in the solid state. It means the Material is in the form of wire, laminates, and rolls. The important thing is to keep in Mind that the solids based sustain the materials to transfer into the solids phase.

The example of this process are FDM, SLS and basically my work is based on the FDM.

(c) Powder based prototyping

Basically in this type of prototyping we use power, now whatever the powder we use whether it is a material or a metal it is then heat up. After heating it is sintered for making the mould pattern. With this sintering process is being introduced in powder based RP methods. Powder looks as the grain size. Example of this process is LOM.

### 1.6 The Rapid prototyping process steps are followed as

1. A design of model is created is a design software like (CAD, Pro-e, Auto-cad, Catia).

2. Part is then converted into. STL (Standard Tessellation Language) format**.**
3. The resolution or the thickness of the slice of design made is to be kept minimum to avoid

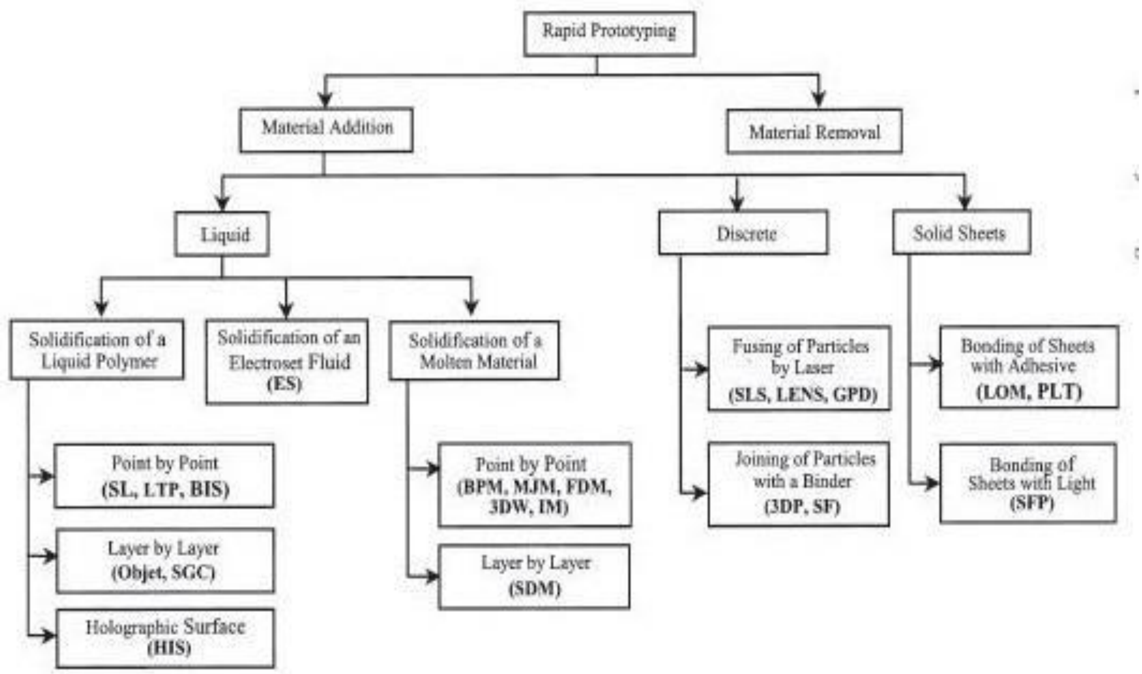


Fig 1.3 A Flow chart of RP Processes based on different phase of materials **(Kruth, 1991)**

**stair stepping or else it will make the surface very rough.**
**4. Prototyping machine load the STL file received and process it.**
**5. Selecting layer thickness of the part or assembly.**
**6. Machine will make the workpiece by layer in repetitive process means in layer after layer up to its thickness.**
**7. The part is removed from the machine and also the supports. And cleaning and finishing of the model will be done.**
**As explained above in the process steps that how will the process of any RP will be done. The steps of the rapid prototyping can be further divided into different variations they are as follows:**

CAD modelling: - **It can be done in many ways or can say there are many methods of doing a modelling of a part or assembly for example, SOLIDWORKS, CATIA (by Dassault System), and AUTOCAD (by Autodesk), CREO PARAMETRIC (by PTC), 3-D CAD also these processes are user friendly means which a person can easily to access.**

**9. Create the CAD file using anyone of these software and save the file as**"STL format" **which follow different steps for different software like: -**

**In CATIA, it is selecting the "STL" format command. Giving layer thickness then putting the file name and then click OK.**

**Similarly in SOLIDWORKS 2012 or later, save the file as "STL" file after making the CAD model. Then click the option and select the box in which it is mentioned save in to one file if it has its assembly. And also the operator can save in small deviation with which it will provide output as finer tessellation and in small angle deviation which gives an outcome in form of greater accuracy and considerable in little details. Similarly, the other software can convert the cad file to "STL" format. [10 Tong me et al.1997] purposed a study of the RPT process that we convert CAD file to the "STL" format to manufacture the desired part. They showed its disadvantage that this format is nearly ok but the format is not robust to use. So they explained some neutral formats that can be used in the RP as to slice the part's model like IGES method, STEP method, CT data (for medical applications) or by using HP/GL file. They described some new method that can be used in place of tessellation language that are RPI (Rapid Prototyping interface), CLI (common layer interface), SLC (Slice format) and LEAF (layer exchange ASCII format) so these are some of the reputed or we can say that standard software where we can perform the experiments under this technology.**

1.7 Rapid Prototyping Processes

**There are so many RP processes which are using for fabrication purposes, but the first technique which was introduced by the RP.**

1.7.1 Stereo-lithography **(SLA): SLA is one of the technique of RPT which is used for finding out the three dimension system in Valencia, USA.Since this process of RP method was just the initiation but it becomes the revolution in the world in terms of manufacturing. Once this process is being introduced people start using this process and they realized that it is very reliable process which take less time to perform. With this process a person can make any complex kind of prototype in less interval of time. Even many of the researchers have worked on this using this particular process and many more**

**are doing on this process like Raju BS worked on the SLA method and found that complex shapes also give good surface finish using this method. Further a researcher can modifies the parameters and work on this particular technique.**

Applications of SLA techniques

**(i) Patterns are used for investment casting, sand casting and modelling.**

**(ii) Prototypes which are used for design analysis, verifications and functional testing.**

**(iii) Tools are used in raft number for fixtures, tool design and also for the production tooling.**

**(iv) Models which are used for conceptualization, packaging and presentation.**

Advantages of SLA process

**(i) The computerized process serves as good user support.**

**(ii) The SLA also has a good accuracy while performing it.**

**(iii) The SLA can also obtain one of the best surface finish amongst all the best RP techniques.**

**(iv) There is a wide range of materials from the general purpose materials to speciality materials for specific applications.**

**(v) The SLA can be used continuously.**

Disadvantages of SLA Process

**(i) It requires support structures.**

**(ii) It also requires post-processing.**

**(iii) Also post-curing to cure the objects completely and also ensure the integrity of the structure.**

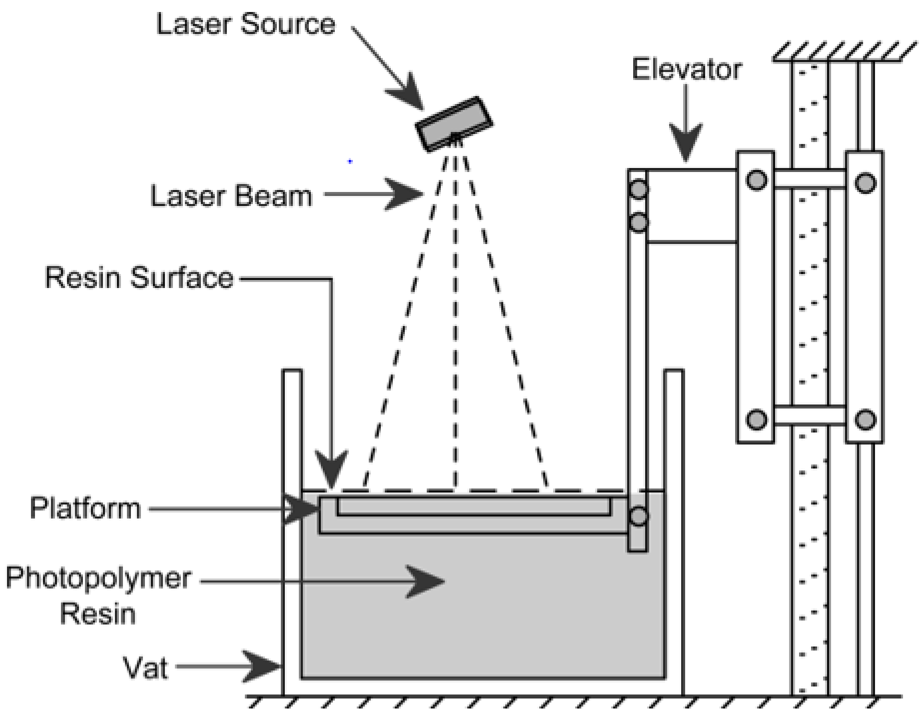


Fig 1.4 **Stereo Lithography Process [7]**

1.7.2 Selective Laser Sintering (SLS): **If we see the history of SLS process it is not that old and it is produced by the DARPA and this particular process is being patent under Dr.Carl Deckard in early 1980s. It is basically a layer manufacturing process in which a layer is being formed with the help of laser scanner.SLS process used CO2 as the main heat source to melt the material. Similarly many researchers worked on this and many more are working on this particular process.**

**The SLS process is based on the following two principles they are:**

**(a) The parts which are built by sintering which has a CO2 laser beams hits a thin layered of powdered material. The interaction of these layer beams with the powder raises the temperature to the point of melting ,resulting in the particle bonding ,fused the particles to themselves and the previous layer to form a solid.**

**(b) The building of the part is done layer by layer. Each layer of the building process contains the cross sections of one or many parts. The next layer then is built directly on top of the sintered layer.**

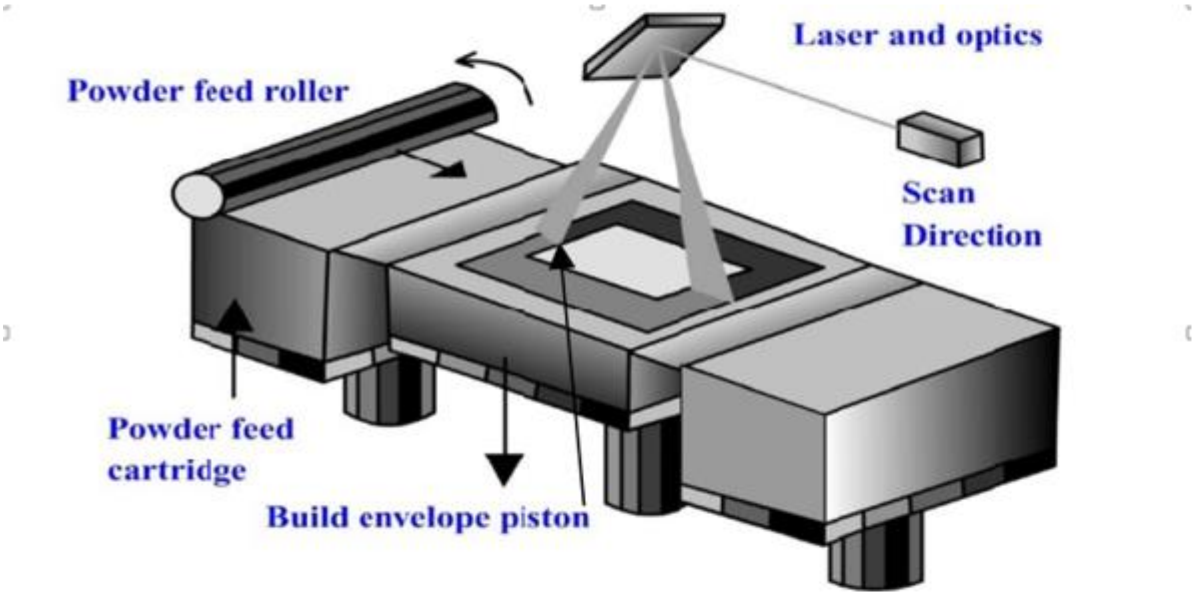


Fig 1.5 **Schematic of the Selective Laser Sintering Process [8]**

Applications of SLS

**(i) The process utilizes a concept models.**

**(ii) The parts which can withstand has a limited functional testing or fit that can operate within an assembly.**

Advantages of SLS Process

**(i) This process has a good part stability.**

**(ii) This process has ability to use wide range of processing materials.**

**(iv) This process needs a little post-processing.**

Disadvantages of SLS Process

**(i) This process has a large physical size.**

**(ii) It has a poor surface finish while performing it.**

**(iii) It also has the high power consumption.**

**The materials which we are using this process are thermoplastics, composites, metals and ceramics.**

1.7.3 3 D Powder Based: **In this particular system, in order to build a part, the machine spreads a single layer of powder onto the movable bottom of a build box. A binder is then printed each layer by layer of powder to form the shape of the cross-section of the model. The bottom of the build box is then lowered by one layer thickness and a new layer of**

