Jurnal
Teknologi

**Full Paper**

# APPLICATION OF TAGUCHI METHOD TO OPTIMIZE FUSED DEPOSITION MODELING PROCESS PARAMETERS FOR SURFACE ROUGHNESS

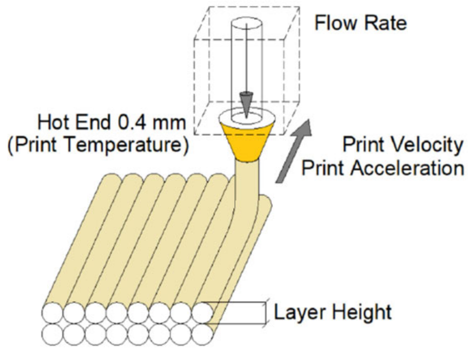
Shajahan Maidin, Irdawati Fadani, Norilani Md. Nor Hayati, Haroun Albaluooshi

Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

**Article history**
Received
*16 March 2022*
Received in revised form
*22 July 2022*
Accepted
*25 July 2022*
Published Online
*23 October 2022*

*Corresponding author
shajahan@utem.edu.my

## Graphical abstract



## Abstract

Surface quality is one of the limiting aspects of additive manufacturing (AM). This paper presents the findings from a study to optimize Fused Deposition Modeling (FDM) process parameters to improve the surface roughness of the printed test specimen. Taguchi $3^4$ and L9 orthogonal array were used to design the experiment. Samples models of the same size were fabricated with an open source FDM printer using acrylonitrile butadiene styrene (ABS) material and were examined to see the structural differences. Taguchi method S/N ratio and means analysis was used to find the optimum process parameter for surface roughness. The results indicate that flow rate is the most influential process parameter towards better surface roughness, followed by layer height, printing temperature and print speed. The surface roughness of printed test specimen was found to be rougher with the increase in levels of flow rate. The flow rate is responsible for the unevenly aligned section of the deposited filament. It was discovered that the optimal proses parameter levels for surface roughness by the CR-10S Pro FDM machine are 0.1 mm of layer height, 90% of flow rate, 230°C of printing temperature, and 35mm/s of print speed. Thus, Taguchi method has proven to be a useful approach for optimizing parameters to improve the surface roughness of printed parts.

*Keywords:* Process parameters optimization, surface roughness, fused deposition modeling, Taguchi method, s/n ratio

## Abstrak

Kualiti permukaan adalah salah satu aspek yang mengehadkan penggunaan proses pembuatan tambahan (AM). Artikel ini membentangkan dapatan daripada kajian untuk mengoptimumkan parameter proses Pemodelan Pemendapan Bercantum (FDM) untuk menambah baik kekasaran permukaan spesimen ujian yang dicetak. Susunan ortogonal Taguchi $3^4$ dan L9 telah digunakan untuk merancang eksperimen. Sampel ujian dengan ukuran yang sama telah dicetak dengan mesin FDM menggunakan bahan acrylonitrile butadiene styrene (ABS) dan telah diperiksa untuk melihat perbezaan struktur. Kaedah nisbah S/N Taguchi dan analisis sarana telah digunakan untuk mencari parameter proses optimum untuk kekasaran permukaan. Dapatan kajian menunjukkan kadar aliran adalah parameter proses yang paling berpengaruh terhadap kekasaran permukaan, diikuti oleh ketinggian lapisan, suhu pencetakan, dan kelajuan cetakan. Kekasaran permukaan specimen ujian yang dicetak didapati lebih kasar dengan peningkatan kelajuan aliran. Kadar aliran bertanggungjawab untuk bahagian permukaan yang tidak rata. Parameter optimum untuk kekasaran permukaan oleh mesin CR-10S Pro FDM adalah ketinggian lapisan 0.1 mm, 90% laju aliran, suhu pencetakan 230°C,

84:6 (2022) 29–37 | https://journals.utm.my/jurnalteknologi | eISSN 2180–3722 | DOI: https://doi.org/10.11113/jurnalteknologi.v84.18430 |

dan kelajuan cetakan 35mm/s. Kaedah Taguchi telah terbukti menjadi pendekatan yang berguna untuk mengoptimumkan parameter proses untuk *memperbaiki kekasaran permukaan bahagian yang dicetak.*

*Kata kunci:* Pengoptimuman parameter proses, kekasaran permukaan, pemodelan pemendapan bercantum, kaedah Taguchi, nisbah s/n

## 1.0 INTRODUCTION

Additive manufacturing (AM) has become very widely accepted in many fields of engineering and industry over the last decade. AM has been stated by the American Society for Testing and Materials (ASTM) International Committee as a process of joining material to produce objects from 3D model data, generally layer by layer as opposed to subtractive manufacturing and including conventional machining [1]. AM provides benefits to produce any complicated geometry to shorten the processing time at minimal cost because no tools are needed. This technology also includes a wide range of thermoplastic polymer material availability, easy change of material, not require supervision, no harmful materials and process of low-temperature procedures. However, the main downside of AM technology is that the changes in nozzle temperature during the printing process could result in poor surface quality [2].

