Optimizing Process Parameters of FDM Printer using Design of Experiments Method

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Abstract - *Fused Deposition Modeling (FDM) is a 3D printing technology that is used in many 3D printing processes. While printing part, many process parameters of the printer are required to be considered. Such process parameters affect the mechanical properties such as strength and processing time of the part. To achieve optimum quality of the part, these process parameters set differently according to the requirement of the application. In this study, three parameters (layer thickness, printing speed, infill density) each having three levels are considered. Taguchi's Partial factorial DOE method is used. For the analysis orthogonal array L9 is used. The optimization is done using Taguchi's S/N ratio analysis method. The optimum strength obtained by analysis is 32.211 MPa with a processing time of 82 min. It is obtained for the layer thickness of 0.3 mm, printing speed of 40 mm/min, and at 100% infill density.*

***Key Words*: Fused Deposition Modelling, Design of Experiment, Signal to Noise ratio, Infill density, and orthogonal array.**

1. INTRODUCTION

Additive manufacturing is a technique in which layer by layer deposition of material takes place which produces a 3D object from a CAD model. In FDM, the material is feed in to the nozzle. In the nozzle the material is melted and extruded to create the layers of required thickness to produce the 3D object. Therefore, FDM is based on the extrusion principle. In FDM mostly two materials are used. Those are PLA and ABS. But as PLA is a biodegradable thermoplastic, having excellent mechanical properties, chemical resistance, and good surface finish also its melting point is 1800 – 2000 which is low as compared to ABS, so in this study PLA material is chosen over ABS.

In FDM different process parameters such as layer thickness, part orientation, infill density, infill pattern, printing speed, nozzle temperature, raster angle etc. have impact on mechanical properties and printing time of 3D object. In this study, three parameters are selected such as layer thickness, printing speed and infill density. Using CAD, 3D model of object is prepared and then STL file is given to the CURA software which generates G-Code and using this code object is produced in the printer. Then the partial Taguchi analysis is performed to obtain the optimum set of selected parameters using Minitab V18.0 software.

2. LITERATURE REVIEW

Jibisha Blessie et. al. studied the impact of printing process parameters such as printing pattern and infill density on pattern of PLA material on tensile strength of the FDM printed parts. The optimization is performed to obtain maximum tensile strength [1]. V. Durga Prasad Rao et. al. studied the effect of layer thickness, print temperature, and infill pattern on tensile strength of carbon PLA specimen using ANOVA analysis. In this study, he has found that layer thickness have high impact on tensile strength of material [2]. Abhinav Chadha et. al. studied the impact of bed temperature and layer thickness of pattern on tensile strength and bending strength of part. It was found that bed temperature and layer thickness have significant effect on the strength of component [3]. A. E. Tontowi et. al. studied different parameters to improve the quality of PLA printed part. In this study three parameters are such as layer thickness, raster angle and temperature are considered and using Taguchi method and Response surface method analysis was performed. In this study tensile strength is taken as response variable [4]. T. Nancharaiah studied effect of various parameters like layer thickness, air gap and raster angle on processing time. For this study partial factorial method of DOE is used and data was analyzed using Signal to Noise ratio and ANOVA technique. It was found that layer thickness parameter have significant effect on process time of component [5].

3. EXPERIMENTAL WORK

3.1 Design of Experiment

Design of experiment (DOE) is an optimization tool introduced by the Taguchi to improve the products quality. As like fishbone (Ishikawa) diagram it gives cause and effect relationship. Design of experiment is a method which is used to determine the impacts of process parameters on the output of the process. It is method which determines the impact of multiple parameters on the response variables. DOE is a statistical process to find out the minimum number of experiment required to perform, so that optimum output parametric values are obtained.

$$\text{Full Factorial DOE} = \text{Level}^{\text{Factor}} \quad \text{..... (equation 1)}$$

$$\text{Partial Factorial DOE} = \text{Level}^{\text{Factor}-1} \quad \text{..... (equation 2)}$$

In this study partial factorial DOE method is used. Procedure followed for design of experiment contains first to find out the response variables to be optimized. Then the process is selected is parameters levels. With the use of MiniTab software appropriate orthogonal array was determined. Lastly data was analyzed using signal to noise ratio to determine the optimum set of parameters.

Table -1: Parameters and its levels

Factors	Level 1	Level 2	Level 3
Layer Thickness (mm)	0.15	0.22	0.30
Printing Speed (mm/min)	40	45	50
Infill Density (%)	20	50	100

Parameters and their levels chosen for the analysis of process are mentioned in the above table. It was found that layer thickness, printing speed and infill density have large effect on various properties of 3D printed object.

