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A REVIEW: FUSED DEPOSITION MODELING – A RAPID PROTOTYPING PROCESS

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Abstract - *Rapid Prototyping involves set of process that can quickly fabricate model or prototype via. Additive manufacturing technique using three dimensional computer aided design (CAD) data. Rapid Prototyping technique are mainly classified into solid based RP, liquid based RP, & powdered based RP system. From these various types of system solid based RP processes are mostly used due to effectiveness & their ability to making impossible geometries possible. In this review paper an attempt has been made to show the details of one of the solid based RP system process i.e. Fused Deposition Modeling.*

Key Words: Fused deposition modeling, Rapid Prototyping, Additive manufacturing.

I. INTRODUCTION

Rapid Prototyping was introduced in late 1980's.RP processes are used for making prototype much quickly & cost effectively. Fused Deposition Modeling is an additive manufacturing technique, which uses layer manufacturing technique for build part, is commonly used for modeling, prototyping & production application. RP is developed by S-Scrott Crum (1980's) & was commercialized by Stratasay (1990's).

1.1 FDM Process

The Principal of Fused Deposition Modeling Process is based on layer manufacturing technique. It involves three basic steps Pre-processing, Production & Post-processing. [1][2]

Pre-processing - Build Preparation software first slices & position 3D STL file & calculates a path for extruding thermoplastic material & any necessary support structure needed.

Production - The FDM head heats the spool or cartage form thermoplastic material, into a semi-liquid state & deposited it in ultrafine beads along the extrusion path. While extruding from the nozzle, it cools & solidifies to form required model. When supports or buffering is required, buffer head deposits water soluble or break-away support material.

Post-processing - The user breaks away support structure or dissolves it by using water. The part is ready to use.

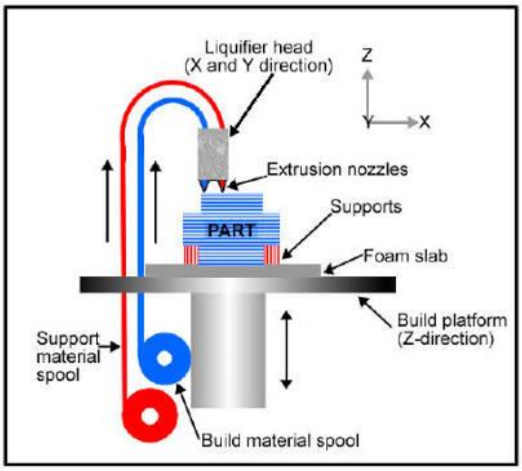

Fig -1: Schematic Representation of FDM Process

1.2 Materials

In FDM process materials are used in two forms, build material for building parts & support material for generating support structure. Most of the FDM machines use thermoplastic materials as build material. Acrylonitrile Butadine Styrene (ABS) & Polylactide (PLA) are the common materials use in FDM process. Apart from this the materials such as polycarbonate, ABS plus thermoplastic, ABS-M30 thermoplastic ,ABS M30i thermoplastic, PC-ABS thermoplastic, PC-ISO thermoplastic, PPSF/PPSU thermoplastic, ULTEM 9085 are also used.[11]

2. Build Parameter Considerations

There are number of parameters need to be consider while preparing to build FDM part. To achieve optimum quality it is require to select the parameters based on application of the build part. Some of the parameters are as follows [5][6]

2.1 Orientation

It refers to the inclination of the part in a build platform with respect to the X-Y-Z axis .The X & Y axis are considered in parallel direction to build platform & Z axis is considered along the direction of built part.

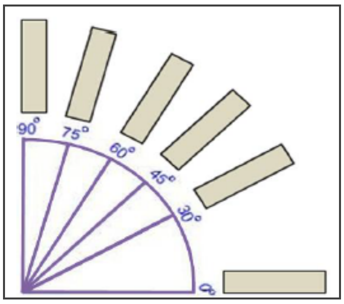

Fig -2: Orientation [12]

2.2 Layer thickness

It is the slice height of each layer measured in the direction as shown in figure.

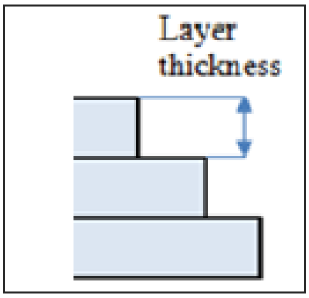

Fig -3: Layer Thickness [12]

2.3 Build style

It is the manner in which the beads are deposited by the FDM tip in each layer during part building process. The types of build styles are spare, solid-normal & spare double. [4]

2.4 Build time

It is the time required to build the model.

2.5 Model build temperature

It is the heating element temperature for model material. It controls on the flow of material while extruding through the nozzle.

2.6 Part Raster Width (raster width):

It is thickness of the bead (or road)) deposited by nozzle on FDM machine

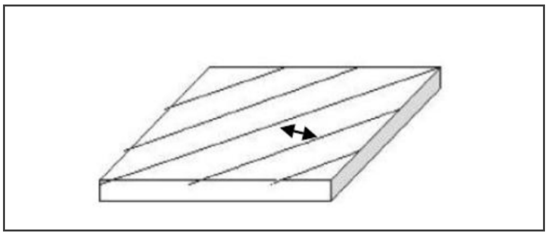

Fig -4: Raster Width [3]

2.7 Raster Angle

It denotes the raster orientation measured from the x-axis on the bottom part layer as shown in figure.

