

PARAMETRIC STUDY OF FUSED DEPOSITION MODELING PROCESS

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ABSTRACT-Fused depositions modeling is an additive manufacturing process in which digital three-dimensional (3D) design data is used to build up a component in layers by layer by depositing material. In contrast to traditional manufacturing techniques such as milling and forging which are based on subtractive and formative principles respectively, but, fused deposition modeling (FDM) are based on additive principle for part fabrication process. The major advantage of FDM processes is that an entire 3D consolidated assembly of parts can be fabricated in a single setup without any requirement of tooling / human intervention. Further, the fabrication of part methodology is independent of the complexity of the part geometries. FDM is very useful for various industrial applications in terms of elimination of expensive tooling and flexibility in part fabrication. The major limitation of FDM process is that performance of prototypes are sensitive to process parameter variation. The quality of the product is highly dependent on process parameters. In the present paper, the review has been made to study the some aspects of performance of FDM process. Some important conclusions have been made from the study. From the present study, it is noticed that FDM is very advantageous and well suited for advanced manufacturing industries.

Keywords- Additive manufacturing, Fused deposition modeling, FDM Process parameters, FDM performance parameters

INTRODUCTION

As per American Society for Testing and Materials (ASTM) committee F42 for additive manufacturing technologies (AMT), AMT refers to a process or operation by which digital three dimensional (3D) design data has used to build up a products in layers by depositing material systematically [1]. Since 1980's additive manufacturing processes are using to produce models and prototype parts. Later on as technology advances, these techniques are applying to wider range of advanced applications to make fine finish or quality parts. In additive manufacturing (AM) technique, computer aided design (CAD) has been transforms into thin, virtual, horizontal cross-sections and then creates successive layers until the complete model is made. AM processes are very much useful to create almost any shape or geometric features from simple to complex shapes on the work-piece can be built very quickly. The different AM techniques are: stereo-lithography (SLA), selective laser sintering (SLS), laminated object manufacturing (LOM), fused deposition modeling (FDM), etc. Currently, FDM is using wide range of applications compared to other techniques, because of its ability produce different parts with good output responses. The major applications are medical applications, automotive, aeronautics etc. FDM can also have capability to compete with conventional polymer processing techniques. But only disadvantage in this process is that the range of filaments used for FDM is costly. And availability filaments in the market are also limited which hinders the use of this technology for manufacturing final products. The research works based on FDM is not much reported in the literature. The scope to understand and analyze the process is very high for FDM to make the process more understandable to industries.

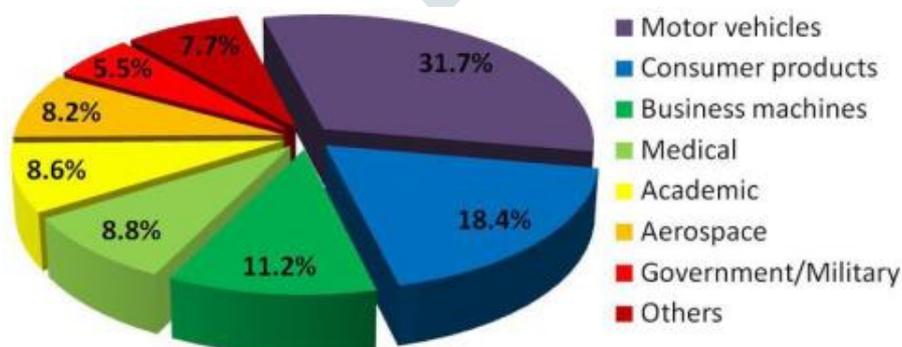


Fig 1: Percentage use of rapid prototyping worldwide[2]

FUSED DEPOSITION MODELING

Fused deposition modeling (FDM) is a one of the important type of additive fabrication or rapid prototyping (RP) / rapid manufacturing (RM) technology used in advanced manufacturing industries. The FDM process was first proposed and developed

by S. Scott Crump in the late 1980s. Later it was commercialized in early 1990s[3, 4].