**powder is spread into it. This particular of process is repeated for every layer or cross-section of the model.**

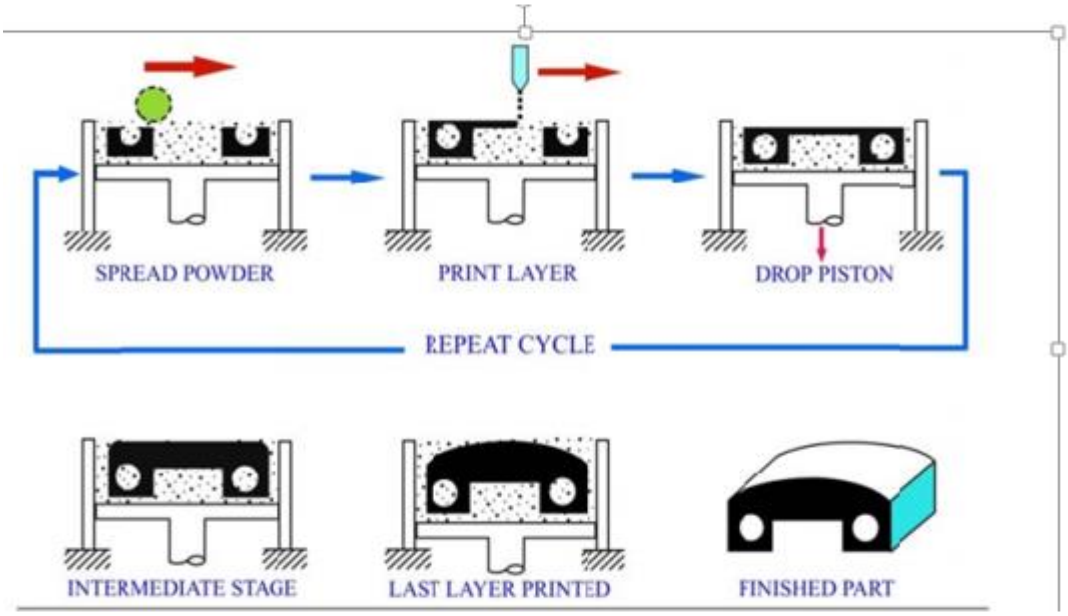


Fig 1.6 **Schematic of the 3 D Systems [9]**

1.7.3.1 Laminated Object Manufacturing**: If we talk about the history of this process it was originally developed by Helisys Corporation in 1985, but the first machine which was shipped was later on the year of 1991. In this particular technology, the objects are built by gluing profiled pieces of paper, plastics or we can say another web material in a proper layered manner. The paper which was used has its own surface coated with the plastics coatings that melts when it is heated. This particular technique is suitable for producing parts from the laminated papers, plastics, metals etc. The setup of this process is shown below. According to the set up a laser beam cuts the contour of part cross section. Several such sections when glued or welded yield the prototype. The layers are built up by pulling a long, thin sheet of pre-glued material across the base plate and fixing it in place with a heated roller that activates the glue. Then a laser beam is scanned over the surface and cuts out the outline of that layer of the object. The laser intensity is set at just the level needed to cut through a single layer of material. Then the rest of the paper is cross hatched to make it easier to break away later. The base plate moves down, and the whole process starts again. The sheet of material is made significantly wider than the base plate, so when the base plate moves down, it leaves a neat rectangular whole behind. This scrap material is wound onto a second roller, pulling a new section across the base plate. At the**

**end of the build process, the little crosshatched columns are broken away to free the objects. The material used is usually paper, though acrylic plastic sheet, ceramic felts can be used. The LOM is particularly suitable for large models.**

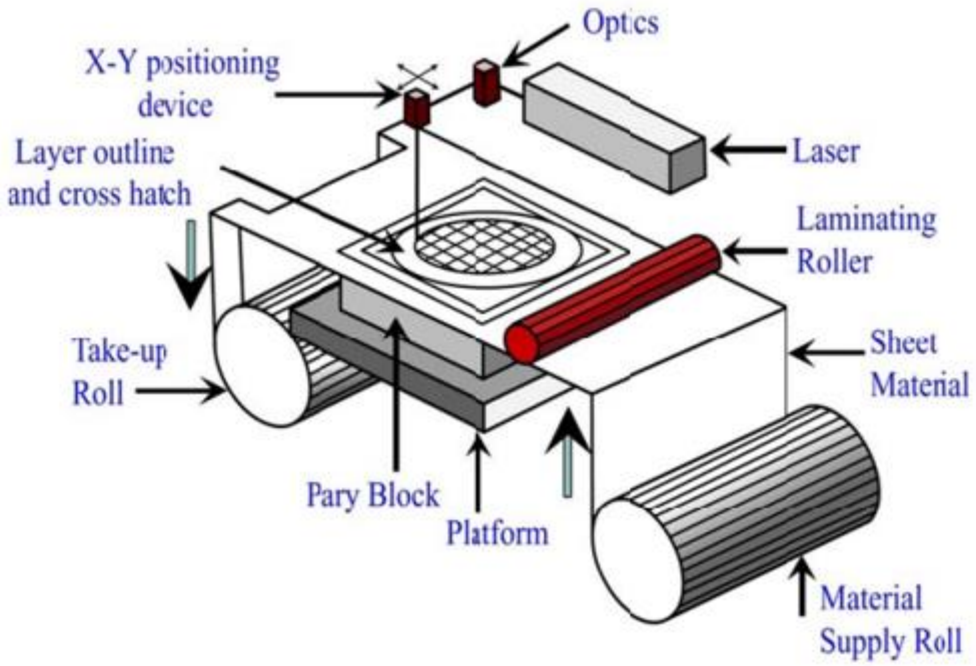


Fig 1.7 **Schematic of Laminated Object Manufacturing Set Up in RPT [10]**

Advantages of Laminated Object manufacturing (LOM)

**(i) Low cost due to readily available raw material.**

**(ii) Paper models have wood like characteristics, and may be worked and finished accordingly.**

**(iii) Dimensional accuracy is slightly less than that of SLA and SLS but no milling step is necessary.**

**(iv) Relatively large parts may be made, because no chemical reaction is necessary.**

1.7.3.2 Solid Ground Curing (SGC): **The Solid Ground Curing (SGC) system is developed and commercialized by Cubial Ltd, Israel in 1991. This process has the advantages of curing the entire layer of a photo- curable resin at a time, which overcomes the speed limitation of SLA, where a point of energy source is used for curing. SGC uses several kinds of liquid and cured resins to create objects. A water soluble wax is used to create support structures and ionographic solids tones are used to create can erasable image of the computer- generated cross section on a glass mask. SGC consists of two main steps namely mask generation and layer fabrication, which are repeated a number of times to**

**complete the part. In the mask generation step, the first cross- sectional image of the part is generated on a transparent substrate (glass mask) by ionographic printing process, a technique similar to photocopying. The image is formed by depositing a black electrostatic toner that adheres to the ion charged portions of the substrate. This is used to mask the uniform illumination of the collimated UV lamps. Cubital's RP technology creates highly physicals models directly from computerized three- dimensional data files. Parts of any geometric complexity can be produced without tools, dies or moulds by Cubital's RP technology. The Cubital's SGC process includes three includes three main steps such as data preparation, mask generation and model making. In this first step, the CAD model of the job to be prototyped is prepared and the cross sections are generated digitally and transferred to the mask generator. The software used are Cubital's Soldier DFE (Data Front End) software. DFE accepts CAD files in the STL format.**

Various Stages of the SGC Process

**(a) The layer fabrication stage starts with spraying a photo sensitive resin on the build platform as it passes under the resin application station.**

**(b) Then the build platform is transferred to the UV light curing station, where the photo mask from the mask generator is placed above the build platform and aligned under the UV light.**

**(c) A shutter is opened allowing the photosensitive resin layer to be exposed to UV light through the photo mask.**

**(d) When UV light is passed through this glass mask onto the liquid resins, the resin is polymerized wherever light is allowed to pass.**

**(e) The surrounding unexposed resin remains liquid, which is removed using a vacuum. The glass mask is cleaned and a new mask is generated on the plate for the next layer.**

**(f) Molten wax is spread into the empty space created after collecting the unsolidified resin and the wax is solidified under a cooling plate.**

**(g) Then the surface of the layer is mile to its exact thickness, this step also produces a roughened surface of cured photopolymer, assisting adhesion of the next layer to it.**

**(h) A new layer of photopolymer is then applied to this mile surface and the cycle is repeated until the object is completely formed within a wax matrix.**

Advantages of SGC Process

**(i) As each layer surface is mile before generating a new layer, the SGC process facilitates a high degree of accuracy in the Z direction.**

**(ii) The process is self-supporting and does not require external support structures as continuous structural support for the parts is provided by the wax. The supporting wax is melted away or dissolved during post processing.**

**(iii) In contrast to SLA, the SGC process is considered a high capacity production process and the high capacity is achieved by hardening each layer of the photosensitive resin at once.**

**(iv) Multiple parts can be created simultaneously on the sample platform because of the large work space and the milling step maintains vertical accuracy.**

**(v) It is a time and cost saving process. Its production costs can be 25 % to 50% lower.**

**(vi) Because the parts are completely cured during the build process itself no post curing is necessary and associated shrinkage, warping and curling problems are completely eliminated in SGC.**

Disadvantages of the SGC Process

**(i) Requires large physical space. The size of the system is much larger than other systems with a similar build volume size.**

**(ii) Wax gets stuck in corners and crevices. It is difficult to remove wax from parts with intricate geometry. Thus, some wax may be left behind.**

**(iii) Waste material produced. The milling process creates shavings, which have to be cleaned from the machine.**

**(iv) Noisy: The Soldier SGC system generates a high level of noise as compared to other systems.**

**(v) The process lacks widespread market acceptance because of complex nature of the process requiring skilled workers to monitor.**

**(vi) However, the benefits of this process have been utilized in other photo polymerization processes by simplifying the fabrication procedures.**

**(vii) Once such process is Object's Polyjet process- a hybrid of material printing and stereo lithography, developed by Object geometries, Inc, Israel.**

Application of the SGC Process

**(i) Conceptual design presentation, design proofing, engineering testing, integration and fitting, functional analysis, exhibitions and pre-production sales, market research and inter- professional communication.**
**(ii) Tooling and Casting applications: In this particular investment casting, sand casting and rapid, tool- free manufacturing of plastic parts takes place.**
**(iii) Mold and Tooling: Silicon rubber tooling, epoxy tooling, spray metal tooling and plaster mould casting takes place.**
**(iv) Medical imaging: In this diagnostic, surgical, operations and reconstruction planning and custom prosthesis design are considered.**

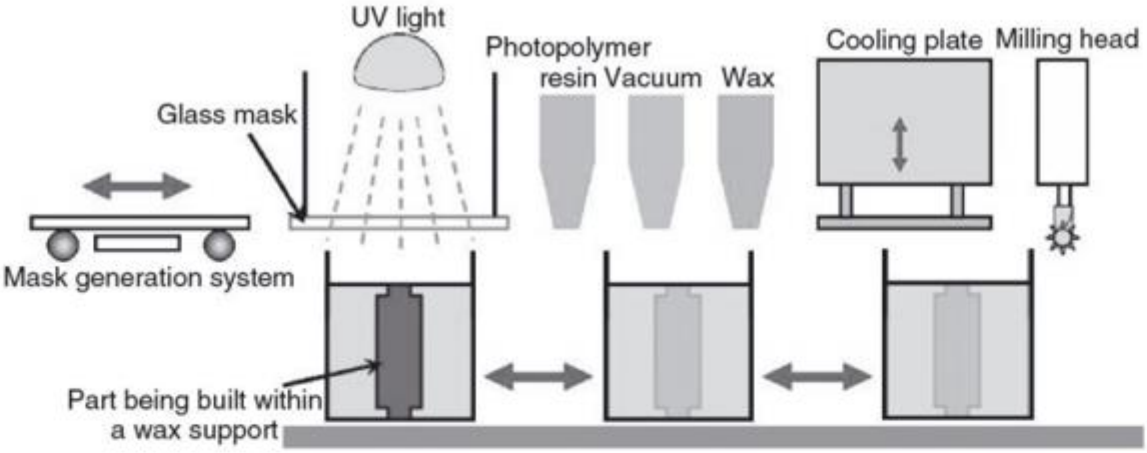


Fig 1.8 **Various stages of the SGC Process [15]**

1.7.4 Fused Deposition Modelling: **Fused deposition modelling is a RPT technique used to build the model layer by layer. This technology was developed by Scott Crump in the late 1980s and was used in 1990 by Stratasys Inc. (USA).Sometime it is also know with the name of Plastic jet Printing (PJP).To with stand in the market every company wants that the product can be produced at minimum time with minimum cost. And this is the reason where FDM is introduced which combines sub -assemblies into single function assembly at CAD.Comercially we are using ABS with grade of P400 with this we make the pattern using the machine. Generally stratasys software is used in FDM machine so that it can automatically make the mould of the product. What this particular software it changes the 3D file into 2 D and its subparts .Now the basic parts of FDM machine consists of drive wheel, a heater and liquefier, a tip, a platform and a piston. Specially the nozzle has this mechanism which allows the flow of melted material to be turned on and off .This**

