Experimental Investigation of FDM 3D Printing Process Parameters For Optimization of Mechanical Properties By Using Taguchi Method

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Abstract*- 3D printing is a fast-growing and popular method for producing complex geometrical components. It is also known as Additive manufacturing. Fused Deposition Modeling (FDM) is part of the Additive manufacturing process. In the FDM printing process, the filament is fused and added layer by layer to create a component. The 3D printing process involves different process parameters. Impact Strength is a desirable feature in every manufactured product. Some process parameters are associated with the strength of manufactured components. So optimization of these parameters is essential. In this paper, three parameters are taken into consideration: Infill pattern, Infill Density, and Shell Thickness. The sample is prepared by using ASTM D 256 standard. Different types of filaments are used in FDM. In this study, the filament used is Poly Lactic acid (PLA). It is a thermosetting plastic. The paper is based on the optimization of parameters by using the Taguchi optimization method. The results are analyzed by using Taguchi L27 array in Minitab software.*

Keywords- Additive Manufacturing, Fused Deposition Modeling, PLA filament, Taguchi Method, Optimization

I. INTRODUCTION

Additive manufacturing forms a 3-dimensional object. This process is layer by layer the addition of material to get a precise shape. Additive manufacturing is one of the leading sectors which is fast growing. Various manufacturing techniques are developed drastically. With innovations, different materials are used in additive manufacturing [1]. In traditional manufacturing process involves subtracting raw materials to get the final product. In AM process the material is added to get layer by layer to get the product. In Fused Deposition Modeling, material thermoplastic materials are used. The thermoplastic filament is in the form of wire in a roll. The roll is mounted on the machine. The filament passes through a heated nozzle. It becomes viscous and extruded layer by layer. The layers fused and solidify as the temperature decreased. The layers bonded together [2]. FDM process is a low-cost, safe, and efficient process. This process is preferred for prototype and low-volume production. New product development requires high cost but additive manufacturing gives a low-cost operation. Other than new product development it is used in different research applications [4]. New research is going on in FDM 3D printing. The parameters commonly selected to improve mechanical properties are layer thickness, raster angle, and infill percentage [3] Nozzle diameter and cooling rate are also important. Shell thickness, Infill pattern, and infill density are the parameters that need to be studied for optimization [5].

II. DESIGN OF EXPERIMENTAL SET UP

A. Design of Experiment

It is a commanding data collection and analysis tool, used in a variety of experimental conditions, helps in identifying effect of many input factors and their effect on a desired output (response). Taguchi standardized form of DOE has appealed more researchers for identifying such effects. Taguchi method not only allows reduction in variance but also helps in finding out best suitable set of parameter. Hence Taguchi method is applied to collect optimized value under varying three parameters Shell Thickness, Infill Pattern, Infill Percentage with levels are and Printing Pattern. The selected values are mentioned in below table.

TABLE I. Parameter and Levels

Level	**Parameters**		
	Shell Thickness	**Infill Pattern**	**Infill Percentage**
Level I (Low)	0.8	Line	20%
Level II (Medium)	1.6	Hexagon	40%
Level III (High)	2.4	Triangle	60%

L27 Orthogonal array is prepared as mentioned in

Table II and sample specimens are built and tested.

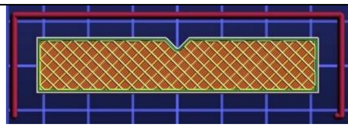
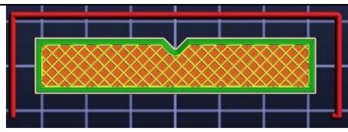
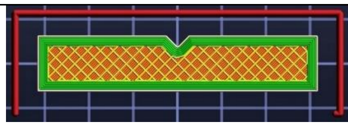
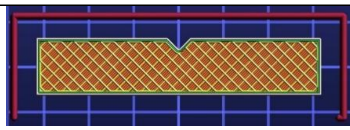
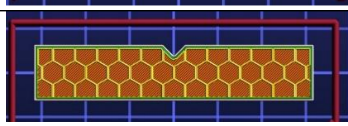
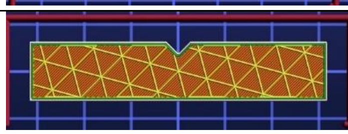
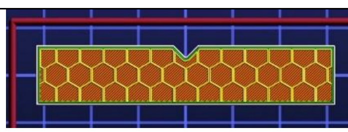
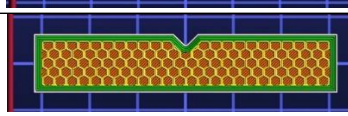
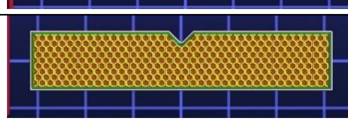
	Shell Thickness
A	
B	
C	
	Infill Pattern
D	
E	
F	
	Infill percentage
G	
H	
I	

