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PROCESS PARAMETER OPTIMIZATION OF 3D PRINTER USING RESPONSE SURFACE METHOD

M. A. Nazan[1], F. R. Ramli[1, 2], M. R. Alkahari[1, 2], M. N. Sudin[1, 2] and M. A. Abdullah[1, 2]
[1]Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia
[2]Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia
E-Mail: muhd_afdhal@hotmail.com

ABSTRACT

The purpose of this paper is to minimize the warp deformation that usually occurs to plastic part produced by 3D printers. The process involved 3D solid modelling to design, 3D printing with coated adhesive applied on the printing platform, warping deformation measurement and statistical analysis. The optimization processes involved Design on Experiment (DOE) technique where Responses Surface Methodology (RSM) is applied by using Minitab 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 192°C, 13%, 0.20mm and 0.30mm respectively.

Keywords: 3D printer, warping deformation, response surface method.

INTRODUCTION

Open source 3D printer is an additive manufacturing technology that has revolutionized the manufacturing field and has been slowly replacing the conventional subtractive process. As a good example, the additive manufacturing allowed complex geometry to be produced [1] in simple three dimensional axes of production. The capability of the new technology has grown and slowly replacing the conventional. These recent years, it has drawn significant attention to industry and academia [2] due to the ability to capitalize on the consolidated advantages of independent process such as FDM.

Fused Deposition Modelling is a process that using similar conventional technique, injection moulding product formation. The different about moulding using FDM machine is, it does not use any housing or moulding to form the product but use a platform that has flat surface such as glass and steel. The process involved molten plastic or wax extruded by a hot end nozzle that traces the parts cross sectional geometry layer by layer [3]. FDM is also popular with Rapid Prototype technology which widely used in industries to build complex geometrical functional and shape parts in short time [4-5]. Generally, it was used to fabricate prototypes, tool and functional parts without geometrical complexity limitations [6].

However, one of the drawbacks of open source FDM 3D printers is the plastic filament that comes out from its nozzle tends to shrink and warp, and sometimes peel away from the bed platform. This warped deformation issues in 3D printers have been highlighted by several researchers [7-8]. Refer to K. Herman and other [9], without heating platform there was known as warping issues that are most severe for elongated, rectangular shaped objects. Additional surface preparation by applying synthetic polymer adhesive between the printing bed and the first layer had been performed to counter this problem [10-11]. Due to the different 3D printer process parametersettings, warping deformation may still occur and because of that, the best 3D printer parameters sett need to be figure of to obtain the best printing quality. 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 Response Surface Method (RSM) 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].

METHODOLOGY

The investigation started with 3D modelling to prepare a design by using solid modelling 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 100.0mm of length, 30.0mm of width and total height of 5.0mm as shown in Figure-1. 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.

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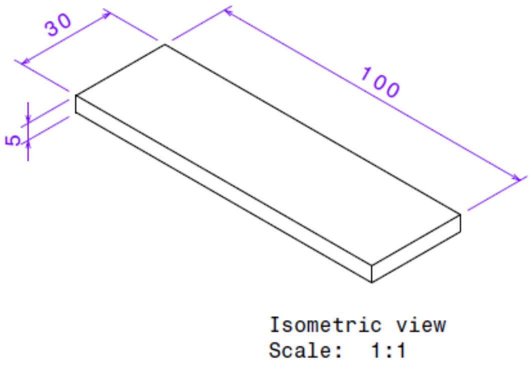

Figure-1. Size of cuboid model which designed in millimetre unit.

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 stereolithography (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.

Table-1. The parameter of independent variables.

Symbol	Independent variables	Parameters
T	Layer temperature (°C)	180°C -200°C
ρ	Fill density (%)	0% - 30%
h_1	First layer height (mm)	0.2mm-0.4mm
h_2	Other layer height (mm)	0.2mm -0.3mm

With the DOE techniques, a screening process of four parameters which are layer temperature, infill density, first layer height and the other layer height was varied and 16 samples were prepared as summarized in Table 1 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 sett ranges are in between as mentioned in the parameter column in the Table-1.

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-2 shows the method to measure the warping deformation.

$$warping\ deformation, y = y_1 - y_2 \quad (1)$$

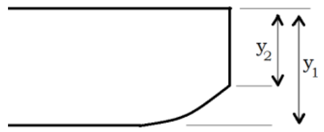

Figure-2. Method of measurement at each sample's corner.

