

PROCESS PARAMETERS CONSIDERATION IN FDM: A CRITICAL REVIEW¹Dr. S. M. Kherde, ²Prof. R. M. Kshirsagar

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ABSTRACT

Additive manufacturing, or 3D printing, has been a popular method of creating prototypes since the 1980s and is quickly becoming the fastest, most affordable way to create custom consumer goods, as well. There are several different methods of 3D printing, but the most widely used is a process known as Fused Deposition Modeling (FDM). FDM printers use a thermoplastic filament, which is heated to its melting point and then extruded, layer by layer, to create a three dimensional object. This paper focuses on the FDM process and Manufacturing technique.

Keywords: Fused Deposition Modeling (FDM), 3D printing & Additive manufacturing

INTRODUCTION

Additive manufacturing technology is an advanced manufacturing technology used for fabricating parts layer by layer directly from a computer aided design (CAD) data file. The process builds objects by adding material in a layer by layer fashion to create a three-dimensional (3D) part, offering the benefit to produce any complex parts with shorter cycle time and lower cost compared to traditional manufacturing process. There are many commercial additive manufacturing systems available in the market but this paper is specifically focusing on fused deposition modeling (FDM). Additive manufacturing process offers an efficient technique of building complicated geometry to shorten the design and production cycle time at the lowest cost due to the absence of any tooling needs.

The technology behind FDM was invented in the 1980s by Scott Crump, co-founder and chairman of Stratasys Ltd., a leading manufacturer of 3D printers [1]. The Brooklyn-based company MakerBot (now owned by Stratasys), was founded on a nearly identical technology known as Fused Filament Fabrication (FFF). FDM is now commonly used for modeling, prototyping, and production applications.

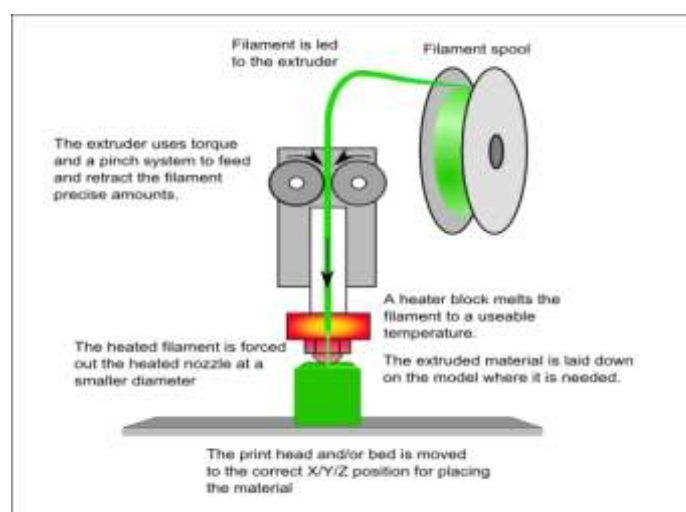


Figure 1: Fused deposition modeling process [2].

In FDM, the material is fed from a spool through an extrusion nozzle where either the nozzle or the platform is moving, so as to again trace the cross-section of the desired part at the given layer onto the platform.

The nozzle has control to turn the flow on/off and in general applications, the nozzle are heated to melt a thermoplastic material, which immediately hardens, solidifying to the layer below it. This process can be seen in the following figure 1. A wide range of materials are available for this manufacturing process such as acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polylactic acid (PLA), PC-ABS blend etc. During printing, these materials take the form of plastic threads, or filaments, which are unwound from a coil and fed through an extrusion nozzle. The nozzle melts the filaments and extrudes them onto a base, sometimes called a build platform or table. Both the nozzle and the base are controlled by a computer that translates the dimensions of an object into X, Y and Z coordinates for the nozzle and base to follow during printing.

