AN OVERVIEW: FUSED DEPOSITION MODELING PROCESS

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Abstract – Termed as Rapid prototyping (RP), it is a phenomenal technique accustomed for instantly fabricating a sample, or a reference model of an assembly or a mere individual part by the means of data obtained from the 3D computer aided design (CAD). This can be further categorized into various systems, but in general into 3 mainline systems namely, solids, liquids and paste. Among these types of systems, the RP that is based on solids are widely used due to their ability of making certain unusual and difficult geometries feasible. Additive manufacturing, as the name suggests build 3D objects, by the virtue of layer by layer additions, and has potential to create any sort of geometries and shapes. One of the most prominent and economical additive manufacturing technique is the Fused Deposition Modeling (FDM) or Fused Filament Fabrication. In the current review paper, exclusive detailing of the technical aspects regarding technique and its description has been attempted.

Keywords: Additive Manufacturing, Fused Deposition Modeling (FDM), Rapid Prototyping (RP).

1. INTRODUCTION

Rapid Prototyping technique came into existence after its introduction in the late 1980s. The processes used in this technique have an added benefit of making the prototypes much quickly & cost effectively. A prominent method for joining individual materials to produce components after layer-by-layer CAD modelling for any particular part is termed as Additive manufacturing (AM). The creation of a virtual solid model is the underlying principle that has been driving almost all AM machines. This is immediately followed by break down of the obtained structures' data into a series of 2D cross-sections. These broken data are further transferred to an AM machine, which combines it layer by layer to develop the actual 3D structure. In 1989, this technique was patented by Crumpin, who later, in the year 1989 started Stratasys Corporation, which works on a basic principle, but is capable of manufacturing impossible geometrical structures. FDM technique has been commonly used for modelling, prototyping & production application. Being a melt extrusion AM based process, as shown in Figure1, there is a feedstock filament given by the device which in turn is controlled by a driving motor.

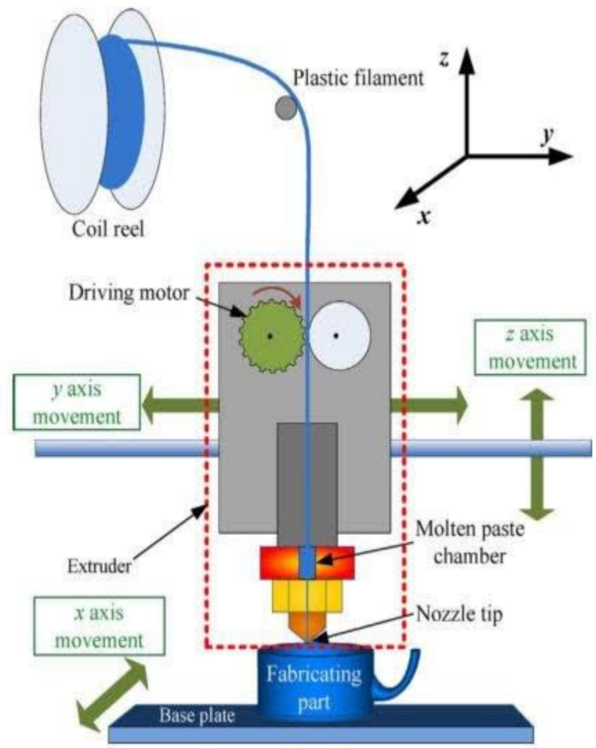

figure – 1: fdm process schematic.

1.1 FDM PROCESS

The entire process is based on the principle of Layer manufacturing technique. This is comprised of three main steps namely, the pre-processing, the production & the post-processing.

Pre-processing – It involves Building algorithm or a software for Preparation, which slices & then positions 3D STL file, which is followed by calculating a path for any necessary support structure and the extruding thermoplastic material required in the process.

Production – Here, spool or cartage is heated by the FDM head, converting it from a thermoplastic material to a partially liquefied state. Now this material gets along the path of extrusion in the ultrafine beads. It is said to get cooled & solidified right while getting extruded from the nozzle, in order to form the desired model. Besides, whenever buffering is required, for depositing water soluble break-away material a buffer head is present for serving the purpose

Post-processing - The support structure can be broken away or dissolved by the user, using water. The obtained model can now be used.

1.2 MATERIALS

Two important categories of materials are used, a build material and a support material for building parts and generating support structure respectively. Mostly, thermoplastic materials are used as build materials by many FDM machines. Polylactide (PLA) and Acrylonitrile Butadine Styrene (ABS) are used commonly. Apart from this, other materials such as Carbonic acid, polymer with 4,4'-(1-methylethylidene)bis(phenol), ABS-M30 thermoplastic, polycarbonate-Acrylonitrile Butadine Styrene thermoplastic, Polycarbonate-ISO thermoplastic, Polyphenylsulfone and Polyphenyl sodium fluoride thermoplastic are also being sought for this purpose.