By referring to Equation-1, the value of warping deformation, y is obtained by subtracting the value of , 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, DOE and RSM 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 of the RSM and the optimization process

RESULTS AND DISCUSSIONS

Figure-3 shows a cuboid printed sample where warping deformation occurs at its corners as in circles. All samples taken in this experiment have more or less deformation around their corners.

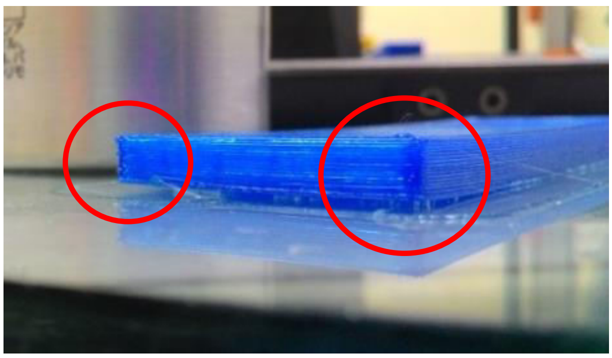

Figure-3. Deflected sample by warping deformation problem shown in the circles.

ARPN Journal of Engineering and Applied Sciences

Table-2. DOE result of warping deformation.

No.	Independent variables				Dependent variables			
	Layer Temperature, (°C)	**Infill Density, (%)**	**First Layer Height, (mm)**	**Other Layer Height, (mm)**	**Corner Y1 (mm)**	**Corner Y2 (mm)**	**Corner Y3 (mm)**	**Corner Y4 (mm)**
1	180	10	0.2	0.2	0.10	0.03	0.09	0.09
2	180	10	0.4	0.2	0.17	0.17	0.04	0.12
3	180	30	0.2	0.2	0.23	0.15	0.22	0.20
4	180	30	0.4	0.2	0.19	0.09	0.08	0.19
5	180	10	0.2	0.3	0.02	0.02	0.04	0.05
6	180	10	0.4	0.3	0.03	0.11	0.02	0.02
7	180	30	0.2	0.3	0.03	0.20	0.03	0.10
8	180	30	0.4	0.3	0.05	0.09	0.06	0.06
9	200	10	0.2	0.2	0.21	0.26	0.27	0.19
10	200	10	0.4	0.2	0.18	0.35	0.21	0.29
11	200	30	0.2	0.2	0.27	0.26	0.19	0.18
12	200	30	0.4	0.2	0.19	0.25	0.30	0.34
13	200	10	0.2	0.3	0.10	0.13	0.05	0.03
14	200	10	0.4	0.3	0.04	0.01	0.14	0.13
15	200	30	0.2	0.3	0.18	0.18	0.06	0.04
16	200	30	0.4	0.3	0.17	0.17	0.18	0.16

Table-2 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 millimetres which meant that there is no corner had any effect. Figure-4 below shows example of Pareto chart that shows the trending of the effects of each independent variable that are tested for corner Y1. It shows that the height effects variable is D, other layer height followed by A, layer temperature and B, infill density. Based on the data, first layer height variable, C had less influence on the warping deformation.

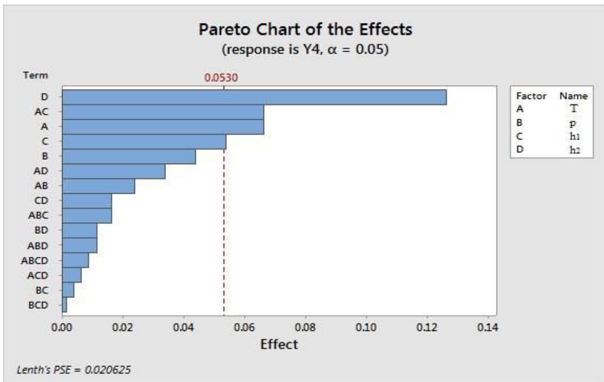

Figure-4. Pareto chart of the effects at Y4.

The obtained main effect plotted in Figure-5 shows that the temperature, infill density and other layer height has high influence on the deformation values compared to first layer height parameters as well as the Pareto chart above. The first layer height does not show any major effect on the warping deformation by having the lowest gradient trend.

