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# Overview of Fused Deposition Modeling Process Parameters

Dr.P.Mallesham[1],
* (Principal &professor ,Department of Mechanical,Sri indu college of college of engineering & technology,JNTU HYD INDIA - 501510
Email: mallesham.principal1955@gmail.com)

**ABSTRACT :** *The paper is to review for different process parameters of FDM.Reduction of product development cycle time is the major concern in industries for achieving competitive advantage. Thus theindustries are shifting from traditional product development methodology to rapid fabrication techniques. The Fused deposition modeling (FDM) is one of the rapid prototyping technologies by which physical objects are created directly from CAD data. The quality of FDM processed parts mainly depends on careful selection of process variables. The quality of FDM fabricated parts are significantly affected by various process parameters used in this process. So it is necessary to know the effect ofvarious process parameters of FDM. To improve the quality of FDM parts, the thorough knowledge of various process parameters and its effect is essential.Thus, identification of the FDM process parameters that significantly affect the quality of FDM processed parts is important. The entrepreneurs, industrial people,beginners and researchers have to be explored a number of ways to improve the mechanical properties and part quality using various experimental design techniques and its concepts.Review of various materials, various process parameters of FDM process is discussed in this section which is used by researchers to carry out the experiments further or to improve work in the same area.*

## I. INTRODUCTION

The word **Rapid Prototyping** (RP) was first used in mechanical engineering field in the early 1980s to describe the act of producing a prototype, a unique product, the first product, or a reference model. In the past, prototypes were handmade by sculpting or casting, and their fabrication demanded a long time. Every prototype should undergo evaluation, correction of defects, and approval before the beginning of its mass or large scale production. Prototypes may also be used for specific or restricted purposes. With the development of information technology, three-dimensional models can be devised and built based on virtual prototypes. Computers can now be used to create accurately detailed projects that can be assessed from different perspectives in a process known as computer aided design (CAD). To materialize virtual objects using CAD, a computer aided manufacture (CAM) process has been developed. To transform a virtual file into a real object.

The competition in the world market for manufactured the product has intensified tremendously in recent years. It has become important the new product to reach the market as early as possible for achieving competitive advantage. So future is clear as rapid prototyping (RP) is now becoming the key technology that shorter product development cycle time for faster building of physical prototypes, tooling and models. Fused deposition modeling(FDM) is one of the RP systems that produced prototype from plastic materials by laying tracks of semi molten plastic filament on to a platform in a layer wise manner from bottom to top[1]. The quality of FDM manufactured parts is affected by various process parameter used in this process. There is a need for optimizing the process parametersboth from technological and economic point of view. Optimization of process parameters helps to finding out the correct adjustment of parameter[2].

The term rapid prototyping (RP) designates a set of technologies that allow the realization of automatic physical models based on design data, all through the aid of a computer. These "three-dimensional printers" allow designers to quickly generate defined prototypes of their designs, rather than the simple two-dimensional images. These Prototypes of such achievements provide valuable visual aids. The shift from the visual to the visual-tactile representation of physical objects introduced a new kind of interaction called "touch to comprehend". In the early days of RP, automotive and aerospace industries dominated the RP application. But this is no longer the case as RP has spread into many industries.The emergence of the RP technology into prosthodontics has innovated the clinical and laboratory procedures by eliminating some intermediate stages and independing the quality of the outcomes from the practitioner's skills. This indicates the potential of the new method, which is capable of replacing the traditional "impression-taking and waxing" procedure. RP methods are used to substantially shorten the time for developing patterns, molds, and prototypes. However, the field of RP is still new with much effort to be expanded on improving the speed, accuracy and reliability of the system and widen the range of materials for prototype construction.