**particular whole system contained within a heated environment so that the amount of energy can be reduced which is needed to melt the filament at the nozzle.FDM is commonly used for prototyping and rapid manufacturing rapid prototyping which gives iterative testing and also very short run. It is therefore relatively inexpensive.**

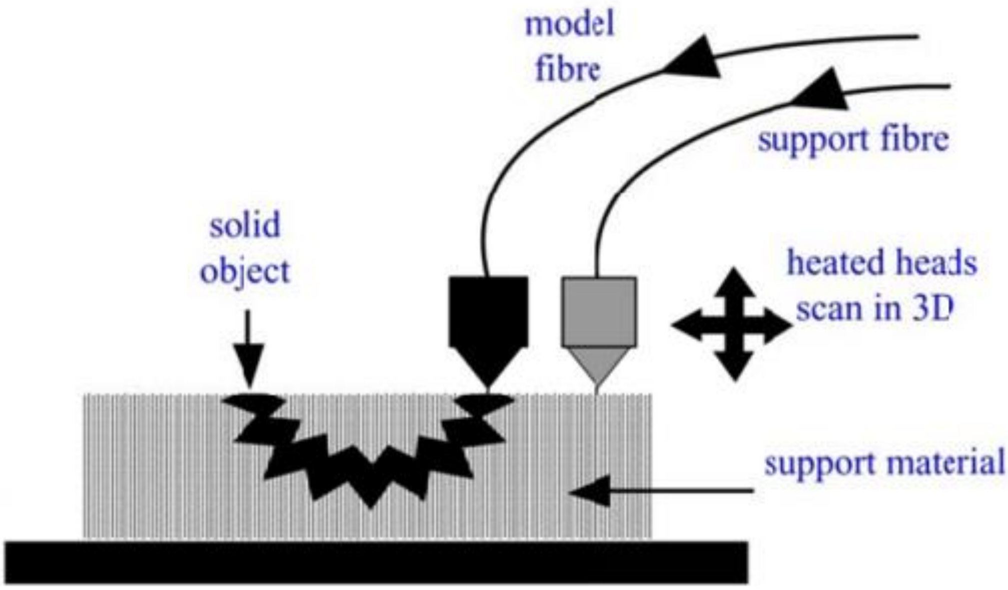


Fig 1.9 **Schematic of the Fused Deposition Process [17]**

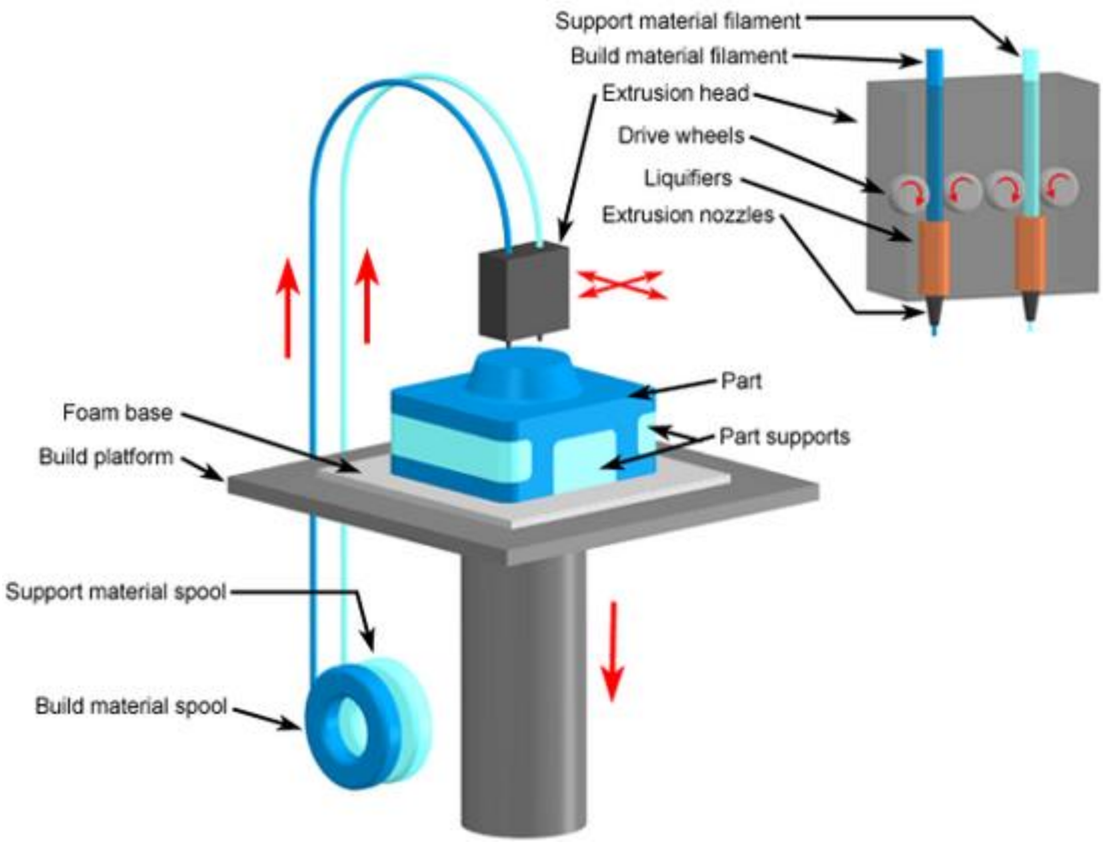

Fig 1.10 **Set of Fused Deposition Modelling [17]**

1.7.4.1 Material Used in Fused Deposition Modelling

**The various type of materials which can be used in this process are ABS, ABSi, PPSF, PC and ULTEM 9085 etc. The reason why these materials only used because these materials are heat resistance. But out of these materials ABS is only the material which is one of the best material and widely used as an alternative for conventional wax pattern tooling. Fused deposition modelling has a disadvantage that build time is slow for some of the products. Apart from this some model has a very poor layer to layer adhesion and can't be as tight as water for the points that come in contact with other liquid layers. Fused deposition modelling is growing very rapidly in day to day life due to its excellent results. It also saves time to make a product and also the printing time which depends on the size of the object being manufactured. The small objects which is just a few cubic inches in shape made earlier than a larger one which take more time to implement which is likely to gets its geometric complexity of the print. The problem in fused deposition modelling is in its surface finish and accuracy which are poorer than the normal machining time, but it also made the complex shapes in comparison to the CNC machining and also earlier than CNC which gives good view in the field of market. In Fused deposition modelling, no programming is done it is like CNC machine in which we have to design and make the prototype by using the software. The main problem is in slicing (choosing slice height) which has a direct effect on surface finish and build time. Slice height is depending upon fused deposition modelling machine, tip size and material used. Fused deposition modelling has more qualities like it is very simple to use, safe and there will be no waste of material due to extrusion process and it is very true and reliable to perform. It can easily make different build styles by changing some parameters like raster width and angle, air gaps etc. It is very easy to remove its support, and also it is having potential to hold different materials like polymers and composites. As the material processed in spool or cartridge therefore it is very easy to change the material. The problem in fused deposition modelling is only in its surface finish due to round shape of the bead deposited which makes the surface curved and have surface finish of having grains which make trouble of doing it. Build time is very high to maintain its speed because the material which is depositing on layer by layer by a single extrusion nozzle to make each layer and redefining the part of the model. More viscous will be the material more will be the**

**restriction in the flow rate of material which also increases the build time. Apart from this orientation of the model plays a vital role on worktable which makes the effect to mechanical strength of model in different build of orientations. We will be observing the different process parameters like slice height (thickness of layer on which the STL is cut for model building), tip size (size of opening of extrusion nozzle), build temperature (temperature of the building material which is coming through heat coils of the nozzle to maintain the viscosity of materials), raster width, raster angle (angle of path of material with x-axis), air gap, interior style and part fill style (pattern or path of tool bead made by nozzle on work model surface). When the object manufactured take out of the printer its supporting material is then removed from the surface of prototype by dipping it in water or any detergent solution. Just in case of thermoplastic supportive material it is then removed by hands.**

Advantages of Fused Deposition Modelling

**(i) Safe, simple and easy to use: In this fused deposition modelling process it is easy to use for safe mass production, eco-friendly and also the material plays a vital role with its simplicity for using on large numbers with no harm, apart from this heating factor and laser are also being used.**

**(ii) No wastage of material: Perhaps there is a melting of material through heating coil which is deposited on the work table. The material remained unchanged after when the model is being created using the melting of that particular material. So, this particular machine estimates the time to build before the processing of the model takes place and also the material quality.**

**(iii) It has a different build style in the FDM process as we can use different types of build style which is being used in step by step layer by changing the process with using the different variables like fill pattern, raster width, air gaps, and raster angle now the user can use the internal layer solid and filled.**

**(iv) This is having a very easy to support the removal material in FDM products which are made up of generally thermoplastics in which there is a support and can also be removed very easily with hands. It can also be removed with water jets and also by water work soluble support system which make easier for the operator to remove the support.**

**(v) It has a new material handling potential ability. In FDM, there is a good property to use the new material in an easy way. It also can add any of the material like ceramic**

**polymer composites etc. Apart of this it also has a good potential ability to change the parameters for a new material to get optimum results.**

**(vi) Fused deposition modelling uses different polymer materials like ABS, PC, and PPSU/PPSF etc. All these material has a good strength, good mechanical properties and thermal properties too.**

**(vi) It can easily change the material in fused deposition modelling machine as it uses the different cartridge for feedstock filament which require minimum efforts to remove the previous material to replace with the new one.**

Disadvantages of Fused Deposition Modelling

**(i) FDM process has a bad surface finish while manufacturing the prototype using the extrusion nozzle which makes the prototype layer by layer.**

**(ii) It also has a poor accuracy due to layer by layer manufacturing through the nozzles of the machine.**

**(iii) Fused deposition modelling process makes parts large as well as small, but while making the large parts it takes more time to build the parts because of which it has some limitations on the FDM.**

**(iv) FDM process can make the build direction while manufacturing into different directions or in different orientations due to which it has poor mechanical strength.**

1.8 Fused Deposition Modelling consists of the following steps

**(i) Create a CAD model of the design.**

**(ii) Convert the CAD model to STL format.**

**(iii) Slice the STL file into the thin cross sectional.**

**(iv) Construct the model one layer a top another.**

**(v) Clean and finish the model.**

**These are the steps which are being followed while working on the FDM. The most common printing material for FDM is Acrylonitrile-butadiene styrene (ABS), and a common thermoplastic that is used to make many consumer products. Fused deposition modelling**

**Uses mostly thermoplastic due the environmental stability along with the fact that the part does not change with conditions like room temperature and time. Along with this ABS, and some FDM machines also do print in other thermoplastics, like polycarbonate**

**(PC) or poly-etherimide (PEI). Support materials are usually water-soluble wax or brittle thermoplastics, like polyphenylsulfone (PPSF).**

## 1.9 Properties of Material

**(a) ABS (ACRYLONITRILE-BUTADIENE-STYRENE): This is recyclable thermoplastic which has a very good fluidic properties, high impact resistance, very good thermal resistivity, and also flame opponent (retardant), which can withstand with rough handling.**

**(b) PC (POLYCARBONATE): It has a good high impact strength, stability and heat resistant.**

**(c) PC-ABS (POLYCARBONATE) THERMOPLASTIC: It has very good mechanical properties, heat resistance and very high impact strength.**

**(d) PPSF/PPSU (POLYPHENYL-SULFONE): It has a capability of heat resistive, high chemical resistance, sterilization is possible with ethylene oxide**

**(e) PC-ISO THERMOPLASTIC: It is having good material for medical applications, best choice for high strength requirement product.**

**(f) PCL (POLYCAPROLACTONE): It is biodegradable and also used for tissue work.**

**(g) FDM THERMOPLASTIC MATERIAL (ULTEM-9085) [A Bagsik et al. 2011]: This Material has been developed for aerospace and marine application and also having flame resistive properties which has a good performance of thermoplastic, high heat deflection temperature, high strength/weight ratio. They have purposed paper explaining of the fused deposition modelling technique with changing some of the parameters. They have evaluated the dimensional deviation in the parts of fabricated and also studied the effect of the angle on which the part is being fabricated. Some advanced materials in present world has many advanced materials which are being used in FDM like silicon nitrate.**