Fused Deposition Modeling (FDM) is an extrusion-based method that generally creates objects from a 3D CAD model layers upon layer to fabricate a three-dimensional part. The process is mainly used to construct complex and efficient geometric parts in a short time and at a lower cost [3]. FDM was widely used as part of AM technology because of its capacity to deliver complex geometrical parts accurately and securely. FDM produces parts from a variety of thermoplastic filament materials which have excellent mechanical, thermal and chemical resistance, including thermoplastic fibre, namely Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS) [4]. ABS was chosen as prime material in this study to print the samples. ABS is a shiny material with high strength because it contains chemical compositions of styrene and butadiene, respectively [5]. It is relatively inexpensive, easily available, and has versatile applicability and low melting point, better strength and good chemical resistance.

Surface roughness is one of the important specifications that must be controlled for industrial parts made by the 3D printing method [6]. It is considered a vital quality indicator because it directly affects the dimensional accuracy of the finished part [7]. Functional parts with better dimensional accuracy can enhance tighter tolerances. The surface quality can be improved without extra costs with the correct modification of process parameters [8]. Generally, the lower value of surface roughness indicates better surface quality [9].

Therefore, this paper aims to optimize the process parameters, namely layer height, filament flow rate, print speed, and printing temperature, to reduce the surface roughness of ABS printed parts. Taguchi design of experiment was adopted to run the experiment with four factors and three levels. S/N ratio and mean analysis was used to find the optimum process parameter for surface roughness. The Taguchi method is a commonly popular approach that implies a systematic and effective design for the optimization process. Previous studies used the Taguchi method as their analysis proved that main parameters such as bed temperature, number of loops, nozzle temperature, print speed, layer thickness and infill influence surface texture and circularity error in ABS printed parts [9]. Lastly, this approach focuses on four industries' market goals: short production time, reduced cost, high efficiency, and high quality. Optimal parameter settings can be calculated in the Taguchi method depending on the objective of the experiment [10].

## 2.0 BACKGROUND STUDY

### 2.1 Fused Deposition Modeling Process

FDM process was implemented in the early 1990s by Stratasys Inc., USA. The Process is also known by its other names such as Fused Filament Fabrication (FFF), Material Extrusion (ME) in the market. FDM system is becoming ubiquitous today because it is widely used for prototyping and product applications. This technology allows the fabrication of 3D products directly from CAD software and can print any intricate parts. Acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) are the most common materials used by FDM.

Before the manufacturing process begins, a user must prepare the design in CAD model through solid modeling software and has to be input into the slicing software in form of STL file for slicing the model into individual layers [11]. The slicing software has various options for controlling the FDM parameters including layer thickness, infill density, shell thickness, raster angle, printing speed, air gap, bed temperature, and nozzle temperature. The software also generates the G-code for the object generated through the FDM process.

FDM machine consists of an extruder head with a nozzle for extruding heated filaments, some machine has either a single nozzle or multiple nozzles. One of the nozzles is used for the deposition of part material and the other for the deposition of support material. The tool path of the extruder head is based on a computer numerical control system that allows the material to be processed in a complex shape and also controls the motion of the platform [12].

The manufacturing process begins in which semi-molten materials are extruded through a nozzle and deposited on desired arena layer after other layers which get solidified to create a solid object. The extruded thermoplastic filament material is squeezed on the print bed line by line in X-Y based on the pre-designed tool paths to create a layer. Next, when the layer deposition is done, the movable platform moves downward in the z-axis and another layer is then deposited to the previous layer. This step is repeated until the part is completely fabricated. Finally, the thermoplastic filament material cools and solidifies approximately a few seconds in a short period, it sticks to the surrounding material depending on the material of the filament.

### 2.2 Process Parameters

FDM technique plays a major role in the conversion of design thinking into reality at ease, but it has certain undesired effects on the 3D prototypes, such as poor surface finishing, lesser strength, and slow print speed. Various research is undergoing to overcome these vital drawbacks. The quality of 3D parts is influenced by several parameters that need to be carefully calibrated to achieve an optimum condition for better performance. These critical parameters significantly affect mechanical properties. Optimization of process parameters helps to evaluate the right set of parameters that enhance the quality of products.

The quality and performance of FDM parts rely on several process parameters. Therefore, it is essential to understand the process parameters to obtain the desired quality characteristics in the parts. The analysis of the effect of each process parameter on the response characteristics of the FDM parts helps to modify the level of the process variable leading to an improvement in the quality of the products [13]. Generally, the strength and surface quality are significant parameters that must be controlled [14].