Fused Deposition Modeling (FDM) is the rapid prototyping technology that forms three-dimensional objects from CAD generated solid or surface models. A temperature- controlled head extrudes ABS plastic wire layer by layer and as a result, the designed object emerges as a fully functional three-dimensional part. Rapid prototyping (RP) is used to save time and cut costs at every stage of the product development process. Prototypes can now be produced in a matter of hours that have typically taken weeks or even months to make.Fused deposition modeling (FDM) and 3D printer are commercial RP processes while neon composite deposition system (NCDS) is an RP test bed system that uses neon composites materials as the part material. “With rapid prototyping, companies are now able to verify and change designs with much less investment in time and money”, Fused deposition modeling(FDM) and 3D printer are commercial RP processes while neon composite deposition system (NCDS) is an RP tested system that uses neon composites materials as the part material.

FDM begins with a software process which processes an STL file (stereolithography file format), mathematically slicing and orienting the model for the build process. If required, support structures may be generated. The machine may dispense multiple materials to achieve different goals: For example, one may use one material to build up the model and use another as a soluble support structure, or one could use multiple colors of the same type of thermoplastic on the same model.

The model or part is produced by extruding small flattened strings of molten material to form layers as the material hardens immediately after extrusion from the nozzle

A plastic filament or metal wire is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off. There is typically a worm-drive that pushes the filament into the nozzle at a controlled rate. The nozzle is heated to melt the material. The thermoplastics are heated past their glass transition temperature and are then deposited by an extrusion head.

The nozzle can be moved in both horizontal and vertical directions by a numerically controlled mechanism.The nozzle follows a tool-path controlled by a computer-aided manufacturing (CAM) software package, and the part is built from the bottom up, one layer at a time. Stepper motors or servo motors are typically employed to move the extrusion head. The mechanism used is often an X-Y-Z rectilinear movements and working principles are are shown in Fig.1, and Fig. 2