## 1.10 Chemical Vapour Smoothing (CVS)

**CVS is the process of smoothing the part surface of ABS 3-D printed products with using Acetone Vapour bath. The acetone will be kept at temperature of around 70-80º C. At this temperature the acetone starts vaporizing. Vapour formed will start rising towards outside where the fabricated part is being attached the vapours which strikes the surface of the parts. The roughness which was in the form of stair case will be melted due to the vaporization.. The product roughness is now eliminated and the surface of the fabricated**

**part is highly smoothed as compared to the initial part. Acetone vapour bath can also be applied on the materials like PC, Poly-sulfone, and Acrylic etc.**

1.10.1 Properties of ACETONE: - **Acetone is chemically formulated as [(CH3)2CO]. It has good solvent properties and also can evaporate very easily. The main merit about acetone is that it affects the plastic parts as it can dissolve with them. When ABS gets the environment of acetone vapours the surface of ABS get dissolved and gives a very clean and shiny surface.**

Fig 1.11 **Parts before and after CVS [S.Desai et al]**

1.11 RP process tooling method based on manufacturing

**(i) Direct Method of RP process.**

**(ii) Indirect Method of RP process.**

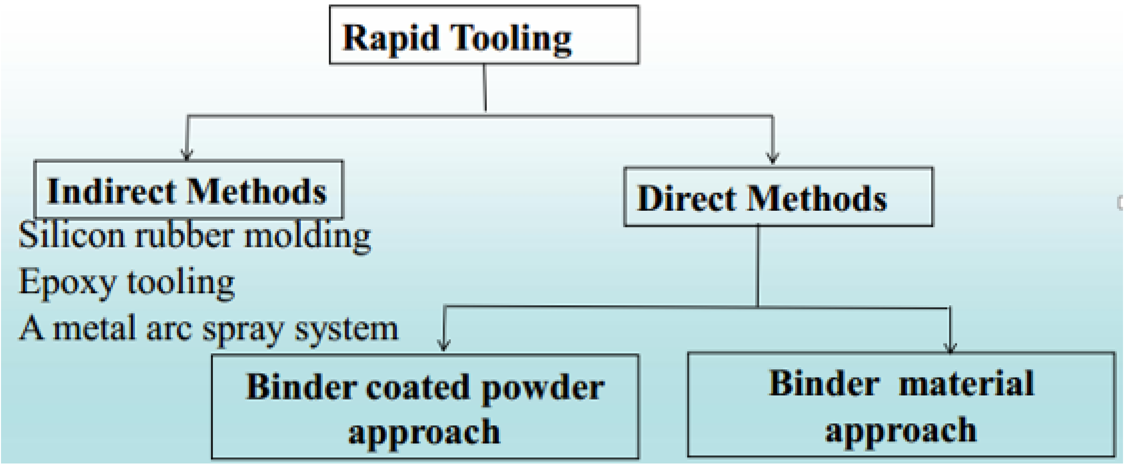


Fig 1.12 **Classification of Rapid tooling [19]**

**Direct Tooling: It is referred to when the tool or die is created directly by the RP process. As an example in the case of injection moulding, the main cavity and cores, runner, gating and ejection systems, can be produced directly using the RP process.**

**Indirect Tooling: On the other hand, only the master pattern is created using the RP process. A mould, made of silicon rubber, epoxy resin, low melting point metal or ceramic is then created from the master pattern.**

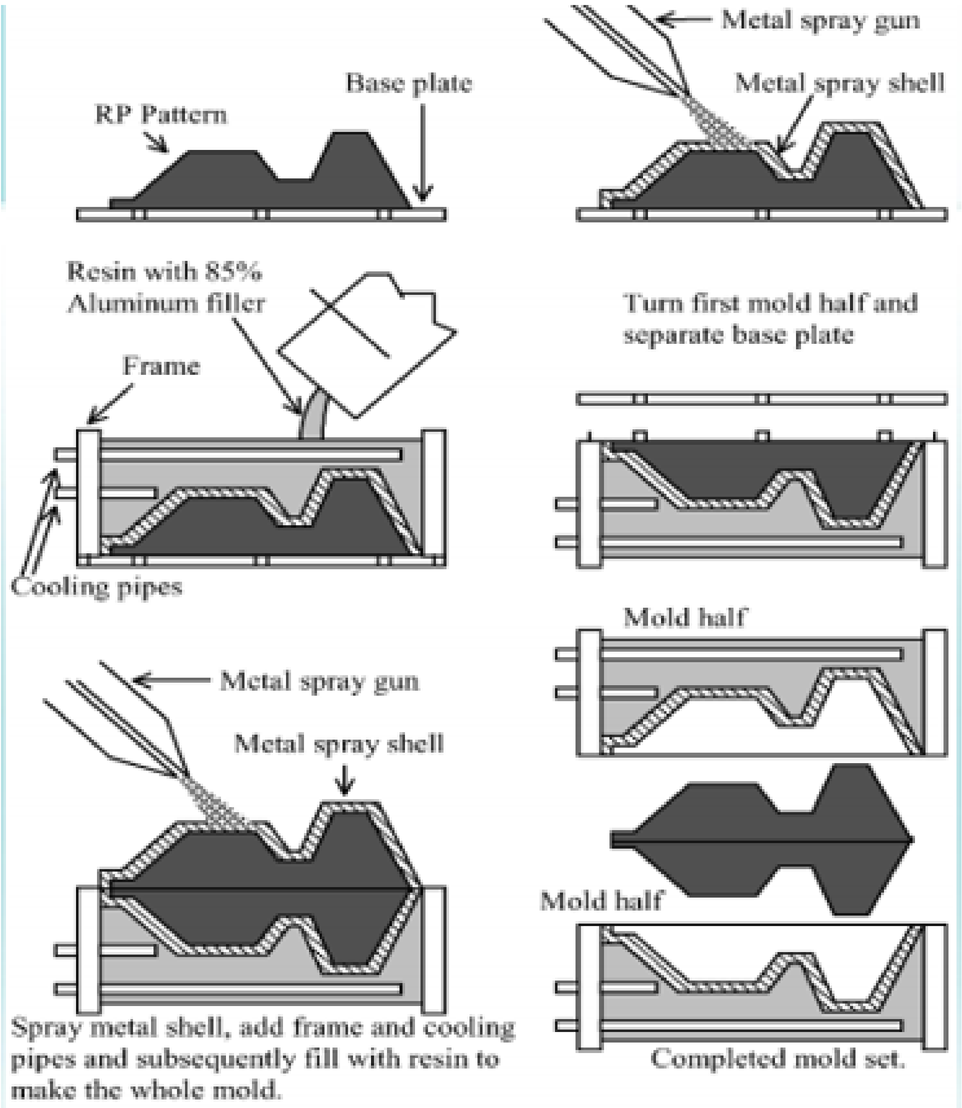


Fig 1.13 **Indirect Tooling [20]**

**To overcome some of the drawbacks of indirect methods, some RP apparatus manufacturers have proposed new rapid tooling methods that allow injection molding and die-casting inserts to be built directly from 3D CAD models. The first group includes less expensive methods with shorter lead times that are appropriate for tool validation before changes become costly; known as firm tooling. RT processes for firm tooling fill the gap between soft and hard tooling, producing tools capable of short prototype runs of approximately fifty to a hundred parts using the same material and manufacturing process as for final production parts. The second group includes RT methods that allow inserts for pre-production and production tools to be built. RP apparatus manufacturers market these methods as "hard tooling" solutions. Hard tooling are based on the fabrication of sintered metal (steel, iron and copper) powder**

**inserts infiltrated with copper or bronze (Keltool™ from 3D Systems, DTM Rapid Tool™ process, EOS INT Metal from EOS, Three-Dimensional Printing of metal parts from Soligen).**

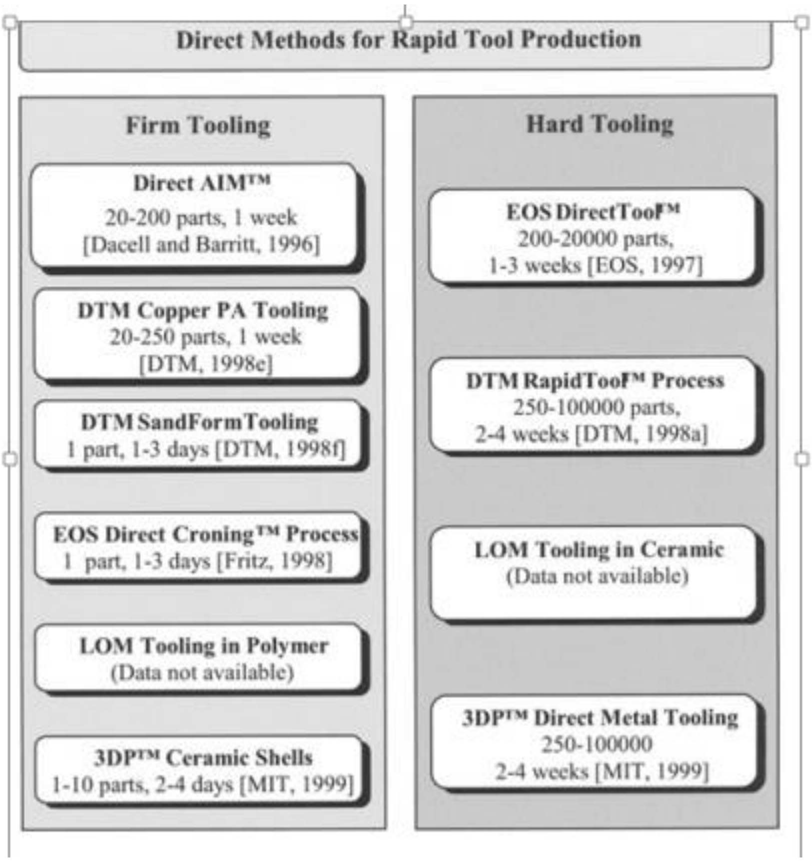


Fig 1.14 **Classification of Direct Method [21]**

## CHAPTER 2: LITERATURE REVIEW

**There are some studies on the improvement of surface finish with the help of changing some of the parameters such as surface finish which depends upon the process parameters of fused deposition modelling. Also it has done many numerical modelling which is**

**completely based on fused deposition modelling. Some of the researchers used effect of parameters whereas some researchers changed the design of experiments.**

Xue Yan et al. (1996): **These people reviewed the whole RP processes by explaining all the detail about every processes like their advantages, disadvantages, industrial applications and also the future scope in the field of developments in RP. He also proposed the basic working of the processes and told that why there is a need for RP process and what we can do with it.**

**He told about the cost of manufacturing, market demand and decreasing the time to build the different parts. Also explained the RP with tessellation or without tessellation he also showed some of the programs like INTERSECT. He grabs more attention toward the problems in material and explained how a complex shape can be manufactured. He also gave a difference between conventional and non-conventional methods of manufacturing. So this is the all done by them.**

Yardimci et al. (1998): **They have done their studies on various build orientation and raster angle on thermal expansion coefficients and tensile properties of the FDM processed material. The specimen which was used in the testing was based on ABS material which were being used in fused deposition modelling machine and has grade of 1650 or of variant 1650.**

James G. Conley et al. (1999): **They performed their studies on the working application of rapid tooling processing of laminated object manufacturing in sand the casting. The study discussed the problems in the process which includes error sources, geometry consideration, shrinkage effects and propagation. Also they represented a case study on the improvement of time and cost saving in Laminated Object Manufacturing (LOM) approach. Based on these parameters they performed their experiments.**

E.S. Lee et al. (2000): **They investigated on their views about the vacuum die casting process. They studied on the defect which are free for casting and also with the best mechanical properties of the product. They also worked industrially for their results to make a defect free die casting. They made a combination of injection for the excellent result of defect free die casting models or products. They used vacuum effect before injection and applied squeezing effect after injection moulding which results in a fabulous**

**output. For the trial they cast a support reaction shaft in industry. The shaft was made up of hyper eutectic Al- 15% Si alloy.**

Bharath et al. (2000): **He analysed that the part orientation and layer thickness have maximum effect on the roughness of parts which were manufactured by using the FDM 1650 machine and the surface quality of fused deposition modelling fabricated parts by analysing the two parameters that provide Rq (root mean square) and Ra (average roughness) values and concluded that root mean square value has a greater value than average roughness value since isolated errors affect the RMS surface a lot.**

V. Ismet et al. (2001): **They observed the accuracy of wax pattern which were used in investment casting process they also have done the statistical analysis for the process. They have produced both tools one is hard and other is soft. Hard one was made up of polyurethane mould and the soft one was made up of RTV mould. For getting the good dimensional accuracy, it was necessary to use optimum injection parameters of wax patterns. By doing the much more studies it has been proved that polyurethane produce more accurate patterns than silicone mould. Optimizing the injection Moulding parameters it has been observed that appropriate care should be taken by choosing the hold time for the optimum accuracy and also have to use lower pressure and higher temperature at some instant.**

