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A Critical Review of Process Parameters of Fused Deposition Modeling

Jayant Kumar Jha[1] and Andriya Narasimhulu[2]

[1,2]Division of Manufacturing Processes and Automation Engineering
Netaji Subhas Institute of Technology, New Delhi-110078
E-mail: [1]jayantjha90@gmail.com, [2]andriya.nsit@gmail.com

Abstract—*Fused deposition modeling popularly acronymic as FDM is most used extrusion-based additive manufacturing process. Low-cost operation of this process makes this process more favorable and important as application point of view. This paper comprises of a brief review of the process variable on the properties of processed part and application of FDM while explaining process fundamentally. This paper helps in outlining the FDM process as well as defining further research direction. In addition to the process variable, this review presents a sketch of the mechanical properties and surface morphology of FDM processed parts.*

Keywords*: Fused Deposition Modeling, Process parameter optimization, Mechanical Properties, Surface finish, Additive manufacturing.*

1. INTRODUCTION

Earliest design and development of FDM machines were done by Stratasys [1].FDM process is a filament extrusion-based process. It consists of CAD systems, material selection, automation using computer numerical control and extrusion process to manufacture 3D parts directly from a CAD model[2].Usually, FDM is done in four phases[3]:

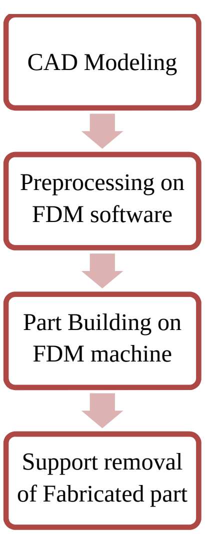

Figure 1: Different Phases of FDM process

- CAD modeling–A solid model is being created on CAD system, and then converted into an STL format by tessellating the model to make a faceted approximation of the model.
- Preprocessing on FDM software–Preprocessing includes estimating the part orientation, slicing into the thin layers, selection of FDM parameters and how the supports are being generated.The further preprocessed file is then fed into the FDM machine.
- Part Building on FDM machine–In this process, polymer material in the form of coil reel or spool is heated into the molten state in a liquefier head, and further extruded out to deposit a thin layer onto the platform. This layer by layer process repeats until the required thickness is not obtained.
- Support removal of fabricated parts -Completed parts are removed from FDM machines and support structure are directly cut out from the model.

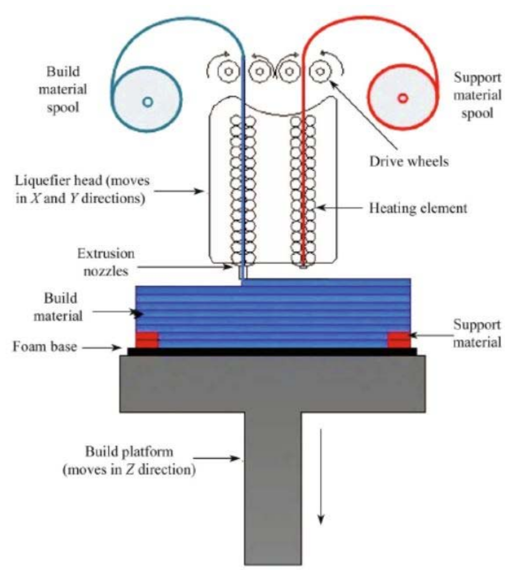

Figure 2: FDM process[4]

FDM process one of the most commonly used additive manufacturing for modeling, Prototyping and manufacturing applications. Numerous materials can be processed with FDM. Some of the common FDM materials are acrylonitrile butadiene Styrene (ABS), polycarbonate (PC), PC – ABS mixture blend, Polylactic acid (PLA), Polycaprolactone (PCL), Polymethyl methacrylate etc.[5]. Some of the advantages of FDM are reliability, safety, no material wastage, wide available manufacturing method, large number of polymer system, ease of material change, simplicity of removal of location support yet it has some drawback like surface finish and accuracy, build speed, feedstock element anisotropic properties and layer thickness option limited to 0.078 mm.

2. FDM PROCESS PARAMETERS

Due to the requirement of highly perfect parts, building high-quality parts, higher productivity rates, reliable, low-cost manufacturing. In order to achieve this process parameters must be controlled.FDM is a highly complex process which shows difficulty infinding the optimal parameters because of the presence of a huge number of interacting parameters that will affect the quality and properties of the obtained parts. The part quality and properties are dependent on the proper selection of process parameters. Figure 2 represents all the parameters while encountering the FDM process that need to be optimized.Usually, parameters can be divided into two categories i.e. pre-processing parameters and working parameters. Some of the working parameters are slice height, Model tip size, Model build temperature, Raster width, Raster Angle, air gap, part fill style, part interior style.

