Characteristics of Process Parameters in Fused Deposition Modelling Process

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Abstract: Additive manufacturing has received incredible attention as a crucial emerging technology as three-dimensional printing offers wide range of industrial applications. This article outlines empirical analyses on the influence of key process parameters such as print speed, infill speed and layer resolution on roughness of the surface and time taken of Fused Deposition Modelling (FDM) processed of Polylactic Acid (PLA) part. Influence of each parameter couple with analysis of variance were utilize using full factorial design. The optimum parameters setting for best surface roughness and lower machining time also being determined. Experimental results indicate that optimal factor settings for each performance characteristic are different.

Keywords: Additive Manufacturing, 3D Printing, Fused Deposition Modelling, Polylactic Acid, Taguchi Method

1. Introduction
Additive manufacturing is recognized as a crucial element in technological advancement and has gained considerable interest from many industrial applications [1]. Additive manufacturing technique integrates the use of computer aided design (CAD) and computer aided manufacturing (CAM) in the manufacture of the specific geometry component using a three-dimensional printer. Through AM technique, the first step is to transform the 3D model which was modeled using CAD application into STL format which is an object's triangular mesh. The computer program will divide the model piece into 2D profile layers in the STL format. Next, the 3D component is developed by each layer that is sliced into 2D model layers and bonded to the previous layer on the build platform until it is completed as required in the original CAD software as in the 3D model [2].

According to the standard of ISO/ASTM 17296 standard on Additive Manufacturing (AM) Technologies [3], it stated that there are seven types of AM processes and can be distinguished into material jetting, material extrusion, direct energy deposition, sheet lamination, binder jetting, powder bed fusion and vat photo polymerization. 3D printing can be classified as laminated object manufacturing, selective laser sintering, fused deposition modeling (FDM), and PolyJet technology. Between those techniques, the most prominent 3D printing technologies is FDM as it offers basic AM concept, robust technology, ease of use, relatively small scale and cost effective. Polymeric materials, metallic materials, inorganic nonmetallic materials, and composite materials are commonly used material in 3D printing. However, in FDM, thermoplastic polymer materials including acrylonitrile-butadiene-styrene (ABS) resin, polylactic acid (PLA), nylon, and polycarbonate are mainly used.
Researchers have been actively investigating ways to attain high-quality FDM finished products in recent years by investigating the FDM process parameter in order to optimize the 3D printing process in accordance to industrial demands. Rational processing parameter is the essential in producing high quality FDM products. However, the effect of each processing parameter on 3D printed products has not yet been widely understood due to the complexity of processing parameters and the uncertain relation between processing parameters and product performance [2]. Thus, to prepare suitable FDM products, the law of parameter selection must be explored.

This study investigates the characteristics of the FDM process parameter includes print speed, infill speed and layer resolution in relation to the fabrication performance namely surface roughness and machining time using full factorial design.

2. Details experimental

2.1 Processing Parameters

In order to investigate the impact of various processing parameters on PLA specimen’s 3D printing products, this work scrutinizes the effects of print speed, infill speed and layer resolution on FDM PLA parts through a full factorial design paired with variance analysis (ANOVA) for printing process optimization. The processing parameter defined as follows:

a. Printing speed: The moving speed of the nozzle.

b. Infill speed: Percentage count for compact models to be filled with the material when printed

c. Layer resolution (thickness): The layer slice thickness by the software.

For the FDM product performance responses:

a. Surface roughness (Ra): FDM final products surface finish and can being used directly.

b. Total machining time: Total time taken to complete the product by FDM.

To assess the influence of process variables, impact on printed products, a same model see Figure 1, was built under various input parameters conditions. The process parameters involved are (1) print speed, (2) infill speed and (3) layer resolution. The printed products were manufactured using RPMAKER by MYCRO 3D printer machine and using PLA plastic as model build material. The selected values of process parameters are tabulated in Table 1. To design the experiments run, three factors with full factorial design (L8) is applied by using the process parameters as shown in Table 2.

Figure 2 shows, the 3D printer machine, RPMAKER manufactured by MYCRO while in Table 3 shows some of the technical specifications. The surface roughness measurement was attained by using ALICONA Infinite Focus Microscope IFM-Infinite Focus Surface Metrology System as shown in Figure 3. The measurement recorded follows the guideline from ISO 4288 standards. For each sample test, the data were taken at three different positions on the sample surface and averages of those values were taken as final experimental data of surface roughness.

