Quality Improvement of the 3D Print Using Design of Experiments

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Abstract – *The 3D printing technology is being intensively used to build functional prototypes of the new product for demonstration and testing. However, the default settings of the 3D printer process parameters set by the manufacturer, in some cases, do not provide the required quality for the 3D print. In addition, the conflicting research findings of the same 3D print process parameter may lead to more confusion in selecting optimum settings. This study aims to determine the effect of print speed and layer height on the printing time of the ABS Plus 3D print. Design of Experiment (DOE) is used to analyze the data. The result findings show a non-linear relationship between the printing time and the print speed. It is concluded that for the print speed between 20 mm/s to 67.88 mm/s the printing time decreases with the print speed increase and the layer height. For the print speed between 67.88 mm/s to 80 mm/s, printing time increases with print speed and the decrease in the layer height.*

*Key Words***:** 3D printing, DOE, RSM., Rapid Prototyping, FDM, Layer Manufacturing

1. INTRODUCTION

In the Rapid Prototyping (RP) machine, the computer-aided design (CAD) file is sliced into a series of 2D CAD files that represent the cross-section of the part [1,2]. The 3D printer extrusion head moves accurately along the profile of each cross-section of the region, depositing a layer of molten thermoplastic filament over it. The worktable is then lowered by a layer height [3]. Each layer is built on the preceding layer until the 3D physical model is created. Therefore, layer height and print speed are two important process parameters that help produce high-quality 3D prints. The incorrect layer height settings may result in overhangs of sagging sections in 3D print [4].

Similarly, incorrect print speed settings may lead to insufficient bed adhesion of the 3D print, print layer separation or wrapping within the 3D print, shifting layers or leaning prints, sagging sections in the prints, and weak infill's [4]. The RP technology can be successfully implemented by improving the surface quality, part strength, build time, accuracy and repeatability of the 3D prints [5,6]. Therefore, one expects that the research findings of the same 3D print process parameter will be similar. Otherwise, the user will lack confidence in adopting the RP technology. However, the previous studies showed conflicting research findings for the layer height and the print time. For instance, [3] research findings concluded that an increase in layer height increases print time. Whereas [7] research finding states that the printing time is reduced with increased layer height. This study aims to find (1) whether there is a linear or non-linear relationship between the print speed and the print time and (2) how the layer height and print time are related. These research findings will contribute to the literature on optimising the process parameters to improve the quality of the 3D print.

2 METHODOLOGIES

2.1 Material

The CAD file of the 3D print model is made using the Autodesk Inventor Professional 2016. The specimen is made of ABS Plus material. The material has an operating temperature between 220 °C to 260 °C.
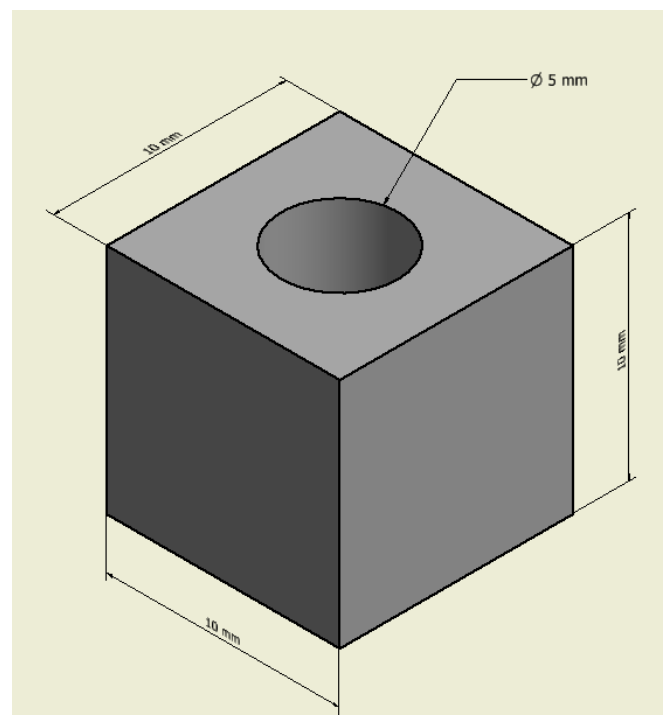

Fig - 1: Specimen part model

2.2 Equipment
    a.   Creality3D Ender-3 printer settings used.
    b.   Autodesk Inventor Professional 2016.
    c.   Cura engine [8].
    d.   Minitab 2019 software.