### 2.3 Layer Height

Layer height defines the thickness of each layer to be printed. On the other side, the layer height influences the thickness of each layer. From the previous investigation, layer height strongly impacts the surface quality and product accuracy [15]. The significance of the layer height is supported further by a correlation study which shows a significant direct relationship to surface roughness.

Often, the normal layer thickness is 0.2 mm, which allows for decent printing results. Stratasys values are only specified for the default 0.010" (0.25 mm) layer thickness, which is not specified for any other layer thickness. When measured diagonally across the building direction, perpendicular to the building direction, or parallel to the building direction, the thin layer produces a smoother surface than the thick layer. The lower or thinner the layer, the higher the quality of the 3D print that will be produced. However, decreasing the layer thickness means that more layers will be required to be printed, which will increase in build time.

### 2.4 Flow Rate

The flow rate is the multiplier of the filament output stream depending on the part geometry. 3D printer flow rate refers to the setting of the slicer that determines the amount of plastic to be extruded. Depending on the slicer, the flow rate is set to 1.0 or 100 %. Thus, if the flow rate was set to 1.1 or 110%, the flow rate rises by 10%. In addition, the incorrect flow rate will result in poorly printed parts. A low flow rate will lead to extrusion such as the sample will have a gap between lines. Meanwhile, a high flow rate will lead to over extrusions such as too much material in the corners and uneven layers.

The distance between one layer and the next layer on a vertical axis is referred to as the layer height in AM. The extruder temperature is described as the temperature of the printing nozzle, and the printing speed is defined as the amount of space occupied by the printing nozzle in one unit of time during the printing process. Furthermore, the printing acceleration is the speed gain obtained throughout the printing process, and the flow rate is the multiplier of the filament output stream based on the complexity of the part [16].

### 2.5 Print Temperature

The printing temperature's function is to control the temperature extruding nozzle. Further research was conducted to study the impacts of temperature on the ABS printed parts. The non-uniform gradient of temperature inhibits stress. Stress is slowly rising and distorting, with dimensional imprecision and a cracking inner layer, since the heat has dissipated too quickly [17]. The conduction and convection of the temperature difference led to a quick solidification of the material. The correlation to another layer at the top caused the melting of the previous layer. Inconsistent fluctuations in temperature have caused stress.

### 2.6 Print Speed

Print speed dictates how fast the 3D printer nozzle moves when the heated filament is extruded, while the extruder temperature affects the extruding nozzle's temperature. Printing speed affects how rapidly the 3D printer moves while the heated filament is extruded [18]. A speed multiplier is featured in the FDM machine to increase the deposition speed. The 1X and 1.3X speed multipliers are approximately equivalent 16 mm/s and 21.33 mm/s respectively.

## 3.0 METHODOLOGY

The open source FDM printer used to print the specimen is CR-10S Pro that manufactured by Creality. It comes with a built size of 300 x 300 x 400 mm and 0.4 mm nozzle diameter. CR-10S Pro as shown in Figure 1 capable of printing PLA, ABS, TPU and other composite filaments. It is user-friendly and has features such as power loss detection, filament sensors, and automated bed levelling. In addition, it has additional features such as automatic bed levelling which the touch probe's sensor will check the height of the bed at 25 different points on the build surface to compensate for any minor differences. CR-10S Pro comes with its own CURA software has a lot of profiles that allowed users to configure printers and make appropriate printing options. Moreover, CURA software has a beginner-friendly setting because it has many settings that make it better to optimize parameters such as reducing the build time or enhancing the surface quality.

**Figure 1** FDM CR-10S Pro machine

The orthogonal array was built for this study by utilising Minitab 19, which refers to the Taguchi method. The design of the experiment used Taguchi L9 orthogonal array with 3 levels for every 4 parameters. For this study, four parameters are used as shown in Table 1 which is layer height with the range between 0.1 - 0.3 mm, flow rate between 90 – 110 %, print temperature between 230 – 250°C and print speed between 35 - 45 mm/s. Each factors' range of the levels was decided based on the best setting of the printer to print ABS material. Taguchi was used to reduce the number of experiments required to identify optimum factors that influence surface roughness improvement of printed specimen. The L^9 orthogonal array used in this study was designed as shown in Table 2.