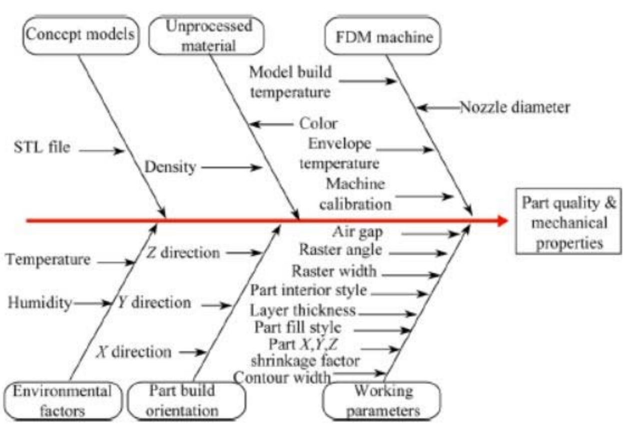

Figure 3: Ishikawa diagram or cause and effect diagram [4]

Alafaghani et al[6] investigated six parameter effects on mechanical properties, dimensional accuracy, and repeatability. Six parameters were building direction, printing speed, extrusion temperature, layer height, infill percent and infill patterns. For dimensional accuracy and repeatability manufactured parts were compared from the 3D CAD model. For mechanical properties, tensile test was conducted on the manufacturedspecimen.In addition, FEM analysis was also conducted. It was found that dimensional accuracy was dependent on building direction, extrusion temperature and printing speed whereas mechanical properties was dependent on building direction, extrusion temperature and printing speed significantly. Figure 3 and Figure 4 shows this.

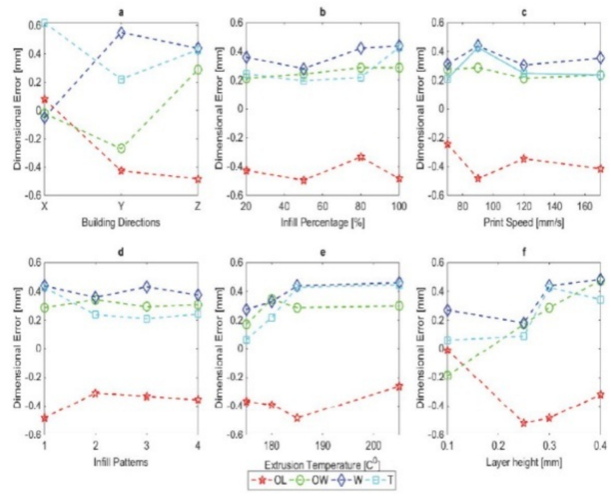

Figure 4: Dimension accuracies found due to process parameters[6]

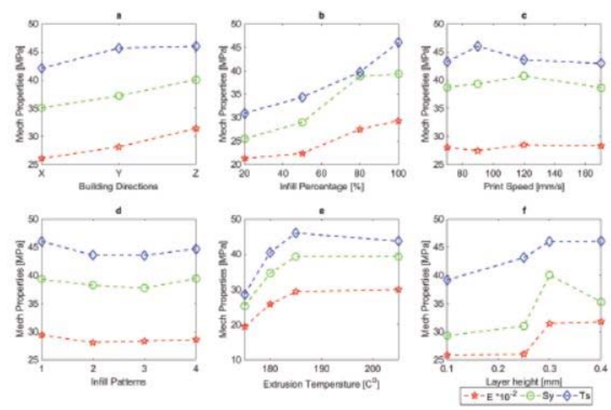

Figure 5: Resultant mechanical properties plotted against the parameters [6]