FDM process also involves basic principles followed by the other AM processes like collection of lasers, powders, resins, etc. The mechanism of the FDM process is shown in Fig. 1. FDM process uses the heated thermoplastic filaments those are extruded from the tip of nozzle in a temperature controlled surroundings. FDM consists of material deposition subsystem (MDS) known as head with two liquefier tips. One tip is exclusively intended for model the material, and other tip intended for support material deposition. During the operation of FDM, both the liquefier tips works alternatively.

The piece forming material is supplied to the head in the form of a flexible strand of solid material. One pair of pulleys or rollers have a nip in flanked by are utilize as material advance mechanism to grip a flexible filament of modeling material and advance it into a heated dispensing or liquefier head. The material is heated above its solidification temperature by a heater on the dispensing head and extruded in a semi molten state on a previously deposited material onto the build stage following the desired tool path. The head is attached to the coaches and it moves along the X-Y planes. The build platform moves along the Z direction. The drive motions are provided to build the platform selectively, and dispensing head relative to drive motions in a predetermined pattern through constrain signals process to the drive motors from CAD/CAM system. Once the build process is completes, the FDM built part can be visualized as a laminate composite structure with anisotropic material properties. The fabricated part takes the form of a laminate composite with vertically stack layers, each of which consists of contiguous material fibres or raster width interstitial voids. Fibre-to-fibre bonding within layers generated by a thermally-driven diffusion bonding process during solidification of the semi-liquid extruded fibres[5, 6].

The quality levels of FDM'ed parts are highly depend on the correct selection of process parameters. The optimum input parametric setting ensures the quality of products, improved dimensional precision, avoid unacceptable wastes and large amount of scraps, enhance productivity rates and reduce production time and cost[7]. The important output responses which are generally consider for FDM products and most important input parameters of FDM are given below:

FDM process parameter: Some of the important process parameters which expected to influence the output responses of the product are given as follows:

- i. Orientation: Part build orientation or orientation refers to the inclination of part in a build platform with respect to X, Y, Z axis, where X and Y-axis are considered parallel to build platform and Z-axis is along the direction of part build.
- ii. Layer Thickness: It is a thickness of layer deposited by nozzle. Thickness layer mainly depends upon the type of nozzle used.
- iii. Raster Angle: Raster angle calculated in the direction of raster relative to the X axis of build table. Specifying the raster angle is very important in parts that have small curves. The raster angles typically allowed for many parts are from 0 to 90°.
- iv. Raster Width: Width of raster pattern used to fill interior regions of any part curves.
- v. Air gap: It is the gap between two adjacent raster's on same layer.
- vi. Number of contours: It is the number of contours built around all outer and inner part curves
- vii. Contour width: It refers to the width of the contour tool path that encloses the component coils.
- viii. Contour to contour air gap: It refers to the distance between contours when the component packing style is set to several contours.

Performance parameters: Some of the important performance characteristics in FDM process are given as follows:

- i. Built time: Fabrication of part using FDM is quite time consuming process so there must be need to minimize the total time required to complete part fabricated using FDM.
- ii. Flexural strength: For getting functioning part fabricated from FDM, part must possess good strength. Strength must be either tensile, compressive or shear depends upon the application.
- iii. Surface roughness: It is treated as quality factor which used to describe quality of the part. It should be optimized for obtaining desired functional aspects of parts.
- iv. Feed stock material consumption: Materials used in FDM are generally costlier. So minimization of material consumption per part is very important.
- v. Dimensional accuracy: It is also considered one of the important performance parameter in optimization of FDM. It is also most affected by process parameters as like other responses.

Methodology for FDM operation: FDM is newly developed advanced manufacturing process which extensively using for producing of almost any type complex shapes on parts. The general working procedure for FDM is given as follows:

- i. First step is to study and understand the concept of rapid prototyping technology, and fused deposition method
- ii. Geometrical modeling of part / job with 3D software's like AutoCAD / CATIA / any other design tool.
- iii. Conducting analysis using ANSYS software to calculate the stresses of given 3D model.
- iv. Making prototype for developed model.
- v. Testing of prototype model.
- vi. Results representation by changing various parameters.
- vii. Graphical plots for representing both temperature and stress across the thickness directions developed model.
- viii. Confirming final product among different combinations.

Fused Deposition Modeling (FDM) is a leading RP technology that is used for fabricating solid prototypes in various materials directly from a computer-aided design (CAD) data. The quality and the strength of the FDM build parts are

dependent essentially on the process parameters.

