Improving Strength of the ABS 3D-Print Using RSM

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Abstract—**Rapid Prototyping technology is instrumental in building prototypes for new product development. However, the default settings of the 3D printer process parameters, in some cases, do not provide the required strength for the 3D print. There are several process parameters to be considered. This study aims to find the relationship between the infill density and the layer thickness as they affect the strength of the 3D print. Online Cura software is used to slice the specimen. Response Surface Method is used to analyse the data. The results show infill density, layer thickness, and interaction between infill density and layer thickness are significant at α = 0.05. It is concluded that there is a non-linear relationship between the infill density and the layer thickness.**

***Keywords*— Fusion Deposition Method, Response surface Method, 3D Print strength, ABS Plus.**

I. Introduction

The Fusion Deposition Method (FDM) digital part file is uploaded to the machine and translated into physical dimensions. Materials for FDM include polymers such as polylactic acid (PLA), Acrylonitrile Butadiene Styrene (ABS). The machine feeds these materials as threads through the heated nozzle. Therefore, the part is built by depositing melted filament material over a built platform layer by layer. FDM technologies have limitations due to the rough surface and lack of strength in the 3D prints [1]. The model orientation and layer thickness significantly minimise the production time and tensile strength of the 3D print [2]. The vertical-horizontal part orientation could lower surface roughness and better mechanical characteristics [3]. In a horizontal-vertical position, each layer acts against the force, increasing the strength of the 3D print, and reinforcing itself [4]. The primary reasons for the decrease in their mechanical properties are the formation of the voids, and thermally induced stresses in FDM built parts [5]. Infills serve as the internal support structure for the part, adding some stiffness and preventing the walls of the part from deforming and the roof from caving. The reduction in the infill density leads to a decrease in the print quality and part success [6]. Infill density has a major effect on the strength of the 3D part [7].

It is evident from the above literature that the infill density and layer thickness impact the strength of the part printing along the horizontal-vertical direction. Therefore, this research aims to find the relationship between the infill density and the layer thickness—the infill density and the layer thickness effects the weight of the 3D print. So, weight is considered a response variable. Response Surface Method (RSM) gave better tensile strength prediction [8]. RSM was considered a better method for finding the optimum printing parameter setting than Taguchi [9]. Therefore, RSM is used for this research. This study intends to contribute to understanding the process parameters to improve the strength of the 3D print.

II. Methodology

A. Material

ABS Plus filament material is used for the specimen of size 10 mm x 10 mm x 10 mm and through-hole of diameter 5 mm as shown in Fig. 1. The material has an operation temperature between 220 °C to 260 °C.

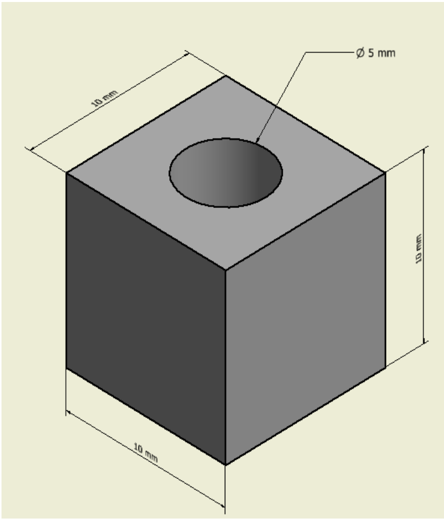

Fig. 1: 3D Print specimen dimensions

B. Equipment

a. Creality3D Ender-3 printer settings used.
b. Autodesk Inventor Professional 2016.
c. Cura engine [10].
d. Minitab 2019 software.

C. Specimen Preparation

The specimen part file is created using Autodesk Inventor Professional 2016 software. The part file is saved as a *.stl file and exported into the cura engine slicer [10].

D. Parameters, Levels and Responses

Table 1 shows the level settings of the 3D printing process parameters: infill density and layer thickness. The part build direction is parallel (0 ° orientation) to the machine bed. The weight of the sliced specimen is selected as the response.

