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## Optimization Parameter Effects on The Quality Surface Finish of 3D-Printing Process using Taguchi Method

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**Abstract.** Fused Deposition Modelling (FDM) is a process for developing Rapid Prototype (RP) objects according to numerically defined cross sectional geometry by depositing fused layers of material. This RP may use straight to the application. Therefore, this research has been done to optimize the best parameter towards better roughness on the surface. Plus, this research is to explore the influence of layer height, outline speed and extruder temperature with the surface roughness. A specimen has been proposed to fulfil the objective of the research. In order to build the specimen, it has been drawn by CAD. The, it was transfer to Standard Triangulation Language, (STL) file. The STL will read and the FDM will deposits the material from the bottom curve and build up the model to the top curve. In order to reduce experimental runs, Taguchi Method based on central composite design is adopted. L9 was used to run the specimen. Thus, there is nine experiment that will run. Specimens are prepared to improve surface roughness of the 3D printing. The specimen was measured by Mitutoyo CS3000 525-780EI. Relations among responses and process parameters are determined and their validity is proved using analysis of variance (ANOVA). Response surface are analysed to establish main factor effects and their interaction on responses. The specimen is proposed in flat and curve surface. For the result, it is stated that layer height was the main parameter that effects of the surface roughness, compare to the outline speed and extruder temperature.

### 1. Introduction

Rapid prototyping (RP) is a class of technologies that can automatically construct physical models from Computer-Aided Design (CAD) data and fabricate directly a physical model printed layer-by layer [1]. These "three-dimensional printers" helps designers to create tangible prototypes of their designs quickly with give advantages to reduce the time in manufacture industries [2-3]. Nowadays, Industries are transformed to develop a product from traditional to Rapid fabrication methods [4]. Hence, it is important to understand the process parameter used to build a part and that will affect of part strength, surface quality, build time, accuracy and repeatability [5-7]. There are several important specifications must be controlled in this 3D printing methods. Strength and surface quality are generally important specifications for industrial parts made by 3D printing method [7-8]. Anitha [9] has made some research



to determine the capability fused deposition modeling (FDM) parts concurrently from surface roughness using FDM 3000 machine has been done. Optimization parameter effects on the quality surface finish of the three-dimensional printing (3D printing) Fused Deposition Modeling (FDM) has also been reported.

Taguchi Method approach is an efficient method to identify the important parameters that operates consistently and optimally over a variety of condition to improve the resistance and quality of the surface of the piece through several experiments [10]. Therefore, design of experiment parameters, being a simple and inexpensive method, is adopted to understand the process parameters and their interaction effects on responses like accuracy of dimensions in different directions [11-14]. Analysis of variance (ANOVA) is also included as statistical method for the analysis and optimization of process parameters to find the significant factor that influence of the quality part [15-17].

## 2. Methodology

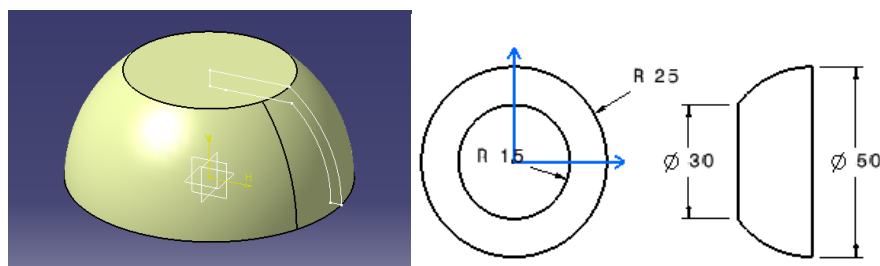
This research explores the relationship between the variable parameters' settings and output part quality characteristics, in order to predict the surface roughness of resulting part and the influence of FDM process parameters. A building goal is targeted of the FDM parts in this research is surface roughness. To improve this characteristic from the FDM building process, an investigation is carried out to study the variable parameters of FDM process. The experimentation plan consists of the following steps as shown in figure 1.



