Parametric Optimization of 3-D Printer Printing Process to Minimize the Wrapping Deformation

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ABSTRACT

At the present time 3D printing has become a famous technology. This technology is in industries where the prototyping is an important limitation. The main aim of this study is to minimize the warp deformation that usually occurs to plastic part produced by 3D printers. The process involved 3D solid modeling to design using Catia V5, 3D printing with coated adhesive applied on the printing platform, warping deformation measurement using vernier height gauge and statistical analysis using Minitab 17 software. The optimization processes involved Design on Experiment (DOE) technique where Taguchi Method is applied by using Minitab 17 software. The experiment produced the minimum result of warping deformation value when the layer temperature, infill density, first layer height and other layer height is 160°C, 10%, 0.3mm and 0.3mm respectively.

Keywords: *3D printing, DOE, Minitab17, Taguchi Method, Wrapping Deformation, Catia V5.*

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1. Introduction

3D printing technology is the most popular technology in present era reason being that it reduces the manufacturing cycle time by producing fast prototype of any required part. As mentioned in previous study [12], it is very difficult to achieve the best characteristics in the fabricated parts of understanding the impact on the process variables. The work presented in this paper study on how the 3D printer parameters affect the warping deformation and what are the best process parameter values to minimize the warping deformations. It is essential to optimize the printing parameter to achieve desired quality characteristics in the parts of developing open source 3D printer [13-14]. This involved Design on Experiment (DOE) and Taguchi Method in the finding. These methods have been used for optimization of process parameters in various fields in the function of to investigate the optimum factor levels for fabricating parts [15-17].

1.1 Problem Statement

The samples taken in this experiment have more or less deformation around their corners. The main aim of this project is minimize the wrapping at the four corners of specimens by selecting the optimized set of printing process parameters.

1.2 Aim and Objectives of Study

Aim: The main aim of this project is minimize the wrapping at the four corners of specimens by selecting the optimized set of printing process parameters.

Objectives:

- To design the experiments using Taguchi Method & MINITAB 17 software.
- To find the optimum set of process parameters so we get the minimum wrapping at 4 corners of specimens.

1.3 Methodology Implemented

The following flow chart shows the methodology implemented for the present research work.

Figure 1 Research Methodology

The investigation started with 3D modeling to prepare a design by using solid modeling software, CATIA V5 software. This is used as specimens of the investigation into reducing the warping deformation height. Hence, a cuboid model was designed with size of **150.0mm of length, 35.0mm of width and total height of 7.0mm** as shown in Figure 2. As mentioned by the previous researcher, the rectangular shape objects have high tendencies to warp around its corner [9]. This digital model is then converted into printing instruction in the use of open source 3D printers by using Slic3r software.

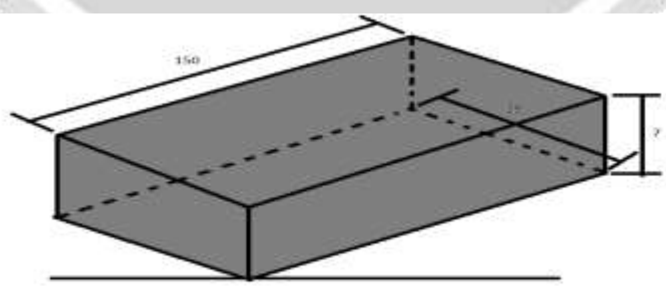

Figure 2 Size of Cuboid Model

The conversation of the digital solid model to the printing instruction is needed by the open source 3D printer where the Slic3r software changed it from stereo lithography (STL) format to machine instruction or known as G-Programming Language (G-Code). This is requiring to setting all parameter of the printer such as platform size and shape of it to avoid the failure in printing. In order to convert the STL and creates the G-Code files, there are several independent variables that need to be set to control the printing process. In this case, the several settings are used as the independent variable where it posits on the variables that affect the printing result as the objectives stated.