R.Anitha et al. (2001**): They performed the experiments to assess all the influences of the parameters which is based on the quality of the prototype. They design matrix L18 orthogonal array which tells about Taguchi's method. They found layer thickness which is effective from 49.37% at 95% of significance level, but after polling it was found that the layer thickness is effective to 51.57 % at 99 % level of significance. The other factors which she considered are road width and speed contribution and she found according to S/N analysis the layer thickness is more effected when it is at the level of 3 ( 0.3556mm). [22]**

Ahn et al. (2002): **They worked on the different properties of ABS parts which are fabricated by the FDM 1650. They also examined all the different parameters of fused deposition modelling like air gap, bead width orientation and model temperature made using design of experiments. Using ABS P400 material tensile strength and compressive**

**strength of directionality fabricated specimen were measured. After performing the experiments they found that air gap and raster orientation affects the tensile strength of an FDM parts and other factors have little effects.[23]**

Navarro R et al. (2002): **They analysed the ABS (Acrylo-nitrile-butadiene-styrene) about the material strength and also the tensile modulus and all other properties which can affect the process or model or parts in fused deposition modelling. They also observed the effects on the part if the ABS started shrinking and result out the dimensional accuracy of the part which is improved with FDM 1650. They also worked on the calculation of maximum shrinkage factor of the part for FDM 1650 which were found to be 1.7 or 0.7% after observations has been made.**

Sungil Chung et al. (2003): **They explained a new technology that can be used for MRT (i.e. micro replication technology) which is made up of silicone rubber mould. They also described that the replicas of master pattern can be fabricated. Master pattern which are made by conventional methods are having the high cost and time consuming as well. In addition to this PDP barrier ribs can also be manufactured as an applications of the MRT. For verification, the reliability of applying SRM (i.e. Silicone rubber mould) to MRT, its transferability was then analysed, and then it was employed to the manufacturing of PDP barrier ribs actually.**

Pandey et al. (2003): **They employed a model for surface roughness of fused deposition modelling of hot cutter machined parts, which gives a result of good surface finish of 0.3µm value with 87% confidence level. This approach improves surface finish and functionality of RP parts. And they also investigated the surface quality of the parts obtained by FDM that has a poor stability due to staircase effect which were generated while deposition of material layer by layer.**

S.Shajiet. al. (2003): **They have investigated the possibility of using graphite as lubrication medium to reduce the heat generated at the grinding zone in surface grinding. They also studied the effect of different parameters such as speed, feed, in feed etc. He carried out the nine experiments using Taguchi standard method.**

L. Yanjin et al. (2004): **They investigated on the product of development application and showed a manufacturing system and rapid design. They have proposed two ideas for manufacturing system that is to be started from a sample and beginning from a design of good concept. Using the reverse engineering technology it is starting with a software then simulation i.e. structural analysis, module of the input and also the optimization at last for the better result for integrated manufacturing which improves the reliability of product and its efficiency by doing so and also reduce the work time and no. of design iterations while performing.**

K.Thrimurthulu et.al. (2004): **For enhancing parts surface finish and reducing built time. They tried to attempt towards obtaining optimal parts of deposition modelling process. He develop model for evaluation of average parts and surface finish and built time. For this he considered two objectives. [24]**

Lee et. al. (2005): **They performed different trials for finding the optimal process of parameters which are based on fused deposition modelling. Using RPT machine to get maximum flexibility which is of ABS type. They trial on the basis of Taguchi method, S/N ratio and ANOVA. After performing this they found that layer thickness raster angle and air gap affects the ABS prototype significantly. [25]**

B H Lee et al. (2005): **They proposed a study for the optimization of FDM parameters like Layer thickness, part orientation, raster angle air gap on FDM3000 machine using flexible ABS as a material. The analysis was carried out with the help of using ANOVA, S/N ratio, main effect and an orthogonal array to investigate to achieve the optimized elastic performance of a ABS prototype.**

Anitha et al. (2005): **They investigated the FDM process parameters effect on part fabrication. They considered three parameters with three levels each for surface roughness of the fused deposition modelling parts. Three parameters were raster width, layer thickness and deposition which are being used. They concluded by saying that layer thickness will be most affective parameter which affects the surface roughness and afterwards deposition speed and raster width accuracy of the master was uniform and over the duplicate part and better than 1%.**

Nico Kamperman et al. (2006): **They investigated SLS parts from Rapid manufacturing. They also observed from the result that Layered Manufacturing Technologies in application of rapid prototyping which were found out that it has high potential of giving the output as per the requirement on the personal as well as physical requirements. The unit of manufacturing also have done experiments on rapid manufacturing like micro SLA, Selective laser sintering (SLS) and multi material ink jet printing to take them at a level where these can be used as perfect rapid manufacturing techniques. They also presented their studies on ongoing research on the basis of selective laser sintering process. Focusing on reproducibility, coatings for parts, material properties and design rule for SLS.**

Ulaset.et al. (2007): **They worked on artificial neutral network and regression model to predict surface roughness in abrasive water jet machine. They also considered some parameters such as transverse speed, water jet pressure, standoff distance, abrasive grit size and abrasive flow rate. He also take help of Taguchi and ANOVA. [26]**

Anoopet.et al. (2008): **They worked on the different efficiency which is based on pulse Nd.YAG for different laser surface which is a structure of porous alumina ceramic. The result which they considered are the pulse width, rate of repetition and also the scanning speed. They also used method of Taguchi's and ANOVA. After their experimentation work they concluded that the pulse repetition rate is one of the most significant factor. [27]**

Jia-Hung et al. (2008): **They particularly investigated on making of vehicle components which are using underwater by rapid prototyping processes. These types of vehicle have been developed in many rescue applications and the ocean explorations. Commercially the non-availability of critical components in small scales are also a huge problem. In this particular paper the author wants to brief about the hull structure, major components and propellers for an underwater micro scale vehicle which were developed in the prototyping operations.**

B Aneesh Reddy et al. (2008): **They employed a new technique i.e. curved layer fused deposition modelling which is also a part of RP techniques. The aim of the study is to direct the material deposition to the curved layers in comparison to flat layers as in FDM.**

**The advantage of applying new technique was for thin parts and also for curved parts as the stair-step effect is the main purpose of reducing it. Also, while doing analysis there has been a conclusion that the part strength and number of layers' decreases.**

L. Rendong et al. (2009): **In this particular the author studied about the rapid prototyping and manufacturing technology and its application, development trends, representative techniques, and also the principles. They outline the integrated study of Rapid prototyping and manufacturing technology in many different cases. Also studied about RP processes like FDM, 3 DP for moulding. At the end they concluded that rapid manufacturing will change the face of market in future with its accuracy and applications because since it started as a latest trends.**

Ramos et al. (2009): **In the recent development era these people studied the technical procedure for making or manufacturing the medical implant prototypes. They used a new hip implant design and manufacture it with different materials like metal alloys with ASTM (F75) which are now using in biomedical sector. They compared the dimensional parameters of CAD (computer-aided design) geometry, surface roughness and the prototypes. Lost-wax casting were also used to make prototypes for testing surface roughness which were measured for all prototypes and the final geometry was controlled dimensionally using parameters of different types like maximum and minimum deviations of the performance etc.**

Singh et al. (2010): **They analysed their study based on rapid prototyping mould operations with the help of silicone moulding process by which they can make the plastic components. They also check the study process of silicone moulding process for the dimensional accuracy. However they also observed the study and concluded that it can be used to improve the dimensional accuracy of the part which has been made. The result of the investigation found that Polyjet printing process lies in ±4.5sigma (σ) limits in concern to dimensional accuracy.**

Y.S Morsi et al. (2010): **They worked in the field of bio medical implants to evaluate the error in machine or process. The use of skull which were using for manufacturing of the workpiece. The main advantage of this work is that it can be used for any gender, size and shape. In the design of this implants the sample of the CT scan data which is**

**converted in to STL and made the pattern and evaluated the same for the result which found that a small deviation occur of 0.24 % with 0.16 percent of skull model which they used.**

L.M. Galantucci et al. (2010): **They gave the concept of CVS (chemical vapour smoothing) applying on the prototype by which we found the surface finish of the part changed dramatically. Afterwards, they observed the mechanical strength and other properties as well. With this there are so many changes occurs in the prototype such as part roughness has reduced; very less reduction in tensile strength were observed but the most interesting thing was that a ductility was found on a very high grade. Moreover, bending tests also showed the improvement in the flexural strength.**

A.K Sood et.al (2010): **They trial the effect of fused deposition modelling process parameters which is for the mechanical strength of different specimens. All they adopted (CCD) and also ANOVA after performing his experimental work. They concluded that the layers which are required for distortion effect and the layer thickness will be minimized. And therefore the strength will automatically increase.**

A.K Sood et. al (2011): **In this they referred different effects taking five parameters of fused deposition modelling parameters like thickness of layer, air gap and raster width along with part bill of orientation. These experiments were conducted using CCD method. At the end they come to the conclusion that at particular length and orientation the effect was good.**

D.Chakradhar et. al. (2011): **They investigated the effect and parametric optimization of process parameter for electro chemical machining of EN-31 steel. The process parameter which they took as consideration as feed rate, electrolyte consideration and applied voltage. He also use ANOVA from the result he concluded that material removal rate can be maximize and overcut and cylinder city error , surface roughness can be minimized through this method.**

Ratnadeep,SamAnand (2011): **They wanted to convey that the rapid manufacturing (RM) processes have evolved from (RP) and doing this the main advantages of RP methods to**

**produce more complex shapes and they concluded the effect of build orientation on cylinder city error.**

M. Chhabra et al. (2011): **They explained about the rapid prototyping tooling such as direct, indirect RP processes in this there are many processes like DMLS (Direct metal laser sintering), Laser engineered net shaping (LENS), Pro Metal and direct ACES Injection Moulding (Direct AIM). And indirect RP consist of SM/VC (Silicone moulding), IC (Investment casting) etc., both techniques are being used for making moulds and further casting etc. So basically about the different techniques using the RP tooling processes in this paper.**

Rupender Singh (2012): **He investigated fabrication with FDM for plastic components .He wanted to convey that FDM is an additive manufacturing technology which is commonly used for modelling, prototypes. He made a conclusion that the tolerances grade of the components prepared with ABS replicas are consistent. It can also accept the surface finish and hardness as per the industrial standards and future scope may be analysis of surface cracking of the shell.**

Ivan Kuric et al. (2012): **They investigated about different materials in fused deposition modelling that can be used and can give good results about finding the new material for making high product strength ,flexibility, stiffness from metals ceramics composites and also polymers-ceramic composites like TLCP, curing of models etc. They also used different materials to compare with the new, materials like ABS, ABSPC, ISO-PC, PC, POLYETHYLENE, POLYAMIDE etc. Apart from this they compared their tensile modulus and strength or the material which is used previously. They outlined the fact and future scope of about Polymer/metal composites for direct Rapid prototyping of models. They showed an interest on the defects of using injection moulding instead. They used a sample of a Lamborghini model to make it capable of handling low and high temp. (-20 to 60) and reaching the target speed of 300kmph.This was really a reccombadable achievement by their team.**

M. Macku et al. (2012) : **They researched on FDM patterns which is made of casting with silicone moulds in which they evaluated the dimensional changes during the production of parts and also in between they made a drawing and making of pattern with the help of**

**machine. The main difference can be predicted while making the drawing is pattern which really creates problem while making its prototype because it came up with the disadvantage of drawing that it may not made as per the pattern which is set into the machine. The FDM pattern was made using ABS. They mainly focused on the work that how the deviation is being occurred in the particular process of making pattern, casting of the different prototypes and its results out the shrinkage effect and maintain the stability of the material as per the needs of the customer. They also used the wax of blayson of grade A7-RT/27 and done the further investigation using the technique called investment casting.**

P Jain et al. (2013): **They discussed about their work using the technique called rapid prototyping and made a procedure in such a way that it exists up to some limit and can sustain their limit. The uses of Auto cast-X software is then converted into CAD to STL format after that we apply the concept of Oldham coupling using a RP process which is completely based on FDM. As a result they observed that the rapid prototyping plays a vital role in this revolution in the field of manufacturing era. They also used both investment casting and sand casting and then finally they come to the conclusion that investment process far much better for the even complex shapes and complicated designs.**

P Kumar Gurrala et al. (2014): **They investigated some major parameters such as part accuracy, volumetric deviation (change) and the effect of 'curl' type geometry in FDM process. And the part was made by ABS material as a model using the same material. They also established a DOE for minimum number of experiments which is to be carried out and employed the method called ANOVA for the analysis of the results. A parametric equation in then made which really helps the designers for modelling in future. The horizontal and vertical direction are meant to be more predominate in case of shrinkage and curl over model interior. And because of which they used scanning electron microscope for analysing the surface of their prototype.**

P.J. Nunez et al. (2015): **They evaluated their study using optimum configuration in FDM. They also studied FDM process using ABS. The aim of performing such experiments are to pointed towards analysing the surface texture, dimensional accuracy and the flatness of the parts made by using this method. After the experimentation work the part has to**