3.2 Orthogonal Array

Orthogonal array is a matrix which is used to determine all possible combinations of factors and their levels. Orthogonal array gives the information about number of experiments which are to be performed, based on number of input parameters and their level selected. In this study the L9 orthogonal array is designed for three parameters and three levels. Hence, total 9 dogbones are printed using printer as per the experimental set of an orthogonal array.

Table -2: Orthogonal Array

Experiment No.	Layer Thickness (mm)	Printing Speed (mm/min)	Infill Density (%)
1	0.15	40	20
2	0.15	45	50
3	0.15	50	100
4	0.22	40	50
5	0.22	45	100
6	0.22	50	20
7	0.30	40	100
8	0.30	50	20
9	0.30	45	50

Above orthogonal array with three parameters and three levels is used to print 9 dogbone shapes for the process.

3.3 3D Printing Process

Fused Deposition Modeling (FDM) is an additive manufacturing technique, based on the extrusion principle. In the nozzle head the material is feed in the solid filament form. In the nozzle head, the material is heated up to its melting point. The liquefied material is extruded through nozzle and layer by layer material is deposited on the bed till the object is printed completely. Ultimaker CURA is slicing software in which the object is sliced into number of layers. The Computer Aided Design model is converted into STL format and it is imported into CURA software. In the software, given STL file is converted into G-code which is then provided to the 3D printing machine.

All required parameters are provided in the CURA software which then converted into G-code. Depending upon the factors layer thickness, printing speed and infill density values are determined. The bed temperature and printing temperature kept same for all levels as those parameters were not considered in this study. Nozzle diameter of machine is always kept constant throughout the process.

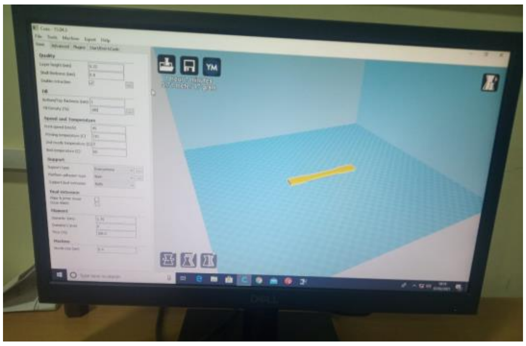

Fig 1: Ultimaker CURA Software

CURA software windows is shown in above figure in which various parameters like infill density, layer thickness and printing speed values were provided to print the required dogbone shape. Three different levels of printing parameters were used to print the nine dogbone shapes. Layer thickness refers to the thickness with which the component is printed. Layer thickness of 0.15 mm, 0.22 mm and 0.3 mm were used in this analysis to print the shapes. Infill density provides us information about the material present inside the object. A object is hollow if infill density is 0% and dense if infill density is 100%. Infill density has direct relation with strength of shape printed and time required for printing. In this project PLA material is used because PLA have low melting point of about 185^0C to 220^0C and its thermal properties are also stable means it cools down in less time and its expansion rate is less.

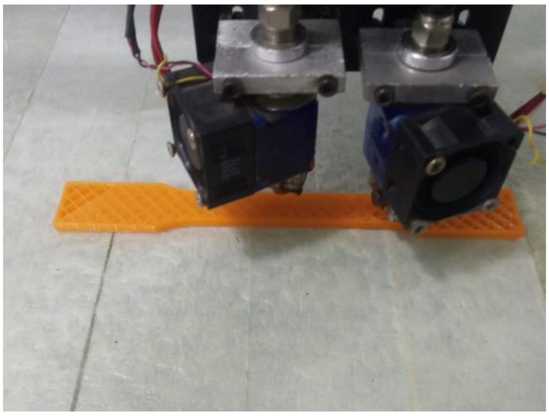

Fig 2: FDM 3D Printing Machine

Printing of 3D dogbone shape is shown in above figure. In 3D printing FDM machine component is printed layer by layer and nozzle moves in required axes to deposit each layer of required thickness. Depending upon the printing parameters time varies for printing the required shape.

3.4 Tensile Test

Specimen required for tensile test were prepared using ASTM standard D638 for which model was prepared in Computer Aided Design software CATIA and then this was stored in STL format and imported into CURA software for 3D printing.

Fig 3: Mounting of specimen for tensile testing in UTM

Fig 4: 3D printed specimen tensile tested in UTM

UTM machine is shown in above figure. Tensile tests were conducted according to ASTM D638 standard. Tests were carried until the fracture of specimen and changes in specimen were observed after testing. Total 9 dogbone shape specimen were tested in UTM and their tensile strength was determined.

4. RESULTS AND DISCUSSION

Tensile testing was carried out for 9 dogbone shapes and their strength for combination of different printing parameters was determined. Tensile testing was carried using ASTM standard for which specimen having width of 10 mm and thickness of 5 mm were used.