2. BUILD PARAMETER CONSIDERATIONS

While preparing to build the FDM part, a few parameters are supposed to be taken into account. Based on the application of build part, to achieve better results, optimum parameters have to be selected. Some of them are mentioned below [5][6].

2.1 ORIENTATION:

It is inclining the part in designing structure in context to the X-Y-Z axis .Here, for building its platform, X & Y axes are taken parallely whereas the Z axis on other hand, is considered to be along the direction of built part.

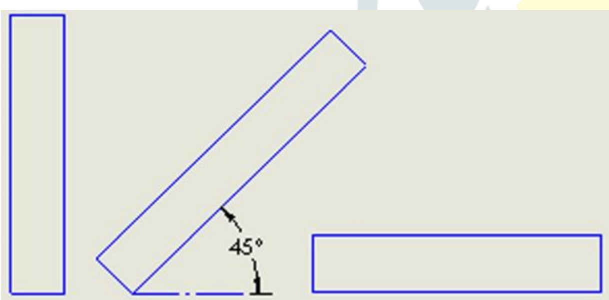

figure-2: orientation [18]

2.2 LAYER THICKNESS:

It denotes the height of the slice of individual layer that is measured along the direction, as denoted in the figure.

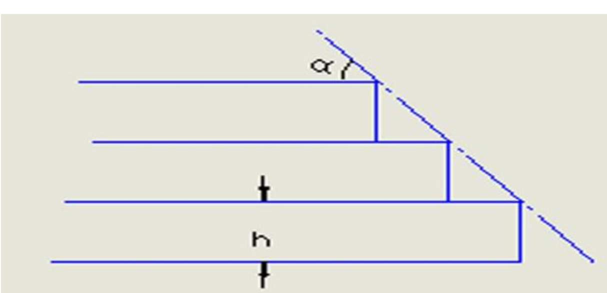

figure-3: layer thickness(h) or height of alices.[19]

2.3 BUILD STYLE:

It refers to the manner during part building process, wherein each layer is deposited with the beads by the help of a FDM tip. Spare, spare double & solid-normal are the types of build styles, in general. [3]

2.4 BUILD TIME:

It refers to the time needed for building a 3D structure.

2.5 MODEL BUILD TEMPERATURE:

This refers to the temperature for heating the model material. In addition, while being extruded through the nozzle, it is said to control the flow of material.

2.6 PART RASTER WIDTH (RASTER WIDTH):

In an FDM machine, it represents the bead's thickness (or a road) that the nozzle deposits.

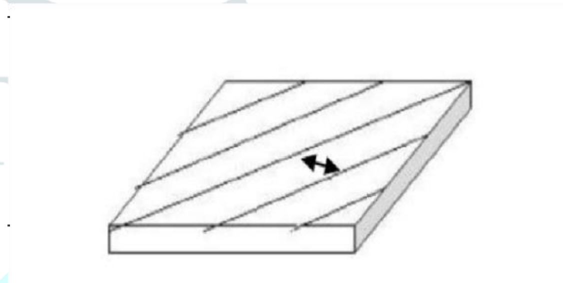

figure-4: raster width [4]

2.7 RASTER ANGLE:

As seen in the figure, it represent the direction of the raster that is scaled on the lower most layer of the model from the x axis

figure-5: Raster Angle [4]

2.8 AIR GAP (RASTER TO RASTER GAP):

As shown in the figure, it is the spasmodic space present between the rasters that are used in the process. Studies have shown that a positive air gap can effectively reduce the build time.

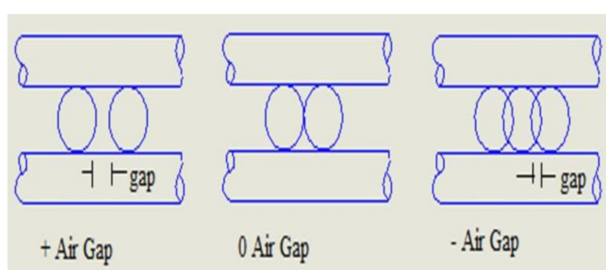

figure-6: air gap.[18]