Table-1: 3D Printing Process Parameters

	Low Level	High Level
Infill Density (%)	10	100
Layer Thickness (mm)	0.1	0.3

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E. Response Surface Method (RSM)

The Minitab 2019 software is used to create a randomised run order for the experiment involving two process parameters at two levels. The Central Composite Design (CCD) consists of 8 factorial points and 6 centre points or 14 points (Run 1-14). The CCD is shown in Table 2.

Table-2: Central composite design of RSM

Run Order	Infill density (%)	Layer Height (mm)
1	55	0.2
2	100	0.2
3	0	0.2
4	55	0.3
5	55	0.2
6	55	0.1
7	55	0.2
8	100	0.3
9	55	0.2
10	55	0.2
11	55	0.2
12	100	0.1
13	10	0.1
14	10	0.3

F. Procedure

The specimen *.stl file is exported to the Cura slicer. The first run order values of the infill density and the layer thickness are entered into the Cura software. On completion of the sliced operation, the weight of the sliced specimen is recorded. Similarly, the response values are recorded for all the run orders. Afterwards, Minitab software is used to analyse the response surface design with a confidence level of 95% (α=0.05). The residual plots showed that the errors are random, independent, normally distributed and have constant variance across all factor levels.

III. Results

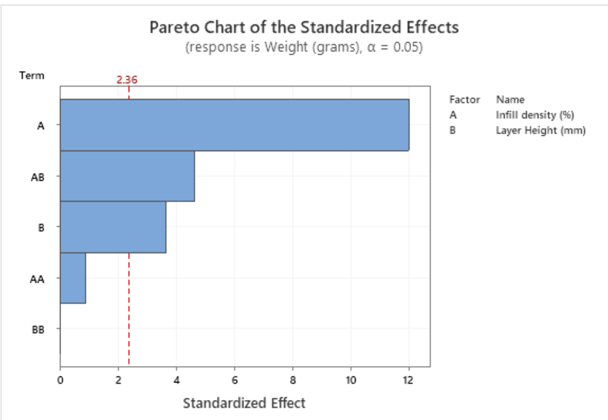

Fig. 2: Pareto chart showing the significant parameters

The Pareto chart (Fig. 2) shows that infill density, layer thickness and the interaction of infill density and layer thickness are significant at α = 0.05. The refined regression equation with R^2 = 95.98% is

$$\text{Weight (grams)} = 0.9298 + 0.001492\ \text{Infill density (\%)} + 0.3117\ \text{Layer Height (mm)} - 0.003889\ \text{Infill density (\%)}*\text{Layer Height (mm)}$$

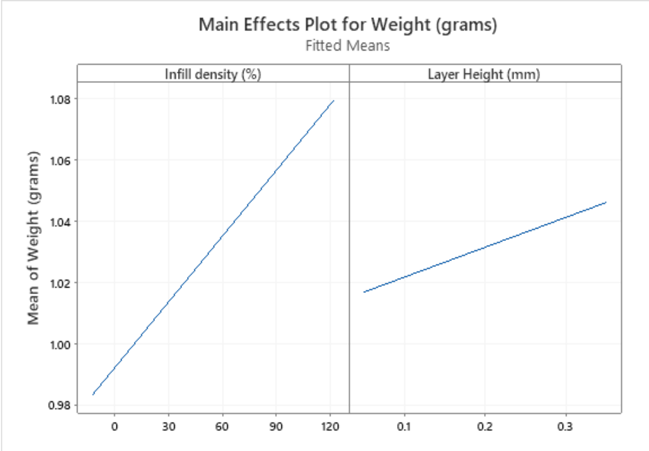

Fig. 3: Main effect plots of process parameters and response

The main effects plots (Fig. 3) show that the increase in infill density and the increase in layer thickness leads to an increase in the weight of the 3D print.