**Table 1** Levels of process parameters

| Factor | Level | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Layer height, mm | 0.1 | 0.2 | 0.3 |
| Flow rate, % | 90 | 100 | 110 |
| Printing temperature, °C | 230 | 240 | 250 |
| Print speed, mm/s | 35 | 40 | 45 |

**Table 2** L9 orthogonal array

| Run | Input factors | | | |
|---|---|---|---|---|
| | Layer height | Flow rate | Printing temperature | Print speed |
| 1 | 0.1 | 90 | 230 | 35 |
| 2 | 0.1 | 100 | 240 | 40 |
| 3 | 0.1 | 110 | 250 | 45 |
| 4 | 0.2 | 90 | 240 | 45 |
| 5 | 0.2 | 100 | 250 | 35 |
| 6 | 0.2 | 110 | 230 | 40 |
| 7 | 0.3 | 90 | 250 | 40 |
| 8 | 0.3 | 100 | 230 | 45 |
| 9 | 0.3 | 110 | 240 | 35 |

### 3.1 Specimen Preparation

After the 3D CAD model of the sample is drawn, the drawing was converted to STL file format which is accepted by AM systems because the printer used can only accept the file in STL format. Consequently, it will convert to pro-processing data which will slice the file into thin cross-sectional layers. The printer has some default setup options which are particular to that process. In this phase, one manipulation for the setup parameters was required which is surface roughness. Four input factors with three levels were used namely layer height, flow rate, print temperature and print speed.

Moreover, ABS material was used as a specimen material in the experiment due to its acceptance among users in conjunction with its availability. Thus, the constant variables for this experiment are ABS materials and 100% infill density. Then, the part can be deposited automatically based on the design matrix scheme. However, the process needs to be taken care to avoid power failure or material shortages. After the part is completely fabricated, it can be removed from the machine. Lastly, all the samples were labelled according to the number of experiments and kept in plastic seals separately. One of the 3D printed parts is depicted in Figure 2. The sample was design in rectangular build shape and having dimensions of 15 mm x 15 mm x 25 mm

**Figure 2** Printed sample

### 3.2 Surface Roughness Measurement and Testing

Surface roughness, Ra is the recognized standard in this study to measure the surface roughness of the printed parts. ISO 1997 was the measuring standard used. The surface roughness was measured by using portable surface roughness tester Mitutoyo SJ-301 as shown in Figure 3. To reach maximum accuracy, the calibration of the equipment must be done before measuring the surface roughness on the printed parts. Nine values of surface roughness were taken for each sample which represents different process parameters. The printed surface was measured vertically to the feed mark.

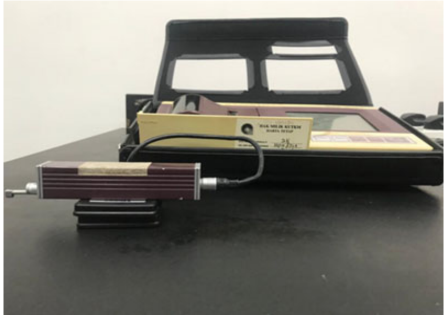


**Figure 3** Surface roughness portable tester

Furthermore, in this study stereomicroscope was used to examine the surface characteristics of the printed sample. Stereo microscope compatible with pro-VIS software allows making inspection and study the surface defect of the printed sample whether it is normal or poor in terms of surface quality. It is paired with a digital camera and a computer and is used to capture and display the visual of the sample surface. The Meiji stereo microscope is illustrated in Figure 4.

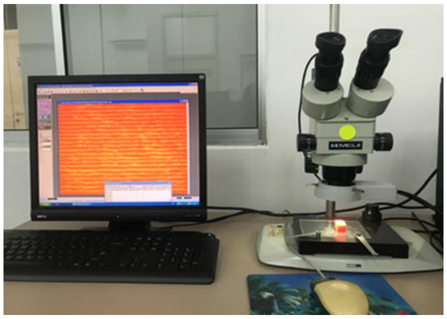


**Figure 4** Optical microscope

## 4.0 RESULTS AND DISCUSSION

### 4.1 Surface Roughness Results

In total, 9 specimens with all four parameters were printed. By using surface roughness (Ra) data, the Taguchi design of experiments was implemented in this study. The result of surface roughness was measured by using Mitutoyo Suftest SJ-301 surface roughness tester. The surface roughness of the specimen was measured at measuring speed 0.25 mm/s and evaluation length of 0.75 mm. The larger values indicate the rougher the surface while the smaller the values indicate the smoother the surface.

The surface roughness of each printed part was measured and recorded in Table 3. The surface area of the specimen was taken 5 times reading to get a more accurate average surface roughness, Ra value. The average reading of Ra can be obtained by adding the values of the five readings r1, r2, r3, r4, and r5, and then using the Taguchi method to generate statistically valid results.