2.3 Specimen preparation

The CAD part file is saved as a *.stl file and exported into the Cura engine slicer [8].

2.4 Parameters, Levels and Responses

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

Table -1: Process parameter levels

Process Parameter	Low Level	High Level
Print Speed (mm/s)	20	80
Layer Height (mm)	0.1	0.3

2.5 DOE

Initially, the Minitab 2019 software is used to design the run order for the full factorial experiment with two blocks, two centre points per block and one replicate. The main effect plots showed a non-linear relationship between the print speed, layer height and print time. Therefore, Response Surface Method (RSM) is used to prepare the Central Composite Design (CCD) consists of 8 factorial points and six centre points or 14 points (Run 1-14). The CCD is shown in Table 2.

Table -2: Central composite design of RSM

Run Order	Print Speed (mm/s)	Layer Height (mm)
1	50	0.2
2	20	0.3
3	80	0.3
4	50	0.2
5	20	0.1
6	50	0.2
7	80	0.1
8	7.6	0.2
9	50	0.34
10	92.4	0.2
11	50	0.06
12	50	0.2
13	50	0.2
14	50	0.2

2.6 Procedure

The specimen *.stl file is exported to the Cura slicer. The first run order values of the print speed and the layer height are entered into the Cura software. On completion of the sliced operation, the print time 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.

3. RESULTS
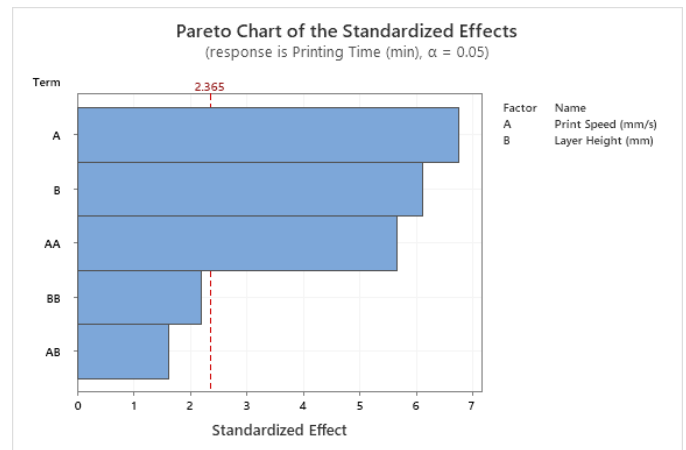
Fig -2: Pareto chart

The Pareto chart (Fig. 2) shows that print speed, layer height and the square term of the print speed are significant at α = 0.05. Whereas, square of layer height and the interation between the print speed and the layer height are insignificant at α = 0.05. The refined regression equation with R^2 = 88.77% is,

Regression Equation   (1)

Printing Time (min) = 36.15 - 0.657 Print Speed (mm/s) - 46.73 Layer Height (mm) + 0.00485 Print Speed (mm/s)*Print Speed (mm/s)
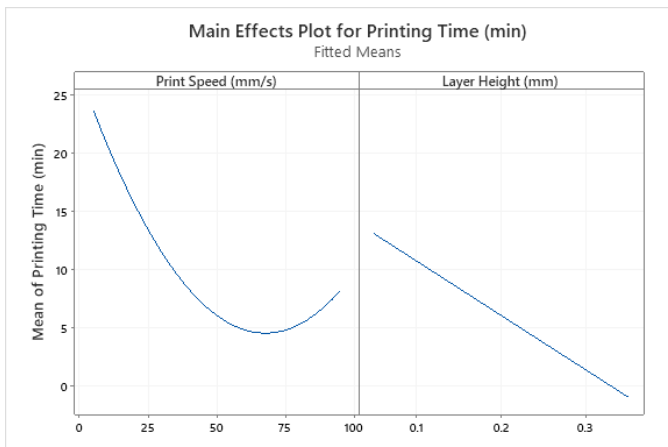
Fig -3: Main effect plots