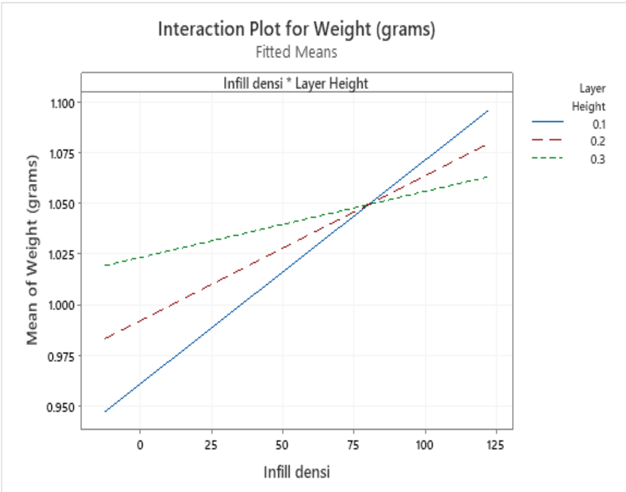

Fig.4: Interaction plots of process parameters and response

The interaction plots (Fig. 4) show that upto 81% (approx.) infill density, the 0.3 mm layer thickness has a more significant effect on the increase in the weight of the 3D print compared to the layer thickness values of 01. 0.2 mm. Above 81% infill density, the layer thickness value of 0.1 mm has a more significant effect on the increase in the weight of the 3D print compared to the layer thickness values of 0.2 mm and 0.3 mm, respectively.

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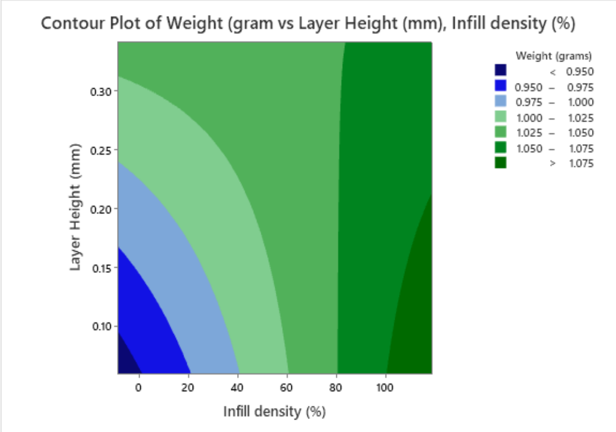

Fig. 5: Surface plot of process parameters and response

The surface plots (Fig. 5) show that till 81% (approx.) infill density, the layer thickness increases the weight of the 3D print. Above 81% infill density, the decrease in the layer thickness leads to an increase in the weight of the 3D print.

IV. Discussion

The infill density, layer thickness, and the interaction between the infill density and the layer thickness have a significant effect (Fig. 2) on the weight of the 3D print. This finding agrees that layer thickness is an important process parameter for 3D printing [2]. The significant interaction between the infill density and the layer thickness shows a non-linear relationship between the process parameters. The interaction plot (Fig. 4) shows that till 81% (approx.) infill density, there is a linear relationship between the infill density and the layer thickness. As a result, an increase in both these parameters leads to a rise in the weight of the 3D print. Whereas, above 81% infill density, the reduction in the layer thickness leads to more increase in the weight of the 3D print. This result confirms the presence of a non-linear relationship between infill density and layer thickness. The higher inclination angle of the infill density line graph with horizontal plane compared to that of the layer thickness (Fig. 3). It shows that an increase in infill density contributes to the increase in weight of the 3D print than the increase in the layer thickness. It might be why infill density has a significant effect on the strength of the 3D print [7]. Laboratory experiments will be able to confirm whether more weight leads to an increase in the strength of the 3D part.

V. Conclusion

It is concluded that 1) There is a non-linear relationship between the infill density and the layer thickness. 2) Below 81% infill density, a higher value of layer thickness contributes to the weight of the 3D print, whereas above 81% infill density decrease in the layer thickness value makes more contribution to the weight of the 3D prints. Therefore, in the case of the ABS Plus filament, it will be helpful to keep the infill density between 10% and 81% and layer thickness value between 0.1 mm and 0.3 mm, respectively. The limitation of this study is that only two process parameters are studied. Further research is suggested to study the effect of infill density, layer thickness and incorporation of supports on the strength of the 3D prints.

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