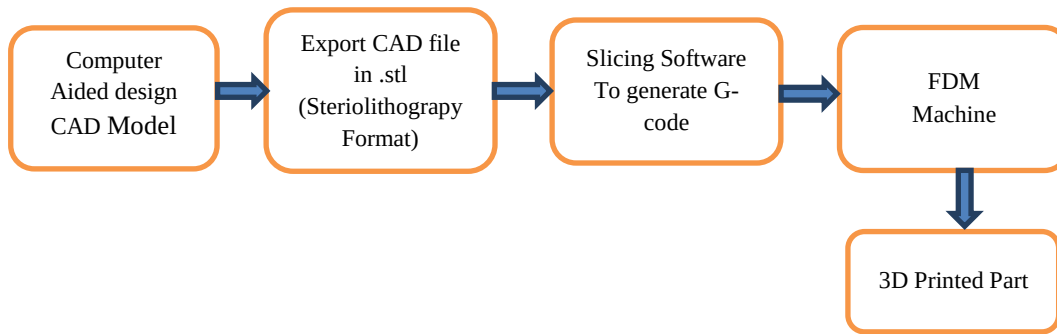


Figure 2: General Flow chart for FDM Printing

FDM PROCESS PARAMETERS

FDM process are required to deliver superior part quality, high productivity rate, safety, low manufacturing cost, and short lead time. In order to meet the customer needs and satisfaction, the additive manufacturing process conditions must be established for each application. The key success of the additive manufacturing process depends upon the proper selection of process parameters. Determination of the optimum process conditions is an important task for production engineers. It plays an important role to ensure quality of products, improve dimensional precision, avoid unacceptable wastes and large amount of scraps, enhance productivity rates and reduce production time and cost. FDM is a complex process that exhibits much difficulty in determining optimal parameters due to the presence of a large number of conflicting parameters that will influence the part quality and material properties. The part quality and mechanical properties of fabricated part can be attributed to proper selection of process parameters.

These FDM processing parameters include air gap, build orientation, infill percentage, raster angle, layer thickness, etc. Depending upon the application, for which the part is manufactured, careful selection of these process parameters, needs to be done.

The main process parameters are described below

- **Air gap:** The gap between two adjacent raster's on a deposited layer. The air gap is called negative when two adjacent layers are overlapped.
- **Build orientation:** Build orientation is defined as the way to orient the part in a build platform with respect to X, Y, and Z-axes.
- **Extrusion temperature:** The temperature at which the filament of a material is heated during the FDM process. Extrusion temperature depends on various aspects, for example, the type of material or print speed.

- Infill density: The outer layers of a three-dimensional (3D) printer object are solid. However, the internal structure, commonly known as the infill, is an invisible inner part covered by the outer layer(s), and it has different shapes, sizes, and patterns. Infill density is the percentage of infill volume with filament material. The strength and mass of FDM build parts depend on the infill density.
- Infill pattern: Different infill patterns are used in parts to produce a strong and durable internal structure. Hexagonal, diamond, and linear are commonly used infill patterns (figure 3).
- Layer thickness is the thickness of layer deposited by nozzle tip, as shown in (figure 4). The value of layer thickness depends on the material and tip size.

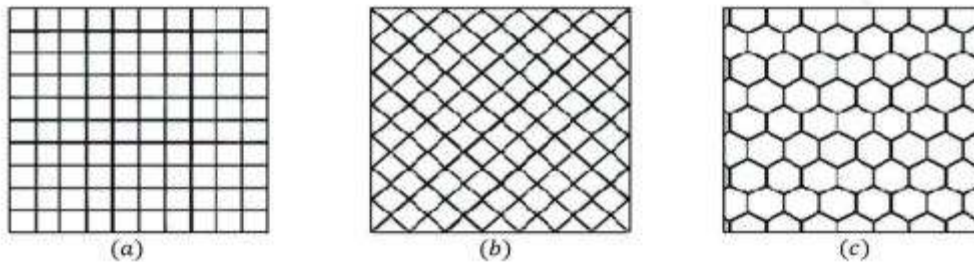


Figure 3: Infill pattern (a) linear (b) diamond (c) hexagonal

- Print speed: This is the distance traveled by the extruder along the XY plane per unit time while extruding. Printing time depends on print speed, and the print speed is measured in mm/s.
- Raster width: Raster width is defined as the width of the deposition beads. It depends on the extrusion nozzle diameter.
- Raster orientation: This is the direction of the deposition bead with respect to the X-axis of the build platform of the FDM machine.