3. CERTAIN METHODS FOR OPTIMIZING THE PARAMETERS

Since various parameters have pivotal role in altering the quality of the resultant structures via FDM, it is obvious that they can be enhanced by the virtue of optimizing the parameters. Various methods such as gray relational, fuzzy logic, ANN, GA and so on can be employed for achieving this optimization. Based in various studies and reviews it has been concluded that, for experimental design, Taguchi method is best approach in the context that it simplifies the experimental plans and also significantly reduces the number of experimental runs. Certain tools of this method such as S/N ratio, orthogonal array and ANOVA analysis have been proven to be highly reliable in determination of significant factors that tend to create an impact on the performance. [7][10]

4. SURFACE ROUGHNESS

The lost-wax casting makes the structures in the FDM process; the final finish of the surface of these structures is dependent on the pattern's surface finish. Although thermoplastic used in general, can be effectively used to make patterns for lost-wax casting, it is evident with poor surface finishing in the parts as compared to the conventional castings, wax patterns; and this has been considered to be a major drawbackof the technique. Therefore, usage of plastic patterns instead of wax requires an works to be done on surface finishing of the FDM parts for further improvements.
As mentioned above, various factors and parameters tend to alter the surface roughness of FDM parts. Since surface roughness is a reflection of Impact caused by multiple parameters from various processes, significant improvements can be achieved with proper adjustments. An experimental study was carried out using response surface technique and analytical model was developed followed by the analysis of their resultant plots for studying individual factors and the interaction amongst them to find out how they alter surface roughness. Further conclusion was made that a factor imparting notable effect on the surface roughness was the part build orientation, while the one imparting the least was raster angle. [15]

Having studied all these, for obtaining an exceptionally smooth finishing in the surface, multiple scientists and experts have been designing the parts of FDM that would be highly compatible and apt for investment casting. Also, multiple literatures available in in this context state that there are a plethora of methods that can help improve the surface finish, with each one of them having their own pros and cons. Although, some of these methods can choose a particular build orientation thereby reducing the layer thickness of build material, they still fail to decrease the build time and in adjusting the parameters in FDM machine, or require any certain post processing technique like chemical treatments.[14] Besides, there has been a studied method, in which the author uses a filler that comprises of aluminium filled epoxy resin, for improving the tool that helps in wax injection, which is fabricated by this technique. It has been found to improve the surface roughness of wax pattern by a degree of 83.85%.

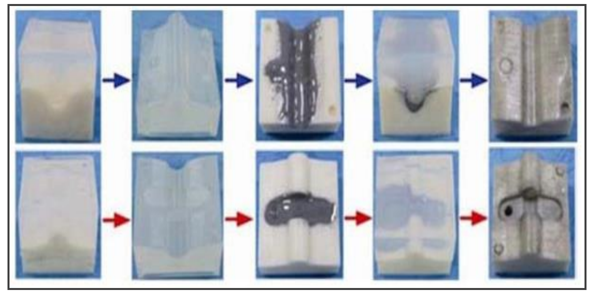

figure -7: workflow for optimizing the surface quality wax injection tool's core as well as the cavity [12]

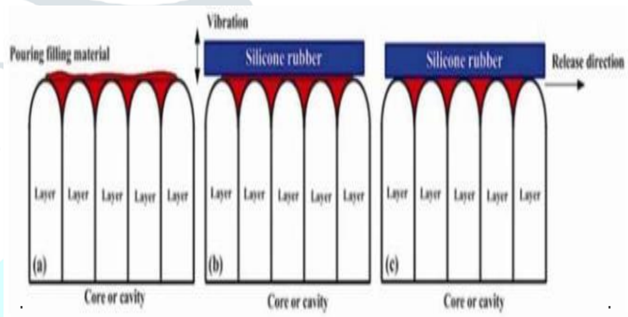

figure -8: schematic representation of filling process of epoxy-based composites. [12]

In another similar study, on the surface of tool that's used for FDM, the authors have applied a metal paint. Although this has shown good thermal conductivity, at temperatures exceeding 80ºC, there is a drastic decline in the coping ability of the paint with the wax. [17]

Another similar research was carried out that involved a thin polymer solution coating and then immediately rubbing with an abrasive paper in order to bring sanding effect; this helps in surface enhancement of FDM tools. But the usage of abrasive paper has to be carried out manually and demands specific hand-on skills for the process. [16]

5. FDM MC MACHINES

For aiding direct digital manufacturing and also for providing a compressive range of versatile RP systems, there is the existence of machines called FDM manufacturing centres (MC). Insights^{TM} software is a platform through which all the MC machines are supplied with and they assist in importing STL format files.

The machines are of 2 important categories: Professional and hobbyistic. FDM 200mc (low-end) and Maxum as well as FDM 900mc (top-end) are the best examples for professional machines whereas, Cube (from 3D system), Replicator (from MakerBot) and Mojo (from Stratasys) are important examples of hobbyistic machines; and these machines come in varied price tags.