**come across with minimum layer thickness with the solid density and with best surface finish.**

Garg et al. (2015): **They looked on chemical treatment of the FDM parts and made a consensus that the part accuracy, strength makes the impact. FDM quality has been observed to be improve the chemical vapour smoothing while putting onto the prototype Then the comparison of the layer shown with the help of the SEM images which intricate the smoothness after performing the CVS process.**

Singh et.al. (2016): **They made an effort to study the influence of FDM and CVS process parameters on the selected linear and radial dimensions as well as on repeatability of ABS replicas. They also used Taguchi's method with L18 orthogonal array. As they took certain parameters like orientation, part density and interaction between two significantly affect the dimensional accuracy of ABS replicas. And at the end they concluded that at 90 degree orientation, high density, five no of cycles and cycle time of 4 seconds.**

# CHAPTER 3: PRESENT WORK AND METHODOLGY

## 3.1 Problem Occurred In Previous Work

**The literature reviews which have been reviewed by me with different types of work by various researchers on additive fabrication layered manufacturing such as selective laser sintering (SLS), fused deposition modelling FDM), three-dimensional printing technology (3DP) and Poly jet technology etc. No, doubt that they put a tremendous job in their respective fields, unfortunately the quantity of work on combining FDM and CVS are quite less. In the recent 10 to 20 years of the research work on FDM, it is being extended to a very much high and the techniques used by them were very much explored at present like barrel finishing, optimizing parameters etc. If we compared to them with Galantucci et al. 2009 & 2010 which were employed with a new technique with the help of CVS to extend their research efforts in combining both CVS and FDM which are more productive. As we know that doing something in batch production is not possible with the help of RP methods because of two valid reasons, they are cost and time factor. So direct RP tooling methods are being used in my research work. The research field is not so much vast in case of fused deposition modelling is concerned and also the work has been done on FDM which has a RP technique perhaps it has not been much explored using different parameters of RP with some optimum phase, so because of which it has been proved to be a true rapid manufacturing and also there have not been done any qualitative work yet. So, with this we have certain objectives so that we can overcome with all these objectives so that in future no such kind of problems occurs.**

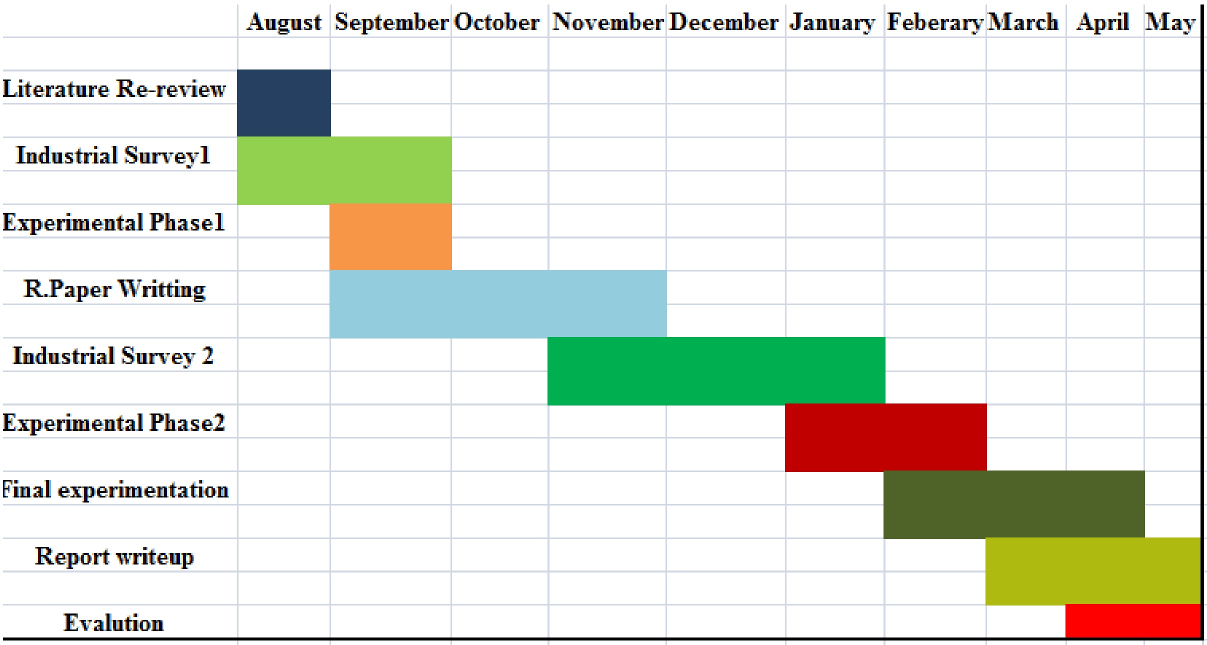


Fig 3.1 **Work Plan of my thesis work [28]**

## 3.2 Objectives

**1. To fabricate before and after performing FDM and CVS, the material gets reflow and the surface roughness becomes fine.**

**2. By performing the first experiment on surface roughness orientation gets the best result.**

**3. Similarly in the dimensional deviation speed and orientation shows the best result after doing the full analysis.**

**4. To study the effect of CVS process on various properties of FDM based on ABS replicas.**

**5. Detailed analysis of surface roughness and dimensional deviations by taking four different parameters of the benchmark components took as output during each processes.**

## 3.3 Methodology

**Analysis of four parameters at two different levels requires 81 (30) different experiments if conventional design of experiments (DOE) was used. By using the same results it can obtained the Taguchi array method to employ with very least number of experiments. In Taguchi array design, orthogonal array selection is a major concern for acquiring valid conclusions.**

**Since our four parameters of each at two levels and also the interaction of orientation with each factors are being analysed, the total DOF (i.e. Degree of freedom) will be 8. The**

**reliable orthogonal array which can be productive for the study is L9 orthogonal array (30). This array design will be consisting 4 columns for assigning interaction and 9 rows designating experiment conditions. The final L9 array table is seems to be look like:**

Table 3.1**: Taguchi L9**

| Sr No. | Orientation | Frequency | Speed | Smoothing time |
|---|---|---|---|---|
| 1 | 0 | 1 | 60 | 8 |
| 2 | 0 | 2 | 70 | 12 |
| 3 | 0 | 3 | 80 | 16 |
| 4 | 30 | 2 | 70 | 16 |
| 5 | 30 | 3 | 80 | 8 |
| 6 | 30 | 1 | 60 | 12 |
| 7 | 60 | 3 | 80 | 12 |
| 8 | 60 | 1 | 60 | 6 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

Fig 3.2 **Depiction of the Hip Joint**

**The research work is proposed to be carried out as per the flow chart.**

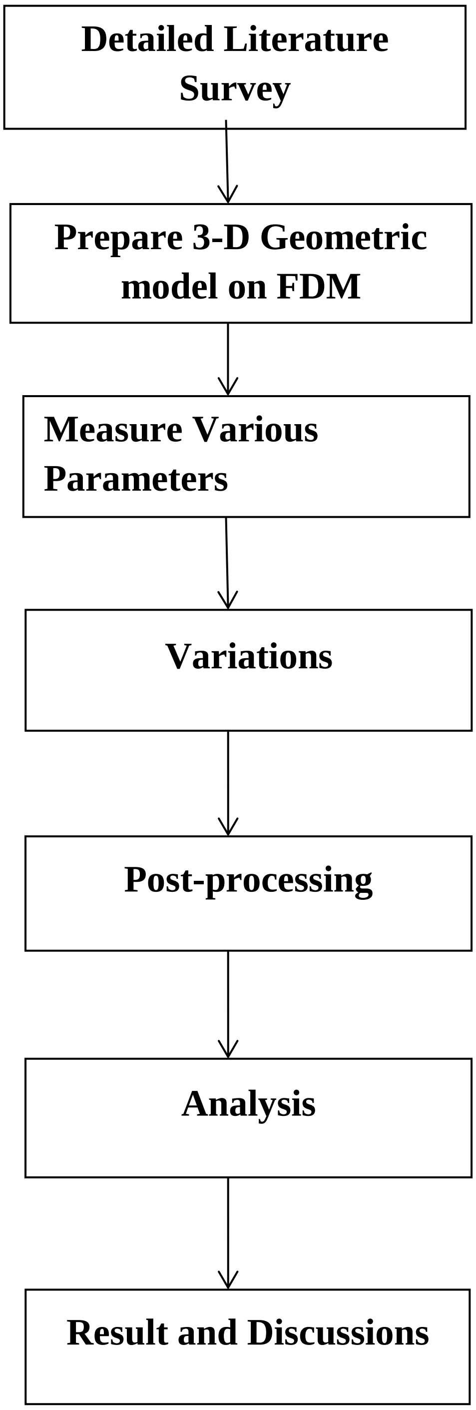


Fig 3.3 **Depiction of the Various Steps of the Research Work.**

## 4.1 Experimentations & Results

**The experiments of different phases are shown in table. From these results, it has been noticed that the part fabrication at 30 degree orientation has better surface smoothing as compared to rest of the parts has been improves tremendously after applying chemical treatment . Also there were small deviation in dimensional which are not considerable. Taguchi L9 array was used for experimentation shown in table in which there are different parameters are taken such as orientation, speed, surface smoothing and frequency these all shown in table.**

## 4.2 Observations

**Before performing the chemical vapour smoothing on the different prototypes the dimensions were different but when chemical vapour smoothing is done on each prototypes the dimensions were changed, the table is given below:**

Table 4.1 **Showing Variations after Performing Experiments Using Different Components.**

| Sr.No | Output from stage 1 (mm) | After CVS of stage 1 (mm) | Output from stage 2 (mm) | After CVS of stage 2 (mm) |
|---|---|---|---|---|
| 1. | 6.48 | 6.08 | 26.48 | 23.92 |
| 2. | 6.28 | 6.18 | 26.20 | 23.50 |
| 3. | 6.52 | 6.26 | 26.30 | 23.10 |
| 4. | 6.20 | 6.08 | 26.48 | 23.82 |
| 5. | 6.32 | 6.14 | 26.40 | 23.83 |
| 6. | 6.42 | 6.24 | 26.58 | 23.80 |
| 7. | 6.14 | 6.08 | 26.28 | 23.90 |

| | | | | |
|---|---|---|---|---|
| 8. | 6.28 | 6.18 | 26.90 | 23.92 |
| 9. | 6.30 | 6.25 | 26.60 | 24.02 |

**However, after performing CVS whatever the values obtained we just subtract those values with one dimension of benchmark component and the second dimension with second benchmark component so with this we got the two different responses i.e. 2 and 3.The table which shown below is showing the same thing.**