**Figure 1.** Flow chart of research

### 2.1. Specimen preparation

Acrylonitrile Butadiene Styrene (ABS P400) was used in the experiment as the material for specimen and figure 1 shows the design specimen using 3D CAD software. The designed consists of shapes such curve and flat surface and the dimension are shown in figure 2. The model saved to the STL format file, which is accepted by the rapid prototyping systems to convert it consequently to pro- processing data to start the building process using Flash Forge 3D printer.



**Figure 2.** Proposed Specimen in 3D and 2D drawings

### 2.2. Experimental Design

The experiment design used Taguchi L9 orthogonal array with 3 levels for each 3 parameters selected. These parameters used are layer height, outline speed and extruder temperature that mostly influence the surface roughness of the part. The orthogonal array was created by using software minitab19 refers to the Taguchi method. Taguchi method can reduce the number of experiments necessary to find the optimized parameter which affects the surface roughness of the 3D printing part. Table 1 shows the parameters that will used in the experimentation, and Table 2 shows the orthogonal array.

**Table 1.** The process parameters and their levels.

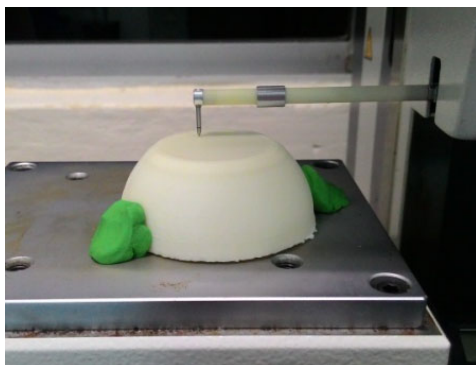
| Factor               | Level   |         |         |
|----------------------|---------|---------|---------|
|                      | 1       | 2       | 3       |
| Layer height         | 0.10 mm | 0.25 mm | 0.40 mm |
| Outline speed        | 35 mm/s | 40 mm/s | 45 mm/s |
| Extruder temperature | 220°    | 225°    | 230°    |

**Table 2.** L<sup>9</sup> Orthogonal Array

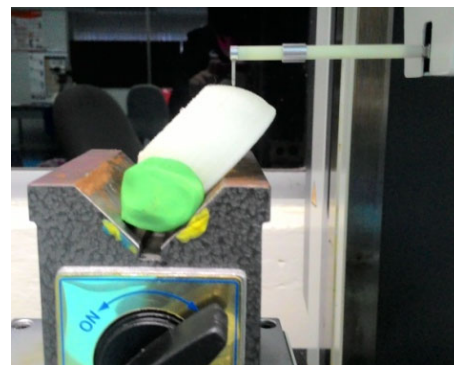
| Experiment no | Control factors |               |                      |
|---------------|-----------------|---------------|----------------------|
|               | Layer height    | Outline speed | Extruder temperature |
| 1             | 0.10 mm         | 35 mm/s       | 220°C                |
| 2             | 0.10 mm         | 40 mm/s       | 225°C                |
| 3             | 0.10 mm         | 45 mm/s       | 230°C                |
| 4             | 0.25 mm         | 35 mm/s       | 220°C                |
| 5             | 0.25 mm         | 40 mm/s       | 225°C                |
| 6             | 0.25 mm         | 45 mm/s       | 230°C                |
| 7             | 0.40 mm         | 35 mm/s       | 220°C                |
| 8             | 0.40 mm         | 40 mm/s       | 225°C                |
| 9             | 0.40 mm         | 45 mm/s       | 230°C                |