**Table 3** Results of surface roughness

| Run | Surface roughness, Ra (µm) | | | | | Average, Ra (µm) |
|---|---|---|---|---|---|---|
| | R1 | R2 | R3 | R4 | R5 | |
| 1 | 6.55 | 6.10 | 6.51 | 6.23 | 6.59 | 6.396 |
| 2 | 6.91 | 6.95 | 7.16 | 7.06 | 7.26 | 7.068 |
| 3 | 10.15 | 8.91 | 13.55 | 8.82 | 12.61 | 10.808 |
| 4 | 9.32 | 9.03 | 9.85 | 9.95 | 9.01 | 9.432 |
| 5 | 9.91 | 10.26 | 9.15 | 9.64 | 10.45 | 9.882 |
| 6 | 10.87 | 10.42 | 10.86 | 10.39 | 11.19 | 10.746 |
| 7 | 10.71 | 9.27 | 10.18 | 8.68 | 9.70 | 9.708 |
| 8 | 9.17 | 9.65 | 10.47 | 9.05 | 10.02 | 9.672 |
| 9 | 10.87 | 10.72 | 9.64 | 11.68 | 10.49 | 10.680 |

The result from Table 3 reveals that the different combination of parameter settings for experimental run 1 with the combination of layer height 0.1mm, flow rate 90%, print temperature 230°C, and print speed 35mm/s has the lowest average Ra value, which is 6.396 µm, followed by experimental run 2 and experimental run 4 which have the average Ra value of 7.068 µm and 9.432 µm respectively. Experimental run 2 is the combination of layer height 0.1mm, flow rate 100%, print temperature 240°C, and print speed 40mm/s while the experimental run 4 is the combination of layer height 0.2mm, flow rate 90%, print temperature 240°C, and print speed 45mm/s.

On the analysis of surface roughness, it can be observed these three experimental runs that have relatively lower average Ra values compared to other experimental runs. They possess the common layer thickness which is 0.1 mm and 0.2 mm. Hence it can be concluded that a layer thickness of 0.1 mm can fabricate the FDM product that has a lower surface roughness which indicates better surface quality.

The importance of layer height is further supported by the correlation analysis which shows a significant direct relationship to surface roughness [18]. The lower or thinner the layer, the higher the quality of the printed specimen produced [19]. However, reducing the layer thickness means that more layers were required to be printed, which will result in a longer build time [19]. Based on the available literature, the study finds layer height as the most important process parameter influencing surface finish [20].

Furthermore, the different combination of parameter settings for experimental run 3 with the combination of layer height 0.1mm, flow rate 110%, print temperature 250°C, and print speed 45mm/s has the highest average Ra value, which is 10.808 µm, followed by experimental run 6 and experimental run 9 which has the average Ra value of 10.746 µm and 10.680 µm respectively. Experimental run 6 is the combination of layer height 0.2mm, flow rate 110%, print temperature 230°C, and print speed 40mm/s while experimental run 9 is the combination of layer height 0.3mm, flow rate 110%, print temperature 240°C, and print speed 35mm/s.

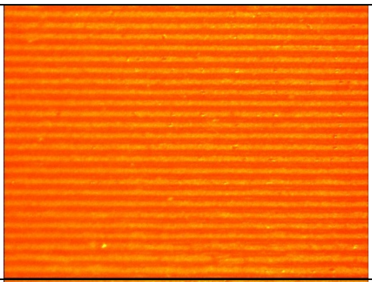
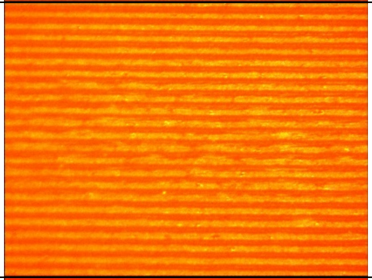
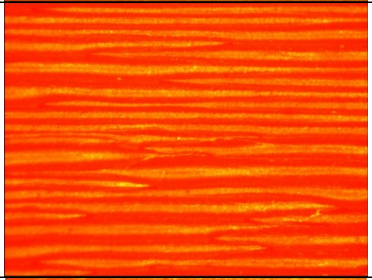
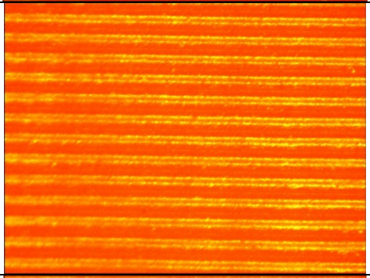
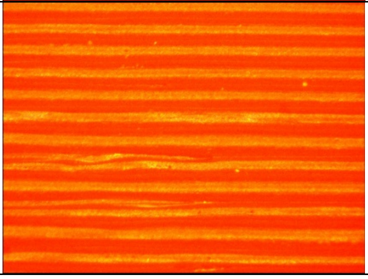
On the analysis of surface roughness, it can be observed these three experimental runs that have relatively higher average Ra values compared to other experimental runs. They possess a common flow rate which is 110%. Hence it can be concluded that a flow rate of 110% will fabricate a part that has a higher surface roughness which indicates bad surface quality.

The average Ra value indicates that the lower the average Ra value, the better the surface quality of the part produced. Therefore, experimental run 1 with the parameters setting of layer height 0.1mm, flow rate 90%, print temperature 230°C, and print speed 35mm/s can fabricate the FDM part with good surface quality as it has the lowest average surface roughness, Ra value. Therefore, experimental run 1 is chosen as the combination which can fabricate the best surface quality of the FDM part.