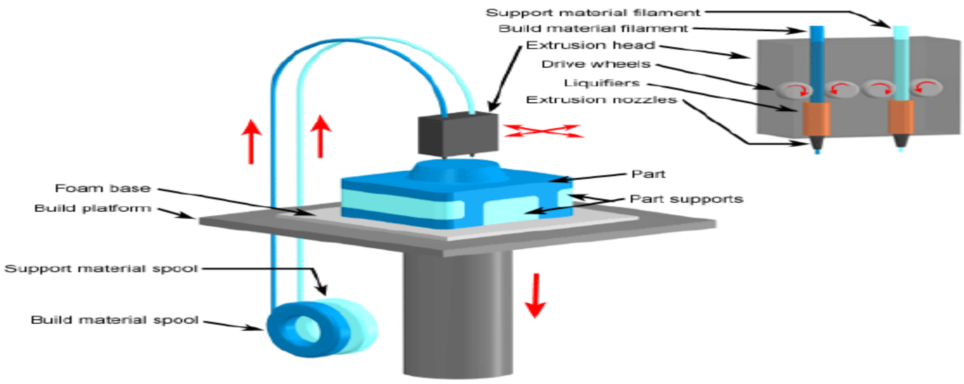


Fig : 1Principle of FDM process

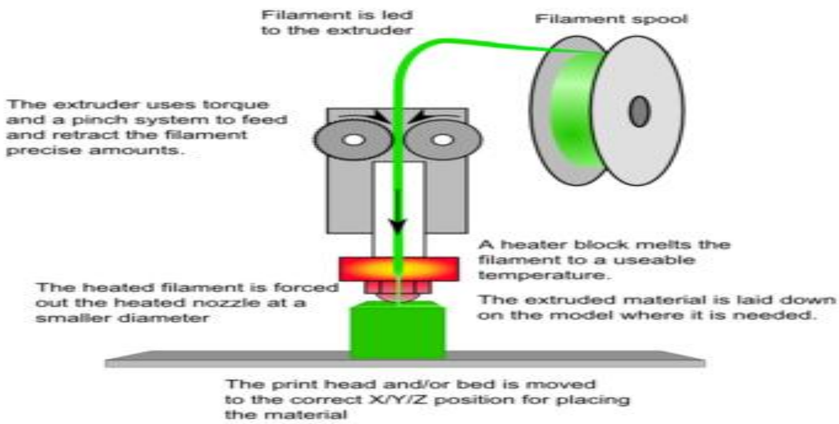


Fig : 2Principle of FDM process

## II. HISTORY

FDM hardware is based on **material extrusion**. Here a semi-liquid material -- and most usually a hot thermoplastic -- is deposited from a computer-controlled print head. This process was invented by Scott Crump in 1988, who set up a company called Stratasys to commercialize his invention. Crump chose to name the technology '**fused deposition modelling**' or '**FDM**', and patented and trademarked these terms. FDM refer to this kind of 3D printing. Only Stratasys actually makes FDM 3D printers. Others manufacturers names are '**thermoplastic extrusion**', **plastic jet printing**' (PJP), the '**fused filament method**' (FFM) or '**fused filament fabrication**' (FFF). The hype around 3D printing is fairly new but the technology has actually been around for about 20 years. Let's take a step back to understand the major milestones in its history.

**1984-1986:** Charles Hull invents and patents stereolithography (one form of 3D printing) and cofounds 3D Systems.

**1986:**Carl Deckardfiles for a patent for selective laser sintering, another 3D printing technology. The first commercial machines are built in 1989 by DTM (acquired by 3D Systems in 2001).

**1989:** S. Scott and Lisa Crump, the cofounders of Stratasys, invent and patent "fused deposition modeling," a technology for 3D printing where a material is extruded out of a nozzle and creates a 3D object layer by layer.

**1992:** 3D Systems makes its first commercial sale of a stereolithography system.

**1993**: MIT developers invent 3D printing techniques called 3DP and license them to Z Corporation (acquired by 3D Systems in 2012).

**2001:** Luke Massella receives one of the first 3D-printed bladders thanks to the Wake Forest Institute for Regenerative Medicine. It's a combination of 3D printed biomaterials and his own cells.

**2007:** Objet (later acquired by Stratasys) launches the Objet Connex, the first 3D printer that can print an object with multiple materials.

**2007:** RepRap, an open source project to create 3D printers that can print their own parts, creates its first-generation Darwin.

**2009:** The patent for fused deposition modeling expires, helping ignite the industry.

**2009:** MakerBot starts selling DIY kits to make your own 3D printer. The first kit to build aCupcake CNC sells for $750.

**2010:** Bespoke Innovations is founded by Scott Summit to bring customized, beautiful 3D printed leg coverings to amputees.

**2011:** The first car with a 3D printed body, Urbee, is created by Kor Ecologicin partnership with Stratasys. It gets up to 200 mpg.

**2011:** An 83-year-old woman gets a 3D printed jaw thanks to researchers at Hasselt University in Belgium and a company called LayerWise.

**2011:** materialise is the first to offer3D printing with gold and silver.

**2012:** President Obama awards $30 million to the National Additive Manufacturing Innovation Institute in Ohio, which hopes to bring additive manufacturing and 3D printing mainstream.

**2013:** At SXSW, MakerBot announces plans for the Digitizer. The Digitizer is a 3D scanner that can transform objects into 3D models, which can then be printed again. Digitizers start shipping in October.

**2013:** The first 3D printed gun, called the "Liberator," is created by Defense Distributed. The company was forced to take down the blueprint for the gun from its website by the Department of tate.

**2013:** Staples starts selling3D printers made by 3D Systems.

**2013:** MakerBot is acquired by Stratasys in a transaction valued at $403 million.

**2014:** 3D printing had its own TechZone at the 2014 International CES.

## III. WORKING PROCESS

We should know how the FDM process works. The first step in generating an FDM part is to create a three dimensional solid model. This can be accomplished in many of the commonly available CAD packages.