### 2.3. Measurement of surface roughness

The surface roughness of the specimen is directly measured by using Mitotuyo surface roughness tester machine F-3000. The technique used is by dragging the stylus across the surface that needs to be measured. After that, the Ra value of the profile surface will be displayed on the screen. Ra value is taken at a curve and flat surface on the workpiece and then the average Ra value will be used for surface roughness analysis. Figure 3 shows how flat surface get the surface roughness's measurement. Clay is used as the tools to grip the specimen, to make sure it is not moved when the stylus read the surface roughness [18-20]. While Figure 3.8 shows how the curve surface get its value of surface roughness. For this measurement, V block is used as a tool to make the specimen are in the correct situation to get the measurement. Plus, the clay also used to grip the specimen from slide when the measurement is measured.



a) Measured for Flat Surface



b) Measured for Curve Surface

**Figure 3.** Measuring specimen

### 3. Results and Discussions

#### 3.1. Result and Analysis for Surface Roughness

The surface roughness of the workpiece is measured at stylus speed of 0.005mm/s, the sample length of 5.00mm and evaluation length of 5.00mm. The larger the values illustrate the rougher of the machined surface. Smaller measurement illustrates the smoother the surface. Results from table 3 shows that the highest surface roughness value is 19.090 $\mu\text{m}$  for the flat surface, 51.410 $\mu\text{m}$  for curve surface. Meanwhile, the lowest surface roughness value is 5.945 $\mu\text{m}$  for the flat surface and 17.357 $\mu\text{m}$  for curve surface. From these results, it shows that surface roughness of the curve surface roughness is rougher than the flat surface.

**Table 3.** Results for Surface Roughness (Ra)

| Experiment no | Control factors     |                   |                          | Value of surface roughness, ra |                              |
|---------------|---------------------|-------------------|--------------------------|--------------------------------|------------------------------|
|               | Layer thickness (a) | Outline speed (b) | Extruder temperature (c) | Flat surface, $\mu\text{m}$    | Curve surface, $\mu\text{m}$ |
| 1             | 0.10mm              | 35mm/s            | 220 $^{\circ}\text{c}$   | 10.33                          | 17.36                        |
| 2             | 0.10mm              | 40mm/s            | 225 $^{\circ}\text{c}$   | 8.60                           | 19.86                        |
| 3             | 0.10mm              | 45mm/s            | 230 $^{\circ}\text{c}$   | 7.95                           | 18.44                        |
| 4             | 0.25mm              | 35mm/s            | 230 $^{\circ}\text{c}$   | 10.19                          | 28.64                        |
| 5             | 0.25mm              | 40mm/s            | 220 $^{\circ}\text{c}$   | 11.68                          | 25.95                        |
| 6             | 0.25mm              | 45mm/s            | 225 $^{\circ}\text{c}$   | 7.87                           | 31.81                        |
| 7             | 0.40mm              | 35mm/s            | 225 $^{\circ}\text{c}$   | 14.56                          | 51.41                        |
| 8             | 0.40mm              | 40mm/s            | 230 $^{\circ}\text{c}$   | 18.75                          | 46.15                        |
| 9             | 0.40mm              | 45mm/s            | 220 $^{\circ}\text{c}$   | 19.09                          | 44.51                        |

#### 3.2. Result and Analysis for Surface Roughness

The S/N ratio obtained for each surface is presented in table 4, it shows that layer height (a) give a significant affect to the results of surface roughness of the flat and curve surfaces. The combination of the parameters is a1b3c3 for the confirmation test are run to optimize the surface roughness value for a flat and curve surfaces. Table 5 shows the summary of the parameters to optimize the surface roughness for both surfaces.

**Table 4.** Average S/N Ratio

| Level  | Flat surface |        |        | Curve surface |        |        |
|--------|--------------|--------|--------|---------------|--------|--------|
|        | a            | b      | c      | a             | b      | c      |
| 1      | -18.15       | -21.23 | -21.22 | -25.35        | -29.38 | -29.37 |
| 2      | -19.81       | -21.83 | -21.83 | -29.16        | -29.17 | -29.34 |
| 3      | -24.78       | -19.67 | -20.03 | -33.49        | -29.44 | -29.27 |
| Change | 6.63         | 2.16   | 1.46   | 8.14          | -0.27  | 0.08   |
| Rank   | 1            | 2      | 3      | 1             | 2      | 3      |