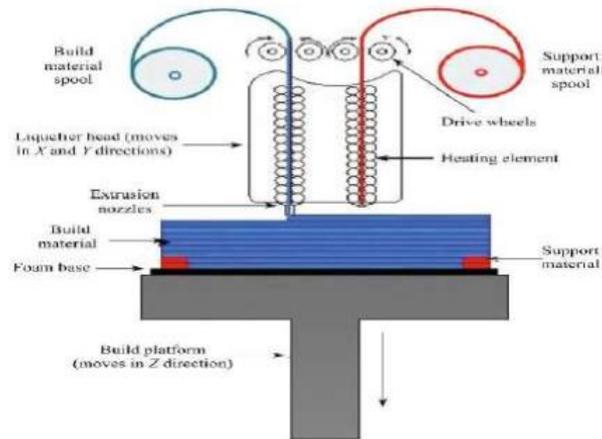


Figure 1: Principle of FDM process[8]

LITERATURE SURVEY

Analysis of FDM has focuses to the performance of process relates input parameters such as orientation, layer thickness, raster angle, raster width, air gap, number of contours, deposition direction of filament roads, road width, gap sizes between filaments, etc. and output responses like part strength, surface quality, build time, dimensional accuracy, etc. In the present paper, literature review has been made to study the recent developments in enhancing the performance of FDM process.

There are significant variations in geometry and properties among identical parts built on different machines. The research work in fused deposition modeling is done considering different machine, material and process parameters. Vikram[9] stated that RP technology can provide flexibility in fabrication of complex geometry shape parts directly from CAD models automatically. Researcher had also presented the brief review of RP Technology related to its advantages: it integrates design and manufacturing into one; it requires minimum time for product design and development; it is capable for producing higher production rates; fully automated process etc. Nicolaean and Ian [10] Presented the important aspects like applications of CAD and virtual prototyping in RP technology to produce physical, hand hold able parts or products. Some of the important aspects related to procedure of RP tools: how to get a good 3D solid model; how to transfer it to RP machines; how to produce quickly a physical prototype; how to increase production, etc., have been discussed. The RP models could be used as master models for vacuum casting, metal spraying, investment casting and other advanced manufacturing processes. Researchers concluded from their study are that rapid prototyping is developed based on concept modeling, functional testing, tooling and manufacturing. Ludmila et al., [11] Discussed the applications of FDM for producing products from different materials such as Acrylonitrile Butadiene Styrene (ABS), polyamide, polycarbonate, polyethylene, polypropylene, silicon nitrate, PZT, aluminum oxide, hydroxyapatite and stainless steel for a variety of structural, electro-ceramic and bio-ceramic purposes. Christopher[12] presented the detailed review of working principles of RP technologies to fabricate metallic parts directly from CAD models. Three specific technologies namely laser engineered net shaping (LENS), selective laser sintering (SLS), and multiphase jet solidification (MJS), and their functional aspects had been discussed and some concluding remarks had been made from the study.

Mohamed et al. [13] studied the influences of input parameters: layer thickness, air gap, raster angle, build orientation, road width and number of contours on build time, feedstock material consumption and dynamic flexural modulus. Investigators had been identified from their study is that process parameters in FDM are highly influencing the output responses. Nidagundi et al. [14] conducted the experimental investigation to study the interactions between the input process parameters: layer thickness, orientation angle and fill angle and output responses: ultimate tensile strength, surface roughness, dimensional accuracy and manufacturing time in FDM process. Panda et al. [15] carried out research work for modeling of FDM for predicting the good output responses by controlling the input parameters like layer thickness, orientation and raster angle. Miguel et al. [16] studied the effect of pattern (i.e. line, rectilinear and honeycomb) and infill density like 20%, 50% and 100% on mechanical properties of desktop 3D printing system. Nuñez et al. [17] studied the effects of different input parameters on quality parameters like dimensional accuracy, flatness error, and surface texture in manufactured products obtained from FDM of ABS-plus material. Lee et al. [18] investigated four important process parameters viz. air gap, raster angle, raster width and layer thickness on elastic performance of compliant ABS prototype material. They concluded from their study is that input parameters have significant effect on elastic properties of ABS material. Kumar et al., [19] studied the influences of FDM parameters namely layer thickness, air gap, raster width, contour width, and raster orientation on surface roughness of ABS- M30i material in FDM operation.