6. STRENGTHS

- **Functional parts Manufacture-** FDM is a phenomenon that can manufacture fabricate sample prototypes using the same constructing material used for making the actual 3D structure. With Acrylonitrile Butadine Styrene thermoplastic, the manufactured functional parts of sample prototypes would be 85% strong as compared to 100% of the final 3D structure; he ones manufactured using ABSplus (Acrylonitrile Butadine Styrene plus), possess the efficiency and strengths to rival injection molded parts. This phenomenon is particularly helpful in designing products that need quick prototypes for having their functions tested.

- **Minimal wastage-** FDM process helps in building it by applying the partially liquefied constructing material onto the model. As a result of this, only the materials that are needed for building the part and its support are needed, thereby cutting down on material wastages. Besides, cleaning up of the model is only required marginal after the part has been built.

- **Ease in removal of support** – The extra structures that are usually generated during the FDM building process can be removed by employing BASS^{TM} and WWSS^{TM} on dimension series. This enhances the convenience for short span obtaining of the prototypes.

- **Ease in changing the material** - Handling of the spool or the cartridges, which are the formats of supplied build materials, is easy and can be readily changes whenever there is a shortage of the materials in the system. This helps in simple operation of the machine and also in relative easing of its maintenance.

- **Large build volume-** The machines used for FDM, in specific the top-end machines like Maxum and FDM 900mc, provide increased build volume as compared to the generally available low-end RP machines.

7. WEAKNESS

- **Restricted accuracy-** Accounting the shape of the constructing material used in FDM, there is always limited accuracy in the built parts, in general. Even the filaments used in FDM typically have a radius of 0.635 mm and this limits the accuracy of the part that is to be designed. However with enhancements, the recently developed machines come with tremendous advancements in this area, thereby solving this problem by the virtue of better machine control.

- **Slow Process-** Since the entire volume of the 3D structure to be filled with the constructing material, the process of manufacture is comparatively time consuming. The rate in which this material is extruded from the extrusion head, also acts as a limiting factor for gaining speed. Also considering the fact that it is thermoplastics that are generally used and the relatively viscosity for them are high; it is a tedious job to speed up the process.

- **Unpredictable Shrinkage-** Taking into account the rapid cooling of material on deposition, this has high incidence of occurring.

8. APPLICATION

Taking into consideration the current trend for FDM technique, it can be seen that already more than 250 machines of FDM are in various sectors of the Indian continent, such as in Business sectors, Automobile, Astrionics, Academic workshops, colleges and universities, military sector and hobbyistic purposes. [2]

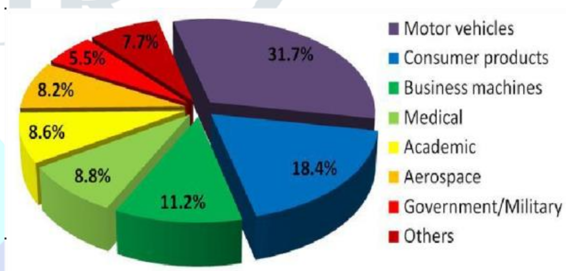

figure -9: pie chart depicting the worldwide distribution of fdm in various sectors [2]

- **In Aerospace-** In Aerospace industries FDM technology is used in many implications because of the fact that it is flexible with different types of thermoplastics that are used in designing for aerospace applications. FDM has been used by major Indian giants in the sector including ISRO & Piper Aircraft (Kaveri Engine Project).

- **Models for conceptualization & presentations-** Models can be marked, sanded, printed, drilled & thus can be manufactured with striking similarity to the final obtained 3D structures. [9]

- **Prototypes for design, modeling & model testing-**The system can boil fully functional prototype with ABS or other common plastics used in industries. And the resulting parts designed from it have shown to have a strength of more than 85%. [9]

- **Pattern & masters for tolling -**Models obtained from this technique gains application in being used as a patterns for investment casting, vacuum forming, as well as sand casting & modeling. [9]

9. CONCLUSION

Covering major concepts and experimental aspects, this paper presents a brief overview of an AM based Modeling using FDM. Having focused on the workflow and on various parameters as well as their effects on the results, this paper also deals with the surface roughness of the part obtained as an end product. The study has also helped us understand the importance of certain parameters mentioned in the due course of the article, and how they interfere with the part's quality. Parameter optimization is another concept that can be achieved by various approaches of FDM process and different techniques in order to have a better quality part. Ultimately proper technique utilization, appropriate performance of optimization followed by suitable analysis of parameters can help in improving the quality of the entire setup.

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