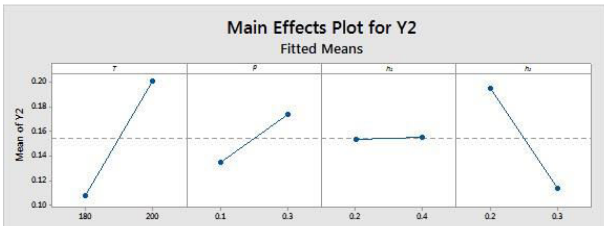

Figure-5. Main effect plot correspond to warping deformation for Y2.

In order to create the response surface plot, an improvement is needed to be complete. This step is to plot the independent variables that have high impact on the dependent variables. Other experiments are also needed in order to analyse the result. The analysis would be more focusing on the factors that really affect the warping deformations.

Table-3. Improved data analysis by creating response surface design.

No.	Independent variables				Dependent variables			
	T	ρ	h_1	h_2	**Y1**	**Y2**	**Y3**	**Y4**
1	180	10	0.3	0.20	0.17	0.17	0.04	0.12
2	180	30	0.3	0.20	0.19	0.09	0.08	0.19
3	180	10	0.3	0.30	0.03	0.11	0.02	0.02
4	180	30	0.3	0.30	0.05	0.09	0.06	0.06
5	200	10	0.3	0.20	0.18	0.35	0.21	0.29
6	200	30	0.3	0.20	0.19	0.25	0.30	0.34
7	200	10	0.3	0.30	0.04	0.01	0.14	0.13
8	200	30	0.3	0.30	0.17	0.17	0.18	0.16

ARPN Journal of Engineering and Applied Sciences

In creating the response surface design, the maximum and minimum values of the independent variables is needed. As shown in Table-3, there are only 8 samples left after the first layer height is made constant at 0.3 millimetres. By using these data, the experiment is continued with creating the response surface design using central composite analysis with these factors, which are full design selection and 20 unblocked runs.

Table-4. Central composition analysis.

No.	Independent variables				Dependent variables			
	T	ρ	h_1	h_2	Y1	Y2	Y3	Y4
1	180	0.10	0.3	0.20	0.13	0.17	0.04	0.12
2	200	0.10	0.3	0.20	0.15	0.18	0.21	0.29
3	180	0.30	0.3	0.20	0.14	0.09	0.08	0.19
4	200	0.30	0.3	0.20	0.10	0.25	0.26	0.24
5	180	0.10	0.3	0.30	0.13	0.11	0.09	0.03
6	200	0.10	0.3	0.30	0.04	0.01	0.14	0.13
7	180	0.30	0.3	0.30	0.19	0.09	0.11	0.06
8	200	0.30	0.3	0.30	0.18	0.17	0.18	0.16
9	173	0.20	0.3	0.25	0.11	0.18	0.14	0.13
10	206	0.20	0.3	0.25	0.11	0.09	0.19	0.14
11	190	0.03	0.3	0.25	0.12	0.17	0.12	0.24
12	190	0.37	0.3	0.25	0.13	0.25	0.06	0.15
13	190	0.20	0.3	0.17	0.09	0.08	0.10	0.10
14	190	0.20	0.3	0.33	0.11	0.07	0.07	0.07
15	190	0.20	0.3	0.25	0.10	0.05	0.04	0.10
16	190	0.20	0.3	0.25	0.10	0.05	0.04	0.10
17	190	0.20	0.3	0.25	0.10	0.05	0.04	0.10
18	190	0.20	0.3	0.25	0.10	0.05	0.04	0.10
19	190	0.20	0.3	0.25	0.10	0.05	0.04	0.10
20	190	0.20	0.3	0.25	0.10	0.05	0.04	0.10

By referring to the Table-4 above, the central composition is representing the analysis to second degree of function. This result is more specific presenting another six points of the box. As seen at sample number 9 and 10, the temperatures are shown at 173 °C and 206 °C followed by other independent variables, where density and other layer height are calculated by the Minitab software. As a result, all the samples had been measured and gathered to fill in the dependent variables which are the warping deformation values. As shown in the Figure-6 below, the main effect plot for Y3 that an analysis of the second degree for response surface design was obtained. These parabola plots are the vertex point of warping deformation at Y3 depending on the value of the factors that are set while slicing the model. The graph shows that the lowest value of the warping deformation on each factor is around 180°C to 195°C and for the other layer temperature factor, near 20 percent of infill density and in between 0.24mm to 0.32mm for the layer height.

