# Investigation of Fused Deposition Modeling (FDM) Process Parameters Influencing the Additively Manufactured Part Characteristics: A Review Paper

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**Abstract** The 3D printed parts made by using the additive manufacturing (AM) process are presently high in demand due to many advantages. This includes well-known features such as the cost-effective method of producing customized parts made of thermoplastic material and having a shorter lead time for a wider range of applications. However, it has also a few limitations like poor dimensional accuracy and resolution. Thus, this technology is not suitable for parts having interior details. So, it is very much essential that the parts being produced using this technology must be characterized and analyzed accordingly so as to increase their potential use in the present market. For this, a review paper has been made in order to study all the main characteristics affecting the rise in demand of parts. Several statistical and optimization techniques have been examined and reviewed. The optimal parameters corresponding to the specific characteristics causing an effect to a large extent have been observed.

**Keywords** Additive manufacturing · Process parameters · Fused deposition modeling · Part quality · Part characteristics · Mechanical properties

## 1 Introduction

Additive manufacturing (AM) technology, popularly known by its other names such as rapid prototyping and 3D printing, is a production process used for producing the parts by adding layers in such a manner as one layer placed over another consecutively [1]. The G-codes is exported to the computer numerically controlled 3D printing machine so as to form the object [2]. AM finds its applications when producing complex parts required for medium- to small-sized batches of highly demanding personalized and customized parts and products to have shorter lead times with increased throughput levels [3, 4]. Also, AM helps in reducing the wastage of raw material being used for producing the solid objects, because there is only single

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operation involved in the building of parts [5]. The art of developing a product rapidly is mainly concerned with the following aspects as development speed, development time, product performance, and development cost [6].

### 1.1 Methods and Materials

Out of the various 3D printing technologies, FDM 3D printing technology has been found as the field of study because of many advantages like as it can produce neat, clean and complex 3D parts within the stipulated time [7]. The various 3D printing technologies, depending upon the state of input material (solid, liquid, and powder) along with the basic principles on which these technologies are based, are shown in (Fig. 1).

### 1.2 FDM Process

FDM belongs to the family of material extrusion. In the FDM process, it starts with slicing the CAD data into layers and then this data is imported to the FDM machine. Wherein, the part starts to build up in a layerwise manner as one layer placed onto another over build platform [10]. There is a need of packing the internal structure of the object with the help of outlines or number of contours as per the required response [11].

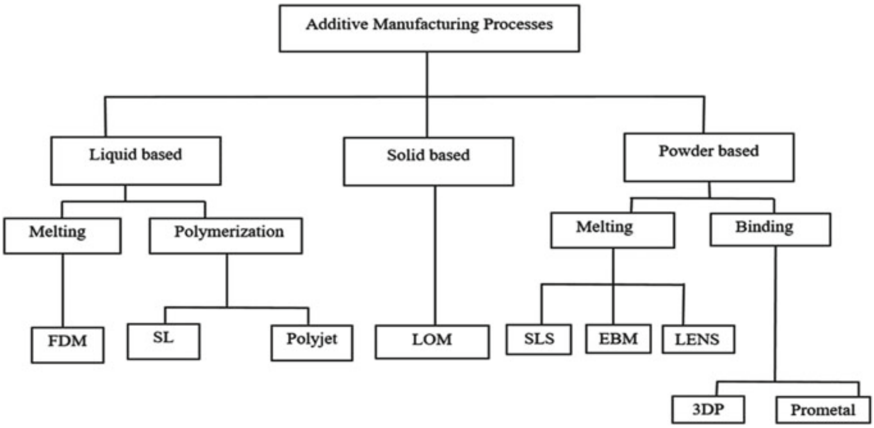


**Fig. 1** Classification of additive manufacturing processes [8, 9]

## 2 FDM Process Parameters Affecting the Characteristics of 3D Printed Parts

The selection of optimized parameters plays a vital role in fulfilling the following qualities of product such as a reduction in material wastage, improvement in quality, high-dimensional accuracy, increased productivity, and reduced production time and cost [12].

### 2.1 FDM Process Parameters

The effect of the selection of process parameters has been observed on the part quality and mechanical properties of a specimen prepared using FDM technique [13, 14]. Table 1 shown below lists the following parameters which are attributed to the characteristics of the specimen made of using FDM 3D printing technology.