1.4 Experimental Unit

Figure 3 Experimental Unit (Kossel Mini Delta 3D Printer Machine)[18]

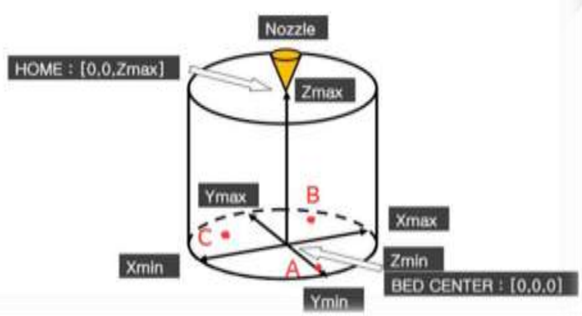

Figure 4 Axes of 3D Printer[18]

Table 1 Kossel Mini Delta 3D Printer Machine Specification

Make	Anycubic
Model	Kossel Linear Plus
Technology	FDM
Frame	Delta
Category	Desktop 3D Printer
Print Area	Φ230 x 300mm
Max. Bed Temp.	100 Degree Celsius
Nozzle Size	0.4mm
Max. Nozzle Temp.	260 Degree Celsius
Max. Z-axis Resolution	0.1mm
Z-axis Accuracy	0.0025mm
X/Y-axis Accuracy	0.0125mm
Max. Print Speed	60 mm/s
Max. Travel Speed	60 mm/s
Printable Materials	PLA, ABS, HIPS
3rd Party Material Compatibility	Yes
Interface	LCD display with scroll wheel
Connectivity	SD card, USB
Printer Size	380mm x 680mm
Printer Weight	7kg
Power Input	AC 110-220V AC, 50/60Hz

The experimental unit used for the project work is as shown in Figure 3. The specimens are made of Polylactic Acid (PLA) . The specification of experimental unit is shown in Table 1.

2. DOE Using Taguchi Method

With the Taguchi technique, a screening process of four parameters which are layer temperature, fill density, first layer height and the other layer height was varied and 9 samples were prepared as summarized in Table 2 to form a factorial regression. Based on the table, it shows that the independent parameters which give credence on the warping deformation height. Based on observation which was made before, the recommended settings ranges are in between as mentioned in the parameter column in the Table 3.

Table 2 Four Parameters and 3 Level Design

Layer Temperature (^{0}C)	**Fill Density (%)**	**First Layer Height (mm)**	**Other Layer Height (mm)**
160	10	0.2	0.2
180	20	0.3	0.25
200	30	0.4	0.3

Table 3 L9 Orthogonal Array Design and Experiment Conduction

	Layer Temp.	Fill Density	First Layer Height	Other Layer Height	Corner Y1	Corner Y2	Corner X1	Corner X2	Average Wrapping(mm)
1	160	10	0.2	0.20	0.02	0.12	0.03	0.03	0.18
2	160	20	0.3	0.25	0.14	0.06	0.07	0.17	0.31
3	160	30	0.4	0.30	0.20	0.10	0.13	0.16	0.47
4	180	10	0.3	0.30	0.03	0.11	0.02	0.02	0.17
5	180	20	0.4	0.20	0.16	0.08	0.09	0.18	0.60
6	180	30	0.2	0.25	0.22	0.13	0.21	0.18	0.60
7	200	10	0.4	0.25	0.17	0.32	0.22	0.28	0.78
8	200	20	0.2	0.30	0.18	0.18	0.06	0.04	0.43
9	200	30	0.3	0.20	0.19	0.19	0.07	0.05	0.46

In the process of fabrication the cuboid model, the Kossel Mini Delta 3D printer machine and Polylactic Acid (PLA) material was used. This machine is built without heating platform and only used a round glass bed with size 180mm diameters and printable height up to 240mm. Hence, the printing platform required to coat by a type of adhesive layer where this paper was used synthetic polymer adhesive, Polyvinylpyrolidone (PVP) to reduce warping deformation of the first layer. The experiments were rotated using different parameter that has been obtained by the DOE process. In order to measure the warping deformation, vernier height gauge was utilized. Equation-1 and Figure-5 shows the method to measure the warping deformation.