The part is then exported tothe FDM Quick slice software via the stereo lithography (STL) format. This format Once the STL file has been exported to Quick slice; it is then horizontally sliced into many thin sections. These sections represent the two dimensional contours that the FDM process will generate which, when stacked upon one another, will closely resemble the original part three dimensional part. This sectioning approach is common to all currently available Rapid Prototyping processes. Obviously, the thinner the sections, the more accurate the part. The software then uses this information to generate the process plan that controls the FDM machine's hardware. Reduces the part to a set a triangles by tessellating it. The advantage of this is that it is a common format that almost every CAD system can export, and reduces the part to its most basic components. The disadvantage is that the part loses some resolution, as only triangles, and not true arcs, spines, etc now represent it. However, these approximations are acceptable as long as they are less than the inaccuracy inherent in the manufacturing process. Once the STL file has been exported to Quick slice, it is then horizontally sliced into many thin sections. These sections represent the two dimensional contours that the FDM process will generate which, when stacked upon one another, will closely resemble the original part three dimensional part. This sectioning approach is common to all currently available Rapid Prototyping processes. Obviously, the thinner the sections, the more accurate the part. The software then uses this information to generate the process plan that controls

The Hardware for the FDM machine is represented in Figure 3. The concept is that a filament, in our case ABS, is fed through a heating element, which heats it to a molten state. The filament is then fed through a nozzle and deposited onto the part it is building.

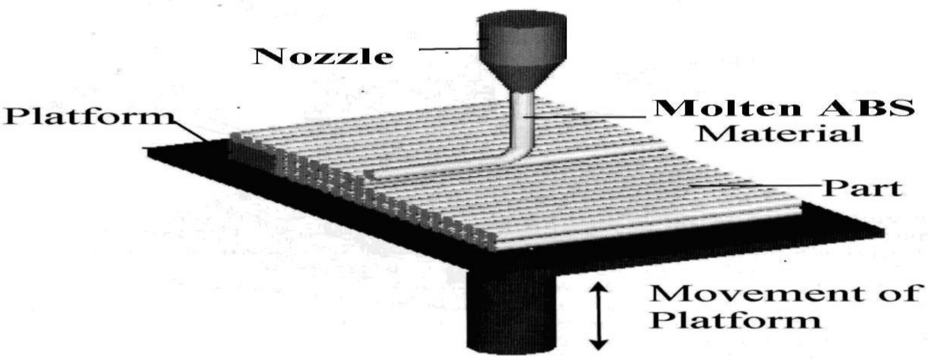


Fig : 3 Fuse deposition modeling process

This aspect is not unlike squeezing toothpaste from a tube. Since the material is extruded in a molten state, it fuses with the material around it that has already been deposited. The head is then moved around in the XY plane and deposits material according to the part requirements from the STL file. The head is then moved vertically in the Z plane to begin depositing a new layer when the previous one is completed. After a period of time, usually several hours, the head will have deposited a full physical representation of the original CAD file.

It is interesting to note that this approach may require a support structure to be built beneath the sections. If one horizontal slice overhangs the one below, it will simply fall to the substrate when the FDM nozzle attempts to deposit it. The FDM machine possesses a second nozzle that 1 Fuse deposition modeling process. Extrudes support material for this purpose. The support material is similar to the model material, but it is more brittle so that it may be easily removed after the model is completed.

**Table1: Capabilities of FDM**

| S. No | Specifications | Details |
|---|---|---|
| 1 | Abbreviation | FDM |
| 2 | Material type: | Solid (Filaments) |
| 3 | Materials: | Thermoplastics such as ABS, Polycarbonate, and Polyphenylsulfone; Elastomers |
| 4 | Max part size: | 36.00 x 24.00 x 36.00 in. |
| 5 | Min feature size: | 0.005 in. |
| 6 | Min layer thickness: | 0.0050 in. |
| 7 | Tolerance: | 0.0050 in. |
| 8 | Surface finish: | Rough |
| 9 | Build speed: | Slow |
| 10 | Applications: | Form/fit testing, Functional testing, Rapid tooling patterns, Small detailed parts, Presentation models, Patient and food applications, High heat applications |

## IV. HOW FUSED DEPOSITION MODELING (FDM) WORKS

In 3D printing, the user first creates a 3D model in a 3D modeling program, saves it as an STL file and the printer’s interfacing software converts the file and slices the model into sections as well as determining how the layers will be printed. Once the model is sent to the 3D printer, the build material is extruded through a heated nozzle layer by layer until the part is complete. The key idea of this new RP technology is based on the decomposition of three-dimensional computer models in the layers section transverse thin, followed physically forming layers and piling layer by layer. The generation of three-dimensional objects in this manner is an idea almost as old as human civilization. The developments since the Egyptian pyramids were probably block developed layer by layer.