Table -3: Printing time and tensile strength of printed specimen

Exp No.	Layer Thickness (mm)	Printing Speed (mm/ mn)	Infill Density (%)	Printing Time (min)	Tensile Strength (MPa)
1	0.15	40	20	125	15.579
2	0.15	45	50	132	13.474
3	0.15	50	100	165	29.053
4	0.22	40	50	91	15.684
5	0.22	45	100	128	24.737
6	0.22	50	20	68	14.947
7	0.3	40	100	82	32.211
8	0.3	45	20	52.31	14.316
9	0.3	50	50	69	13.684

Printing time and tensile strength of 9 specimens are shown in above table.

4.1 Optimization

Using Taguchi method optimization of printing parameters was carried out.

Table -4: Response table showing Signal to Noise ratios

Level	Layer Thickness (mm)	Printing Speed (mm/min)	Infill Density (%)
1	-0.6614	1.1271	0.6353
2	0.4250	0.3424	-0.2453
3	2.1835	0.4778	1.5572
Delta	2.8449	0.7847	1.8025
Rank	1	3	2

Table -5: Response table showing Means

Level	Layer Thickness (mm)	Printing Speed (mm/min)	Infill Density (%)
1	80.02	60.25	48.36
2	57.06	60.81	55.81
3	43.92	59.95	76.83
Delta	36.10	0.86	28.47
Rank	1	3	2

From the table it was found that highest SN ratio for layer thickness is 2.8449 for 3rd level, highest SN ratio for printing speed is 1.1271 for 1st level and for infill density is 1.5572 for 3rd level. Hence, optimized parameters to maximize the printing time and tensile strength were obtained from the response table. The maximum strength and least printing time were obtained for 0.3 mm layer thickness, 40 mm per minute and infill density of 100%.

Delta value for layer thickness is 2.8449 which is highest and for printing speed it is 0.7847 which shows that layer thickness have highest impact on printing time and strength of component while printing speed have least impact on these parameters.

The figure describes the main effect plots for SN ratio and means. It also shows that layer thickness is the highest influencing parameter for strength and printing time while printing speed is least influencing parameter.

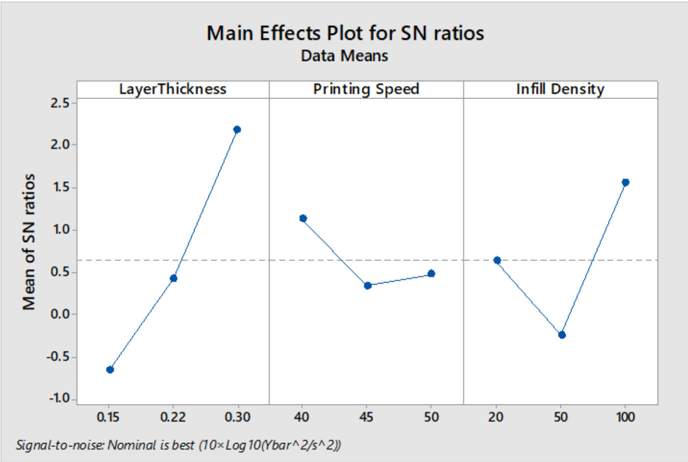

Fig -4: Main effect plot for SN ratios

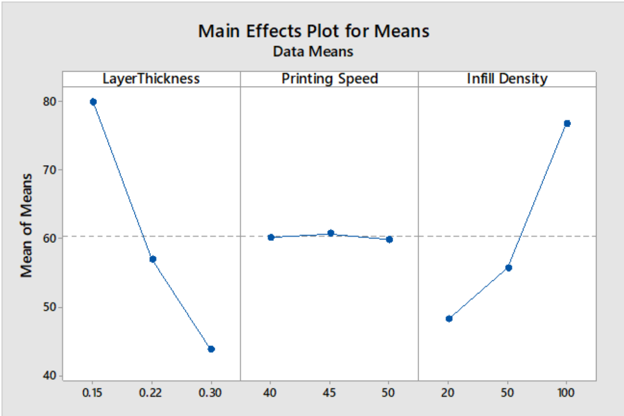

Fig -5: Main effect plot for means

Above plots describes the main effect plots for SN ratio and means. From these plots it can be easily seen that printing speed is the most inflecting parameter affecting the printing time and tensile strength of 3D printed PLA specimens.

5. CONCLUSION

In this study impact of various printing parameters of FDM technique on the mechanical properties like tensile strength and printing time of PLA material is analyzed. Effect of various parameters like printing speed, layer thickness and infill density was analyzed using L9 orthogonal array for 3 levels. From the results it was observed that maximum tensile strength of 32.211 MPa and moderate printing time of 82 min was achieved for layer thickness of 0.3mm, 40 mm per minute of printing speed and infill density of 100%. Also from the this study it was observed that layer thickness have highest impact on the mechanical property like tensile strength and printing time of 3D printed specimen as compared to printing speed and infill density

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