$$\text{Wrapping deformation, } y = y1 - y2 \qquad (1)$$

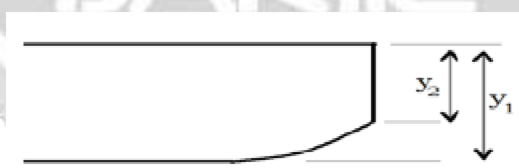

Figure 5 Method of Measurement at each Sample's Corner

By referring to Equation-1, the value of warping deformation, y is obtained by subtracting the value of total height and, the deflected total height. Four corners of the cuboid part with five attempts each were measured and the average value of warping deformation, are calculated. Statistical software, Minitab 17.0 software, Taguchi Method are applied to minimize the warping deformations. The software is used to generate the design matrix for the DOE with each run corresponding to the various factor levels combination that will produce the responses to quality characteristics of dimensional accuracy and surface finishing [12]. A sample of the optimization parameter value was then produced by 3D printers to check for its accuracy.

Table 3 shows the DOE results of tabulation data reading at each four corner and is represented by layer temperature, infill density, first layer height and other layer height. This is as the first step of optimization where the data is collected based on the DOE techniques and the data showed are fluctuations of the reading at each corner as the symbol Y1, Y2, Y3 and Y4 is referred. Based on the result, it shows that the minimum value that ever was measured is 0.01 millimeters which meant that there is no corner had any effect.

3. Results and Discussions

3.1 Effect of Four Parameters on Avg. Wrapping of Corners of Specimens

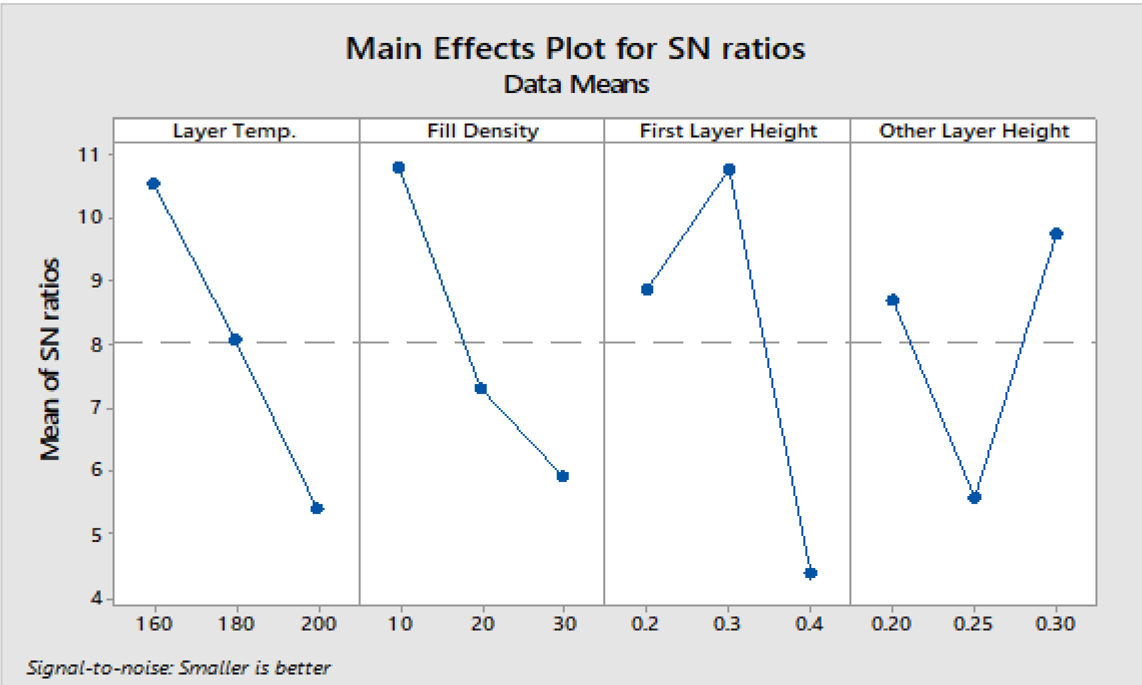

Figure 6 Main Effects Plot for S/N Ratios of Avg. Wrapping at corners

Figure 6 shows that the Optimum parameters level is A1, B1, B2, and D 3 means Layer temp. 160 Degree Celsius , Fill Density 10 % , First Layer Height 0.3mm, and Other Layer Height 0.30mm shows the minimum avg. wrapping at four corners Y1,Y2,Y3,and Y4.