## 4.2 Microstructure Inspection

Microscopic inspection has been carried out to observe and examine the surface finish of the printed specimens. After the surface roughness measurement, the specimens were examined under microscopic inspection to zoom in on the surface finish quality. 9 rectangle specimens were scanned using Meiji Stereo Microscope to observe their surface microstructural differences. To prove the reliability of the findings, the zoom-in surface finishes quality from sample 1 to sample 9 were depicted in Table 4.

**Table 4** Microstructure of surface roughness

| Sample | Microstructure |
|---|---|
| Sample 1 |  |
| Sample 2 |  |
| Sample 3 |  |
| Sample 4 |  |
| Sample 5 |  |
| Sample 6 |  |

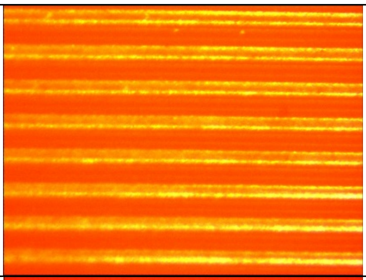
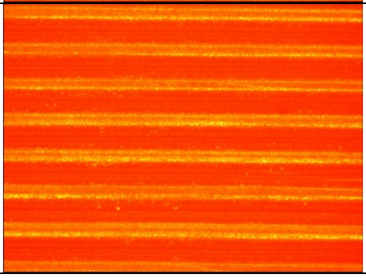
| Sample | Microstructure |
|---|---|
| Sample 7 |  |
| Sample 8 |  |
| Sample 9 |  |

Table 4 shows the optical microscope test result of printed sample 1 when applying the low level of layer height which is 0.1 mm. The height between layers was consistent and arranged, and the layer produced was more even. Physically, the colour pigmentation in sample 1 was uniformly distributed. Therefore, it was found that sample 1 provided the lowest surface roughness value, which is 6.396 µm.

Next, sample 3 demonstrates the imperfections of the surface finish. The defects can be seen in that poor bonding between layers affected the surface quality of the printed sample [21]. The height between layers was not consistently arranged, and line stacking shows discontinuity and uneven layer. It was found that the surface roughness of sample 3 was the highest, which is 10.808 µm when compared to other samples, which leads to poor surface quality.

## 4.3 S/N Ratio and Means

Minitab 19 software was used to evaluate the effects plots for S/N ratio, delta and rank value. Table 5 indicate the response table of the S/N ratio that acts as a guide to choosing the best parameter level of each factor. Delta and rank values have been used to determine the parameter that significantly affects surface roughness. The highest value of delta was in the first rank, and vice versa. It will reveal which parameter is mainly responsible for producing higher surface roughness. From the S/N ratio illustrated in Table 5, it shows that flow rate gives the most important and influential parameter to the results of surface roughness. The flow rate is ranked 1 (Delta = 2.17). The second rank is layer height and followed by printing temperature and print speed.

**Table 5** Response Table for S/N ratio

| Level | Layer height (mm) | Flow rate (%) | Print temperature (°C) | Print speed (mm/s) |
|---|---|---|---|---|
| 1 | -17.93 | -18.45 | -18.82 | -18.86 |
| 2 | -20.00 | -18.86 | -19.02 | -19.12 |
| 3 | -20.01 | -20.62 | -20.10 | -19.96 |
| Delta | 2.08 | 2.17 | 1.29 | 1.10 |
| Rank | 2 | 1 | 3 | 4 |

From the response table for means in Table 6, the flow rate is ranked 1 (Delta = 2.233). The second rank is layer height and followed by printing temperature and print speed. The selected rank is based on the largest to the lowest delta value. According to the response table for means, the level parameter's combination that minimizes the absolute value of surface roughness is layer height 0.1 mm, flow rate 90%, printing temperature 230°C, and print speed 35mm/s.

**Table 6** Response Table for Means

| Level | Layer height (mm) | Flow rate (%) | Print temperature (°C) | Print speed (mm/s) |
|---|---|---|---|---|
| 1 | 8.091 | 8.512 | 8.938 | 8.986 |
| 2 | 0.020 | 8.874 | 9.060 | 9.174 |
| 3 | 10.020 | 10.745 | 10.133 | 9.971 |
| Delta | 1.929 | 2.233 | 1.195 | 0.985 |
| Rank | 2 | 1 | 3 | 4 |

The effect of process parameters can be more clearly be shown with the main effects plot for mean as illustrated in Figure 5. This plot is intended to differentiate the parameters that influence the surface roughness response which is demonstrated by each level of the parameter. In the main effect plots, if the point is close to the average horizontal line, the effect is less significant. Thus, the point with the greatest inclination has the most effect on the response because the mean line is inclined to the x-axis. Figure 5 shows that the layer height, flow rate, printing temperature, and print speed all have the potential to influence the surface roughness.