3D printers that run on FDM Technology build parts layer-by-layer from the bottom up by heating and extruding thermoplastic filament. The process is simple:

1. **Pre-processing:** Build-preparation software slices and positions a 3D CAD file and calculates a path to extrude thermoplastic and any necessary support material.
2. **Production:** The 3D printer heats the thermoplastic to a semi-liquid state and deposits it in ultra-fine beads along the extrusion path. Where support or buffering is needed, the 3D printer deposits a removable material that acts as scaffolding.
3. **Post-processing:** The user breaks away support material or dissolves it in detergent and water, and the part is ready to use.

## V. MATERIALS OF FDM THERMOPLASTICS

Xy comphigh-performance thermoplastic composites are an exceptional metal replacement for both aircraft interior and aero structure applications. Up to 60% lighter than traditional metals, Xycomp components provide a lifetime of reduced emissions and lowered fuel consumption. And molded-in integration of gussets, bosses, ribs and other features reduces part count over metal assemblies.

Excellent corrosion and fatigue resistance ensures long life and reliable performance. They also meet both FST (flame, smoke, toxicity) standards and the 15-minute burn-through requirement. Leading the way in eco-innovation, Xy comp components utilize a manufacturing process with almost zero waste and are completely recyclable at the end of their service life. Myriad materials are available, such as Acrylonitrile Butadiene Styrene ABS, Polylactic acid PLA, Polycarbonate PC, Polyamide PA, Polystyrene PS, lignin, rubber, among many others, with different trade-offs between strength and temperature properties. Recently a German company demonstrated for the first time the technical possibility of processing granular PEEK into filament form and 3D printing parts from the filament material using FDM-technology.FDM Technology uses the same tried and tested thermoplastics found in traditional manufacturing processes. For applications that demand tight tolerances, toughness and environmental stability – or specialized properties like electrostatic dissipation, translucence, biocompatibility, VO flammability or FST (flame, smoke, toxicity) ratings – there's an FDM thermoplastic that can deliver. Most FDM 3D printers can print with both ABS (acrylonitrile butadiene styrene), as well as a biodegradable bioplastic called PLA (polylactic acid) that is produced from organic alternatives to oil. Within a decade developments in synthetic biological are likely to make the direct production of PLA from a range of biomass materials quite common, hence allowing 3D printing supplies to be grown in many a back yard.However,in case of other FDM materials,very little work has been done both in terms of material characterization and FDM process parameters [3].However,there is no published research articles relating to the FDM process variables for thermal, chemical and dynamic mechanical properties of FDM fabricated parts in other material forms. Therefore, much research work is needed in this area in the future.

Effects of process parameters on surface roughness, tensile strength, compressive strength, flexural, impact strength and dimensional accuracy have been studied. But the study needs to be extended to other types of quality characteristics such as hardness, production time, creep, vibration, product and process cost, porosity and stress strain behavior at high-strain-rate loading conditions.

## VI. PROBLEM FORMULATION

In today's competitive market the quality of parts like surface finish, mechanical strength, dimensional accuracy etc. is most important things to satisfy and attract the customers. In the FDM machine the quality of the parts is highly depends upon the various process parameters of the process.

For that, process parameter optimization of FDM process should be carried out. It will improve the quality of functional parts. There are different methods of optimization of process parameter like factorial design, Taguchi method, central composite design, response surface methodology etc. From these different methods of optimization, Taguchi approach is more powerful technique. Currently high quality of the parts with low cost and in shorter time period is the demands from the users. This is the big challenge so it is necessary to optimize the process parameter of respective machines.

## VII. VARIOUS PROCESS PARAMETERS OF FDM PROCESS

The process parameters help to finding out the correct adjustments of parameters which improve the quality of prototypes. The quality of a prototype is manifested by several parameters. The process variables in FDM are road width, build layer thickness, and speed of deposition, though there are other factors like temperature, humidity and wire diameter.