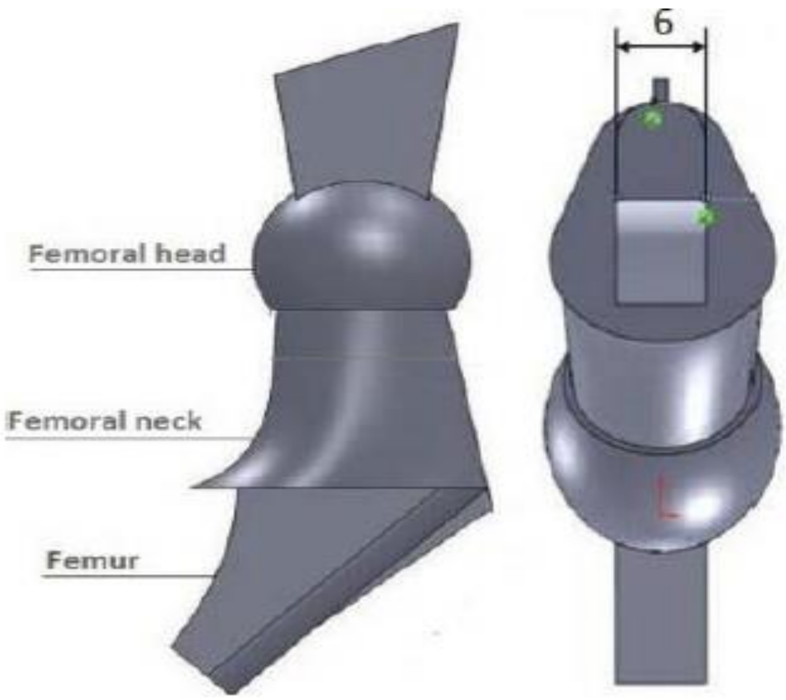


Fig 4.1 **Depiction of a Specimen with one of the dimensional deviation 2 [30]**

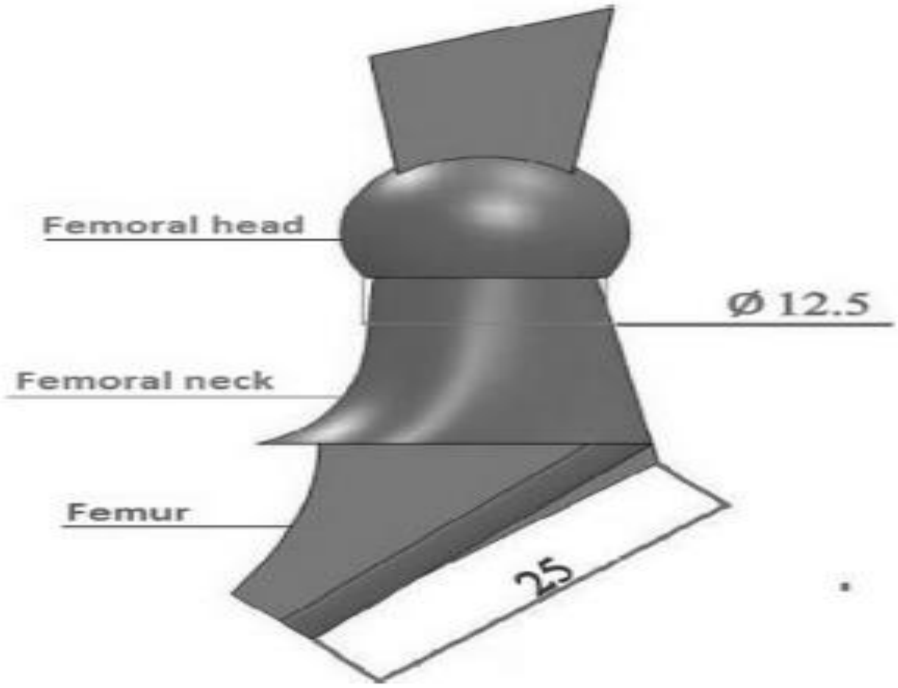


Fig 4.2 **Benchmark Component with taking another dimensional deviation 3.[30]**

Table 4.2 **Showing the Calculations of Dimensional Deviation 2**

| S.No | After CVS of stage 1 (mm) **A1** | Benchmark component dimension (mm) **A2** | **A1-A2** |
|---|---|---|---|
| 1. | 6.08 | 6 | 0.08 |
| 2. | 6.18 | 6 | 0.18 |
| 3. | 6.26 | 6 | 0.26 |
| 4. | 6.08 | 6 | 0.08 |
| 5. | 6.14 | 6 | 0.14 |
| 6. | 6.24 | 6 | 0.24 |
| 7. | 6.08 | 6 | 0.08 |
| 8. | 6.18 | 6 | 0.18 |
| 9. | 6.25 | 6 | 0.25 |

Table 4.3 **Showing the Calculations of Dimensional Deviation 3**

| S.No | After CVS of stage 2 (mm) **A3** | Benchmark component dimension (mm) **A4** | **A4-A3** |
|---|---|---|---|
| 1. | 23.92 | 25 | 1.08 |
| 2. | 23.50 | 25 | 1.50 |
| 3. | 23.10 | 25 | 1.90 |
| 4. | 23.82 | 25 | 1.18 |
| 5. | 23.83 | 25 | 1.17 |
| 6. | 23.80 | 25 | 1.20 |
| 7. | 23.90 | 25 | 1.10 |
| 8. | 23.92 | 25 | 1.08 |
| 9. | 24.02 | 25 | 0.98 |

## 4.3 Taguchi Design of Experiment

**Study of four factors at two levels requires experiments if the design of experiment (DOE) is used at same statistically valid outputs can be obtained perhaps Taguchi method is adopted with few number of experiments [15]. In Taguchi design, selection of orthogonal array is plays a very vital role for obtaining valid conclusions and because of which this is used for design of experimental plan and experiments which are carried out according to desired designed plan. To select an appropriate orthogonal array for the experiments of the total degrees of freedom must be computed significantly. The degrees of freedom are defined as the number of comparisons between process parameters that must be made to determine which level is better and specifically, and also how much better it is having.**

**Two degrees of freedom. The degrees of freedom associated with interaction between four process parameters are given by the product of the degrees of freedom for the four process parameters. For instance we have X number of specimens that we have to subtract 1 from X we will get the desired degree of freedom.**

Table 4.4 **Experimental data of $L_9$ orthogonal array**

| Sr.No | A | B | C | D | Response 1(µm) | Response 2 (mm) | Response 3 (mm) |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 60 | 1 | 8 | 2.360 | 0.08 | 1.08 |
| 2 | 0 | 70 | 2 | 12 | 1.532 | 0.18 | 1.5 |
| 3 | 0 | 80 | 3 | 16 | 0.980 | 0.26 | 1.9 |
| 4 | 30 | 60 | 2 | 16 | 0.750 | 0.08 | 1.18 |
| 5 | 30 | 70 | 3 | 8 | 1.340 | 0.14 | 1.17 |
| 6 | 30 | 80 | 1 | 12 | 1.614 | 0.24 | 1.2 |
| 7 | 60 | 60 | 3 | 12 | 0.580 | 0.08 | 1.1 |
| 8 | 60 | 70 | 1 | 6 | 0.610 | 0.18 | 1.08 |
| 9 | 60 | 80 | 2 | 8 | 0.853 | 0.25 | 0.98 |

**Where A- Orientation.**

**B-Speed**

**C- Frequency**

**D- Smoothing time**

4.4 Signal to Noise Ratio

**In the Taguchi method the loss function is defined as to calculate the deviation b/w the experimental value and the desired value. The signal to noise ratio (S/N) is the ratio which is used to determine the performance characteristics of deviating from the desired values. The advantages of using S/N ratio are that it uses a single measure, loss function which actually incorporates the effect of changes in mean as well as the variation (standard**

**deviation) with equal priority. Moreover, the results behave as a linearly when it expressed in terms of S/N ratios. Perhaps linear behaviour of result is an assumption which is necessary to express performance in the optimum condition. There are three categories types of performance characteristic in the analysis of the signal-to-noise ratio that are the smaller-the-better, bigger-the-better, and the nominal-the-better which are used according to our wills. Here, I have considered as smaller-the-better quality characteristic which can be expressed as:**

$$\eta_{ij} = -10\log(L_{ij})$$

**Where** $L_{ij}$ **are the loss function of i th performance characteristics in the jth experiment.**

$$L_{ij} = {}^{1}/_{n} \sum y_{ijk}^{2}$$

**Using this particular expressions I have calculated the S/N ratio for different responses and with this I have also analysis the graphs of S/N ratio using the software MINITAB.**

Table 4.5 **Calculation of S/N Ratio.**

| S/N RATIO -1 (dB) | S/N RATIO -2 (dB) | S/N RATIO-3 (dB) |
|---|---|---|
| - 7.45824 | 21.9382 | -0.6684 |
| -3.70518 | 14.8945 | -3.5218 |
| 0.17548 | 11.7005 | -5.575 |
| 2.49877 | 21.9382 | -1.4376 |
| -2.5421 | 17.0774 | -1.3637 |
| -4.15807 | 12.3957 | -1.5836 |
| 4.73144 | 21.9382 | -0.8278 |
| 4.43697 | 14.8945 | -0.6684 |
| 1.38102 | 12.0411 | 0.17547 |

4.5 Analysis of Variance

**Experimental analysis is made using Minitab R17 software. The main effect plot for S/N ratio is used to predict the optimum factor level. Perhaps, a statistical analysis of variance (ANOVA) is performed which is used to identify the process parameters and also interactions that significantly affect the performance characteristic. The percentage contribution (%P) of various process parameters and interactions on the selected performance characteristic can be estimated by performing ANOVA test. In addition, significance of factors and interactions can also be determined by comparing calculated F-value with standard F-value at a particular level. Thus, the information about the effect of each controlled parameter on the quality characteristic of interest can be obtained. By using the different formulas we calculated the ANOVA.**

**Based on Response 1: Surface Roughness.**

Table 4.6 **ANOVA Results for Variations in Surface Roughness**

| Source | DOF | Adjust SS | Adjust MS | F-Value | P-Value > F-value | Contribution % |
|---|---|---|---|---|---|---|
| A | 1 | 1.34 | 1.34 | 46.87 | 0.0024 | 48.5 |
| B | 1 | 9.841E-003 | 9.841E-003 | 0.34 | 0.5894 | 0.36 |
| C | 1 | 0.47 | 0.47 | 16.30 | 0.0156 | 17.0 |
| D | 1 | 0.82 | 0.82 | 28.74 | 0.0058 | 29.8 |
| Error | 4 | 0.11 | 0.029 | | | 4.34 |
| Total | 8 | 2.76 | | | | 100 % |

Table 4.8 **ANOVA Results for Variations in Dimensional Deviation 2**

| Source | DOF | Adjust SS | Adjust MS | F-Value | P-Value > F-value | Contribution % |
|---|---|---|---|---|---|---|
| A | 1 | 77.31 | 77.31 | 49.11 | 0.0022 | 54.84 |
| B | 1 | 0.94 | 0.94 | 0.60 | 0.4830 | 0.67 |
| C | 1 | 15.18 | 15.18 | 9.64 | 0.0360 | 10.77 |

| | | | | | | |
|---|---|---|---|---|---|---|
| D | 1 | 41.24 | 41.24 | 26.20 | 0.0069 | 29.25 |
| Error | 4 | 6.30 | 1.57 | | | 4.47 |
| Total | 8 | 140.97 | | | | 100% |

Table 4.10 **ANOVA Result for Variations in Dimensional Deviation 3**

| Source | DOF | Adjust SS | Adjust MS | F- Value | P- Value > F- Value | Contribution % |
|---|---|---|---|---|---|---|
| A | 1 | 1.667E-005 | 1.667E-005 | 0.086 | 0.7835 | 0.037 |
| B | 1 | 0.043 | 0.043 | 224.55 | 0.0001 | 95.56 |
| C | 1 | 6.667E-005 | 6.667E-005 | 0.35 | 0.5883 | 0.148 |
| D | 1 | 4.167E-004 | 4.167E-004 | 2.16 | 0.2157 | 0.926 |
| Error | 4 | 7.722E-004 | 1.931E-004 | | | 3.33 |
| Total | 8 | 0.045 | | | | 100% |

**From figure 4.2, we can see the effect of S/N Ratio Graph for surface roughness in which we have four different parameters they are orientation, speed, frequency and smoothing time. From the graph we can predict that in this particular research work, the effect of some of the selected techniques such as FDM and CVS process parameters the surface roughness has been analysed. The surface roughness before doing the CVS was different and while performing the CVS it effects on the surface of the prototype. Here as we can see in the graph that as the orientation is increasing from 0 degree to 60 degree speed is decreasing with which as we are increasing the no. of frequency We can analyse that the surface finish is becoming much fine. Perhaps the smoothing time is also increase as we take long time to re- flow the acetone which results the fine surface finish.**

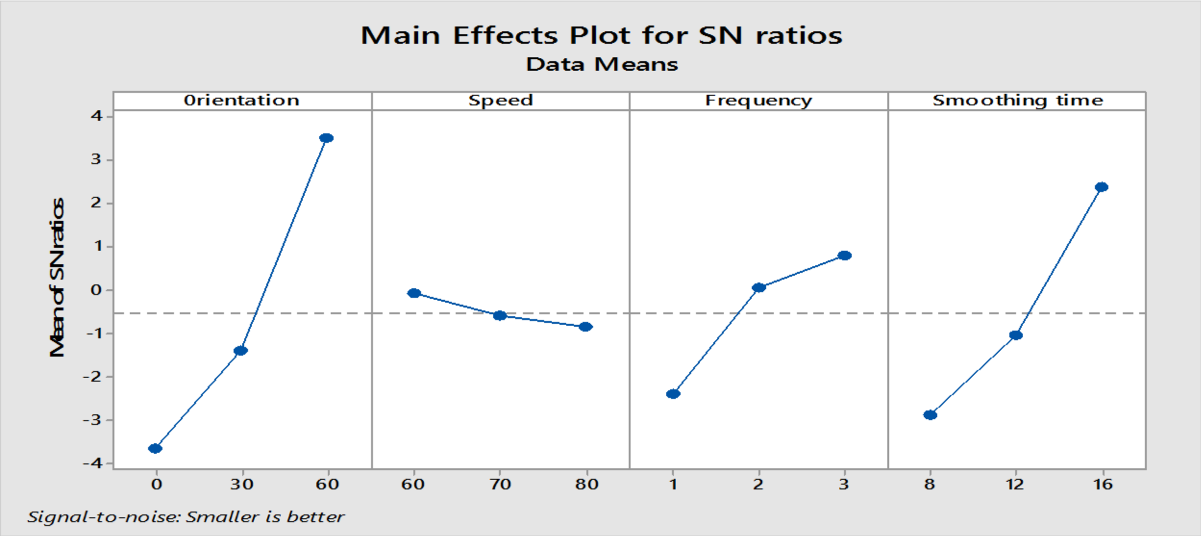


Fig 4.2 **Effect of Main S/N Ratio Graph for Suface Roughness**

**From figure 4.3 we can see the effect of S/N Ratio Graph for dimensional deviation which includes all the three different parameters they are orientation, speed, frequency and smoothing time so from the graph we can say that as the orientation is decreasing the speed is increasing for the dimensional deviation 2 which has a dimension of 6mm and also the frequency is increasing as we are taking the three cycles by taking more smoothing time. So, we can say that as we take more time with more no. of frequency speed has a variation with less orientation so that it shows the best deviation of the prototype.**

