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Optimization of warping deformation in open source 3d printer using response surface method

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ABSTRACT – The purpose of this paper is to minimize the warp deformation that usually occurs in plastic part produced by open source 3D printer. The process involved 3D solid modeling 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) by using Minitab software was applied. The experiment produced the minimum result of warping deformation value when layer temperature, infill density, first layer height and other layer height is 192°C, 13%, 0.20mm and 0.30mm respectively.

1. INTRODUCTION

Open source 3D printer is an additive manufacturing technology that has revolutionized the production of plastic component and has been slowly replacing the conventional subtractive manufacturing process. However, one of the drawback of open source 3D printer is the plastic filament that comes out from its nozzle tends to shrink and warp and sometimes peel away from the bed platform. This warping deformation issues in 3D printer have been highlighted by several researchers [1-2] Additional surface preparation by applying synthetic polymer adhesive between the first layer and the bed platform had been performed to counter this problem [3]. However, due to the different 3D printer process parameter settings, warping deformation may still occur and because of that, the best 3D printer parameters setting need to be figure out to obtain the best printing quality. Hence, the purpose of this paper is to investigate how the 3D printer parameters affected the warping deformation and what are the best process parameters values to minimize the warping deformation.

2. METHODOLOGY

The experiment started with 3D modeling design that was prepared by using CATIA solid modeling software. A cuboid model was designed with size of 100mm in length, 30mm in width and total height of 5mm as shown in Figure 1. This digital model is then converted into printing instruction for the open source 3D printer by using Slic3r software.

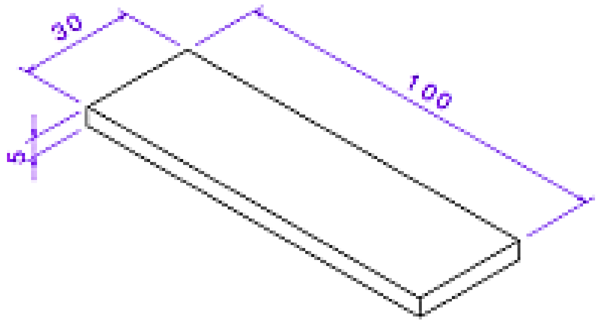

Figure 1 Size of cuboid model in millimeter unit.

Table 1 The parameter of independent variables.

Symbol	Independent variables	Parameters
T	Layer temperature (°c)	180°C - 200°C
ρ	Fill density (%)	10% - 30%
h_1	First layer height (mm)	0.2mm - 0.4mm
h_2	Other layer height (mm)	0.2mm - 0.3mm

By using the DOE techniques, four parameters which are layer temperature, infill density, first layer height and the other layer height were varied and a total of 16 samples were prepared as summarized in Table 1. The Kossel Mini Delta 3D printer without existing heating bed was used to fabricate the cuboid model. The bed platform of the 3D printer was coated by a layer of synthetic polymer adhesive, *poyvinylpyrrolidone* (PVP) to reduce warping deformation of the first layer.

In order to measure the warping deformation, vernier height gauge was utilized. Figure 2 and Eq. (1) shows the method to measure the warping deformation.

Figure 2 Method of measurement at each sample's corner

$$\text{Warping deformation, } y = y_1 - y_2 \quad (1)$$

By referring to the Eq. (1), the value of warping deformation, y is obtained by subtracting the value of y_1 , value of total height and y_2, the deflected total height. Four corners of the cuboid part with five attempts each were measured and the average value of warping deformation, y_{avg} were calculated.

By using Minitab software, DOE and RSM was applied to in order to minimize the warping deformations. A sample with optimize parameter value was then produced by 3D printer to checked for its accuracy of the RSM and the optimization process.

3. RESULTS AND DISCUSSION

Fig.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.

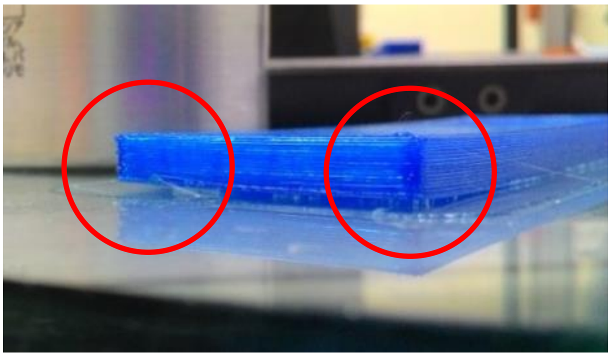

Figure 3 Deflected sample by warping deformation problem shown in the circles.

Table 2 DOE result of warping deformation.

Part No.	Independent variables				Response
	T (°C)	ρ (%)	h_1 (mm)	h_2 (mm)	y_{avg} (mm)
1	180	10	0.20	0.20	0.08
2	180	10	0.40	0.20	0.13
3	180	30	0.20	0.20	0.20
4	180	30	0.40	0.20	0.14
5	180	10	0.20	0.30	0.09
6	180	10	0.40	0.30	0.08
7	180	30	0.20	0.30	0.09
8	180	30	0.40	0.30	0.07
9	200	10	0.20	0.20	0.23
10	200	10	0.40	0.20	0.26
11	200	30	0.20	0.20	0.23
12	200	30	0.40	0.20	0.27
13	200	10	0.20	0.30	0.08
14	200	10	0.40	0.30	0.08
15	200	30	0.20	0.30	0.12
16	200	30	0.40	0.30	0.17

Table 2 shows the DOE results with average warping deformation, y_{avg} for four corners and T,ρ, h_1 and h_2 is represented by layer temperature, infill density, first layer height and other layer height. The obtained main effect plot in Fig.4 shows that the temperature and other layer height have high influence to the deformation value compared to the infill density parameter. The first layer height does not show any major effect to the warping deformation.

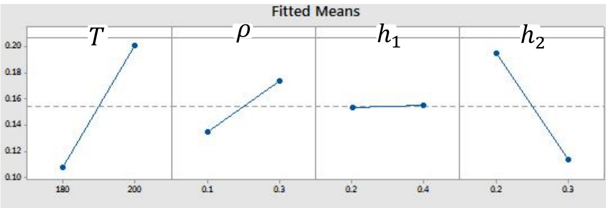

Figure 4 Main effect plot correspond to warping deformation.

Table 3 Optimized result of the Response Surface Method calculated by Minitab software.

Independent variables				Response
T (°C)	ρ (%)	h_1 (mm)	h_2 (mm)	y_{avg} (mm)
192	13	0.20	0.32	0.03

Table 3 shows the result of optimization obtained by using *Minitab* software where the minimum warping deformation, y_{avg} of 0.03mm was achieved. Sample of experimental with optimized parameter was proved the accuracy of the RSM and the optimization result where y_{avg} is equal to 0.04mm.

4. CONCLUSIONS

It is concluded that the optimum value for 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 of are 33%.

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