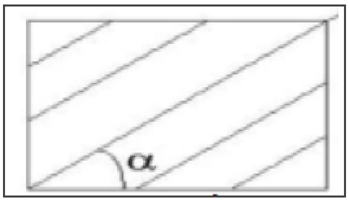

Fig -5: Raster Angle [3]

2.8 Air gap (Raster to Raster gap)

It is the space between the beads of material used in FDM .Positive air gap reduce the build time.

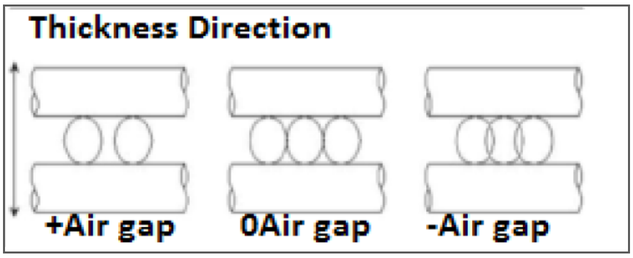

Fig -6: Air Gap [3]

3. Various Approaches for Parameter Optimization of FDM Process in RP Technology

The quality of FDM produced parts are depends upon various process parameters of the FDM process. It can be improved by optimizing the process parameters. For optimization purpose methods such as factorial design, Taguchi method, central composite design, response surface methodology etc are used. From the different reviews it is conclude that Taguchi method is best approach for experimental design because it can be provide simplification of experimental plans and reduced the number of experimental runs. Its tool such as orthogonal array, S/N ratio and ANOVA analysis is helpful in determining the significant factors which affect performance characteristics.[9][10]

4. Surface Roughness

One of the major disadvantages of FDM technique is poor surface finish of parts. A fused deposition modeling (FDM) technology, which uses plastic material, can be effectively used for making patterns for investment casting. The surface finish of the parts made by investment casting depends upon the surface finish of the pattern. Since the patterns are made by using FDM technique, they are not having very good surface finish as compared to wax patterns, which are conventionally used in investment casting. Therefore for useing plastic patterns instead of wax, it is required to improve the surface finish of the FDM parts.

Surface roughness of FDM parts is affected by different parameter such as layer thickness, part build orientation and raster angle. Surface roughness is the function of various process related parameters and can be significantly improved with proper adjustment. Author conducted experiments using response surface methodology and developed mathematical model. He analyzed the response plots to find influence of each factor and their interaction on surface roughness. Experimental result analysis and surface plots concluded that part build orientation has the most significant effect on surface roughness while the raster angle has least significant influence on surface roughness.[14]

In order to achieve good surface finish, various studies have been conducted by many researchers to make FDM parts suitable for investment casting purpose. Literature suggests that there are number of different methods can be used to improve surface finish and each have their own advantages and limitations. Some of the methods are choose suitable build orientation of the part, reduce the layer thickness of build material but it will increase the build time, proper setting of FDM machine parameters, use some post processing techniques such as chemical treatment.[15]
Beside this there are many other methods are there. One of the author used aluminum filled epoxy resin as a filler for improving the wax injection tool fabricated by FDM. This technique has improved surface roughness of wax pattern about 83.85%.

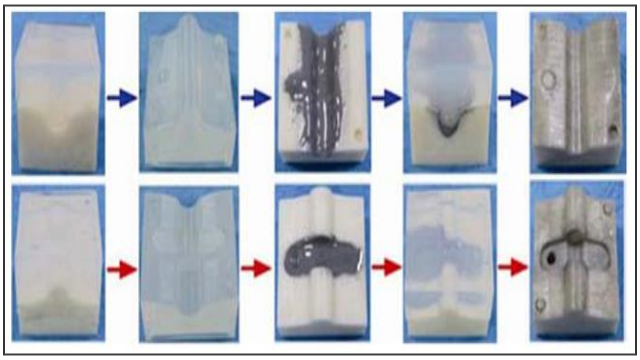

Fig -7: Process flow for improving surface quality of core and cavity of wax injection tool fabricated by FDM [13]

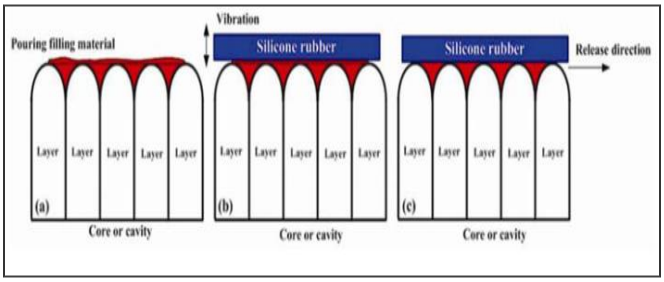

Fig -8: Schematic Representation of filling process of epoxy-based composites.[13]

In one of such studies the authors have applied metal paint on surface of the FDM tool but at temperature above 80ºC the metal paint cannot cope with wax pattern even though it has shown good thermal conductivity. [17]
Similar research was carried out to improve surface of FDM tools by using thin coat of polymer solution followed by providing light sanding using abrasive paper. In this method light sanding using abrasive paper was carried out manually and requires skill. [16]

5. FDM MC Machines

The FDM manufacturing centers (MC) machines provide customers with a compressive range of versatile RP system that are also meant for direct digital manufacturing. All the MC machines are supplied with insights ™ software which imports files with stereo lithography (STL) format.