Analysis of variants (ANOVA) is being used to assess the effect and variance of each factor and interaction compared to the total variance observed in the result. The linear trends of the results is a reasonable assumption to articulate the performance in ideal condition. Experiment analysis is made using Minitab R14 software. For the analysis of data, results were evaluated using analysis of variance (ANOVA) techniques at 5% significant level. The main plot effect is used to predict the degree of the optimum factor. ANOVA establishes the relative effect of each factor for each interaction.

| Test Run | Print speed (mm/s) | Infill speed (%) | Layer resolution (μm) |
|----------|------------------|-----------------|----------------------|
|          |                  |                 |                      |

[Table 1: Factors and Levels]

| Machining Parameters | Low | High |
|----------------------|-----|------|
| Print speed (mm/s)   | 100 | 200  |
| Infill speed (%)     | 10  | 30   |
| Layer resolution (μm)| 100 | 300  |

[Table 2: Experimental Layout]
Table 3: RPMAKER Specification

| Items                | Specification          |
|----------------------|------------------------|
| Build volume         | 150 x 150 x 150mm     |
| Layer resolution     | 60 - 300 μm           |
| Max printing speed   | 80mm/s                |
| Max travel speed     | 200mm/s               |
| Nozzle diameter      | 0.4mm                 |
| Filament diameter    | 1.75mm                |
| Electrical power     | 12 Watt               |

3. Results and discussion

3.1 Surface roughness

The results of mean surface roughness of the FDM products are presented in Figure 4. The value of the surface roughness, Ra for each experimental was the average value of three roughness readings. Based from the result in Figure 4, the resulted mean surface roughness, Ra obtained range from 1.9164 to 2.5812 μm. The smoothest Ra is achieved when cutting condition of Test 3 (print speed 100mm/s, infill speed 30% and layer resolution 100 μm) is employed whereas the roughest Ra is detected with cutting condition Test 8 (print speed 200mm/s, infill speed 30% and layer resolution 300 μm).

Analysis of variance techniques (ANOVA) is used to evaluate the adequacy of the developed model. Using this technique, the measured F-ratio was found to be larger than the tabulated value at a confidence level of 95 per cent; thus, the model is considered adequate. For the models developed, the adequacy of a fitted regression models’ coefficient of calculated R² and adjusted R² values were above 99.9% and 99.97%, respectively. These values indicate that the regression models are quite adequate.

Table 4 shows the details of the ANOVA results with respect to surface roughness. All three variable factors were identified to be statistically significant with the print speed shows the highest effect on surface roughness with a percentage contribution ratio (PCR) of 54%. This was followed by layer resolution and infill speed at reduced PCR’s of 21% and 3% respectively. Two level interactions
between print speed vs layer resolution and infill speed vs layer resolution also found to have 5% significant level with contributions of 13% and 8% respectively. The associated main effects plot for mean surface roughness shown in Figure 5. The interaction plot of parameters for surface roughness is shown in Figure 6. It shows print speed vs layer resolution and infill speed vs layer resolution have significant interaction between factors. Furthermore, it clearly shows print speed vs layer resolution have more strong interaction (PCR 13%) compare others. Figure 7 shows, 3D surface plot of Ra vs print speed, infill speed of interaction graph for surface roughness performance measure.

It observed at A1B2C1 (Test 3- inclusive with interaction) are the optimal levels of the design parameters for improve surface roughness which implies print speed at low level, infill speed high level and lower layer resolution. These combinations give the best surface finished (1.9164 μm) within the specified range.

Table 4: ANOVA result for surface roughness

| Factor          | Sum of Squares | DF | Mean of Squares | F Value  | Prob> F | PCR  |
|-----------------|----------------|----|-----------------|----------|---------|------|
| Model           | 0.342371       | 6  | 0.057062        | 471.97   | 0.0352  | Significant |
| Print Speed (A) | 0.183709       | 1  | 0.183709        | 1519.496 | 0.0163  | 54%   |
| Infill Speed (B)| 0.008945       | 1  | 0.008945        | 73.98212 | 0.0737  | 3%    |
| Layer Resolution (C) | 0.072409 | 1  | 0.072409       | 598.9115 | 0.0260  | 21%   |
| AB              | 0.005655       | 1  | 0.005655        | 46.77504 | 0.0924  | 2%    |
| AC              | 0.043675       | 1  | 0.043675        | 361.2444 | 0.0335  | 13%   |
| BC              | 0.027978       | 1  | 0.027978        | 231.4116 | 0.0418  | 8%    |
| Residual        | 0.000121       | 1  | 0.000121        |          |         |       |
| Total           | 0.342492       | 7  |                 |          |         | *Significant at 5% level |

Std. Dev: 0.010996, Mean: 2.137588, C.V: 0.514389, R-Squared: 0.999647, Adjusted R-Squared: 0.997529, Predicted R-Squared: 0.977408

Figure 4: Mean surface roughness

Figure 5: Main effect plots of surface roughness

Figure 6: Interaction plots of parameters
3.2 Total Machining Time

The results of total machining time of the FDM products are presented in Figure 8. The total machining time obtained range from 25 to 53 minute. The shortest time is achieved when cutting condition of Test 1 (print speed 100 mm/s, infill speed 10% and layer resolution 300 μm) is employed whereas the longest time taken is detected with condition Test 8 (print speed 200mm/s, infill speed 30% and layer resolution 300μm).