Figure 7 shows the effect of layer Temp., Fill Desity, First Layer Height, and Other Layer Height on the avg. wrapping of specimens corner. The avg. wrapping of specimens corner increases as increase in layer temp. The avg. wrapping of specimens corner increases with increase in fill density. The wrapping deformation is minimum at the 0.3 mm first layer height. The wrapping tendency is minimum at 0.3 mm other layer height.

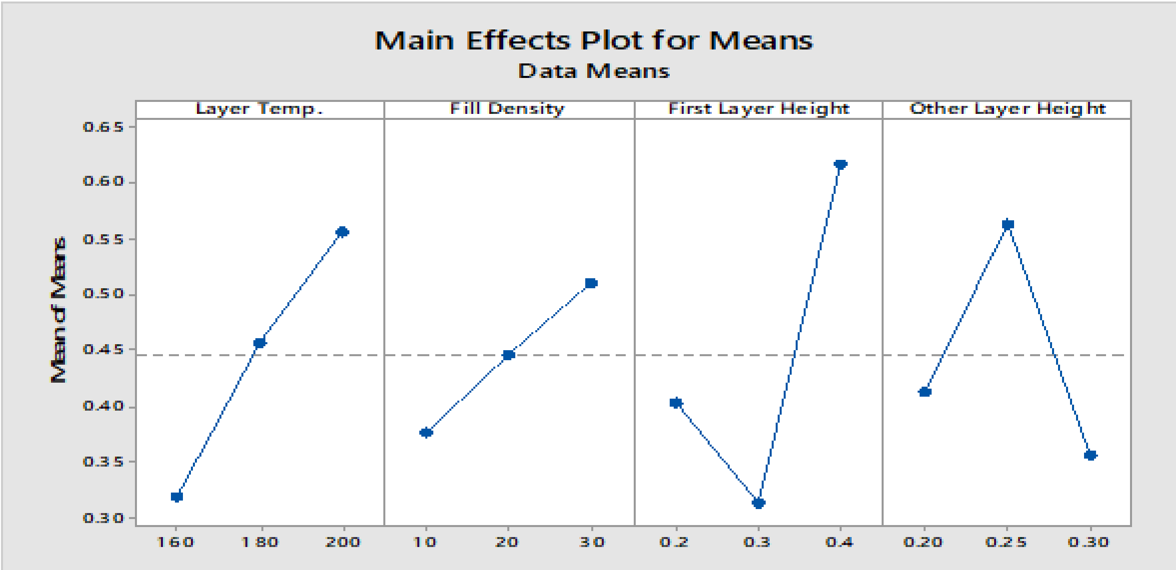

Figure 7 Main Effects Plot for Means of Avg. Wrapping Deformation

3.2 Validation of Result

In the validation phase the repentance of optimum value of avg. wrapping deformation at specimen corners is check by setting the optimum values of four parameters in 3D printer and taking 6 trials. Table 4 shows the validation test performed.

Table 4 Validation of Optimum Value of Avg. Wrapping Deformation

Layer Temp. (^{0}C)	Fill Density (%)	First Layer Height (mm)	Other Layer Height (mm)	Avg. Wrapping Deformation (mm)
160	10	0.3	0.3	0.030
				0.028
				0.032
				0.028
				0.034
				0.028
				Average:0.03 mm

2. CONCLUSION

[1] The Optimum parameters level is A1, B1, B2, and D 3 means Layer temp. 160 Degree Celsius , Fill Density 10 % , First Layer Height 0.3mm, and Other Layer Height 0.30mm shows the minimum optimum avg. wrapping at four corners Y1,Y2,Y3,and Y4.

[2] The avg. wrapping of specimens corner increases as increase in layer temp. The avg. wrapping of specimens corner increases with increase in fill density. The wrapping deformation is minimum at the 0.3 mm first layer height. The wrapping tendency is minimum at 0.3 mm other layer height.

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