The main effects plots (Fig. 3) show that the print speed graph is a parabola. Second, The increase in the layer height leads to a decrease in the print time of the 3D print.
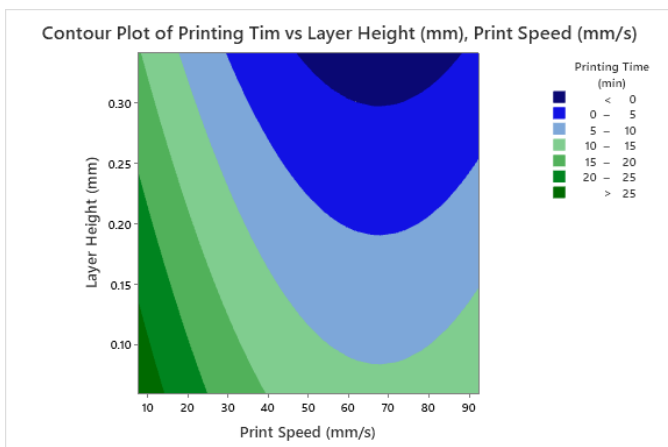

Fig -4: Surface plots for process parameters

The surface plots (Fig. 4) show a decrease in print time with increased print speed and increased layer height. Then, the print time rises with an increase in the print speed and a reduction in the layer height.
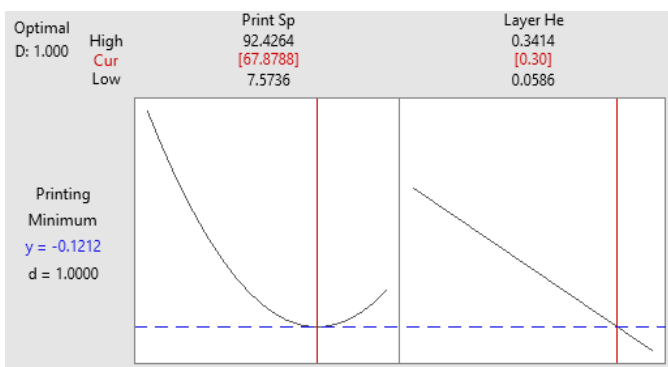

Fig -5: Minimization graph of the print time

The optimization graph in Fig.5 shows exact values of the print speed (67.8788 mm/s) and the layer height (0.3 mm) when the print time (-0.1212 min) is minimum. At the same point, the print time starts increasing with an increase in the print speed and a decrease in the layer height.

4. DISCUSSION

The print speed, layer height, and square of the print speed significantly affect the print time of the 3D part. The finding of layer height agrees that the layer height is a significant process parameter affecting the quality of the 3D print fabricated using the Fusion Deposition Method [9]. The square term of the print speed in the regression equation (1) is responsible for the parabolic nature of the main effect plot of print speed and the print time, as shown in Fig. 3. ABS Plus filament material is used in this study. The minimization graph of the print time in Fig.5 shows that for the print speed between 20 mm/s to 67.8788 mm/s, this study's results agree with [7] that the print time decreases with an increase in the layer height. Whereas, for the print speed between 67.8788 mm/s to 80 mm/s, this study's results do not agree with [3] and [7] , as the print time increases with a decrease in the layer height. Therefore, it is essential to determine the linear or non-linear relationship between the additive manufacturing process parameters.

5. CONCLUSIONS

It is concluded that (1) there is a non-linear relationship between the print speed, the layer height and the print time. (2) This study agrees with [7] that the print speed range between 20 mm/s to 67.8788 mm/s that the print time decreases with an increase in the layer height. (3) The results of this study do not agree with [3] and [7] for the print speed between 67.8788 mm/s to 80 mm/s as the print time increases with a decrease in the layer height. The limitation of this study is that only two process parameters are studied. A suggested direction for further research is to study the effect of build orientation, raster angle, print speed and layer height on the quality of the 3D print.

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BIOGRAPHIES

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