Pollard et al [7]investigated the fluctuation of filament temperature due to a change in feed rate and start/stop motion. Monitoring of temperature was done using thermal camera and thermostats. They concluded that variation of filament temperature can cause low strengthening of the part as low filament temperature leads to low feed rate and hence low strength in part. He et al [8] also investigated the effect on the surface integrity of produced parts for different parameters. They developed a mathematical model for quantifying this. They found that good quality surface can be found by controlling the speed of the filament by synergizing filament driving motors and axis driving motors. Mahmood et al [9]optimize the dimension and tolerance control using Taguchi orthogonal array method. In this approach, they considered 13 variables for optimization for the geometrical characteristics. Moramarco et al [10] measured the residual stress developed in manufactured part due to rapid cooling and heating of the feed and their effect on the specimen. They concluded that residual stress may plays a prominent role in the warping effect of the specimen. Berretta et al [11] manufactured carbon nanotube (CNT) reinforced poly ether ether ketone composite from FDM process. In this study, they analyzed the layer to layer bonding using shear beam test. Galantucci et al[12] compared the surface finish of undipped anddimethylketone–water solution dipped surface for FDM processed parts. DOE method is used to find the mechanical properties of treated and untreated parts. They find that properties enhance with the application of treatment. For a minor reduction in tensile stress, surface finish enhances more. Kozier and Kundera [13] conducted some experimentation for mechanical properties like Young’s modulus and stress relaxation for the uniaxial test. Selected parameters are location and direction of the models on a virtual platform. Experimentation result shows that the effect of print direction on rheological properties of the materials. Figure 5, 6 and 7 shows this.

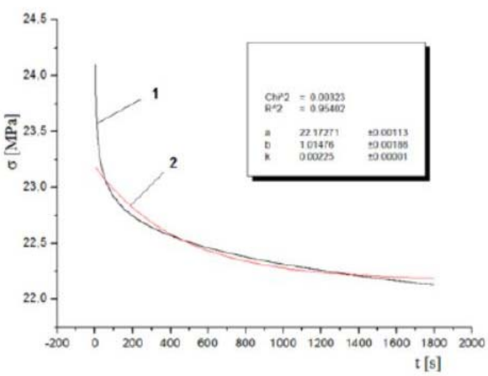

Figure 6 - The relation of stress versus time for a sample at an angle of 0° relative to the building platform[13]

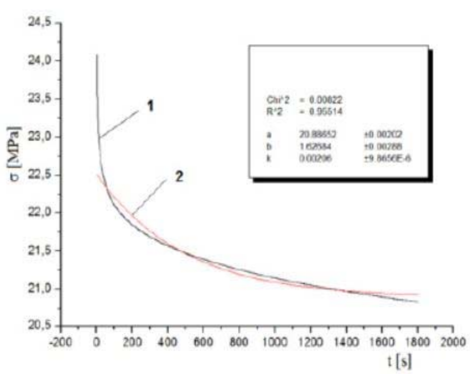

Figure 7: The relation of stress versus time for a sample at an angle of 45° relative to the building platform [13]

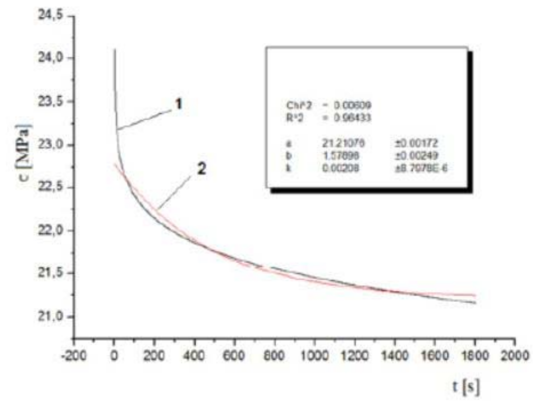

Figure 8: The relation of stress versus time for a sample at an angle of 90° relative to the building platform[13]

Sood et al [14]optimize the process parameters in FDM by advance algorithm techniques like particle swarm optimization and artificial neural network (ANN) They included five parametersin their study named as layer thickness, part buildorientation, raster angle, raster width and air gap on the compressive strength of the obtained part. They concluded that fiber bond strength needs to be strong for higher compressive strength which can be done by optimizing the distortion.Thrimurthulu et al [15]studied attentively towardsoptimizing the part deposition orientation in fused deposition modeling process. This optimization leads to better surface finish and lesser build time.This study posits a pathway for optimization of two contradicting objectives such as build time andaverage part surface roughness are optimized by minimizingtheir weighted sum.Two case studies were also presented todemonstrate the capabilities of the system.

3. SUMMERY

We have presented some brief cases about FDM process parameters in the literature. We have concluded that need for studying other properties or parameters like porosity, hardness, creep, vibration is required. Currently major studies are going on only to tensile strength, compressive strength and tribological studies. Another area is also theoreticalmodeling of the FDM process parameter need to be well understood.

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