Fig 1: Shell Thickness, Infill Pattern, Infill Percentage

B. 3D printer and Test Specimen

Test specimen 3D Drawing is prepared in Autocad software and file is converted in STL format and later processed in Flashprint 3D Slicer**.**

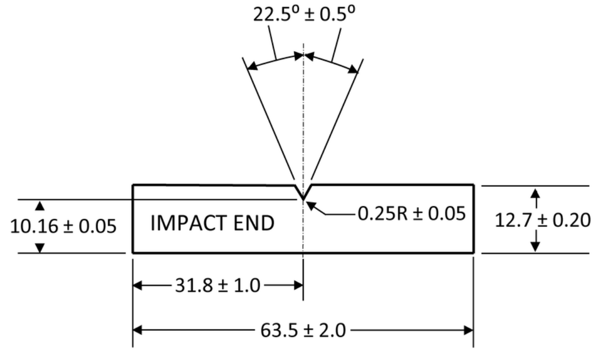


Fig. 2: Test Specimen ASTM D 2240

Program file is then fed to Flashforge Guider IIs FDM 3D printer. It has layer resolution of ± 0.20mm and positioning precision 11 Microns in XY and 2.5 Microns in Z direction [17]. A WOL 3D white PLA filament having 1.75 mm diameter is used for the same.

Fig. 3: Flashforge Guider IIs.

Other parameters kept constant in manufacturing test specimens are extruder temperature-210℃, bed temperature-30℃, nozzle diameter-0.4mm, print speed-80 mm/s, shell count-3, infill density-50%.

Fig. 4: Sample Specimens

C. Izod Impact Tester

Fig. 5: Izod Impact Tester.

Fig. 6: Impact Test on Specimen

III. RESULTS

Following result were obtained after testing sample specimens.

Sr. No.	Infil Pattern	Infill Percentage	Shell Thickness	Impact Value (J)
1	Line	20	0.8	0.10
2	Line	20	1.6	0.13
3	Line	20	2.4	0.13
4	Line	40	0.8	0.12
5	Line	40	1.6	0.10
6	Line	40	2.4	0.10
7	Line	60	0.8	0.10
8	Line	60	1.6	0.14
9	Line	60	2.4	0.13
10	Hexagon	20	0.8	0.10
11	Hexagon	20	1.6	0.12
12	Hexagon	20	2.4	0.13
13	Hexagon	40	0.8	0.12
14	Hexagon	40	1.6	0.12
15	Hexagon	40	2.4	0.12
16	Hexagon	60	0.8	0.13
17	Hexagon	60	1.6	0.13
18	Hexagon	60	2.4	0.14
19	Triangle	20	0.8	0.08
20	Triangle	20	1.6	0.12
21	Triangle	20	2.4	0.16
22	Triangle	40	0.8	0.14
23	Triangle	40	1.6	0.12
24	Triangle	40	2.4	0.14
25	Triangle	60	0.8	0.13
26	Triangle	60	1.6	0.12
27	Triangle	60	2.4	0.12

IV. OPTIMIZATION

Optimization of process parameters are carried out using Taguchi method. The response table for SN ratio and means along with delta and rank value are found using Minitab software shown in Table 3 and 4.

Larger is better

TABLE III. Response Table for SN Ratio

Level	Infill Pattern	Infill Percentage	Shell thickness
1	0.1167	0.1189	0.1133
2	0.1233	0.1200	0.1222
3	0.1256	0.1267	0.1300
Delta	0.0089	0.0078	0.0167
Rank	2	3	1

TABLE IV. Response Table for Means.