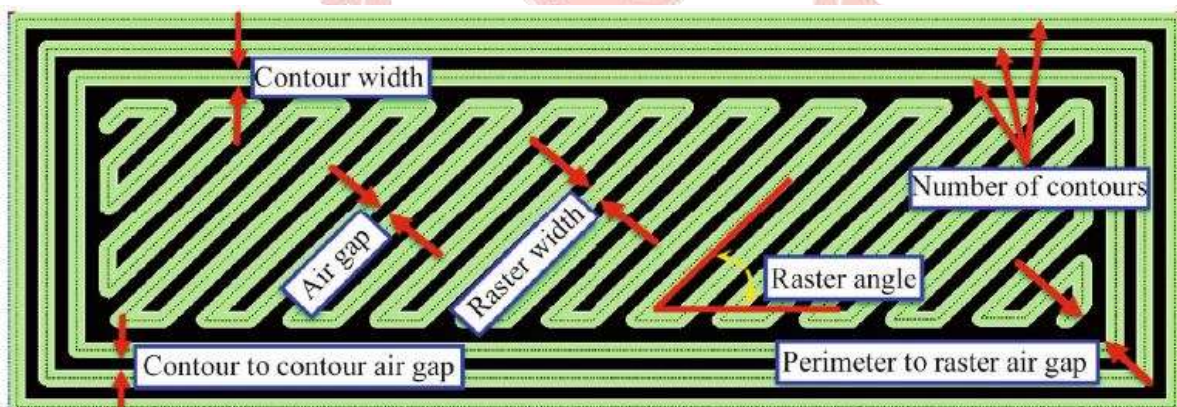


Figure 4: FDM tool path parameter [6].

FILAMENT MATERIALS

In the FDM process, a part is produced by a filament that passes through a nozzle. Different thermoplastics are used as filaments. The commonly used filament materials are described below:

Acrylonitrile butadiene styrene (ABS): ABS, a thermoplastic and amorphous polymer, is one of the commonly used materials to make 3D printed parts via the FDM process. ABS is a copolymer made of acrylonitrile, butadiene, and styrene; impact resistance and toughness are two important mechanical properties of ABS. ABS has a melting point of 230° (standard for printing, although amorphous), which is higher than

polylactic acid (PLA)'s melting point [7]. While PLA is biodegradable, ABS is not, but it offers a lower risk of jamming a nozzle.

Polylactic acid (PLA): PLA is one of the widely used thermoplastics in FDM. The use of PLA is increasing as it is a biodegradable thermoplastic [7]. Also, it needs less energy and temperature to process prototypes and functional parts with good quality. Now, many desktop 3D printers use PLA as a filament as it does not require a heated bed, although it is prone to jamming a printer nozzle during printing. PLA has higher tensile strength, low warp, and low ductility when compared to ABS. For post-processing, PLA built parts required extra care compared to ABS. In Table 1, some important properties of PLA and ABS are summarized. The presented properties will help choose the right filament for the part to be printed.

Polycarbonates (PCs): PCs are a group of thermoplastics known for their good strength, durability, and toughness, and some are transparent. They are high-temperature thermoplastics with good heat resistance, good layer for layer bonding, and they provide a good-quality surface.

Other materials: In addition to the commonly used materials discussed above, there are some other materials that are not commonly used or analyzed as filament materials, for instance, high-impact polystyrene (HIPS), polyphenylsulfone (PPSF), polyethylene terephthalate glycol modified (PETG), thermoplastic polyurethane (TPU), bio-composite filaments, ceramic filaments, and other composite material filaments. Most of these materials are either still in the development process or are not easily obtained on the market.

Property	PLA	ABS
Printing temperature (°C)	180–230	210–250
Build platform temperature (°C)	20–60	80–110
Raft	Optional	Mandatory
Strength	High	Medium
Flexibility	Brittle	Moderately flexible
Heat resistance	Low	Moderate
Biodegradability	Yes	No
Moisture absorption	Yes	Yes

Table 1: Properties of PLA and ABS [4].

CONCLUSIONS

After reviewing above process parameter, it is clear that optimization of process parameters of FDM additive manufacturing technology is one of the most critical design tasks in quality evaluation indicators for obtaining high quality parts, enhanced material response and enhanced properties. There are many different types of FDM machines available in the market. These machines differ in size, build speed, type of material, build volume and range of process parameter settings. To understand the mechanical properties and material behavior of FDM parts, the effects of the process parameters on the quality characteristic of the parts must be studied more thoroughly.

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