(i) Build orientation refers to the way in which the part is oriented inside the build platform with respect to *X*,*Y*,*Z* axes.

(ii) Layer thickness is the thickness of layer deposited by nozzle tip and the value of layer thickness depends on the material and tip size.

(iii) Air gap refers to the gap between adjacent raster tool paths on the same layer.
(iv) Raster angle refers to the angle of the raster pattern with respect to the X axis on the bottom part layer. Specifying the raster angle is very important in parts that have small curves. The typical allowed raster angles are from 0° to 90°.
(v) Raster width is the width of the material bead used for rasters. Larger value of raster width will build a part with a stronger interior. Smaller value will require less production time and material. The value of raster width varies based on nozzle tip size.
(vi) Contour width refers to the width of the contour tool path that surrounds the part curves.
(vii) The number of contours to build around all outer and inner part curves and contours may improve perimeter part walls.
(viii) Contour to contour air gap refers to the gap between contours when the part fill style is set to multiple contours.
(ix) Perimeter to raster air gap refers to gap between the inner most contour and the edge of the raster fill inside of the contour.
Build style refers to the way in which the part is filled. It controls the density of the part. There are three types of build styles.
(i) "Solid normal" fills the interior part completely. It will build a part with a stronger interior.
(ii) "Sparse" minimizes the material volume and build time by leaving gaps. It utilizes a uni-directional raster.
(iii) "Sparse double dense" reduces the material volume and build time. It utilizes a crosshatch raster pattern.
Some other parameters are shown as follows.
(i) Visible surface is used to maintain part appearance while allowing for a coarser,faster fill by normal rasters or fine rasters.
(ii) Part fill style determines the fill tool path of the bead to build the solid model.
(iii) Part *Z* shrinkage factor refers to the shrinkage factor applied in the *Z* axis.
(iv) Part *X*-*Y* shrinkage factor refers to the shrinkage factor applied in the *X* and *Y* axes.
Support style refers to the portions of a model that extend outward to prevent the part from collapsing during the building process. It is of four types.
(i) "Basic" is the standard raster tool path support structure. It supports all part features with small support raster curves.
(ii) "Sparse" reduces the amount of support material volume. It uses less amount of material than basic support.
(iii) "Surround" fills the surround small features or small parts. It is used for all parts.
(iv) "Break-away" is similar to "Sparse",but it contains discrete boxes and it is easier to remove than other three types of support structures.
For many engineering applications, surface finish is an important criterion. The fishbone diagram is adapted to evaluate the major factors affecting the dimensional variability of the castings produced. Various process parameters of FDM are shown in Fish Bone Diagram inFig. 4. Several techniques such as signal to noise ratio, ANOVA, Correlation analysis and Regression analysis are used to optimize process parameters. Layer thickness is the propertywhich significantly affects the quality of the prototypes in RP. Therefore, as layer thickness increases, the surface roughness decreases. A correlation analysis can be made between layer thickness and surface thickness. The regression analysis is attempted for layer thickness asit is the dominant factor. The desired surface roughness is to be as less as possible. The surface roughness value that is required is set at 3.15 Ra. And optimum layer thickness is 0.364Ra.