Layer heights at 0.2 and 0.3mm levels have a higher average response than layer heights at 0.1mm or lower. Aside from that, the average response time for the flow rate parameter at the 110% level is higher than the responses at the 90% and 100% levels. When considering printing temperature parameters, 250 °C is on average more than 230 °C and 240 °C. A higher average response is observed for the print speed parameter at the 45 mm/s levels, compared to the 35 and 40 mm/s levels.

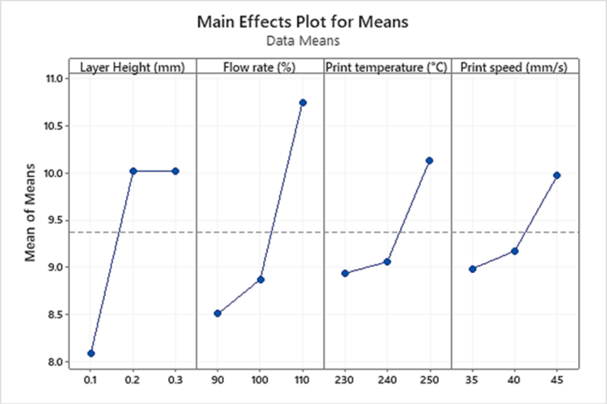


**Figure 5** Main effects plot for Means

The objective function the smaller-the-better type was employed to govern the response when calculating the surface roughness. To optimise surface roughness, the process parameter levels were identified. Regardless of the quality feature category, a greater S/N ratio corresponded to improved quality features. From the main effect plot for the S/N ratio in Figure 6, lower values for surface roughness is obtained by a larger value of the S/N ratio. Based on these linear graphs, the optimum process parameter values and levels are indicated in Table 7. The optimum process parameters for achieving lower surface roughness are 0.1mm layer height, 90% flow rate, 230°C print temperature, and 35mm/s print speed.

**Figure 6** Main effects plot for S/N ratio

**Table 7** Optimum parameters setting

| Layer height (mm) | Flow rate (%) | Print temperature (°C) | Print speed (mm/s) |
|---|---|---|---|
| 0.1 | 90 | 230 | 35 |

As a result, by applying a smaller value for layer height, we can achieve a better surface finish. The higher the flow rate, the higher the surface finish. The greater surface finish is achieved by printing at a lower temperature. By using a lower print speed, we can achieve a higher surface finish.

## 5.0 CONCLUSION

In conclusion, the best process parameters that affect the surface finish of additive manufactured specimen are selected as control variables based on understanding of the literature review. These parameters include layer height, flow rate, print temperature, and print speed. Process parameters in the FDM process are significant for achieving a smoother surface roughness. The behaviour observed in each specimen varies according to the parameter combinations used. Thus, by setting the appropriate parameters, a smooth surface finish can be created.

The Taguchi method was successfully used by maximizing the S/N ratio to reduce the surface roughness. To achieve the best results, all selected parameters of the printing process were analyzed. Base on the analysis, the flow rate has the greatest influence on contributing to the surface roughness of the printed parts, followed by layer height, printing temperature, and print speed. The surface roughness of printed parts was found to be poor with the increase in levels of flow rate. The flow rate is responsible for the unevenly aligned section of the deposited filament. It was discovered that the optimal parameter levels for surface roughness by the CR-10S Pro FDM machine are layer height of 0.1 mm, the flow rate of 90%, printing temperature of 230 °C, and print speed of 35 mm/s. Thus, the Taguchi method has been proven to be a useful approach for optimizing parameters to improve the surface roughness of printed parts.

## Acknowledgement

The authors would like to acknowledge the Universiti Teknikal Malaysia Melaka (UTeM) and the Ministry of Higher Education Malaysia for awarding the Fundamental Research Grant Scheme (FRGS) grant number FRGS/1/2021/TK0/FKP/02/UTEM/02/24.

## References

[1] ISO/ASTM. 2013. Additive Manufacturing - General Principles Terminology (ASTM52900). Rapid Manufacturing Association. 10-12.

[2] Chen, L., X., Zhang, & S. Gan. 2020. Effects of Laser Polishing on Surface Quality and Mechanical Properties of PLA Parts Built by Fused Deposition Modeling. *Journal of Applied Polymer Science*. 137(3): 48288.

[3] Mohamed, O. A., Masood, S. H., & Bhowmik, J. L. 2015. Optimization of Fused Deposition Modeling Process Parameters: A Review of Current Research and Future Prospects. *Advances in Manufacturing*. 3(1): 42-53.

[4] Alsoufi, M. S., & A. E. Elsayed. 2018. Surface Roughness Quality and Dimensional Accuracy-A Comprehensive Analysis of 100% Infill Printed Parts Fabricated by a Personal/Desktop Cost-Effective FDM 3D Printer. *Materials Sciences and Applications*. 09(01): 11-40.