CASE STUDY

As mentioned earlier, obtaining better responses in any manufacturing process is primary aim of the engineer or practitioner. Surface roughness is one of the quality parameters which used to define the quality features of machined part. In the present, the effects of process parameters of FDM on surface roughness have been discussed. Alhubail et al. [20] had reported experimental investigation for studying the significances of input parameters on surface roughness in FDM of ABS- M30i biomedical material. The details of input parameters and their levels are given in Table 1. Researchers applied signal to noise ratio on experimental

data and drawn main effects plots (Fig. 2) for surface roughness.

From the main effects plots of surface roughness of ABS- M30i material as shown in Fig.2, it is found that R_a value is increasing drastically with increase of air gap (B). R_a value is also decreasing drastically with increase of raster width (C) parameter. And significant decrement and increment of surface roughness is noticed with increase of layer thickness (A) and raster orientation (E) respectively. The significance of contour width (D) on surface roughness is small or negligible, as seen from the Fig.2. From the Fig. 2, it is concluded that the variation of the surface roughness (R_a) value is inconsistency with increase of FDM input parameters. Therefore, systematic analysis is required to enhance the performance of FDM operation.

Table 1. Selected Input parameters and their levels (20)

Variable parameters	symbol	Low level	High level
Layer thickness (mm)	A	0.254	0.353
Air gap (mm)	B	0	-0.01
Raster width (mm)	C	0.508	0.80
Contour width (mm)	D	0.508	0.80
Raster orientation (degree)	E	45 ⁰ /-45 ⁰	45 ⁰ /90 ⁰

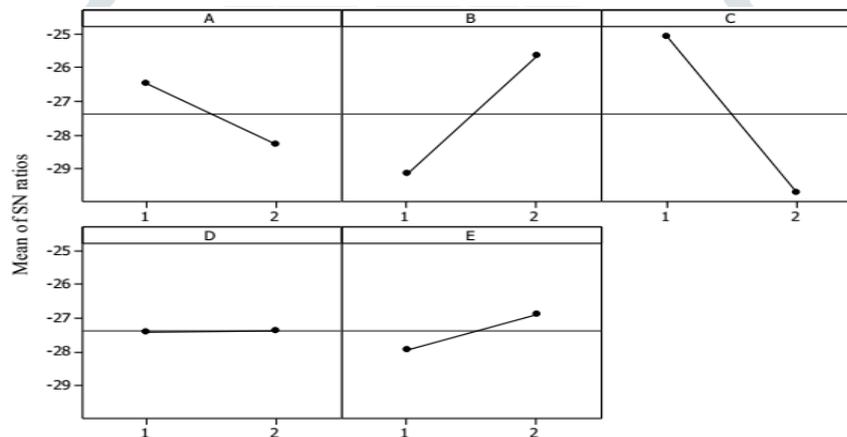


Fig. 2: Main effects for surface roughness[20]

CONCLUSIONS

Present work made to study and review the some aspects in FDM process. The important details about FDM like process information related to input parameters, performance characteristics and methodology, are discussed. The effects of input parameters on surface roughness are analyzed. The followings are the conclusions drawn from the study:

- i. Rapid prototyping (RP) technology is the integration of design and manufacturing.
- ii. Fusion deposition modeling (FDM) process is one of the important additive manufacturing techniques
- iii. FDM process is most useful advanced manufacturing technique which applied to various advanced industrial applications
- iv. The quality of parts produced in FDM is mainly depends on correct selection of parametric combination.
- v. FDM setup and materials used in FDM are costly, so, this process should conduct optimum manner for producing products economically.
- vi. Surface roughness is one important quality factor of parts produced in FDM process
- vii. Surface roughness is influenced by layer thickness, air gap, raster width and raster orientation
- viii. Surface roughness is decreasing with increase of layer thickness and raster width. And it increases with increase of air gap parameter and raster orientation
- ix. The effect of contour width is almost negligible on surface roughness
- x. From the study, it is concluded that systematic analysis and understanding is required to conduct the FDM process economically

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