### 2.2 Mechanical Properties of FDM Printed Parts

Even though FDM technique has a wide number of applications for which it can be used, but it faces inadaptability to predict its nature of mechanical properties without making the 3D model because of the presence of discontinuity existing in the form of voids in the structure of part [17]. While working on FDM machine for the processing of PEEK material, values of parameters affecting the specimen's properties must not be taking either too high or too low because it may be responsible for affecting the

**Table 1** List of FDM process parameters [15, 16]

| Parameters | Description |
|---|---|
| Build orientation (°) | It gives the information about how the part would be printed inside the build platform or it decides how the part, would be positioned inside build platform concerning x-, y-, and z-axis |
| Layer thickness (mm) | The layer getting deposited overprinting platform after extrusion from nozzle tip forming a thickness or height of layers is known as layer thickness and measures in mm |
| Air gap | It is generally defined as the gap between the raster tools paths located adjacent to each other on the same layer |
| Raster angle | It is the angle made by the raster pattern on the bottom layer along with x-axis. It typically varies from 0° to 90° |
| Raster width | It is defined as the width of the deposited material bead along the path of the extruder tool. Higher the value of raster width causes a stronger interior of the part |

surface finish in a poor manner [18]. The mechanical properties also affect the level of crystallinity, which is found to be affected by the printing temperature [19].

**Tensile Strength of Printed Specimens Using FDM**

Parts to have kept at 0° build orientation over build platform, lying down flat in x–y plane, show the maximum tensile strength [20]. The raster angle also causes to noticeable change in the tensile strength of specimen. The parts with 0° raster angle have been examined to have tensile strength more than the parts where fibers arrange themselves to the applied load direction in parallel manner. "Parameters such as low layer thickness and high raster width result in more bonding area, thereby improving the tensile strength of specimens [21]."

**Compressive Strength of Printed Specimens Using FDM**

From the past published literature, it has been found that higher the layer thickness results in the higher compressive strength of the specimen [22].

**Impact or Fracture Strength of Specimens**

The study done in this regard indicated that impact strength was found to be affected certainly with many parameters such as percent infill, infill pattern, number of contours, and air gap. For 100% infill, it was found to be at its maximum value [23]. It was reported that the specimen has a higher impact strength for the infill pattern as crisscross [24].

**Flexural properties of Specimens**

The various input parameters like air gap, contour width, and number of contours, etc., affect the flexural strength of specimens up to a large extent. However, raster angle and raster width parameters have influenced the most to the flexural strength [25].

## *2.3 Part Quality Characteristics*

The smaller value of part orientation and layer height along with the larger value of raster angle reduces wear [26]. From the viewpoint of literature study for the surface finish, it was found that layer height significantly affects the surface finish of the part [27].

**Build Time/Printing Time Quality Characteristics**

Filling velocity and layer height found to be the significantly affecting parameters to the build time [28].

**Dimensional Accuracy Type Characteristics**

The effect of extrusion temperature has been observed on dimensional accuracy of the specimen [29]. If this is too high, it causes material degradation.

## 3 Results and Discussions

Referring to Table 2 discusses the literature survey conducted up to date for optimum parameters selection in the FDM process corresponding to the output characteristics by utilizing different DOE and optimization techniques.

## 4 Conclusions

The characteristics of thermoplastic materials like PLA, ABS, PC, etc., based on products and the input parameters affecting the characteristics of these thermoplastic-based parts have been studied till now by various researchers. However, there are very few studies on materials such as nylon and composite. Moreover, the attention has been mainly focused only upon the mechanical properties of the specimen made up of using the thermoplastic material. The properties of a specimen such as tensile, compressive, and flexural or bending strength were studied. The input parameters studied were very few. Therefore, there could be a scope to analyze properties with some more parameters (environment factors) that have not been yet tested. Several optimization techniques have been used to find out the optimal process parameter selection and settings as well for the required characteristics of specimen printed using FDM. Thus, there is a need to identify the optimal selection and settings of input parameters required for multipurpose response optimization technique in order to simultaneously investigate the number of outputs at a time.