[5] Shubham, P., C., Aggarwal, & S. Joshi. 2018. Optimization of Process Parameter to Improve Dynamic Mechanical Properties of 3D Printed ABS Polymer using Taguchi Method. *International Journal of Mechanical and Production Engineering*. 6: 2321-2071.

[6] Radhwan, H., Z., Shayfull, S. M., Nasir, A. E. H., Abdellah, & A. R. Irfan. 2020. Optimization Parameter Effects on the Quality Surface Finish of 3D-Printing Process using Taguchi Method. *IOP Conference Series: Materials Science and Engineering*. 864(1).

[7] Basavaraj, C. K., & M. Vishwas. 2016. Studies on Effect of Fused Deposition Modeling Process Parameters on Ultimate Tensile Strength and Dimensional Accuracy of Nylon. *IOP Conference Series: Materials Science and Engineering*. 149(1).

[8] Sammaiah, P., Rushmamanisha, K., Praveenadevi, N., & Reddy, I. R. 2020. The Influence of Process Parameters on the Surface Roughness of the 3D Printed Part in FDM process. *IOP Conference Series: Materials Science and Engineering*. IOP Publishing. 981(4): 042021.

[9] Ahmad, M. N., M. H., Ab Rahman, N. A., Maidin, M. H., Osman, M. K., Wahid, H., Mohamed Saiful Firdaus, & N. A. Abd Aziz. 2020. Optimization on Surface Roughness of Fused Deposition Modeling 3D Printed Parts using Taguchi Approach. Lecture Notes in Mechanical Engineering. July: 230-243.

[10] Aslani, K. E., D., Chaidas, J., Kechagias, P., Kyratsis, & K. Salonitis. 2020. Quality Performance Evaluation of Thinwalled PLA 3D Printed Parts using the Taguchi Method and Grey Relational Analysis. *Journal of Manufacturing and Materials Processing*. 4(2).

[11] Sajan, N., T. D., John, M., Sivadasan, & N. K. Singh. 2018. An Investigation on Circularity Error of Components Processed on Fused Deposition Modeling (FDM). *Materials Today: Proceedings*. 5(1): 1327-1334.

[12] Rane, K., & M. Strano. 2019. A Comprehensive Review of Extrusion-based Additive Manufacturing Processes for Rapid Production of Metallic and Ceramic Parts. *Advances in Manufacturing*. 7(2): 155-173.

[13] Prakash, K. S., T., Nancharaih, & V. V. S. Rao. 2018. Additive Manufacturing Techniques in Manufacturing - An Overview. *Materials Today: Proceedings*. 5(2): 3873-3882.

[14] Manikandan, S., A. S. S., Kumar, & C. Sharma. 2015. Investigation on the Effect of Fused Deposition Modeling Process Parameters on Flexural and Surface Roughness Properties of PC-ABS Blend. *International Journal on Recent Technologies in Mechanical and Electrical Engineering (IJRMEE)*. 2(8): 41-47.

[15] Jin, Y.A., H., Li, Y., He, & J. Z. Fu. 2015. Quantitative Analysis of Surface Profile in Fused Deposition Modeling. *Additive Manufacturing*. 8: 142-148.

[16] Barrios, J. M., & P. E. Romero. 2019. Improvement of Surface Roughness and Hydrophobicity in PETG Parts Manufactured via Fused Deposition Modeling: An Application in 3D printed self-cleaning parts. *Materials*. 12(15).

[17] Raffic, N. M., K. G., Babu, & P. Madhan. 2019. Application of Taguchi's Experimental Design and Range Analysis in Optimization of FDM Printing Parameters for PET-G, PLA and HIPS. *International Journal of Scientific and Technology Research*. 8(9): 891-902.

[18] Sukindar, N. A., M. K. A. M., Ariffin, B. T. H. T., Baharudin, C. N. A.,Jaafar, & M. I. S. Ismail. 2017. Optimization of the Parameters for Surface Quality of the Open-source 3D Printing. *Journal of Mechanical Engineering*. SI 3(1): 33-43.

[19] Altan, M., M., Eryildiz, B., Gumus, & Y. Kahraman. 2018. Effects of Process Parameters on the Quality of PLA Products Fabricated by Fused Deposition Modeling: Surface Roughness and Tensile Strength. *Materials Testing*. 60(5): 471-477.

[20] Akande, S. O. 2015. Dimensional Accuracy and Surface Finish Optimization of Fused Deposition Modeling Parts using Desirability Function Analysis. *Int. J. Eng. Res. Technol.* 4(4): 196-202.

[21] Maidin, S., Wong, J. H. U., Mohamed, A. S., & Mohamed, S. B. 2017. Effect of Vacuum Assisted Fused Deposition Modeling on 3D Printed ABS Microstructure. *International Journal of Applied Engineering Research*. 12(15): 4877-4881.