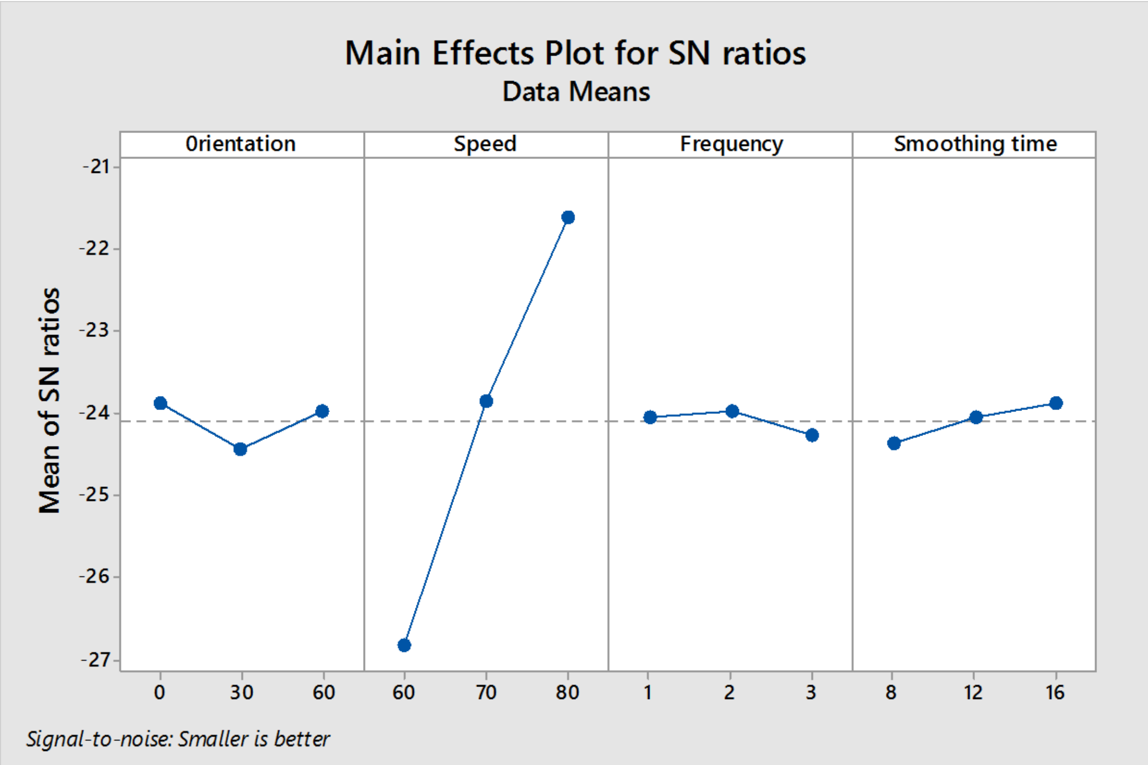


Fig 4.3 **Effect of Main S/N Ratio Graph Dimensional Deviation 2**

**From Fig 4.4 again we have four different parameters and they have different impacts on dimensional deviation of 3 which has a dimension of 25 mm. As we can see that as soon as we increase the orientation 0 to 60 degree the speed decreases and as the frequency decreases with three cycles simultaneously the smoothing time also decreases So we can conclude from the graph that the orientation has a good impact on the dimensional deviation 3 .**

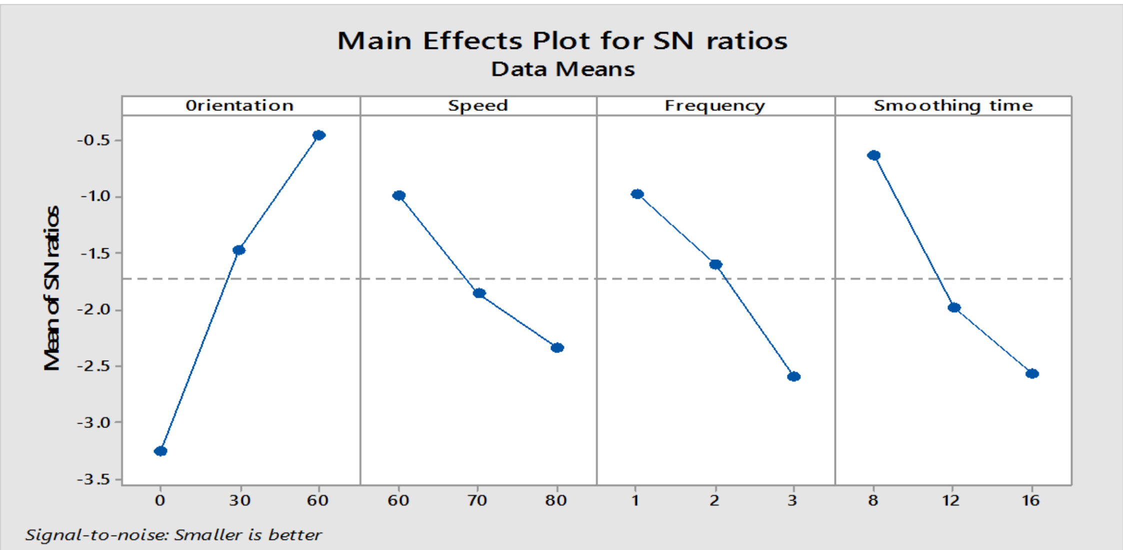


Fig 4.4 **Effects of Main S/N Ratio Graph plot for Dimensional Deviation 3**

**The microscope image taken before and after the CVS process for one of the ABS pattern has been shown in Figure 4.4 & 4.5 respectively. The image has been taken by metallurgical microscope at magnification of 500X. Figure 4.4 clearly shows formation of air gap between the two layers during layer by layer development of the model. After CVS process,the air gap disappears due to re-flow of the ABS material which ultimately reduces the stair-step effects and thus improves the surface finish and dimension deviations.(Refer Fig 4.5).**

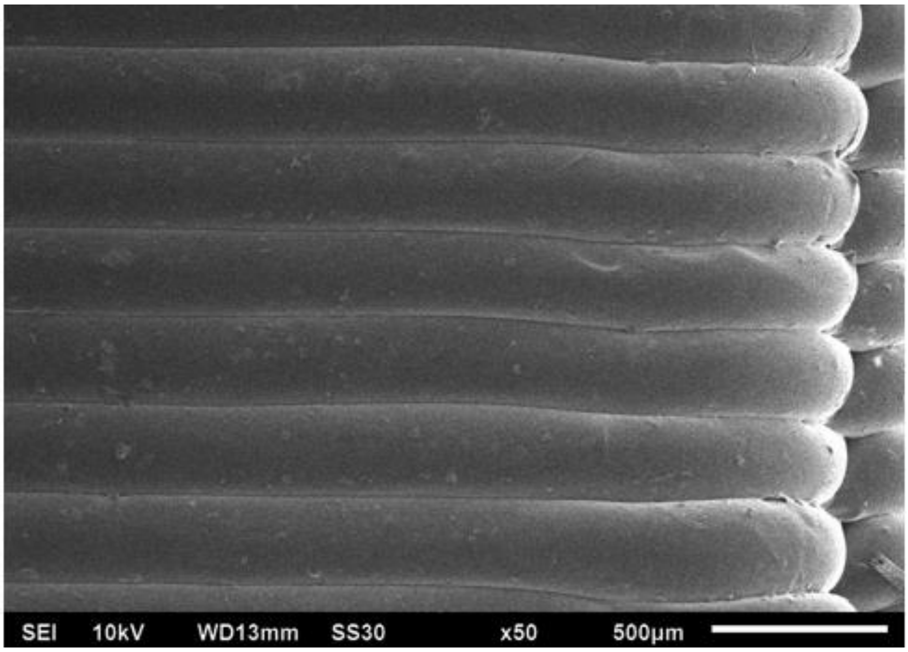


Fig 4.4 **SEM image before the CVS process**

**From the SEM images,it has been investigated that exposing ABS parts to vapors the acetone in smoothing process results in re-flow of the material,which ultimately reduces the stair step effect and also fills the air gap formed during layer by layer fabrication of the model and thus improves the surface finish and dimensional deviations.**

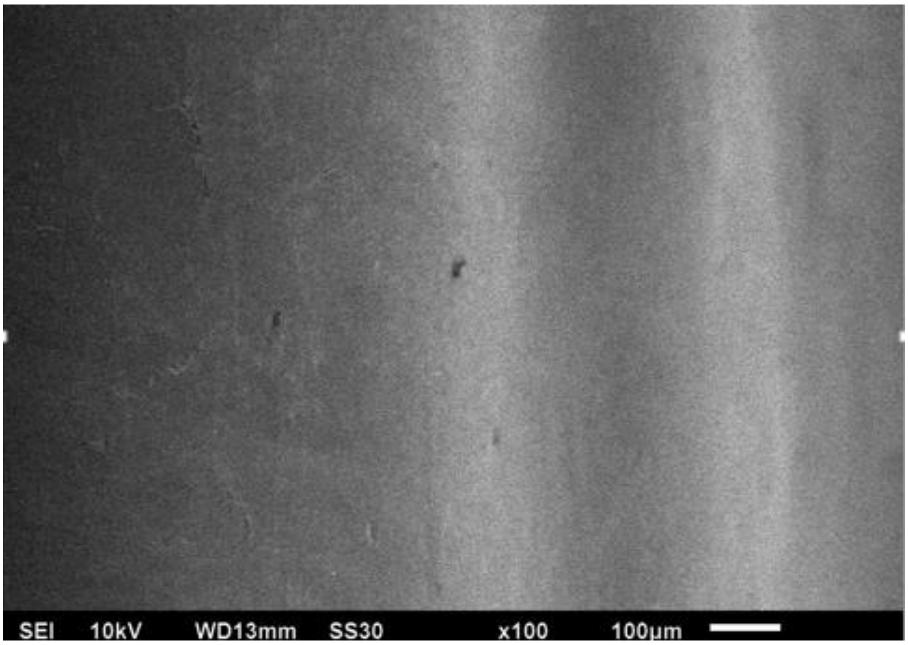


Fig 4.5 **SEM image after the CVS process**

4.6 Confirmation of Experiments

**In this particular section I will discuss the three different responses which I have took in my research work i.e. surface roughness, dimensional deviation 2 and dimensional deviation 3. For Surface Roughness: From the main effect by which we have plot an S/N graph with that we can analyse the best results which are getting with the parameters of orientation ,frequency ,speed and smoothing time. By considering all these parameters we can say that taking 60 degree orientation with a speed of 60 and frequency of 3 cycles and also taking the smoothing time of 16.I am getting the best surface roughness according to the software. But in actual if we compare the experimental results of the surface roughness by performing two experiments I am getting the error of 12% comparatively. Similarly for the dimension deviation of first specimen the best results which I am getting using the software are with taking 60˚orientation ,80 as speed by taking one cycle of frequency and also with 16 secs of smoothing time. But while I performed some of the experiments there is an error of around 17%. Now when I took the last dimension deviation of specimen using the software the best frequency and with 8 secs of smoothing time. But as usual by performing the experiments which were closed to the reading of the dimension deviation there was an error of around 15% as compared to the actual one. So basically by performing the different experiments with or without software we analysed them and also concluded with percentage of error while doing it.**

# CHAPTER 5: CONCLUSION & FUTURE SCOPE

## 5.1 Conclusion

**Based on the experimental work and analysis made on benchmark component some conclusion**

**can be drawn which are as follows: -**

**1. Orientation affects the surface finish significantly followed by smoothing time.**

**2. CVS process dramatically improve the surface finish and also the quality of parts due to reflow of the ABS material, but some minor deviations in the dimensions of the component has been observed after the smoothing operations.**

**3. SEM images confirms the reflow of the material which ultimately enhances the surface finishes of the fabricated parts.**

**4. The parametric settings that gives the minimum roughness are orientation angle $60^0$, speed 80, frequency of cycles 3 and smoothing time of 16 secs.**

**5. Similar to surface roughness, dimensional deviation was found to be highly influenced by the variation in orientation angle and smoothing time. Speed of deposition has negligible effect on the dimensional deviation.**

**6. The parametric settings that gives the minimum deviation are orientation $0^0$, speed 80, frequency 1 and smoothing time 16.**

## 5.2 Future scope

**1. In future research work, the effect of other FDM parameters like extrusion temperature, raster angle, layer thickness etc can be studied on the selected responses.**

**2. Other indirect rapid tooling methods for fabrication of multiple replicas can be utilized in future research for increasing the application domain of FDM technique.**

**3. CVS is still in experimental stage and research work has to be performed on complex geometries to understand the process completely.**

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