**Table 2** Literature survey discussing optimum parameters selection corresponding to output characteristics

| Author and year | Research objective | Selected FDM input parameters for optimization | Optimization technique/method or tool | Optimum input parameters setting corresponding to output characteristic of part |
|---|---|---|---|---|
| Torres et al. [30] | Effect of input parameters on FDM specimen in shear with simultaneous optimized mechanical properties | Layer thickness, infill density, and post-processing heat treatment time at 100 °C | Taguchi L9 OA, regression analysis and ANOVA | Highest shear modulus −1265 MPa at layer thickness −0.1 mm, infill −100%, and post-processing heat treatment time −20 min |
| Zaldivar et al. [31] | To study the influence of processing and orientation print effects on the mechanical and thermal behavior of specimen made of ULTEM-9085 material via FDM 3D printer | Build or print orientation | Digital image correlation (DRC) technique | 1. The part standing on the edge of other printed part lying flat in the x–y plane is the strongest specimen |
| Liu et al. [32] | To study the influence of input parameters on mechanical properties of specimen using ANOVA and gray relational analysis as an optimization technique | Deposition or build orientation, deposition style, thickness of the layer, raster width, and air gap | Taguchi L27 OA method, ANOVA, S/N ratio, and gray relational analysis | Flexural strength, impact strength and tensile strength as 50.34 MPa, 83.51 MPa and 23.07 MPa, respectively, at build orientation, layer thickness, deposition style, raster width and raster interval to be 0°, 0.3 mm, 0, 0.5 mm and −0.1 mm, respectively |

(continued)

**Table 2** (continued)

| Author and year | Research objective | Selected FDM input parameters for optimization | Optimization technique/method or tool | Optimum input parameters setting corresponding to output characteristic of part |
|---|---|---|---|---|
| Raju et al. [33] | Finding out the application of a hybrid PSO–BFO evolutionary algorithm for optimization of FDM process parameters | Layer thickness, material as a support, part orientation, solid interior | Taguchi L18 orthogonal array (OA) | For all output responses, the input parameters were selected as layer thickness −0.07 mm, support material −sparse, part or build orientation (°) −60, and model internal −high density |
| Srivastava and Bhaskar [34] | To experimentally investigate the effect of printing parameters of FDM-based 3D printers on average surface roughness | Layer thickness, temperature of the filament at nozzle and print speed | Taguchi L9 OA, ANOVA, response surface methodology (RSM) | Highest roughness was observed at layer thickness −0.3 mm, nozzle temperature −210 °C, and printing speed −60 mm/s |
| Deng et al. [35] | Optimization of mechanical properties for the poly-ether-ether-ketone-based specimen via FDM | Print temperature, layer thickness, printing velocity, feed rate | Taguchi L9 OA, range analysis | 1. Optimum tensile strength as 40 MPa observed at printing speed – 60 mm/s, printing temperature −370° C, filling rate −60%, and layer thickness −0.25 mm.2. For optimum elongation rate as 14.3% at printing speed −20 mm/s, printing temp. −370 °C, layer thickness – 0.25 mm, and filling rate −40% |

(continued)

**Table 2** (continued)

| Author and year | Research objective | Selected FDM input parameters for optimization | Optimization technique/method or tool | Optimum input parameters setting corresponding to output characteristic of part |
|---|---|---|---|---|
| Fitzharris et al. [36] | To study the effect of improvement in interlayer bonding of material extrusion parts made of polyphenylenesulfide using the Taguchi method | Print temperature, heat treatment of time and temperature | Taguchi L9 OA method, S/N ratio analysis | For percent crystallinity and Young's modulus, parameters were observed to be as heat treatment time −10 min, print temperature −300 °C, and heat treatment temperature −180 °C |
| Zaman et al. [37] | To study the impact of (FDM) process parameters on strength of built parts using Taguchi's design of experiments | Layer thickness, number of contours, infill pattern, infill percentage | Taguchi L8 OA method, ANOVA, S/N ratio analysis | The combination of parameters such as layer thickness −0.2 mm, number of contours −4, diagonal as the infill pattern, and percentage of the infill as 70% was found to increase the compressive strength to its optimal value |

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