There are four machines in the FDM MC series, the FDM 200mc, FDM 360mc, FDM 400mc& FDM 900mc The 200mc, & 360mc offers RP & entry level rapid manufacturing using ABC or ABC plus plastics, while 400mc & the newer 900mc offers a wide range of materials including ABS, polycarbonate(PC),PC-ABC blend & polyphenyl sulphon(PPSF) with better accuracy, finer finish & high reputability, making them suitable for rapid manufacturing. FDM offers two methods of support removal. Water Workes ™ & BASS™.

6. Strengths

- **Fabrication of functional parts**-FDM process is able to fabricate prototypes with materials that of the actual molded product. With ABS, it is able to fabricate fully functional parts that have 85% of the strength of the actual molded part and with ABSplus the strengths of the parts can rival those that are injection molded. This is especially useful in developing products that require quick prototypes for functional testing.

- **Minimal wastage**-The FDM process builds parts directly by extruding semi- liquid melt onto the model. Thus, only those materials needed to build the part and its support are needed and material wastages are kept to a minimum. There is also little need for cleaning up the model after it has been built.

- **Ease of support removal-**With the use of Break Away Support system (BASSth) and Water Workth soluble Support System, or the BST and SST on dimension series, support structures generated during the FDM building process can be easily broken off or simply washed away. This makes it very convenient for users to get to their prototypes very quickly and there is very little or no post-processing necessary.

- **Ease of material change-**Build material, supplied inn spool or cartridge form, are easy to handle and can be changed readily when the materials in the system are running low. This keeps the operation of the machine simple and maintenance relatively easy.

- **Large build volume-**FDM machines, especially the FDM 900mc and the Maxum, offer larger build volume than most of the other RP systems available.

7. Weakness

- **Restricted accuracy-**Parts built with the FDM process usually have restricted accuracy due to the shape of the material used, i. e , the filament form. Typically, the filament used has a diameter of 1.27 mm and this tend to set a limit on how accurate the part can be achieved. The newer FDM machines however, have made significant improvement in easing this problem by using better machine control.

- **Slow Process-**The building process is slow, as the whole cross sectional area needs to be filled with the building materials .Building speed is restricted by the extrusion rate or the flow rate of the build material from the extrusion head. As the build materials used are plastics &their viscosities are relatively high, the build process cannot be easily speeded up

- **Unpredictable Shrinkage-**These are generally occur due to rapidly cooling of material on deposition

8. APPLICATION

Global Scenario of Fused Deposition Modeling Stratus's having more than 200+ FDM Systems Installed in Indian Market in various segments like Education, Defense, Government, Automotive, Aerospace, Consumer Goods and Heavy Industries. [2]

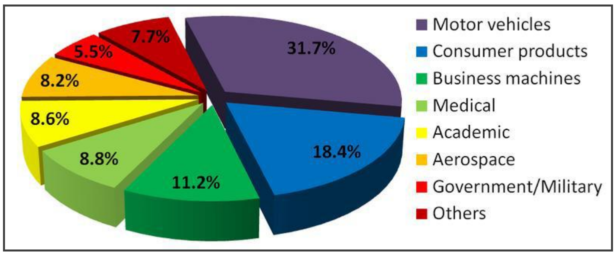

Fig -1: Percentage use of rapid prototyping worldwide [2]

- **In Aerospace-**In Aerospace industries FDM technology used in many applications as it gives flexibility with different thermoplastics designed for aerospace applications. FDM finds application in aerospace icons like NASA (NASA Mars Rover) & Piper Aircraft (Kaveri Engine Project). [8]

- **Models for conceptualization & presentations-** Models can be marked, sanded, printed, drilled &thus can be finished to be almost like the actual product. [7]

- **Prototypes for design, modeling & prototyping testing-**The system can boiled fully functional prototype with ABS or other common plastics used in industries. The resulting parts having more than 85% strength. [7]

- **Pattern & masters for tolling -**Models produced on FDM can be used as a pattern for vacuum forming, investment casting, sand casting & modeling. [7]

9. CONCLUSION

This paper presents brief overview of one of the Rapid-Prototyping technique i.e. Fused Deposition Modeling. It focuses on the working process of the FDM, various parameters involved in it and their effects on surface roughness of the part. From the study it has been understood that the parameters like orientation, layer thickness, raster width and model build temperature directly affects the quality of the part. There are various approaches for parameter optimization of FDM process and different techniques for improving the quality of the part. So by using appropriate optimization method and selecting proper technique quality of the part can be improved.

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