For the models developed, the adequacy of a fitted regression model coefficient of calculated R$^2$ and adjusted R$^2$ values were above 99.9% and 99.8%, respectively. These values indicate that the regression models are quite adequate. Table 5 details the ANOVA results with respect to machining time. All 3 variable factors were found to be statistically significant with layer resolution having the highest influence on machining time with a percentage contribution ratio (PCR) of 45%. This was followed by infill speed and layer resolution at reduced PCR’s of 21% and 11% respectively. However, two level interactions only infill speed vs layer resolution found to have 5% significant level with contributions of 21%. The associated main effects plot for machining time shown in Figure 9. The interaction plot of parameters for machining time is shown in Figure 10. It clearly shows, only infill speed vs layer resolution has significant interaction between factors. Figure 10 shows, 3D surface plot of machining time vs layer resolution, infill speed of interaction graph for machining time.

It observed at A1B1C1 are the optimal levels of the design parameters for improve machining time which implies print speed at low level, infill speed and layer resolution at low level. These combinations give the best machining time (25 minute) within the specified range.

### Table 5: ANOVA result for machining time

| Factor            | Sum of Squares | DF | Mean of Squares | F Value   | Prob> F | PCR   |
|-------------------|----------------|----|-----------------|-----------|---------|-------|
| Model             | 716.75         | 6  | 119.4583        | 955.6667  | 0.0248  | Significant |
| Print Speed (A)   | 78.125         | 1  | 78.125          | 625       | 0.0255  | 11%   |
| Infill Speed (B)  | 153.125        | 1  | 153.125         | 1225      | 0.0182  | 21%   |
| Layer Resolution (C) | 325.125 | 1 | 325.125 | 2601 | 0.0125 | 45% |
|---------------------|---------|---|---------|------|--------|-----|
| AB                  | 1.125   | 1 | 1.125   | 9    | 0.2048 | 0%  |
| AC                  | 6.125   | 1 | 6.125   | 49   | 0.0903 | 1%  |
| BC                  | 153.125 | 1 | 153.125 | 1225 | 0.0182 | 21% |
| Residual            | 0.125   | 1 | 0.125   |      |        |     |
| **Total**           | 716.875 | 7 |         |      |        |     |

| Std. Dev            | 0.353553 |        | R-Squared | 0.999826 |
|---------------------|----------|--------|-----------|----------|
| Mean                | 35.875   |        | Adjusted R-Squared | 0.998779 |
| C.V                 | 0.985515 |        | Predicted R-Squared | 0.98884  |

**Figure 9:** Main effect plots of machining time  
**Figure 10:** Interaction plots of parameters  
**Figure 11:** Surface plot of machining time vs infill speed, layer resolution

### 4. Conclusions
Experimental investigations on the influence of main process parameters such as print speed, infill speed and layer resolution on surface roughness and time taken from the Polylactic Acid (PLA) processed part of Fused Deposition Modelling (FDM) were studied. Based on the analytical results obtained, the following conclusions can be drawn.

1. Print speed and layer resolution are verified to be critical factors affecting surface roughness of the product. Surface finish obtained at high layer resolution was obtained the best quality product. The optimum surface roughness was at parameters; print speed at low level, infill speed high level and lower layer resolution.

2. The thickness of the layer resolution was found to be an influencing parameter which affects total machining time. The build time for higher layer resolution thickness values was lower.

By using the results derived using this study, this analysis could be applied in the direction of prototype development by functionally graded materials.
Acknowledgments

The authors would like to thank the Faculty of Mechanical Engineering (AMTEX), Universiti Teknologi MARA, Universitas Sumatera Utara, Politeknik Sultan Azlan Shah and Ministry of Education, Malaysia for the research funding.

References

1. Bai H, Shuna M, Hui H, Yunchao J, Yingbin X, Huankun H 2018 Study of Processing Parameters in Fused Deposition Modeling Based on Mechanical Properties of Acrylonitrile-Butadiene-Styrene Filament Polymer Engineering And Science, pp 1-9,
2. Anoop K S, Ohdar R K, Mahapatra S S, 2009 Improving dimensional accuracy of Fused Deposition Modelling processed part using grey Taguchi method Materials and Design 30 (2009) 4243–4252
3. ISO 17296-2:2015(en) Additive manufacturing — General principles — Part 2: Overview of process categories and feedstock