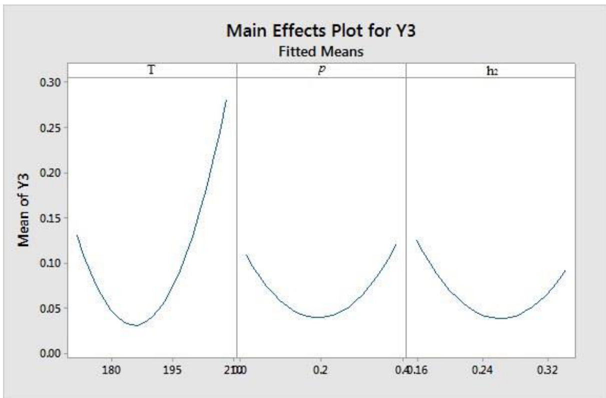

Figure-6. Main effect plot for Y3 corresponded to T, ρ and h_2.

Figure-7 shows the contour plot of the Y3 corner which responded to the factors. This plot is similar with the previous plot in the Figure-6. This contour is showing the best result of minimum warping deformation value is on the middle of the dark blue coloured circle by comparing the relation between the factors such as layer temperature and infill density, temperature and layer height, and also the infill density and the layer height. As referred to the plot of layer temperature versus infill density, it shows that the greatest result of warping deformation is in between the set of 185°C to 190°C of layer temperature and 20% of infill density.

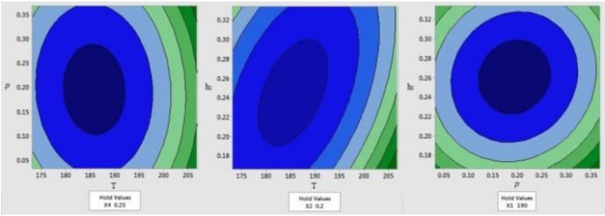

Figure-7. Contour plot of Y3 corresponded to the three factors.

Surface plot is a plot that shows the 3D model of contour plot which is shown in three axes as shown in Figure-8. The figure shows the surface plot of Y3 corner of the density and layer height. As mentioned before in the contour plot graph is shown the best result in reducing the warping deformation is at the middle of the contour plot which is dark blue colour, surface plot is also shown as the vortex at the middle of the 3D graph where it is clearly seen responded to minimized at the middle of plot.

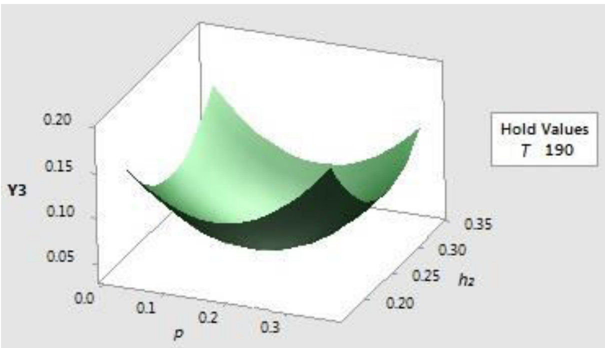

Figure-8. Surface plot of Y3 corresponded to ρ and h_2.

Table-5. Optimized result of the response surface method.

Independent variables				**Responses**	
				Theoretical	**Experimental**
T (°C)	ρ (%)	h_1 (mm)	h_2 (mm)	$y_{T\ avg}$ (mm)	$y_{E\ avg}$ (mm)
192	13	0.20	0.32	0.03	0.04

Table-3 shows the result of optimization obtained by using the MiniTab software and the comparison between theoretical and experimental values, the minimum warping deformation, y_{Tavg} is 0.03mm was achieved. Sample of experimental with optimized parameters were proved the accuracy of the RSM and the optimization result where y_{Eavg} is 0.04mm.

CONCLUSIONS

It is concluded that the optimum value of the independent variables are 192°C of layer temperature, 0.13% of fill density, 0.2mm of first layer height and 0.3mm of other layer height with minimum deformation of 0.03mm. The accuracy of RSM and optimization resulted a small percentages of error is 33%. The objectives are achieved by obtaining the synthetic polymer adhesive shows a good result and also reduced the warping deformation while printing on the glass platform if compared to plain or direct to the glass. This shows that the glass needs an adhesive in order to reduce the warping deformation also resulted the best printing quality. As future suggestions, in order to get a greatest result, the experiment should have a good equipment where it is more precise to measure the deformation, the experiment should be alert to the surrounding temperature because it is believed that another factor for warping deformation and also the adhesive should be apply correctly to all surface of the printing platform to avoid the warping to be worsen.

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