Level	Infill Pattern	Infill Percentage	Shell thickness
1	-18.74	-18.65	-19.03
2	-18.21	-18.47	-18.29
3	-18.16	-17.99	-17.79
Delta	0.58	0.66	1.25
Rank	3	2	1

From the Table 3 and 4 it is observed that maximum SN ratio for Shell Thickness is 0.13 at 3rd level, Infill Pattern is0.125 at 3nd level and Infill Percentage is 0.126 at 3rd level. The delta value for Infill pattern is 0.0089, Infill percentageis 0.0078 and the delta value for Shell thickness is0.016. Optimal factor levels of parameter is determined according to the response of each level and setting target value larger-the-better. Here, the parameters are optimized to maximize the Impact Strength of 3D printed PLA material specimens were obtained from the response table. Shell Thickness ranks 1 in table III and table IV indicating its significance in 3D printing. The maximum Impact strength is obtained at the 2.4Shell thickness andTriangle infill pattern. The Figure 7 and 8 reveals the main effect plots for SN ratio and means. It also shows that the Shell thickness is certainly effecting the Impact Strength.

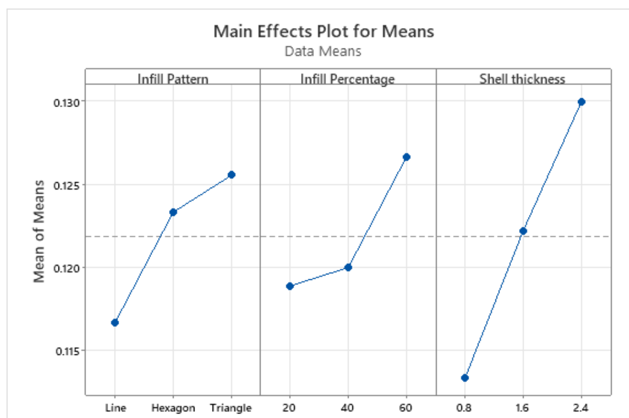


Fig. 7: Main Effects of Plot for SN ratios.

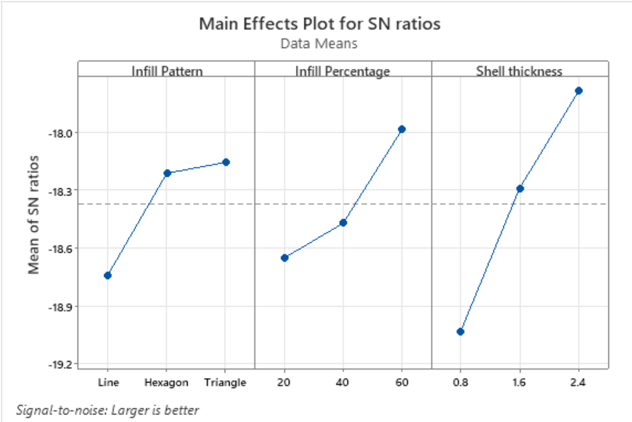


Fig. 8: Main Effects of Plot for Means.

V. CONCLUSION

The objective of the Experimental investigation study was to optimize the effect of process parameters of FDM 3D printing process. The study was carried out to get optimum impact strength. For this parameters viz. shell thickness, Infill pattern, Infill Percentage were selected. Sample specimens manufactured by using PLA material according to Standard ASTM D256. The samples are tested by using Izod Impact Tester and results are optimized by using Taguchi method. The range of analysis shown that the optimized combination of maximum Shell thickness i.e. 2.4 at infill 60 percentage gives a better Impact strength. The above combination set has given Impact strength of 0.16 J which is better than other set of combinations. Shell thickness is most affecting parameter on hardness than infill pattern. Hence it is suggested to keep added Shell thickness for better Impact Strength. Triangle infill pattern proves better than Line and Hexagonal pattern gives better impact strength. This might be due to material structure is more stable pattern as compared to other patterns. This paper covered different levels of experimentation but these results are unable to cover all the important parameter of FDM 3D printing. With different materials, machines and process parameters the result may differ. Due to these results it appears that further research I needed to evaluate effects of shell thickness.

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