**Table 5.** Optimum parameters setting

| Parameter                                   | Flat surface | Curve surface |
|---|--------------|---------------|
| a. Layer height, mm                         | 0.10         | 0.10          |
| b. Outline speed, mm/s                      | 45           | 40            |
| c. Extruder temperature, $^{\circ}\text{C}$ | 230          | 230           |

### 3.3. ANOVA Analysis

From table 6, the  $F_{0.05,2,8} = 4.46$  for a level of significant parameters is equal to the 0.05 (or 95% confidence level). Layer thickness [Fstatistics, flat = 6.80657447 and Fstatistic, curve = 33.60 >  $F_{0.05,2,8} = 4.46$ ] give a significant effect to the surface roughness as their F-statistics value are higher than 4.46. While for outline speed [Fstatistics, flat = 0.72 and Fstatistic, curve = 0.04 <  $F_{0.05,2,8} = 4.46$ ], and extruder temperature [Fstatistics, flat = 0.35 and Fstatistic, curve = 0.01 <  $F_{0.05,2,8} = 4.46$ ] does not give the significant effects to the surface roughness.

**Table 6.** ANOVA Analysis for Dimensional Accuracy

| Factor | Degree Of freedom | Flat surface  |             |         |                | Curve surface |             |         |                |
|--------|-------------------|---------------|-------------|---------|----------------|---------------|-------------|---------|----------------|
|        |                   | Sum of square | Mean square | F ratio | % contribution | Sum of square | Mean square | F ratio | % contribution |
| a      | 2                 | 71.34         | 35.67       | 6.81    | 76.85          | 99.44         | 49.72       | 33.60   | 96.98          |
| b      | 2                 | 7.47          | 3.73        | 0.72    | 8.04           | 0.12          | 0.06        | 0.04    | 0.12           |
| c      | 2                 | 3.61          | 1.81        | 0.35    | 3.89           | 0.02          | 0.09        | 0.01    | 0.02           |
| Error  | 2                 | 10.41         | 5.21        | -       | 11.22          | 2.96          | 1.48        | -       | 2.89           |
| Total  | 8                 | 92.83         | -           | -       | 100            | 102.54        | -           | -       | 100            |

### 3.4. Confirmation test

From the combination best parameters, new specimen was built and the value of surface roughness is taken and the result of the confirmation run for the flat is 6.33 while for the curve is 14.6. The prediction value by using software MiniTab19 for the flat surface is 5.95 and for the curve surface is 15.36. The confirmation test was run to compare the optimization and solutions obtained from the analysis. The confirmation result was compared to estimate whether the predicted optimal parameters were in the acceptable range. The margin of error from the prediction and simulation results was set below than 10%. Margin error was calculated using the equation below:

$$\begin{aligned} \text{Margin error for flat (\%)} &= [(\text{confirmation test result} - \text{predicted result}) / \text{predicted result}] \times 100\% \\ &= [(6.33 - 5.95) / 5.95] \times 100\% = 6.4\% \\ \text{Margin error for curve (\%)} &= [(\text{confirmation test result} - \text{predicted result}) / \text{predicted result}] \times 100\% \\ &= [(14.61 - 15.36) / 15.36] \times 100\% = 4.9\% \end{aligned}$$

The margin error was less than 10%, and it shows that the confirmation test result and the value of optimal parameters were acceptable and reliable.

## 4. Conclusions

Process parameters in FDM process related to some important properties, which is surface roughness of parts fabricated on FDM were investigated in this research. From the design of experiments and ANOVA analysis, it was found that layer height affects the surface quality and part accuracy greatly. But outline speed and extruder temperature have little effect. Also, the interactions outline speed and extruder temperature do not have much influence on the properties (surface roughness). The significance of layer height is further strengthened by the correlation analysis, which indicates a strong direct relationship with surface roughness. On the basis of published literature, the researcher has considered layer height as the most significant process variable that affects surface finish.

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