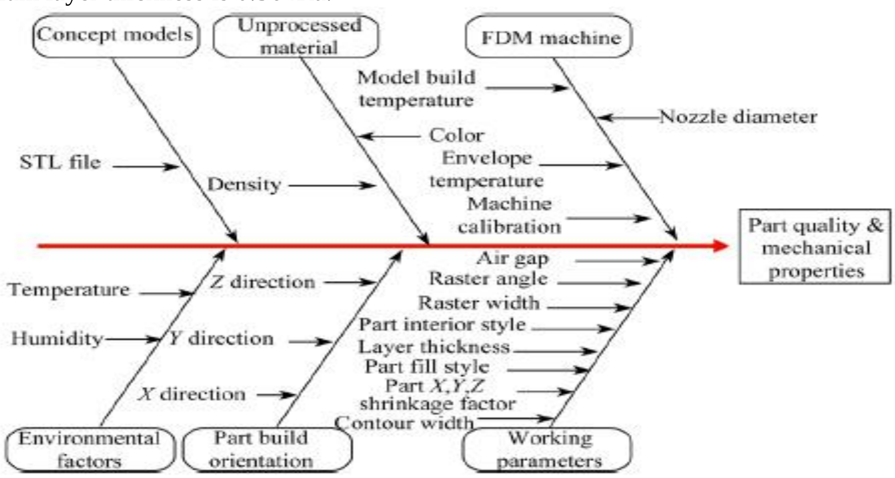

Fig. 4: Various process parameters of FDM as Fish Bone Diagram

## VIII. CHALLENGES OF FDM PROCESS PARAMETERS

As mentioned earlier,different process parameters have effects on the part quality of FDM. Essentially,the quality characteristics of FDM build part such as flexural strength, hardness,tensile strength,compressive strength,dimensional accuracy,surface roughness,production time,yield strength and ductility are the primary concerns to the manufacturers and users. Identifying the optimal process parameters to improve surface finish,aesthetics,mechanical properties, model material consumption and build time is a challenging job for every one. However,there are still no perfect optimal conditions for all types of parts and materials. For most parts,there is always a need to adjust parameters to balance a tradeoff between production time,surface finish,and dimensional accuracy. The properties of the FDM fabricated parts can be controlled by the selected build styles and other FDM parameters. FDM processed parts normally have lower mechanical properties and surface finish than the parts made by conventional manufacturing process such as injection moulding. To improve the part quality and mechanical properties for FDM fabricated parts,it is necessary to understand the relationship between material properties and process parameters. Thus, new mathematical modeling approaches and optimization techniques need to be developed. After reviewing past research works relevant to the areas conducted by the researchers, where main focus was on the optimization of process variables for FDM,the research work leaves a wide scope of improvements and hence more future researches can be performed to explore many aspects of FDM.

To study the mechanical properties and to improve the quality of FDM fabricated ABS parts by optimizing one or several important process parameters is also a challenging job for beginners. From previous studies[4],it has been shown that the quality of FDM built part is highly affected by various process variables. Hence,the identification of the critical process parameters and determination of optimum process parameters can lead to the quality improvement of FDM fabricated part. However,the relationships between the process parameters and the part quality and mechanical properties have not been studied enough especially for various types of materials used by the FDM process. It remains a matter of concern that there are no absolute rules and guidelines designed to assist in their optimization and evaluation method. Thus, there is lot scope with different kinds of materials on FDM.

## IX. BENEFITS OF FDM

The technology is clean, simple-to-use and office-friendly.

1. Supported production-grade thermoplastics are mechanically and environmentally stable.
2. Complex parts, geometries and cavities can be produced with good accuracy and with low cost when compared to conventional manufacturing process.
3. No need for special tooling’s.
4. As simple as printing of copy from normal inkjet printer.

## X. DISADVANTAGES OF FDM

1. FDM is a costlier process.
2. The size of the output product is limited to a very small size.
3. Raw material limitations. (NO metal based filaments can be used due to requirement of high temperatures).
4. FDM is a developing process.

## XI. THE FUTURE OF FUSED DEPOSITION MODELING

Fused deposition modeling is moving in several directions at this time and all indications are that it will continue to expand in many areas in the future. FDM is a new upcoming field. Some of the most promising areas include medical applications, custom parts replacement, and customized consumer products. The potential growth for FDM is in the medical field. As mentioned above, researchers are just starting to experiment with the idea of creating artificial bones with FDM, but the process could potentially be used for so much more. Array of surgeries and more precise surgical and diagnostic equipment based on FDM designs that can be made but not manufactured using traditional means.Therefore certainly a market for FDM can take the industry to new heights.

## XII. CONCLUSIONS

Fused deposition modeling (FDM) isan important Rapid prototyping (RP) technique. It is the one of the key technologies of RP.Itmeets the current needs in the industry to shorten design cycle time and improve the design quality. Various process parameters used in FDM affect the quality of the prototype.Several interesting process parameters and other features of the FDM are revealed.

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